

BIO-CLIMATIC MODELLING OF SOME ENDEMIC AND RARE SPECIES OF THE FAMILY LAMIACEAE DISTRIBUTED IN THE NUROTA BOTANICAL-GEOGRAPHICAL REGION

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Abstract. *The impact of climate change on endemic species leads to highly negative consequences and increases the risk of their extinction. In every region, the reduction of the distribution range of endemic species causes changes in the local flora. This is especially the case when it occurs alongside the recent increase of alien species, which may result in the disappearance of endemic species from the local flora. Therefore, it is essential to assess endemic and rare species in each region using modern methods, which makes it possible to obtain scientific information about their future. In this study, the results are presented on the future distribution patterns of the rare and endemic species *Lagochilus olgae* Kamelin, *Thymus subnervosus* Vved., Nabiev & Tulyag, *Dracocephalum nuratavicum* Adylov, and *Phlomis nubilans* Zakirov, whose natural populations in the Nurota region have been well studied. The distribution of these species during 1970–2000 and their predicted distribution under the RCP8.5 scenario for the year 2070 were analyzed.*

Keywords: *bioclimatic modelling, Nurata, MaxEnt, RCP, plant conservation, endemic species, Central Asia.*

INTRODUCTION

Approaches developed for modeling species distribution in the fields of biology, ecology, nature conservation, and biogeography are widely applied for various purposes. Such models serve as an effective tool in optimizing species management and conservation processes (ELITH & al. 2011). Their main principle is based on the use of bioclimatic variables in determining habitat suitability (STICKLEY & FRATERRIGO 2023), as well as on the use of data about species occurrence points. The model is usually expressed in the form of spatial points (coordinates), with process intensity determined by environmental factors (DANIEL & al. 2020). By comparing data that record the presence and absence of species, it becomes possible to validate the models and assess their reliability. The results obtained in this way serve as a basis for evaluating the boundaries and extent of current suitable habitats. Applying these correlative relationships to future climate scenarios makes it possible to predict potential changes in species distribution (TANG & al. 2020). Evidence shows that global warming significantly affects habitat suitability (SCHNASE & al. 2021). Under the impact of climate change, the habitats of species are bound to change (ELITH & al. 2011). Time- and space-based models make it possible to develop monitoring systems as early warning signals during climate change processes (MAO & al. 2022).

MATERIAL AND METHODS

Today, methods such as ENFA (Ecological Niche Factor Analysis), BIOCLIM (Bioclimatic Envelope Algorithm), CART (Classification and Regression Tree), GLM (Generalized Linear Model), GAM (Generalized Additive Models), and MaxEnt (Maximum Entropy) are widely applied in the fields of biogeography, nature conservation, and ecology for the purpose of modeling species distribution (CÁRDENAS & al. 2023). The MaxEnt (Maximum Entropy) model is one of the most widely used models for simulating the spatial distribution of species (ALIEVA & al. 2025). It is a model for estimating species density and predicting distribution based on algorithms that use environmental data and species occurrence records. In addition, this model is often applied for analyzing species conservation zones and endemic species (VERGARA & al. 2023).

This approach is frequently used to determine species adaptability, restore populations, and forecast the adaptability of endemic species (MAHMOODI & al. 2022). To accurately map future distributions and improve the precision of model predictions, MaxEnt employs climate change scenarios. This is especially useful for several datasets where species distribution data are scarce, and despite certain limitations, it proposes the potential distribution of species (MUGIYO & al. 2022, VERGARA & al. 2023). Through training relationships under real conditions, this model can be used to assess species distribution under variable ecological factors (VERGARA & al. 2023). As a result, the model evaluates the expansion or contraction of species distribution ranges on a global scale (ELITH & al. 2011, TANG & al. 2020).

RESULTS AND DISCUSSION

The problem of modern climate change caused by human activity is one of the most pressing challenges facing humanity in the 21st century (NURIDINOV & al. 2023). It should be emphasized that climate change, due to the extreme weather events it triggers, has become a matter of global concern. Although the average temperature increased by 0.85 °C over the past century, the greatest rise in temperature is expected to reach 8 °C by the year 2100 (LAZKOV 2019). According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), by the end of the 21st century the average global temperature is projected to increase by 3.7 °C under the Representative Concentration Pathways (RCPs) scenario (LEE & al. 2020). As a result of global warming and human activity, scientists have determined that species sensitive to factors such as temperature and precipitation may either become rapidly extinct in the future or undergo shifts in their potential ranges (TOJIBAEV & al. 2022). Although these environmental factors do not negatively affect all species, developing decisive measures for the conservation of rare and endemic species that are geographically isolated, have low reproductive potential, and are sensitive to climatic factors is of vital importance from both scientific and practical perspectives (ERFANFAR & al. 2014).

In this study, four endemic species were selected, and the results obtained based on them revealed the following:

Lagochilus olgae Kamelin

Geographical distribution range: Occurs in the middle and upper zones of the Nurata and Aktau ranges at elevations of 1300–1800 m, on rocky and gravelly slopes and cliffs. This plant was found in the Nurata part of Jizzakh region — in the Nurata Nature Reserve, in the Hayatsoy area (on rocky slopes at about 1575 m a.s.l., 40.521463°N, 66.844122°E) (POWO 2025).

Life form: subshrub (hemicryptophyte).

Phenology: June–July (flowering), July–August (fruiting) (MAMADALIEVA & al. 2021).

Biology: Included in the Red Data Book of Uzbekistan with status category 2, classified as a narrow-range species that requires protection, and mainly reproduces by seeds.

Thymus subnervosus Vved., Nabiev & Tulyag.

Geographical distribution range: Occurs in the middle and upper zones of the Nurata and Aktau ranges at elevations of 1300–2100 m, on rocky and gravelly slopes and cliffs. This plant was recorded on the northern slopes of the Nurata Range, within the Nurata Reserve, in the “Bolo-say” area at 1800 m on May 25, 1982, and in the Aktau Mountains (Jizzakh region), near the village of Khoja Qolishan (Yang-Ogly area) at 1926 m on June 8, 1926 (FLORAGRIDMAP.UZ 2010).

Life form: subshrub (hemicryptophyte).

Phenology: May–June (flowering), June (fruiting) (POWO 2025).

Biology: reproduces mainly by seeds.

Dracocephalum nuratavicum Adylov

Geographical distribution range: Occurs in the middle and upper mountain zones of the Nurata and Aktau ranges at elevations of 1300–2100 m, on rocky and gravelly slopes and cliffs (VOLIS & BESHKO 2023). This species is also found in the Pamir-Alai Range; the Turkiston Range (Guralash part) (ABDULLAEVA & al. 2021), as well as in the Nurata Mountains (ABDULLAEVA 2016). It has been recorded in the Nurota Reserve — Beshko, Hayatsoy, at 1800 m (No. 06072012, July 6, 2012) (ABDULLAEVA & al. 2019).

Life form: subshrub (hemicryptophyte).

Phenology: May–June (flowering), June–July (fruiting) (ABDULLAEVA & al. 2021).

Biology: In the flora of Uzbekistan, it is a narrow-range species that requires protection and mainly reproduces by seeds.

Phlomis nubilans Zakirov

Geographical distribution range: Found in the middle and upper zones of the Nurata and Aktau ranges at elevations of 800–2100 m, on soil-covered and rocky slopes. This species occurs in the Nurata and Aktau ranges, within Jizzakh Region — Hayatsoy, and in Navoi Region near Langar (at approximately 1500–1700 m) (PLANTARIUM).

Life form: subshrub (hemicryptophyte).

Phenology: June–August (flowering), July–September (fruiting) (AKHMEDOV & al. 2023).

Biology: In the flora of Uzbekistan, it is classified as a narrow-range species requiring protection, mainly reproducing by seeds. Included in the Red Data Book of Uzbekistan under category 3. The following list of endemic species was compiled based on the analysis of specimens preserved in the National Herbarium of Uzbekistan (TASH).

It was found that the largest number of herbarium specimens belongs to *Phlomis nubilans* (33 specimens), while the smallest number belongs to *Thymus subnervosus* (1 specimen) (Table 1, FLORAGRIDMAP.UZ).

Table 1. Number of available specimens of these species in the TASH collection.

№	Family	Genus	Species	Number of recorded herbarium specimens
1	Lamiaceae Martinov	<i>Dracocephalum</i> L.	<i>Dracocephalum nuratavicum</i> Adylov	12
2	Lamiaceae Martinov	<i>Lagochilus</i> Bunge ex Benth.	<i>Lagochilus olgae</i> Kamelin	14

3	Lamiaceae Martinov	<i>Phlomis</i> L.	<i>Phlomis nubilans</i> Zak.	33
4	Lamiaceae Martinov	<i>Thymus</i> L.	<i>Thymus subnervosus</i> Vved., Nabiev & Tulyag.	1

When these species were assessed according to the IUCN categories and criteria, the evaluation was as follows. Using **EOO** (extent of occurrence) and **AOO** (area of occupancy) calculated with the help of the GeoCAT (Geospatial Conservation Assessment Tool) program, the species *Dracocephalum nuratavicum*, *Lagochilus olgae*, and *Phlomis nubilans* were assessed as EN—Endangered, while *Thymus subnervosus* was assessed as CR—Critically Endangered (Table 2, VOLIS & BESHKO 2023). In order to determine whether these species will survive in the future or face complete extinction, the MaxEnt (Maximum Entropy) model was applied.

Table 2. Species with georeferenced data, EOO, AOO, Red Book status, and IUCN conservation status.

Species	Number of georeference d data used	EO O, km2	AO O, km2	Uzbekis tan Red Book status	Conservation status assessed according to the IUCN categories and criteria
<i>Dracocephalum nuratavicum</i>	9	319	32	none	EN
<i>Lagochilus olgae</i>	31	108	60	2	EN
<i>Phlomis nubilans</i>	45	295	84	3	EN
<i>Thymus subnervosus</i>	4	91	16	none	CR

Analyzing endemic and rare species that are expected to expand their natural populations and occupy new areas under future bioclimatic scenarios plays an important role in assessing their future distribution and the effectiveness of conservation measures. According to this analysis, a number of endemic species may expand their ranges or adapt to new ecological conditions in the future. The following results illustrate potential future populations and their conservation.

The natural range of *Dracocephalum nuratavicum* during 1970–2000 was mainly confined to the mountainous and foothill areas of Jizzakh, Navoi, Samarkand, and Surkhandarya regions of Uzbekistan. According to the results obtained from the MaxEnt model, the most suitable habitats for the species are shown in red on the map, representing the core areas with the most optimal ecological conditions. These areas are characterized mainly by moderately elevated, temperate mountain slopes. Based on climate projections under the RCP8.5 scenario for 2070, the distribution range of *D. nuratavicum* is expected to slightly expand, with the formation of new potential habitats. In particular, new suitable ecological niches are likely to emerge in Kashkadarya Region and the southern part of Samarkand Region. This indicates the possibility for the species to migrate into new environments. At the same time, an upward shift along the altitudinal gradient is observed, meaning that populations are moving to higher elevations in response to climate change. This clearly demonstrates the impact of global climate change on the distribution of endemic species (**Fig. 1**).

According to the model evaluations, the main bioclimatic and topographic factors influencing the distribution of the species were as follows:

bio4 – Temperature seasonality: indicates that the species is adapted to areas with low fluctuations in mean temperature.

bio7 – Annual temperature range (difference between mean temperatures of the warmest and coldest months): reflects the sensitivity of the species to climate variability.

slope1 ($0.5\% \leq 2\%$), slope2 ($2\% \leq 5\%$), slope7 ($30\% \leq \text{slope} \leq 45\%$): these parameters show the species' preference for certain slope degrees, with moderate and steep slopes being particularly favorable ecological habitats.

Lagochilus olgae occurs in the northern parts of Jizzakh Region. These areas provide suitable ecological conditions and represent the most favorable habitats for the species. The habitats in Jizzakh Region constitute the main distribution areas of the species, where the survival potential of its populations is very high. However, small populations are also found in Kashkadarya and Surkhandarya regions, where they strive to persist under variable climatic conditions (**Fig. 1**).

By 2070, under the influence of climate change, the distribution of *Lagochilus olgae* is expected to undergo some alterations. In Jizzakh, the suitable habitats of the species slightly expand, demonstrating its capacity to adapt to new ecological conditions. New suitable habitats may also emerge in Kashkadarya and Surkhandarya regions, which increases the likelihood of the species expanding southwards. Climate change significantly affects the species' distribution range, yet it still has the potential to adapt to newly available habitats. Such expansion and adaptability may create opportunities for the species to survive in new ecological environments.

During 1970–2000, the main factors influencing the species' distribution were:

- Bio19 (Precipitation of coldest quarter)
- Bio11 (Mean temperature of coldest quarter)
- Slope2 ($0.5\% \leq \text{slope} \leq 2\%$)
- Elevation

For 2070, the factors contributing to the species' distribution shift as a result of climate change are:

- Bio19 (Precipitation of coldest quarter)
- Bio16 (Precipitation of wettest quarter)
- Elevation
- Slope2 ($0.5\% \leq \text{slope} \leq 2\%$)

These factors support the species' adaptation to new conditions and enhance its probability of expanding southwards. Climate change and the emergence of new suitable habitats further intensify ecological impacts. The distribution of *Phlomis nubilans* during 1970–2000 was mainly observed in the central part of Uzbekistan, with its core populations located in Jizzakh and Navoi regions. During this period, the species had a relatively narrow range, occurring primarily in foothill areas and gentle slopes, where it was recorded at high density. Smaller populations were also found in certain parts of Kashkadarya and Surkhandarya regions, indicating that the species was to some extent adapted to the landscapes of south-central Uzbekistan (**Fig. 1**).

The main ecological factors influencing its distribution between 1970 and 2000 were Bio19 (precipitation of wettest month), Bio7 (annual temperature range), Bio12 (annual precipitation), Slope7 ($30\% \leq \text{slope} \leq 45\%$), and elevation. These factors played a key role in determining the ecological niche of the species. According to projections based on the RCP8.5 scenario for 2070, the habitat range of *Phlomis nubilans* may slightly expand. Model results indicate that populations in Jizzakh and Navoi regions are likely to persist, although within smaller, more fragmented areas. However, in the southern parts of Kashkadarya and Surkhandarya regions, suitable ecological

conditions may disappear due to climate change, potentially leading to a decline or complete loss of populations there.

For 2070 projections, the most influential factors affecting the species' distribution were identified as Bio19 (precipitation of wettest month), Bio16 (precipitation of wettest quarter), elevation, Slope7 ($30\% \leq \text{slope} \leq 45\%$), and Slope8 ($\text{slope} > 45\%$). The natural distribution of *Thymus subnervosus* during 1970–2000 was mainly restricted to Jizzakh and Navoi regions. In this period, the species' populations were more densely concentrated in these areas, while a few small populations occurred in other regions, though they were not widespread. The ecological requirements of the species indicate its adaptation to the dry and semi-desert environments characteristic of these regions (**Fig. 1**).

According to projections based on the RCP8.5 scenario for 2070, the habitat of the species is expected to expand significantly. By 2070, populations in Navoi, Jizzakh, Kashkadarya, and Surkhandarya regions may become more established, with new habitats emerging. These changes reflect the species' ability to adapt to the climatic conditions of southern and central Uzbekistan. During 1970–2000, the main factors influencing its distribution were Bio4 (temperature seasonality), Bio7 (annual temperature range), Slope2 ($15\% \leq \text{slope} \leq 30\%$), and Slope1 ($\text{slope} \leq 15\%$). These factors remain significant in shaping its distribution under the 2070 projections as well.

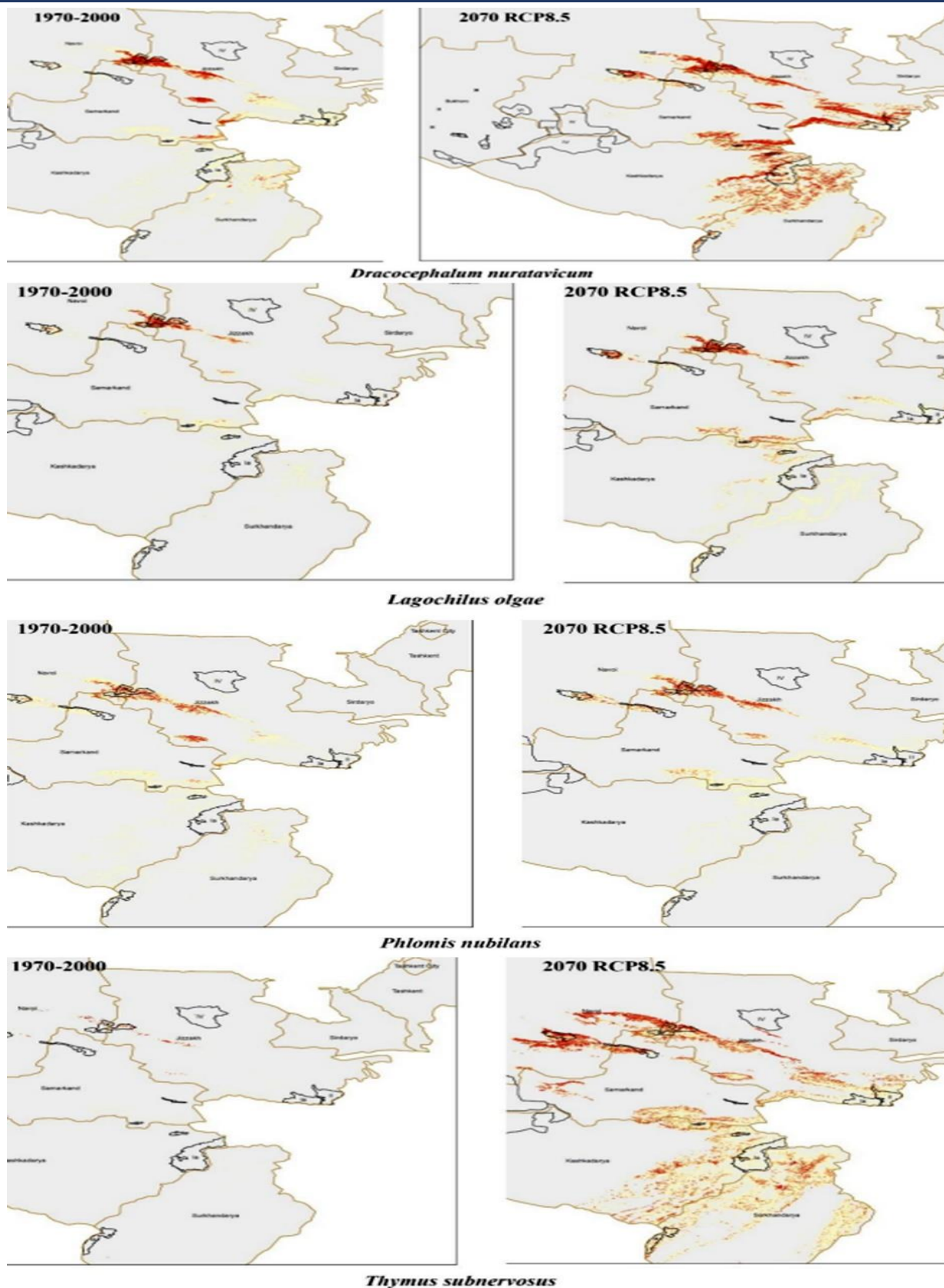


Figure 1. Historical distribution of species during 1970–2000 and its potential changes under the impact of climate change RCP8.5 scenario for 2070.

Conclusion.

According to the results of the conducted study, under all climate scenarios, an increase in air temperature by 1.5–5 °C will lead to the expansion of medium and high development zones of

the modeled species in the future. Among the four studied species of the family Lamiaceae, *Phlomis nubilans* is considered a true narrow endemic, since its projected ranges are restricted solely to the Nuratau Mountains. Model results indicate that populations in Jizzakh and Navoi regions may persist, although within smaller, more fragmented areas. However, in the southern parts of Kashkadarya and Surkhandarya regions, suitable ecological conditions may disappear due to climate change, which could result in population decline or even complete extinction.

The remaining three species, in contrast, have wider ranges, with the Nuratau Mountains constituting only a small part of their distribution. These species may show stronger population establishment in Navoi, Jizzakh, Kashkadarya, and Surkhandarya regions, with the emergence of new suitable habitats. The case study of endemic species distributed in the Nuratau Range demonstrates that most of the surrounding environment is unsuitable for their survival, and projected warming may have devastating consequences for some of them. Under future climate conditions, suitable areas for such species will be highly limited and spatially isolated. For narrowly distributed endemic species, the most appropriate adaptation strategy to climate change is the establishment of populations in newly suitable areas (based on SDM projections and expert recommendations), and if such areas do not exist, the preservation of seeds in seed banks becomes essential.

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