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Authors: Behlül GÜLER

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Effects of Climate Change on Distribution Areas of Formerly Endemic Plant Species *Campanula lyrata* Lam.

Behlül GÜLER*[1]

Abstract

Species distribution models (SDMs) are useful tools for future potential distribution patterns of species in the face of climate change. Turkey is expected to be affected considerably from climatic change i.e., up to 6°C increase in temperature and 50% decrease in precipitation by 2070. Therefore, there is an urgent need for conservation and management practices for future patterns of species. It is aimed current and future (using CMIP5 projected to 2070) potential distribution areas of *Campanula lyrata* Lam., which is formerly an endemic species. To do this, presence-only data was used, which is obtained from the Global Biodiversity Information Facility (GBIF). Bioclimatic data from was downloaded from WorldClim dataset with 10 km^2 resolution. Species distribution modelling was performed using R program. Two regression techniques and two machine learning techniques namely Generalized Linear Models (GLMs), Generalized Additive Models (GAMs), Support Vector Machine (SVM) and Random Forest (RF), were used, respectively. The bootstrapping method as partitioning resampling was also used for all analysis. Considerably high model performances as well as AUC values for all possible models were found. Significant range shifts between current and future climatic conditions were found. The most relevant relative importance variables were precipitation seasonality and precipitation of the wettest month. This study reveals the importance of the future distributional areas of species.

Keywords: Biology, Botany, Vascular plant, Species distribution models.

1. INTRODUCTION

Climatic change is one of the most important environmental issues in the world. Future projections for climatic events reveal that considerable increase in global temperature, decrease in precipitation and a rise in extreme weather events is expected. [1]. Therefore, distribution patterns of the biological organisms are also expected to change [2]. Biodiversity loss may occur [3] and therefore ecosystem functions might be affected [4]. Projections for distribution areas based on changing global environmental conditions clearly contribute to conservation strategies for the biological organisms [5]. According to projections Turkey is expected to be significantly affected by climate change [6]. It is expected that precipitation will be decreased by

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* Corresponding author: behlul.guler@deu.edu.tr

[1] Dokuz Eylul University, Biology Education, Buca, 35350, İzmir, Turkey.

ORCID: https://orcid.org/0000-0003-2638-4340

up to 50% by 2070 projections. Temperatures will also increase by up to 6°C according to the 2070 projections based on HadGEM2-ES/RCP 8.5 scenario [6, 7]. The future trend towards 2100 continues up to 5°C based on ICTP-RegCM3 climate projections [8].

Species distribution models (SDMs) are based on statistical inferences and powerful tools for investigating potential distribution patterns of current and future times [9]. In general presence-only data, presence-absence and abundance data are used for SDMs as species patterns data, while a line of environmental data is used as explanatory data [10]. A number of machine learning methods such as MAXENT, Artificial Neural Networks (ANN), Genetic Algorithm for Rule set production (GARP), Boosted Regression Trees (BRT), Gradient Boosting Machines (GBM), Random Forest (RF) and Support Vector Machines (SVM), and regression methods such as Generalized Linear Models (GLMs), Generalized Additive Models (GAMs) and Multivariate Adaptive Regression Splines (MARS) are used in SDMs statistical inference. These methods could be performed using the *sdm* [11], MaxEnt [12], DOMAIN [13], BIOCLIM [14].

Biological organisms are considerably affected by climate change. In particular, plants and plant communities are significantly affected by changing weather events. These effects strongly depend on the type of climatic event climatic event type and its magnitude [15]. The effects of climate can be as follows: negative effects on community stability [16], extinction of species and plant communities [17], permanent changes on community [18], effects on individuals [16], shifts on ecotones [19], negative effects on amount of photosynthesis, productivity, carbon uptake, biotic interactions such as fine scale community assembly and functionality [20].

Vascular plant diversity in Turkey is quite rich in terms of richness for taxa [21]. Geological and topographical diversity have resulted in a diverse ecosystem for vascular plants. In addition to this Turkey has considerable mountainous regions, and therefore it results in unique habitats for endemic species richness [21-23]. At the same time, Turkey is dramatically affected from the climate change [8]. However, future response of the species and communities in Turkey still remain unclear. Since there may be numerous responses of the species, it should be taken into account to get more information about future responses of species as well as communities.

Campanula lyrata, which I investigated to species distribution modelling in this study, belongs to the Campanulaceae family. It is a hemicriptophyte herbaceous vascular plant species, which mostly grows in stony places, cliffs, river banks. It is a biennial or perennial species and flowering period is between April and July. It could grow up to 50 cm tall and up to 1700 m elevation. *Campanula lyrata* is formerly an endemic species as reported in Flora of Turkey [24, 25, 26] as *Campanula lyrata* subsp. *lyrata*. It distributes across most sub-regions of Western Turkey. However, it is no longer endemic in the current Plant List of Turkey [21]. Therefore, I aimed to reveal current and future potential distribution areas of *Campanula lyrata*, which is projected to 2070 in this study.

2. MATERIALS AND METHODS

2.1. Data compilation

I searched for occurrence data of *Campanula lyrata* from the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/, accessed on February 2021). It resulted in 283 records in GBIF. The basis of the records was fossil specimen 1, human observation 29, living specimen 3, preserved specimen 247 and 3 unknown. I extracted geolocated occurrences, which was finally resulted in 127 occurrences. I performed further analysis using geolocated occurrences.

I downloaded 19 bioclimatic variables from WorldClim database [27-28] with 10 km^2 spatial resolution. These variables were: bio1, Annual Mean Temperature; bio2, Mean Diurnal Range (Mean of monthly (max temp - min temp)); bio3, Isothermality (bio2/bio7) (×100); bio4, Temperature Seasonality (standard deviation ×100); bio5, Max Temperature of Warmest Month; bio6, Min Temperature of Coldest Month; bio7, Temperature Annual Range (bio5-bio6);

bio8, Mean Temperature of Wettest Quarter; bio9, Mean Temperature of Driest Quarter; bio10, Mean Temperature of Warmest Quarter; bio11, Mean Temperature of Coldest Quarter; bio12, Annual Precipitation; bio13, Precipitation of Wettest Month; bio14, Precipitation of Driest Month; bio15, Precipitation Seasonality (Coefficient of Variation); bio16, Precipitation of Wettest Quarter; bio17, Precipitation of Driest Quarter; bio18, Precipitation of Warmest Quarter; bio19, Precipitation of Coldest Quarter.

2.2. Data analysis

Before starting the distribution modelling, I performed multicollinearity analysis among bioclimatic variables. I detected multicollinearity using Variance Inflation Factor [29] through a stepwise procedure. I limited the current distribution range including European terrestrial zone by cropping the map and therefore limiting the area (as same range in Fig. 2a) to be able to obtain more effective collinearity results. Multicollinearity analysis showed that 12 variables from the 19 input variables had collinearity problem. Therefore, VIFs of the remaining variables were without collinearity: bio2, 3.81; bio4, 2.01; bio8, 1.41; bio9, 4.91; bio14, 4.42; bio15, 2.54; bio19, 2.95.

Before fitting the model, I created pseudo-absences on the data. To do this I created 1000 geographically random selected pseudo-absences. Thus, I turned data into presence-background data then presence-only data. Regarding species distribution modelling, I fitted four methods namely Generalized Linear Models (GLMs), Generalized Additive Models (GAMs), Support Vector Machine (SVM) and Random Forest (RF). Each model was evaluated using 10 runs of bootstrapping replications taking 30 percent as a testing data in terms of partitioning methods.

Regarding prediction I fitted both current and future projected analysis. I fitted current potential distribution with ensemble using weighted averaging based on TSS statistic and set optimum threshold criterion as 2 optimization thresholds. For the future projection I used bioclimatic (CMIP5) for the year of 2070 as a resolution of 10 km^2. I ensembled this data as the same method with current data. Further, I revealed distributional change between current and future model based on probability of occurrence. I obtained mean variable importance (and confidence interval) for multiple models based on training dataset. Furthermore, I evaluated the results of each fitted model using accuracy and thresholds. I used the mean values of the thresholds as a parameter to determine extinction, persistence and colonization. I performed the analysis using R program [30]. I used reproducible and extensible *sdm* method [11] for species distribution modelling.

Receiver operating characteristic (ROC) curve is used for evaluation the performance of the models using area under the curve. This is calculated from the specificity (false-positive error) rate and the sensitivity (true positive rate) on the x and y axis, respectively [31]. The AUC values are important to understand model performances. In general, high performance models have >0.9 AUC, moderate performance models have 0.7–0.9 AUC and poor models 0.5–0.7 AUC values [31]. However, 0.8 AUC value is a critical threshold for a model, which could be considered a necessary value [32].

3. RESULTS

All four models result in high accuracy values, which range from 0.98 to 0.99 (Table 1). The results show four models successfully processed and provide considerable patterns. The correlation of the models ranges from 0.91 to 0.95, while TSS values from 0.95 to 0.98. GLMs, GAMs and RF models have higher accuracy values than SVM model. ROC-AUC curves using specificity and sensitivity values of four models is presented in Figure 1. These curves show that all models have quite high AUC values in terms of both training and testing data. Training AUC values is always higher than testing AUC as expected. However, the difference between training and testing data is slightly higher in GLMs, GAMs and SVM than RF. Since I used 30% as a bootstrapping partition testing data is almost predicted in RF as much as training data. This pattern is clearly an effect of model performance. Predictions for current time and the future time as for the year 2070 is presented Figure 2a, b. Projected distributions of *Campanula lyrata* differs from current distribution especially across the Europe as well as in West America. The change of distribution, which is presented Figure 3, clearly shows that the species have potential to distribute not only in Europe and the America's but also Africa and on Asian continents. Figure 4 presents the potential areas of colonization and extinction for *Campanula lyrata* based on mean values of thresholds. Relative Variable Importance (RVI) of four models in terms of bioclimatic variables are presented in Figure 5. However, these variables are used after the multicollinearity check for the analysis.

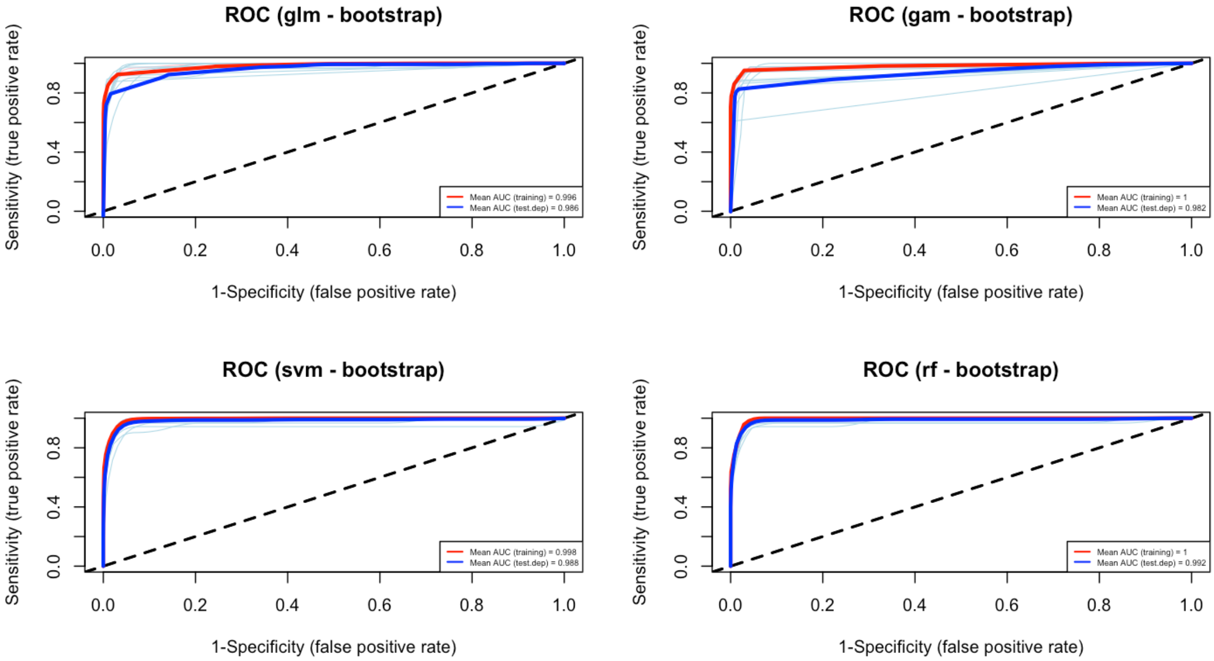

Figure 1 ROC-AUC curves of four models which bootstrapping method is used. The models are Generalized Linear Models (GLMs), Generalized Additive Models (GAMs), Support Vector Machine (SVM) and Random Forest (RF).

Table 1 Mean performance of the fitted models using bootstrap partitioning (Generalized Linear Models (GLMs), Generalized Additive Models (GAMs), Support Vector Machine (SVM) and Random Forest (RF)).

Methods	**AUC**	**COR**	**TSS**	**Deviance**
GLMs	0.99	0.91	0.95	0.29
GAMs	0.98	0.91	0.96	0.82
SVM	0.99	0.92	0.96	0.11
RF	0.99	0.95	0.98	0.06

4. DISCUSSION

Four models in my analysis have quite high AUC values. GAMs model has slightly lower performance than GLMs, SVM and RF. However, correlation of RF was the highest while deviance is the lowest.

Current potential distribution of *Campanula lyrata* is mostly in the Mediterranean climate zone in Anatolia. It has slightly greater distribution in Aegean region than along the Mediterranean seashore. There is also some distributional range from southeast Anatolia to Mesopotamia. For the future time distributional patterns are rather similar to those along the Mediterranean seashore and to Mesopotamia. However, it considerably increases in mid and north Aegean parts and the Marmara region. This shows a clear increase in south Turkey to north Turkey. With regard to Europe, a strong increase of distribution potential is in West Spain. Following this pattern distribution areas increase in Greece, Italy and Croatia as well as partly rise across Europe. In addition, few areas appear for potential distribution in the west part of the Caspian Sea. Regarding global scale distribution areas considerably increase in west America as well as India and mid Africa. No significant pattern appears except from this area across five continents. Regarding colonization potential of *Campanula lyrata*. It occurs in the areas ranged from west America to Asia including Australia. However, extinction appears in the region of northern pole and especially Greenland.

Regarding relative importance variables GLMs model result with annual mean temperature, minimum temperature of coldest month, mean temperature of warmest quarter, mean temperature of coldest quarter, precipitation of wettest quarter performed best. GAMs result with the best variables are temperature seasonality, mean temperature of warmest quarter, mean temperature of coldest quarter, precipitation of wettest quarter, temperature annual range. SVM model shows precipitation seasonality is significantly important than other variables. Following this, mean diurnal range, precipitation of wettest month, precipitation of coldest quarter and precipitation of warmest quarter are also important bioclimatic variables. According to RF precipitation of wettest month performed the best. Variables of precipitation of coldest quarter, precipitation seasonality, precipitation of wettest quarter and precipitation of warmest quarter also more important than other variables. Obviously, precipitation seasonality and precipitation of wettest month performed quite high performance than others in terms of overall variable importance results.

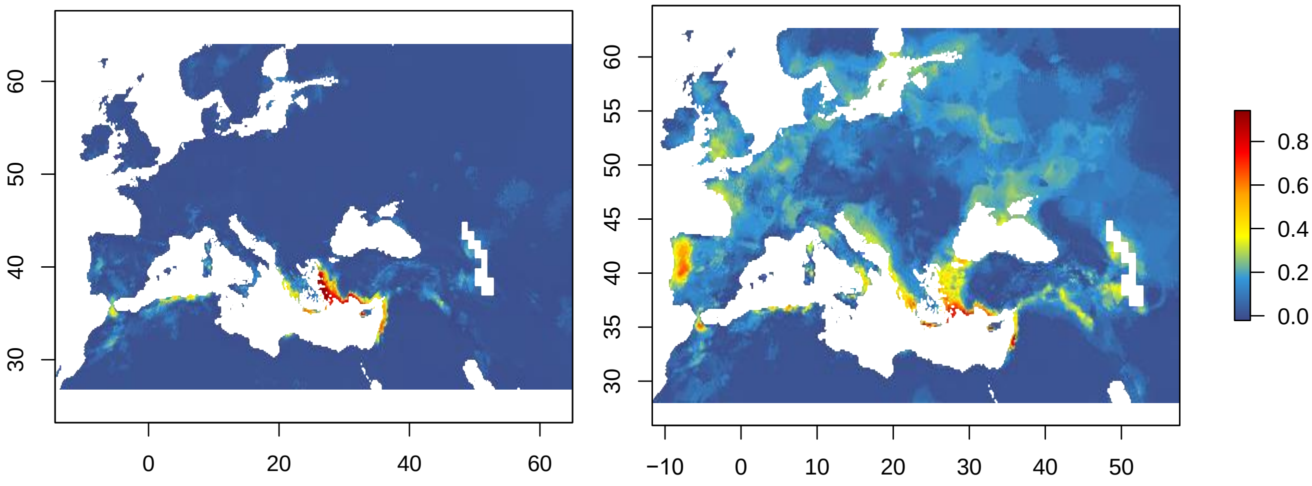

Figure 2a Potential distribution of *Campanula lyrata* for the current time on the left side and for the future (projected as 2070) time on the right side across Turkey and Europe.

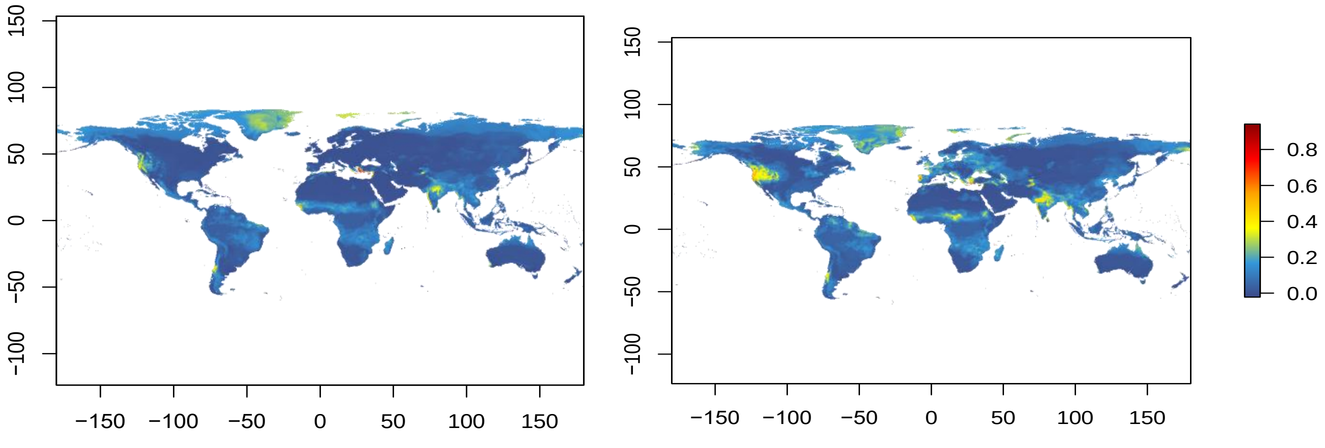

Figure 2b Potential distribution of *Campanula lyrata* for the current time on the left side and for the future (projected as 2070) time on the right side across the world.

For species distribution modelling topographic and biotic variables as well as geologic data are significantly important in addition to bioclimatic variables. Especially biotic relations such as plant-plant interactions and species coexistence patterns constantly affect distribution modelling [33] as well as AUC values of the models [34]. During the modelling process it is important to select highly relevant variables by performing multicollinearity analysis. It might sometimes differ when modelling species is endemic because endemic species could have specific habitat requirements. Therefore, such an important predictor for an endemic species could be eliminated in multicollinearity analysis. This point needs to be considered during variable selection.

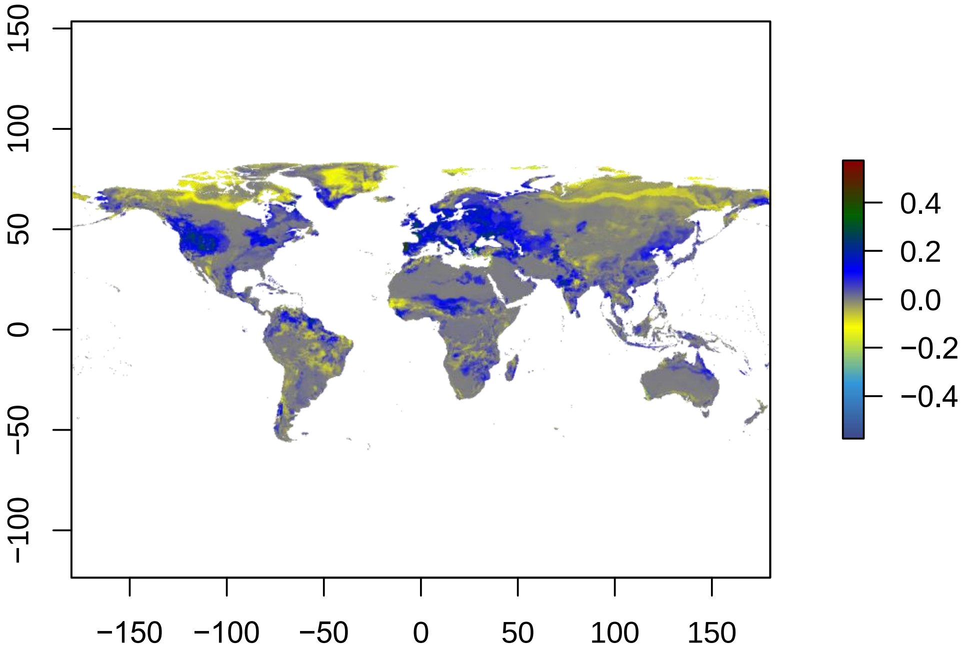

Figure 3 Change of distribution between current and future (projected to 2070) time.

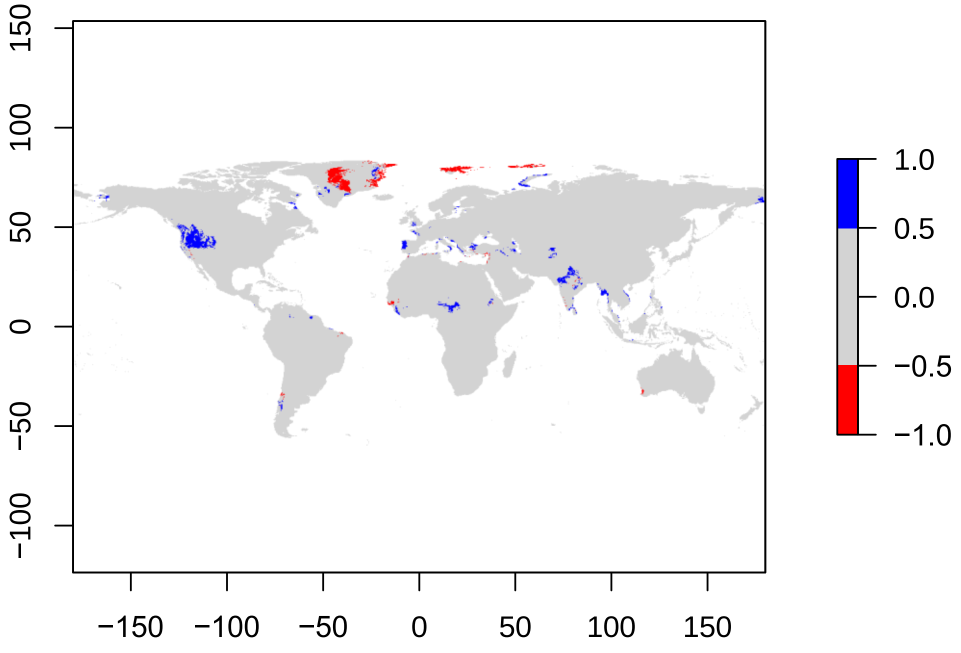

Figure 4 Potential areas of colonisation (blue) and extinction (red) of *Campanula lyrata*.

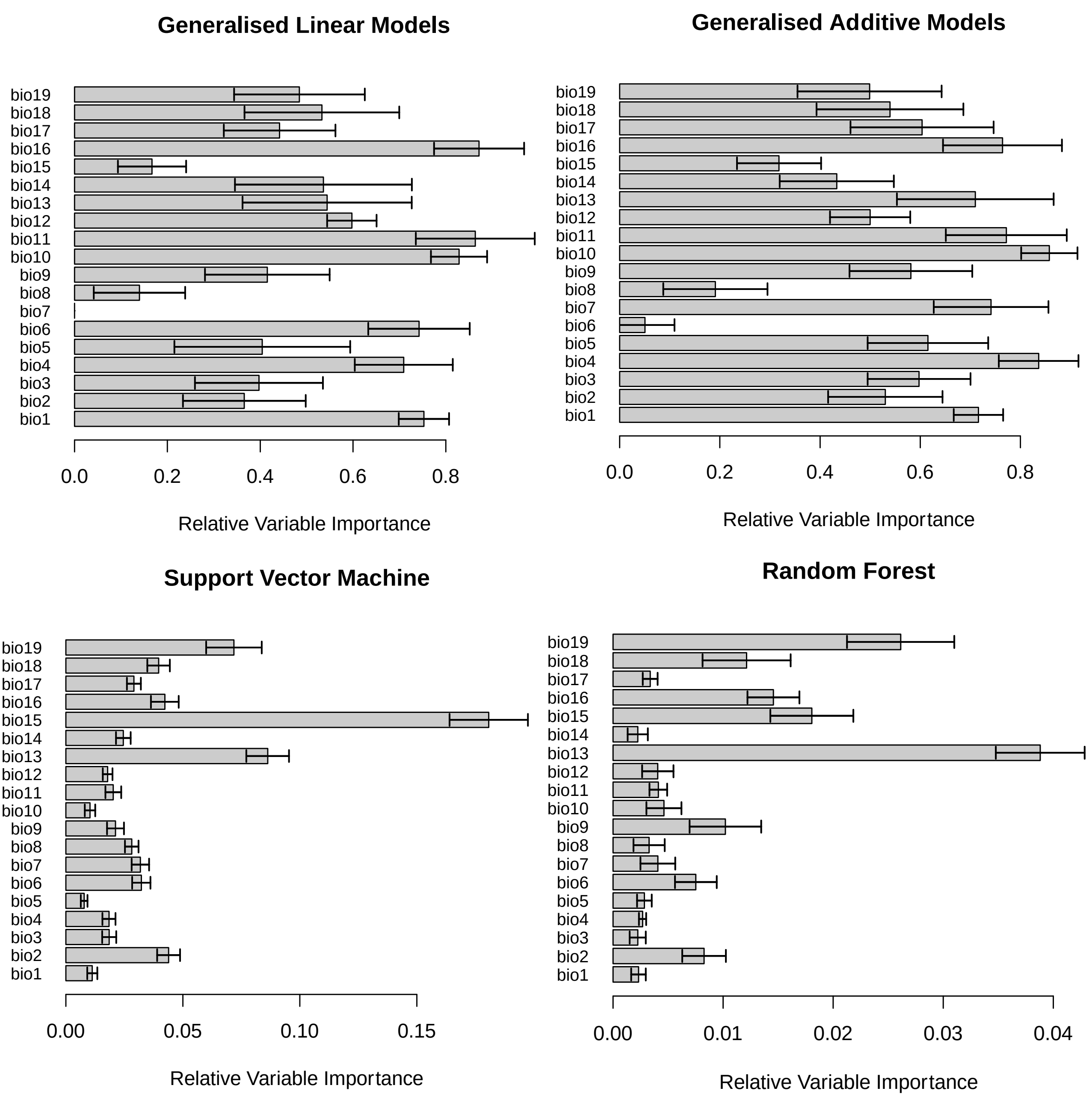

Figure 5 Relative Variable Importances (RVI) of four models in terms of bioclimatic variables.

In conclusion, I found that potential distribution area of *Campanula lyrata* is expected to be increase in Turkey in the future. Climate change would likely affect distribution of the species. However, regarding global scale significant increase does not occur. Instead, potential distribution areas shift from North pole to lower latitudes. Regarding bioclimatic variables precipitation related predictors play an important role for the distribution. Species distribution modelling for *Campanula lyrata* has revealed valuable information about distributional patterns. The method should be performed for various endemic species for Turkey, where the rate of endemic richness is quite high [21].

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The Declaration of Research and Publication Ethics

The author of the paper declare that he complies with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that he does not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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