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*Original Research*

# Potential Distribution Modeling and Mapping of Brutian Pine Stands in the Inner Parts of the Middle Black Sea Region in Turkey

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**Abstract**

Brutian pine (*Pinus brutia* Ten.) is one of the most common and precious coniferous tree species in Turkey. Except for its main distribution areas such as the Mediterranean and Aegean regions, brutian pine can be found in isolated areas due to its different forest site factors. Therefore, our aim was to obtain a model and map of this species in the Aydınca District, which is one of these isolated areas. For these purposes, the presence or absence of data of target species was collected from 453 sample plots. Environmental variables – including elevation, slope, heat index, topographic position index, slope position, bedrock types, BIO1, and BIO12 – were selected for generating a model and map of brutian pine via the generalized additive model. The model and map show that BIO1, BIO12, elevation, heat index, and bedrock were the most important explanatory variables. As a result of the obtained model, potential distribution of brutian pine was determined to range from 400 to 806 m elevation. In addition to this result, climate conditions for brutian pine were areas where the annual mean temperature was 11-12.5°C and annual mean precipitation was 428-439 mm. Besides, more suitable areas for brutian pine occurred where the heat index values are higher. Finally, brutian pine preferred limestone, schist, and other bedrock types in the district. In this study especially, climatic features that depend on elevation showed significant influence on potential distribution of brutian pine in Aydınca.

**Keywords**: Aydınca District, *Pinus brutia* Ten., species distribution model, Turkish red pine

## Introduction

Potential distribution models (PDM) can be defined as equations derived to estimate the appropriate alternative distribution areas in nature using the actual environmental variables in the natural distribution areas of species [1-7]. On one hand one can determine the habitat characteristics of the species through PDM while on the other hand ecology-based information needed for basic concepts such as sustainability, conservation, restoration, and biodiversity can be collected [8-12]. In particular,

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the use of PDMs in forestry enables the implementers to make the right decisions regarding forest operations such as afforestation, improvement of the productivity of the degraded forests, selection of appropriate sites for natural and artificial rejuvenation activities, and ensuring the continuity of forest areas.

Globally, studies on PDM have been conducted on different topics regarding several species, including primarily plants, wild animals, birds, insects, and reptiles [13-17]. On this topic, there are remarkable studies recently conducted in Turkey especially regarding plant species. For example, one of the studies conducted at different times in the Yukarıgökdere Natural Conservation Area, which is an important protected zone in Isparta Province, identified the potential distribution of diverse variety of non-wood forest products [18], while another study determined the geographical distribution models of *P. terebinthus*, which is an important medical aromatic plant species [19]. There are also other studies conducted directly on tree species such as *Cedrus libani* [20], *Juniperus excelsa* [12], *Pinus nigra* [21], and *Quercus cerris* [22-23].

The majority of these studies on tree species mainly focus on primary tree species. This is because there are more common primary tree species in the country and they have a higher economic value. In light of this information, brutian pine (*Pinus brutia* Ten., also known as Turkish red pine) is one of the most important primary tree species in Turkey's forests from economic and ecological perspectives. Especially since this tree species is heavily used in industrial forest operations, it is the number one species in terms of growing stock (270 million $m^3$) [24]. Considering its economic contribution, it is important to protect or extend the presence of this species in forests, improve its characteristics, and ensure its sustainability on one hand, while on the other hand it is essential to manage it actively. To achieve this goal, its potential distribution areas depending on habitat characteristics should be identified to ensure its sustainability.

Although there are studies in literature that focus on the ecology of brutian pine [25-27], there is no study conducted so far on the PDM of this species. It is distributed across a very wide area of 5.6 million hectares, mainly in the Mediterranean and Aegean regions, and it also has an isolated distribution area in various micro-climate zones that have Mediterranean climate characteristics [28-29]. One of the important isolated distribution zones of this species is Amasya Forest Directorate, which is located in the inner parts of the Middle Black Sea Region in Turkey. The actual distribution of brutian pine stands in this area is approximately 8,500 ha. There is no doubt that such local areas are of great importance as regards ecosystem diversity and different habitat characteristics; therefore, their restoration and sustainability should be ensured. To achieve this goal, only information about its overall ecology is not sufficient, while there is a need for further information on ecology based on a model regarding the habitat characteristics in these local areas. To this end, our study aimed at modeling and mapping the potential distribution areas of this species in the Aydınca using the generalized additive model.

## Material and Methods

### Study Area

This study was conducted in the Aydınca District, which is on the inner side of the middle Black Sea region in Turkey. The district covers an area of 7,549.3 $km^2$ and ranges from 220 m to 1,955 m above sea level. The highest peak is Cami Hill (1,956 m) in the northeastern part of the study area, which is located within the transition zone that ranges from the inner parts of the middle Black Sea Region in Turkey to central Anatolia, and is surrounded by the Yeşilırmak and Kelkit rivers. The district is characterized by the different parent materials of schist, volcanic sediment, ophiolitic melange, alluvium, limestone, and other bedrock types. Especially while upper areas are composed of schist, limestone, and ophiolitic melange, lower zones are comprised of alluvium and volcanic sediment. In addition to brutian pine, scotch pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* Arnold.), crimean juniper (*Juniperus excelsa* Bieb.), common beech (*Fagus orientalis* L.), and oaks species are also important tree species in this location. The Aydınca District is located within the transition zone between the middle Black Sea and central Anatolian regions in Turkey. The annual average temperature is 13.6ºC and the average annual precipitation is 460.3 mm [30].

### Data Collection and Environmental Variables

Data was collected from 453 sample plots in the study area. Binary data (presence and absence data) of brutian pine were recorded at each sample plot, which is 400 $m^2$. Latitude and longitude, elevation, and slope degree were numerically recorded at each area by using GPS (m), an altimeter (m), and a clinometer (%), respectively. On the other hand, values of aspect and slope degree were transformed into heat index (*HEATIN*) by means of the formula *HEATIN* = cos (aspect – 202.5º) x tg (slope), where 202.5º is a value that means the warmest aspect (SSW). This formula's results changed between -1 and 1 [31-32]. Climate predictors were represented by 2 bioclim variables [33], which are annual mean temperature (*BIO1*) and annual precipitation (*BIO12*), acquired from the WorldClim database (*worldclim.org*).

In order to generate the potential distribution model and map of brutian pine, environmental variables were obtained by using geographical information systems (GIS). At first, a digital elevation model (*DEM*) was produced from contour lines of the study area in *ArcGIS 10.1* software. An elevation (*ELVTN*) map was reproduced using *DEM*. *ELVTN* of the district ranges from 400 m to 1,923 m above sea level and contained 470 × 279 cells with horizontal and vertical resolution of 100 m and 100 m, respectively. Topographic position index (*TPI*), aspect (*ASPCT*), and slope degree (*SLOPE*) maps were derived by *ELVTN*. After that, landscape was classified into slope position by using *ELVTN* and *TPI*. Five slope position categories were generated: name of valley (*VALLEY*), toe slope (*LSLOPE*), midslope (*MSLOPE*), upper slope (*USLOPE*), and ridges (*RIDGE*) [34]. Six bedrock types were determined during inventory studies and coded as *ALVM* (alluvium), *LMSTN* (limestone), *OPHME* (ophiolitic melange), *OTHBED* (other bedrocks: sandstone-mudstone, pebble stone-sandstone, pebble stone, serpentinite, argillaceous limestone), *SCHST* (schist), and *VOLSED* (volcanic sediment). A lithology map of in the district was provided by the Mineral Research and Exploration General Directorate. Finally, by using each cell of aspect and slope value of the study area, a *HEATIN* map of the study area was derived from Equation 1.

### Statistical Analysis

The generalized additive model (*GAM*) was performed to determine the relationship between environmental variables and potential distribution of brutian pine. *GAM* is a non-parametric extension of the generalized linear model and a non-parametric smoothing function [35-36]. Distribution of brutian pine was carried out within generalized regression analysis and spatial prediction (*GRASP*) in *S – Plus 6.1*. *GRASP* is an extension of obtaining spatial distribution of target species by means of *GAM* [37-39]. A quasi-binomial model was selected for brutian pine presence-absence data. ANOVA (F test) of quasi model was used as the statistical method. Model validation and performance were evaluated by a receiver operating characteristics (*ROC*) curve.

## Results

In this study, for the purpose of producing the potential distribution model and map of brutian pine, presence-absence data of brutian pine were collected from 453 sample plots. Potential distribution of brutian pine was carried out using the *GAM*. *BIO1, BIO12, ELVTN, HEATIN,* and *BEDFOR* variables that were included in the distribution of the brutian pine model. All contribution rates of statistically significant variables are given in Fig. 1. According to Fig. 1, the drop in explained deviance for *ELVTN, BIO1, BIO12, HEATIN,* and *BEDFOR* variables contributed to 11.10%, 16.14%, 48.82%, 22.42%, and 12.97%, respectively. Explained deviance for potential contribution (alone) of *ELVTN, BIO1, BIO12, HEATIN,* and *BEDFOR* were found to be 119.33, 106.64, 150.62, 26.83, and 37.30, respectively.

A possible formula for the final model is:

$$s\,(ELVTN, 4) + s\,(HEATIN, 4) + BEDFOR + s\,(BIO1, 4) + s\,(BIO12, 4)$$

…where s is the spline smoother and 4 is degrees of freedom (df) for the spline smoother.

The partial response curve of environmental variables is given in Fig. 2. According to *ELVTN*'s response curve, a negative correlation was found between brutian pine and elevation. Heat index was positively correlated with brutian pine. Furthermore, schist and limestone, which are bedrock formations, were preferred more than

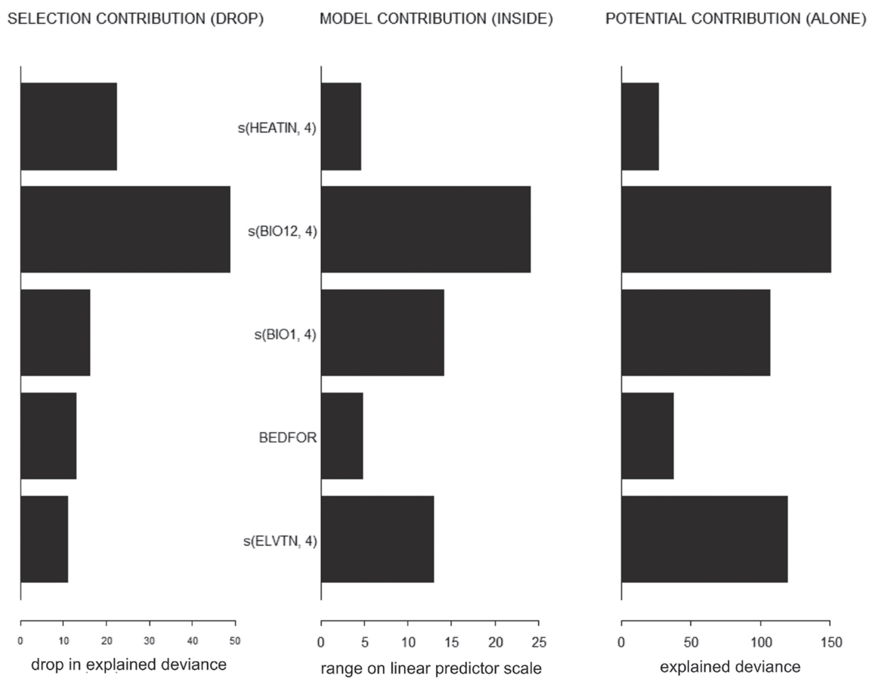


Fig. 1. Contributions of selected environmental variables to the modeling red pine potential distribution.

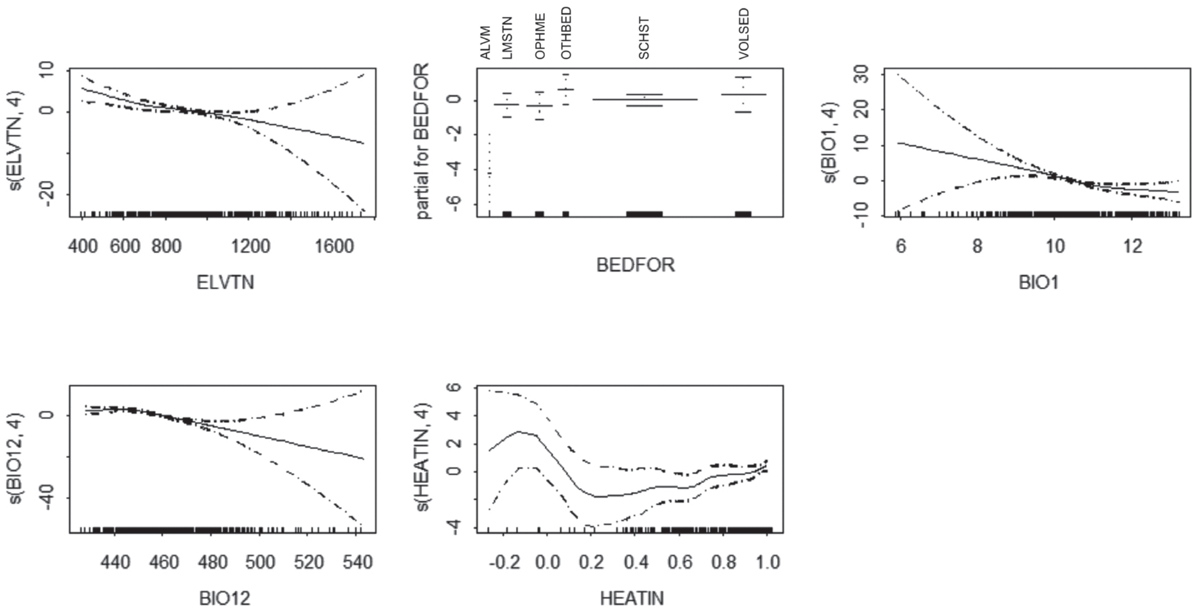


Fig. 2. Response curves of red pine.

other parent materials by brutian pine. Lastly, for both variables, *BIO1* and *BIO12*, a negative correlation was determined. The histograms are shown in which areas are potentially more suitable for target species (Fig. 3). The potentially suitable area preference of brutian pine in the study area ranged from approximately 400 m to 806 m and schist and limestone bedrock formations were more preferred than others. In addition, resulting values for heat index were found above 0.87. Finally, while values of *BIO1* changed between 11.1ºC and 12.5ºC, values of *BIO12* ranged from 428 to 440 mm.

Both validation value (ROC) and cross-validation value (cvROC) were found to be 0.908 and 0.859, respectively (Fig. 4). The results of ROC and cvROC are observed as relatively approximate values.

Finally, a potential distribution map file of brutian pine was performed by *GRASP*. This map was visualized using of *ArcMap 10.1* software (Fig. 5).

## Discussion and Conclusions

This study was conducted to determine the potential distribution area of brutian pine in the Aydınca District. The GAM showed that variables of BIO1, BIO12, *ELVTN, HEATIN*, and *BEDFOR* played an essential role in the

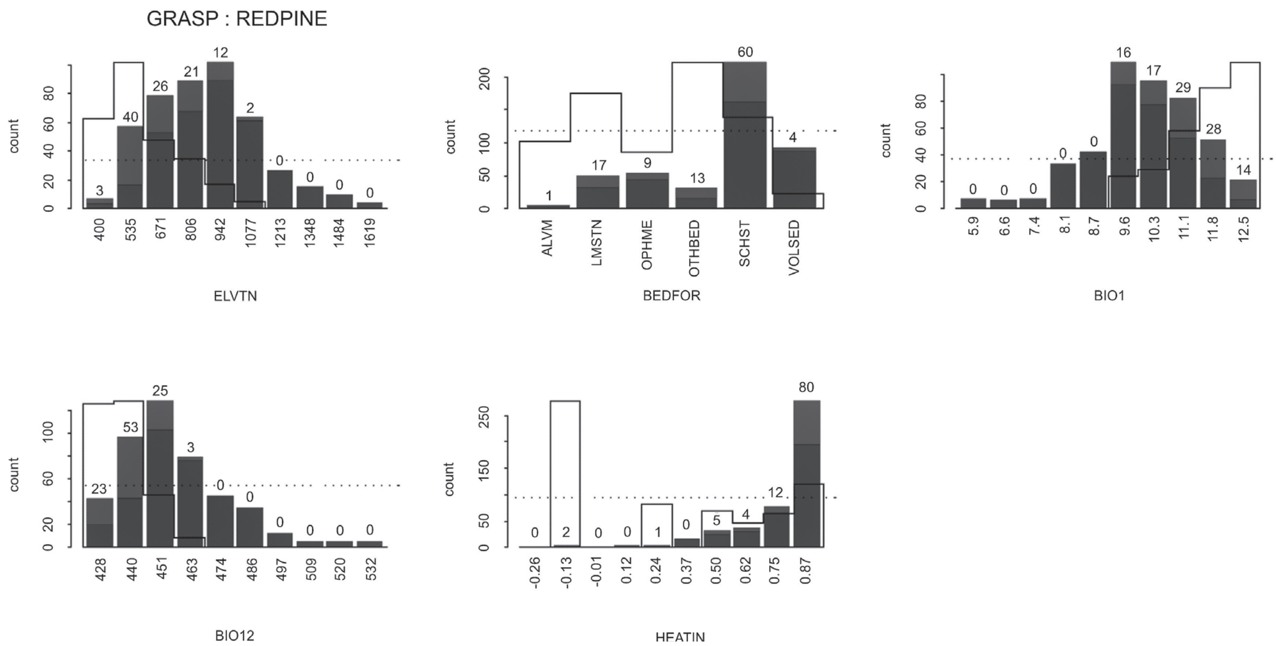


Fig. 3. Histograms of the predictor variables to the modeling of red pine distribution.

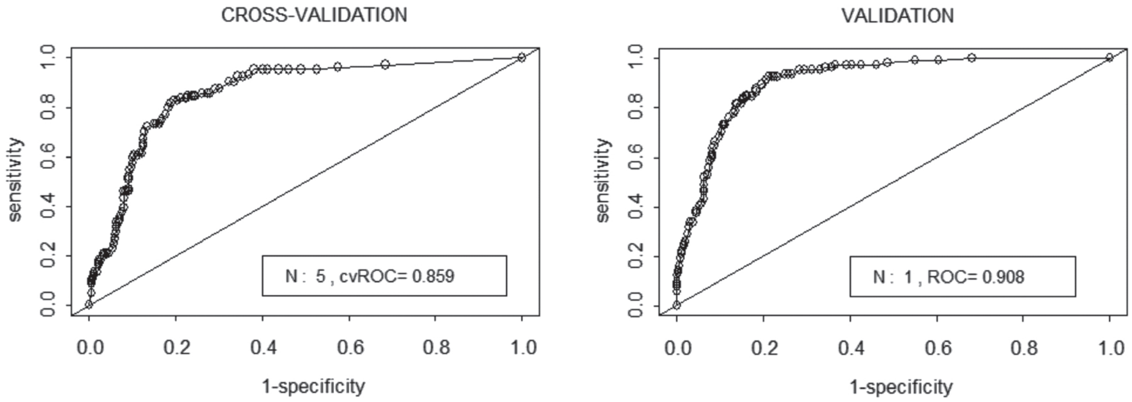


Fig. 4. Validation of the resulting model. AUC values for cvROC and ROC.

potential distribution of brutian pine in the Aydınca district.

As a result of this study, although the potential distribution of brutian pine in the district was found to range between elevations of approximately 400 and 806 m, brutian pine was found to occur at elevations ranging from roughly 400 to 1,077 m. It is known that distribution of many tree species in Turkey is generally related to altitude [38, 40]. In this study, we obtained a similar correlation between altitude and distribution of brutian pine. Whereas some tree species in Aydınca such as black pine and scotch pine were distributed at higher altitudes, brutian pine was located more at lower elevations than these other species. On the other hand, there is also a high correlation between altitude and climate. Brutian pine was found in the study area where annual mean temperature is 11-12.5ºC and annual mean precipitation is 428-439 mm. But distribution of brutian pine was restricted due to the fact that temperature gradually is reduced above 1,100 m elevation. That is to say, Aydınca is located between the Yeşilırmak and Kelkit rivers in the backward part of the middle Black Sea in Turkey where a sub humid-semiarid climate prevails. Annual mean precipitation in these areas are less than 500 mm [41]. Besides, annual mean temperature in the part of the depression area is higher than 12ºC [42]. On the other hand, the depression area located in the backward region of the middle Black Sea in Turkey is prevented both from frost and low temperatures during winter, while high temperatures are able to arise in this area during summer [43]. Due to this situation, potential distribution areas for brutian pine were locally formed by suitable site factors in the district.

Parent materials were found as another important factor that effects the distribution of brutian pine. Mainly schist parent material and partly limestone affected the potential distribution of the species in the district. Contrary to this situation, especially valley or plain areas composed of alluvium bedrock were determined to be unsuitable for potential distribution of brutian pine. It has been pointed out that schist and limestone parent material are covered around Abacı, Aynalı Yaylası, Avşar

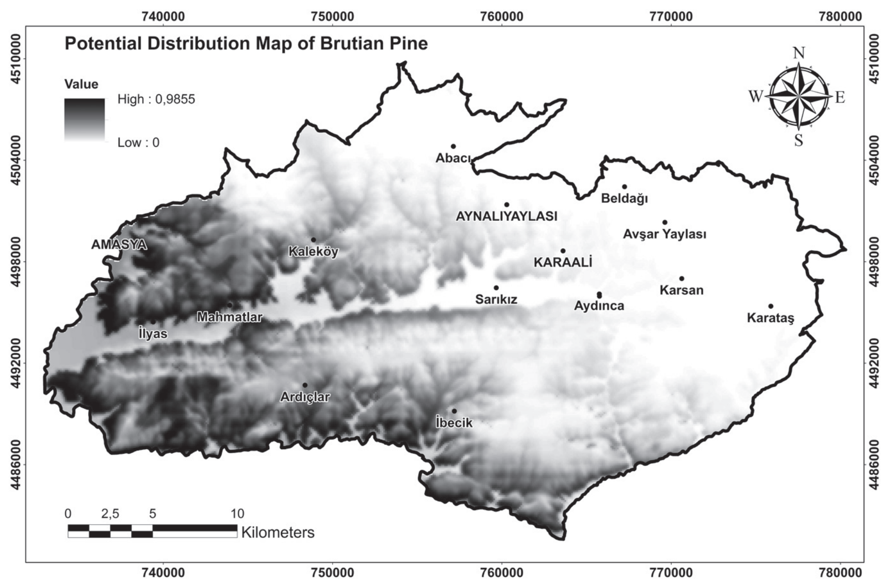


Fig. 5. Potential distribution map of red pine.

Yaylası, and Karataş ve Aydınca in the study area. As said above, these locations were expected to be more suitable areas for the potential distribution of brutian pine. However, it was shown that these locations in the district were unsuitable areas for brutian pine. Due to the fact that these areas are higher than 1,100 m, we think that the potential distribution of brutian pine in these areas is restricted depending on the altitude and climate relationship. This is to say, although brutian pine showed sensitivity to parent materials in the inner part of the middle Black Sea region, it was first adapted to climate conditions and hence maintained potential distribution in these local climate areas. It is known that the main distribution of brutian pine ranges from different parent materials such as schist, conglomerate, serpentine, marn, basalt, and flysch [28, 44]. However, brutian pine prefers more clay schist, marn, and limestone, plus sandstone parent materials in the Mediterranean region. On the other hand, it was expressed that while brutian pine saw its best growth on limestone and schist parent materials, it showed bad growth performance when growing on volcanic rocks and siliceous materials [43-44]. When the obtained results are compared to other research from literature, it was determined that parent materials affected distribution of brutian pine similarly. Finally, as a result of static assessment, heat index was found to be another important factor for potential distribution of brutian pine. Heat index is transformed to aspect and slope cell values by using a formula and represented solar parameters in the environment. As is known, brutian pine is a typically shade-intolerant tree and more light-demanding than many other conifer tree species [45]. As mentioned previously, local areas that show a higher solar radiation index were also determined to be more suitable potential distribution areas for brutian pine. In the same way, Atalay [41] has stated that brutian pine throughout the tectonic depressions in the inner parts of the middle Black Sea region in Turkey were distributed depending upon higher solar radiation.

In conclusion, areas located in the inner parts of the middle Black Sea region in Turkey formed local suitable areas for brutian pine, which is supported by our results. It is very important to protect the ecosystem diversity in the district with areas having suitable climate factors and parent materials known to have potential distribution for brutian pine in the middle Black Sea region in Turkey. Lastly, as a result of future climate change, it will become more important to determine the ecological characteristics of the species that are distributed in such local areas.

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## Conflict of Interest

The authors declare no conflict of interest.

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