ABS ACTA BIOLOGICA SIBIRICA
A journal on the biodiversity of Siberia and the adjacent lands

Acta Biologica Sibirica 12: 1047–1062 (2026)
doi: 10.5281/zenodo.22014679
http://journal.asu.ru

RESEARCH ARTICLE

Climate modeling of some representatives of the *Quercus* genus

Azizullo K. Ibragimov[1], Vladimir F. Zaikov[2], Tatiana A. Sinitsyna[2], Saifiddin K. Davlatzoda[1]

1 *Department of General Biology, Nosir Khusrav Bokhtar State University, 67 Aini Street, Bokhtar, 735140, Tajikistan*
2 *Altai State University, 61 Lenina Ave., Barnaul, 656049, Russian Federation*

Corresponding author: Vladimir F. Zaikov (vz1703@mail.ru)

Academic editor: A. Matsyura | Received 19 June 2026 | Accepted 5 August 2026 | Published 22 August 2026

http://zoobank.org/A20FF636-5886-4C54-8580-E401E4AF5B01

Citation: Ibragimov AK, Zaikov VF, Sinitsyna TA, Davlatzoda SK (2026) Climate modeling of some representatives of the *Quercus* genus. Acta Biologica Sibirica 12: 1047–1062. https://doi.org/10.5281/zenodo.22014679

Abstract
Representatives of the *Quercus* genus are valuable ornamental plants. In Tajikistan, 13 species of the genus are cultivated in botanical gardens. Climate modeling was carried out for eight of these species. According to the results, the temperature regime (in most cases, the average annual temperature and the average temperature of the coldest quarter) plays a significant role in the distribution of species of *Quercus*. For *Q. coccifera* and *Q. ilex*, the amount of precipitation in the coldest quarter is also important. The territory of Tajikistan is most suitable for the introduction of species such as *Q. robur*, *Q. castaneifolia*, and *Q. macranthera*.

Keywords
Climate modeling, introduction, *Quercus castaneifolia*, *Quercus macranthera*, *Quercus robur*

Introduction

One of the key directions of development for each region is greening. With the growing population, the expansion of urban areas, and increasing environmental pollution, the need for regular greening and tree planting is increasing urgently. The more plants there are in a place, the better the health and psychological atmosphere. Therefore, reasonable and systematic measures to greening are not just an aesthetic addition but a crucial requirement for environmental sustainability and development.

Greening is a set of scientific and practical measures aimed at improving the environment, and includes various stages, such as planting trees, shrubs, flowers, and grass, creating lawns, parks, and squares, and providing regular maintenance. Today, it has become a priority in many countries around the world, as it has a significant impact on improving the environment, reducing harmful gas emissions, lowering air temperatures during the hot seasons, and maintaining the ecological balance of cities.

In the Republic of Tajikistan, the issue of greening is also constantly being strengthened at the state level. In 2023, the country adopted the State Greening Program for the period up to 2040, which defines the goals and priorities of this process. This program is an integral part of the country's environmental policy directed at regulating the natural balance, reducing greenhouse gas emissions, adapting to climate change, and creating a healthy living environment. It also promotes the sustainable use and management of biological resources and the transition of the country to a green economy.

Biodiversity informatics and, in particular, geographic information systems (GIS), are actively developing areas in biology, where they are used in modeling the spatial distribution of species (ecological niche) (Dudov 2016; Lisovsky et al. 2020; Lisovsky, Dudov 2020). Such modeling allows us to establish a connection between species locations in nature and environmental factors, thus predicting their distribution (Elith, Leathwick 2009). This technique is used to solve a number of problems, including nature conservation, identification of the potential distribution of invasive species, assessment of the risks to native species in the face of environmental changes, mapping vegetation, study of the continuous changes in plant communities and the historical aspects of biodiversity formation, identification of parameters of species richness distribution (Thomas et al. 2004; Peterson 2005; Dobrowski et al. 2008; Zimmermann et al. 2011; Cord 2014; Dudov 2016).

In greening, woody and shrub plants have a special decorative status. Among these ornamental plants, representatives of the *Quercus* genus (Oak) introduced from various regions occupy a special place due to their longevity, beautiful crown, and high resistance to frost.

Strong and durable oak wood is highly valued in construction and furniture production and is an excellent fuel for heating buildings (Davlatzoda 2024). In the chemical industry, oak bark is used to produce paints and a durable dye for fabrics and carpets. Acorns are used in agriculture and pharmaceuticals. In agriculture, crushed acorns are used as feed for chickens, cows, pigs, sheep, goats, and rabbits. Acorn flour is also suitable for human consumption. Meanwhile, there is a species as *Quercus rubra*, which is considered an invasive species in many regions of Europe, including Belarus and some regions of Russia. It grows rapidly, displacing local tree species (for example, *Quercus robur*), changing the structure of forests. Its foliage takes a long time to decompose, forming a carpet that prevents the growth of local flora. In this regard, we decided to conduct climate modeling of the potential distribution of several species of *Quercus* to identify the most promising ones for introduction in Tajikistan.

Materials and methods

Climate modeling requires location points of the species and environmental data. We used the Global Biodiversity Information Facility (GBIF, http://www.gbif.org) to assess species distribution. This system includes various data sources, and we used species registration points taken from herbarium collections. Distribution maps were prepared using the QGIS 3.40 program (QGIS.org, QGIS 3.40. Geographic Information System Developers Manual. QGIS Association. Electronic document: https://docs.qgis.org/3.40/en/docs/developers_guide/index.html). The predictive species distribution was modeled using the maximum entropy method in the MaxEnt 4.4.1 program (Maximum Entropy Species Distribution Modeling) (Phillips, Dudik 2008). The advantage of this method is that it only requires the species presence to generate predictive maps, whereas other methods require the points of species absence points.

Climate data for 19 variables were taken from the WORLDCLIM database (WorldClim. Global climate and weather data https://www.worldclim.org/) (Bioclimatic variables: BIO1–BIO19: BIO1 – average annual temperature; BIO2 – daily temperature fluctuations (monthly average); BIO3 – isothermality (BIO1/ BIO7) × 100; BIO4 – seasonality of the temperature (coefficient of variation); BIO5 – maximum temperature of the warmest month; BIO6 – minimum temperature of the coldest month; BIO7 – average annual amplitude of temperature fluctuations (BIO5 – BIO6); BIO8 – average temperature of the wettest quarter; BIO9 – average temperature of the driest quarter; BIO10 – average temperature of the warmest quarter; BIO11 – average temperature of the coldest quarter; BIO12 – average annual precipitation; BIO13 – precipitation of the wettest period; BIO14 – precipitation of the driest month; BIO15 – seasonality of precipitation (coefficient of variation); BIO16 – precipitation of the wettest quarter; BIO17 – precipitation of the driest quarter; BIO18 – precipitation of the warmest quarter; BIO19 – precipitation of the coldest quarter). The contribution of climate parameters to modeling was assessed using the jackknife test (Phillips et al. 2006).

When working with MaxEnt, the following settings were used: logistic output format, 30 % of the points as a test sample, and 70 % – as a training sample. The resulting model in MaxEnt was projected onto a map created using the QGIS program, where the threshold value was 10 percentiles (below this value, the probability of finding a species tends to 0). The AUC value (area under the curve), which ranges from 0 to 1, is used to assess the reliability of the resulting predictive model.

If the value is below 0.5, the resulting model is random. Values close to 1 indicate a good quality of the predictive model (0.8–1). In our work, we conducted climate modeling for eight species of the genus *Quercus* introduced in Tajikistan. To do this, we first thinned out species location points to obtain a correct model using the SD-Mtoolbox program (Brown 2014) (Table 1). A good quality model requires at least 100 (or so) species location points.

Table 1. Number of points of the species studied taken into analysis

Species	Total number of points	Number of points after processing
Quercus robur	8676	1192
Q. castaneifolia	189	89
Q. ilex	2481	476
Q. lusitanica	599	119
Q. faginea	4021	264
Q. coccifera	1821	467
Q. macranthera	243	83
Q. suber	1277	304

There is a correlation between climatic variables, and in some studies, it is recommended to exclude them, but there is evidence that such exclusion can lead to the loss of variables that may have a significant impact on species distribution.

The introduction of *Quercus* species into Tajikistan has primarily occurred through botanical gardens and experimental stations. Historically, approximately 13 oak species were introduced under these controlled conditions, though only a few have been utilized for ornamental landscaping. Currently, the primary collections of the genus *Quercus* in Tajikistan are concentrated in four main botanical gardens (Table 2):

1. Botanical Garden of the Academy of Sciences of Tajikistan (Bogi "Iram", Dushanbe);
2. Khujand Botanical Garden;
3. Tillot Boboev Kulyab Botanical Garden (Khatlon Scientific Center of the National Academy of Sciences of Tajikistan);
4. Khorog Botanical Garden (A.V. Gursky Pamir Botanical Garden).

Although 13 *Quercus* species are documented in Tajikistan, eight species were selected for ecological niche modeling. These were chosen based on their high introduction potential and the availability of sufficient occurrence data to generate robust predictive models.

Table 2. Representatives of the *Quercus* genus in the introduction of botanical gardens in Tajikistan

Distribution	Species and form of *Quercus*	Place of introduction
European-Caucasian	*Quercus robur* L. f. *fastigiata* (Lam.) DC f. *pectinata* (Kirchn.) C. Koch	1, 2, 3, 4
	Q. hartwissiana Steven	1
	Q. castaneifolia C.A. Mey	1, 2, 3
	Q. macranthera Fisch. et C.A. Mey	1
	Q. iberica Steven ex M. Bieb.	1
Mediterranean	*Q. ilex* L.	1, 4
	Q. coccifera L.	–
	Q. trojana Webb	1
	Q. faginea Lam.	4
	Q. lusitanica Lam.	4
	Q. suber L.	1
East Asian	*Q. myrsinaefolia* Blume	1
North American	*Q. stellata* Wangenh.	4

Results and discussion

Ecological Niche Modeling and Species-Specific Evaluations

Quercus robur

Quercus robur is natively widespread across western and eastern Europe, western Asia, and northern Africa. The predictive model for this species demonstrated excellent performance (Test AUC = 0.905; Training AUC = 0.914; 10th percentile training threshold = 0.3) (Fig. 1). Jackknife tests indicated that the primary climatic variables limiting its distribution are BIO1 (Annual Mean Temperature), BIO6 (Min Temperature of Coldest Month), and BIO11 (Mean Temperature of Coldest Quarter).

The model identifies the central parts of Tajikistan, including the Districts of Republican Subordination (DRS), the Sughd Region, and areas north of Khujand, as highly favorable for *Q. robur* (Fig. 2). This species is highly polymorphic, possesses a wide ecological amplitude, and is notably light-demanding and drought-tolerant. Its introduction to Tajikistan began in 1930. A 2025 inventory revealed that *Q. robur* is extensively used in urban greening across the Sughd Region (Khujand, Istaravshan, Buston, Kanibadam, Isfara, Bobojon Ghafurov), the DRS (Varzob, Vakhdat, Gissar, Nurobod, Tursunzoda, Rudaki, and four districts of Dushanbe), the Khatlon Region (Bokhtar, Levakant, Kulyab, Norak, and surrounding districts), and the Gorno-Badakhshan Autonomous Region (GBAO) (Zapryagaeva & Gursky 1953; Ibragimov 2025). In these locations, the species exhibits vigorous growth, profuse flowering and fruiting, and successful natural self-seeding around mature trees, indicating high ecological adaptability.

Quercus castaneifolia

The model for *Q. castaneifolia* also yielded excellent results (Test AUC = 0.955; Training AUC = 0.956; 10th percentile threshold = 0.288). As with *Q. robur*, the most significant predictors of its distribution were BIO1, BIO6, and BIO11 (Fig. 3). Natively restricted to the Caucasus (Azerbaijan, where it is Red-Listed) and northern Iran, it has been cultivated in Europe since the mid-19th century.

In Tajikistan, the model predicts high suitability in the western and northwestern regions, including the DRS, Sughd, and Khatlon (Fig. 4). Despite this, its use in urban landscaping remains limited. Historically introduced in 1934 (Lapin 1986), it was planted in the Kulyab Botanical Park in 1988 using stock from Dushanbe. In the Sughd Region, it is currently restricted to the Khujand Botanical Garden. Recent 2024 surveys in Bokhtar identified isolated, 12-year-old specimens (4–5 m tall, 1.5–2 m crown width) on Vakhdat Avenue (Ibragimov, 2024). With the exception of the recently planted Bokhtar specimens, all observed trees exhibit excellent development, lacking leaf scorch, and demonstrating profuse reproduction and self-seeding.

Quercus coccifera and *Quercus ilex*

Quercus coccifera, a Mediterranean species considered a rare ornamental, yielded an excellent model (Test AUC = 0.958; Training AUC = 0.961; threshold = 0.378). Its predictive distribution closely matched its actual range (Fig. 5). The key climatic drivers included BIO1, BIO6, BIO11, and notably, BIO19 (Precipitation of Coldest Quarter). Currently, it is only cultivated in the Khorog Botanical Garden. However, the model suggests that the areas west of Dushanbe offer the most favorable climatic conditions in the country (Fig. 6).

Similarly, the model for the evergreen Mediterranean species *Q. ilex* (known in cultivation since the 16th century) was excellent (Test AUC = 0.913; Training AUC = 0.918; threshold = 0.37), driven by BIO1, BIO6, BIO11, and BIO19 (Fig. 7). Cultivated in Tajikistan since 1941 in Dushanbe and Khorog, historical attempts to introduce it to the Bokhtar zone (Experimental Station for Subtropical and Citrus Crops) in 1952 failed due to severe frost damage in 1956, leading to the removal of the plants (Tsulaya 1961; Ibragimov 2025). The model accurately reflects this cold sensitivity, predicting the most favorable zones for *Q. ilex* to be west of Dushanbe (Fig. 8).

Quercus macranthera

Natively distributed across the mountainous regions of Iran, Syria, Turkey, Lebanon, and the Caucasus, *Q. macranthera* has been cultivated in Europe since the mid-19th century. Its model was highly accurate (Test AUC = 0.983; Training AUC = 0.970; threshold = 0.33). The primary drivers shifted slightly to include Isothermality (BIO3) and Temperature Seasonality (BIO4), alongside BIO11 and BIO6 (Fig. 9). The predicted suitable range is slightly broader than its current actual distribution.

Introduced to the Dushanbe Botanical Garden in 1955, the model indicates that the mountainous parts of the Sughd Region and the DRS are highly suitable for this species (Fig. 10). Despite this high climatic suitability, *Q. macranthera* is currently underutilized in Tajik urban greening. To address this, seeds were obtained from the Dushanbe Botanical Garden in 2022 and sown at the experimental sites of Nosir Khusrav Bokhtar State University, where they are currently progressing through their vegetative stages (Ibragimov 2025).

Quercus faginea, *Quercus lusitanica*, and *Quercus suber*

These three species, native to western/southwestern Europe and northern Africa, were modeled collectively due to their similar ecological profiles (Figs 11–13). In Tajikistan, *Q. faginea* is present in the Khorog Botanical Garden, while *Q. lusitanica* and *Q. suber* are maintained in Dushanbe. The models indicate that the territory of Tajikistan is generally suboptimal for these species. While the models were statistically robust (AUC > 0.9 for both test and training samples), the key variables varied: BIO1, BIO11, BIO3, and BIO6 for *Q. faginea*; BIO1, BIO11, and BIO19 for *Q. lusitanica*; and BIO1, BIO6, BIO11, and BIO19 for *Q. suber*.

Synthesis of Climatic Drivers and Limitations

Synthesis of the ecological niche models reveals that temperature regimes are the primary determinants of *Quercus* distribution in Tajikistan. Specifically, Annual Mean Temperature (BIO1) and the Mean Temperature of the Coldest Quarter (BIO11) were universally critical. For Mediterranean species (*Q. coccifera* and *Q. ilex*), winter precipitation (BIO19) also played a vital role. Based on the modeled climatic suitability, Tajikistan is highly favorable for the broader introduction of *Q. robur*, *Q. castaneifolia*, and *Q. macranthera*.

It is imperative to note that these predictive models are based exclusively on bioclimatic variables. They do not account for edaphic (soil) factors, biological traits, interspecific competition, or anthropogenic disturbances, which are critical for the actual establishment and long-term survival of introduced taxa.

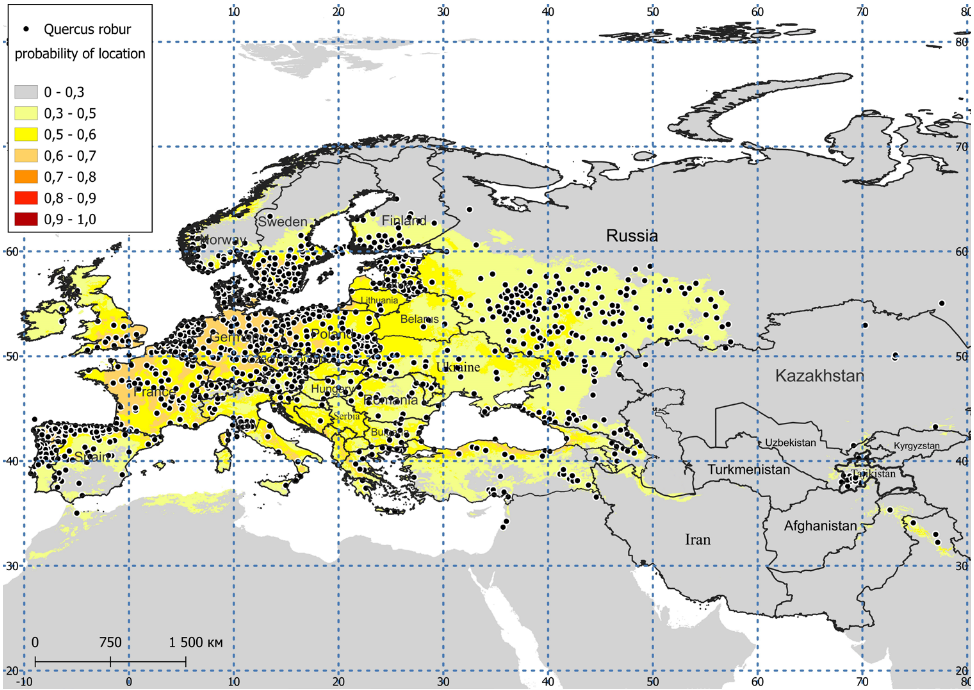

Figure 1. General predictive distribution and location points of *Q. robur*.

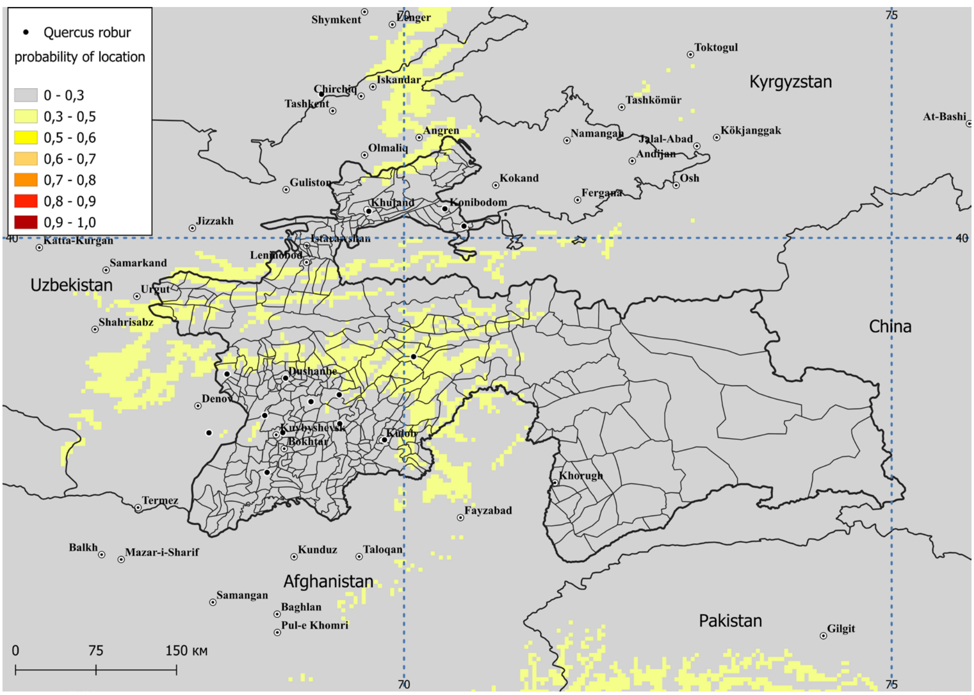

Figure 2. Predictive distribution and location points of *Q. robur* in Tajikistan.

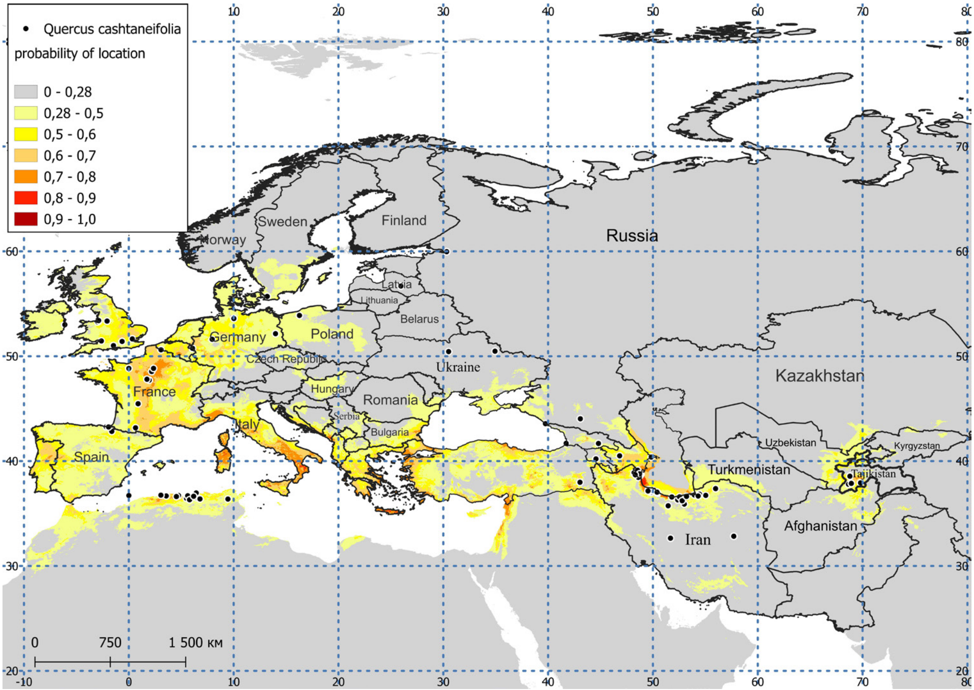

Figure 3. General predictive distribution and location points of *Q. castaneifolia*.

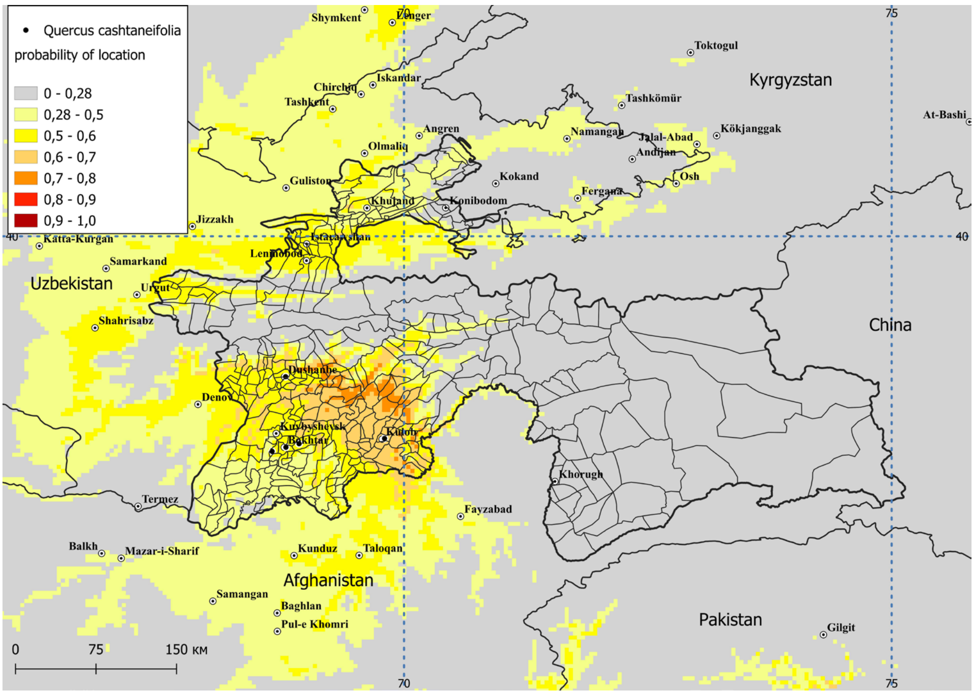

Figure 4. Predictive distribution and location points of *Q. castaneifolia* in Tajikistan.

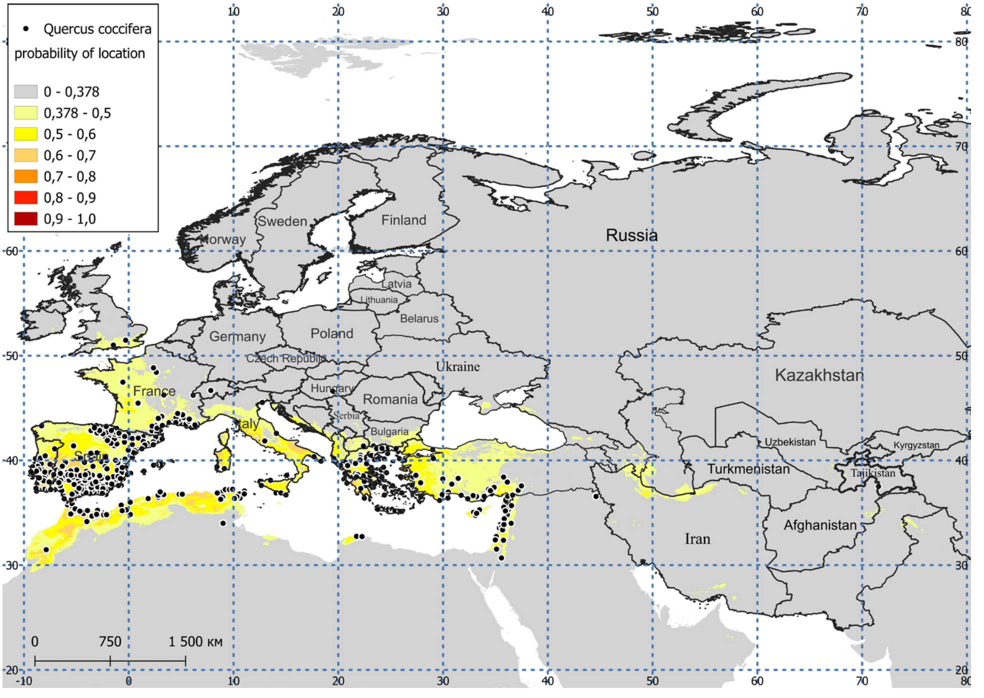

Figure 5. General predictive distribution and location points of *Q. coccifera*.

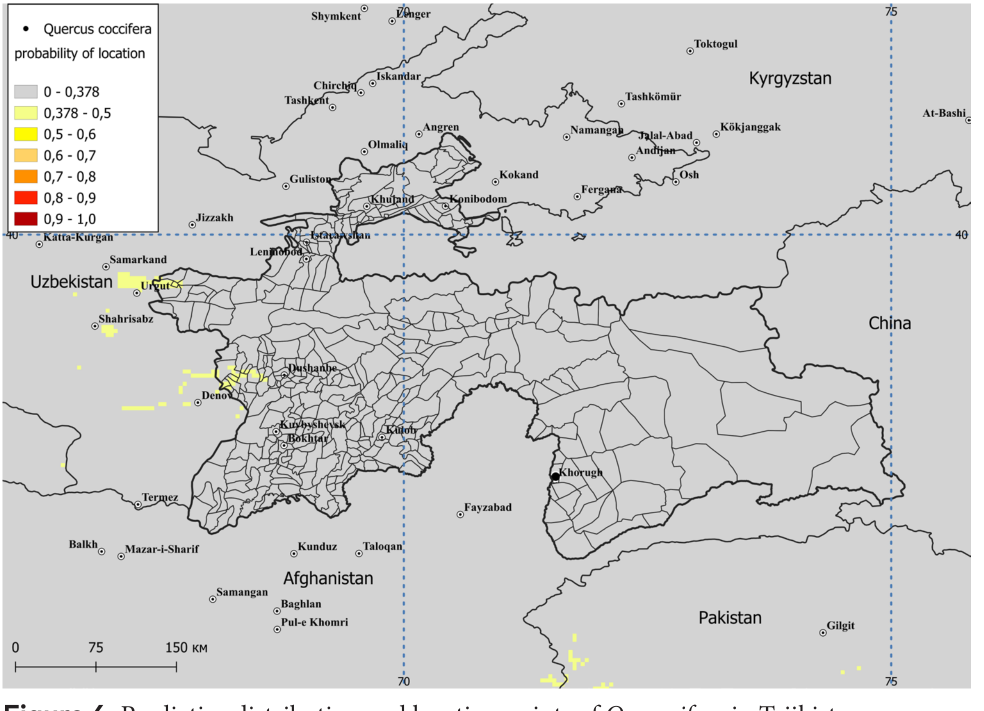

Figure 6. Predictive distribution and location points of *Q. coccifera* in Tajikistan.

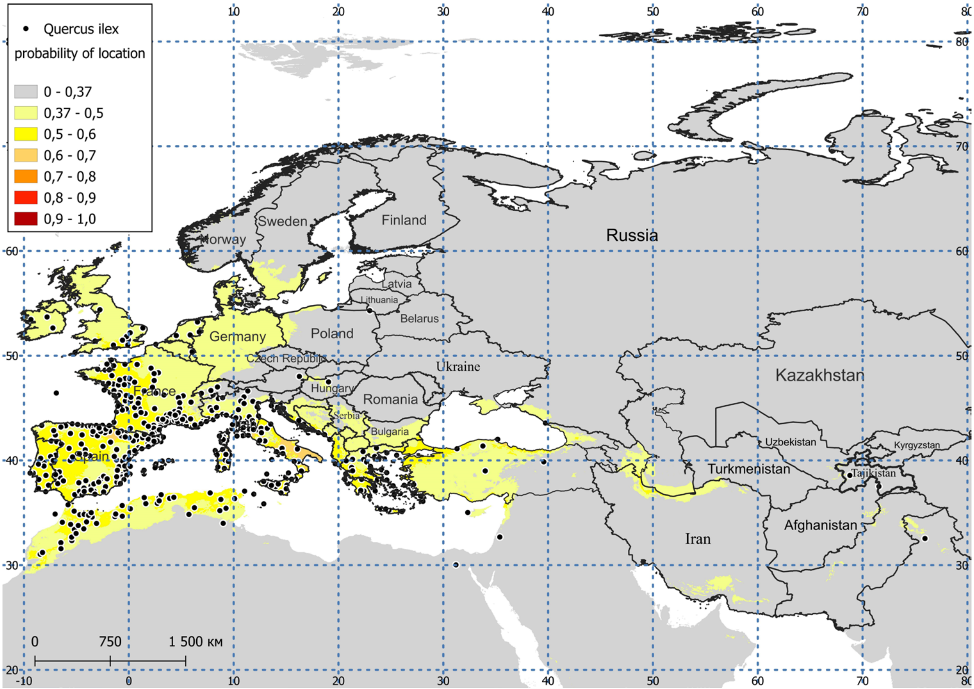

Figure 7. General predictive distribution and location points of *Q. ilex*.

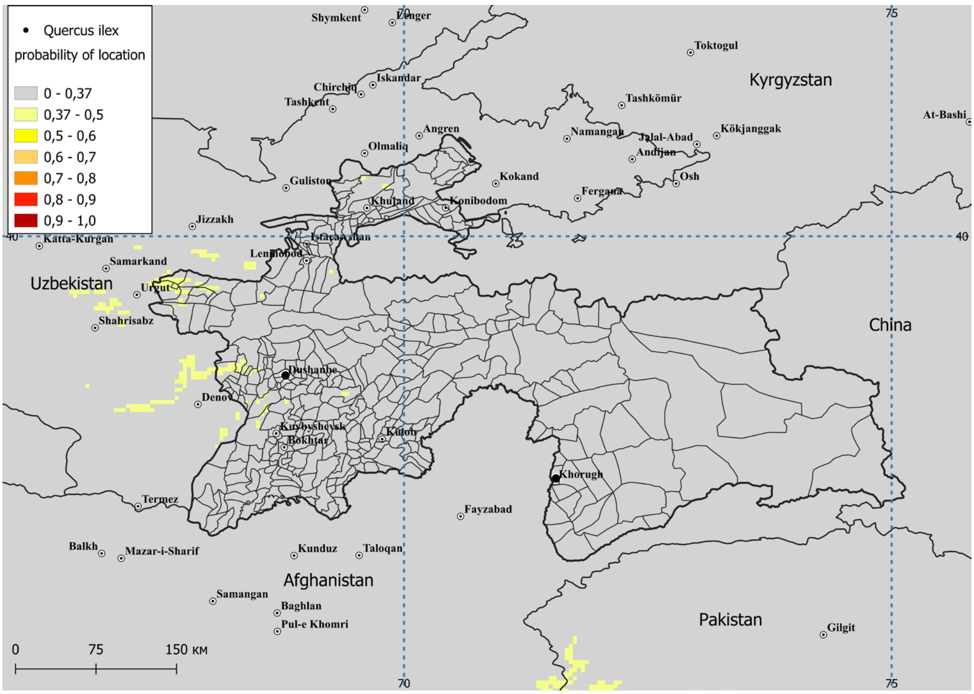

Figure 8. Predictive distribution and location points of *Q. ilex* in Tajikistan.

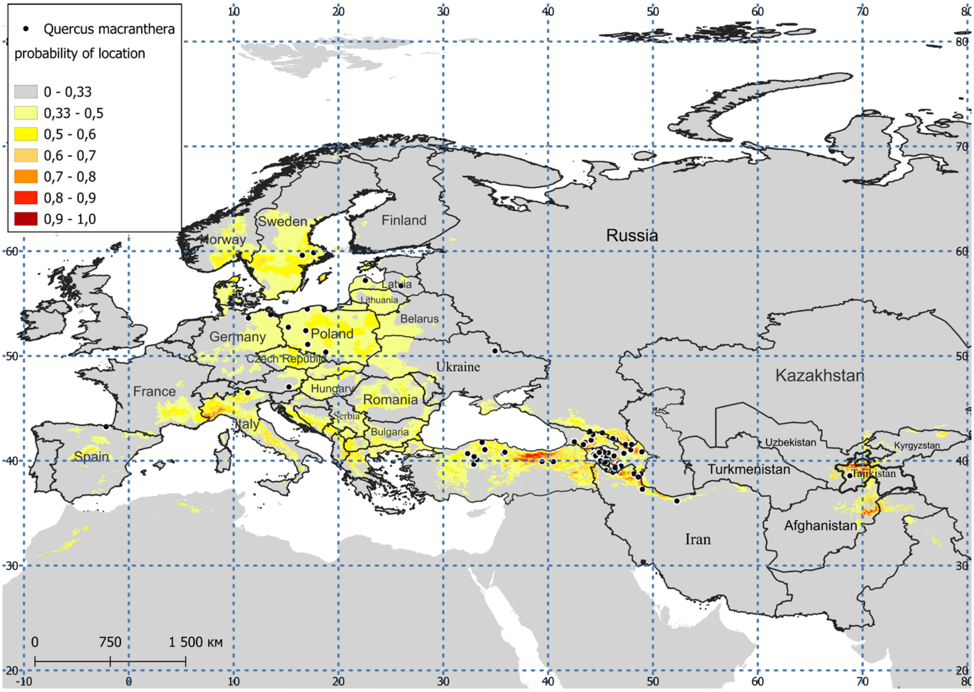

Figure 9. General predictive distribution and location points of *Q. macranthera*.

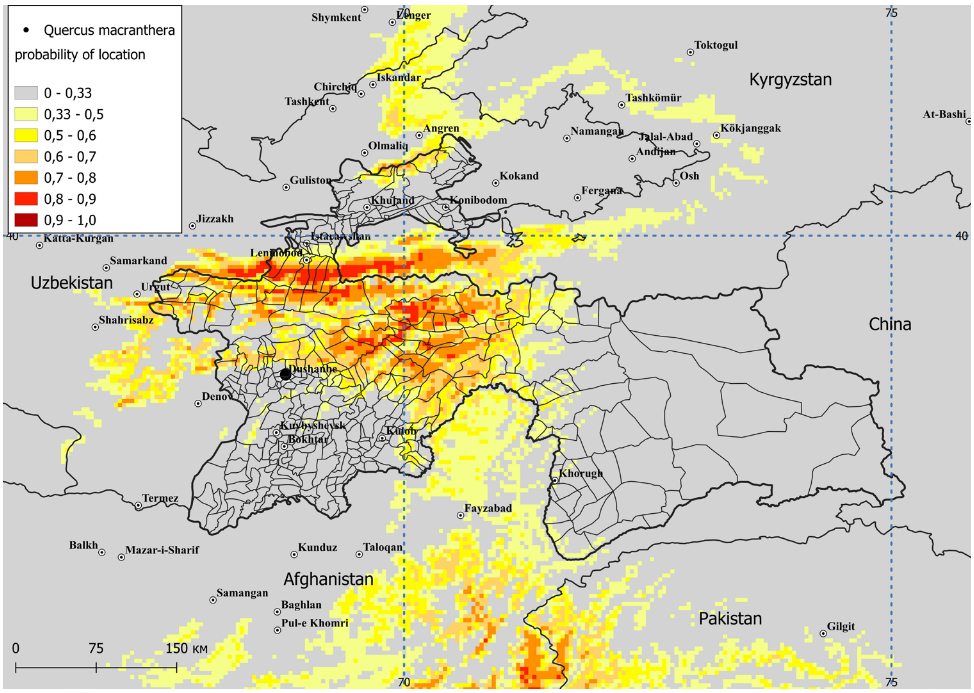

Figure 10. Predictive distribution and location points of *Q. macranthera* in Tajikistan.

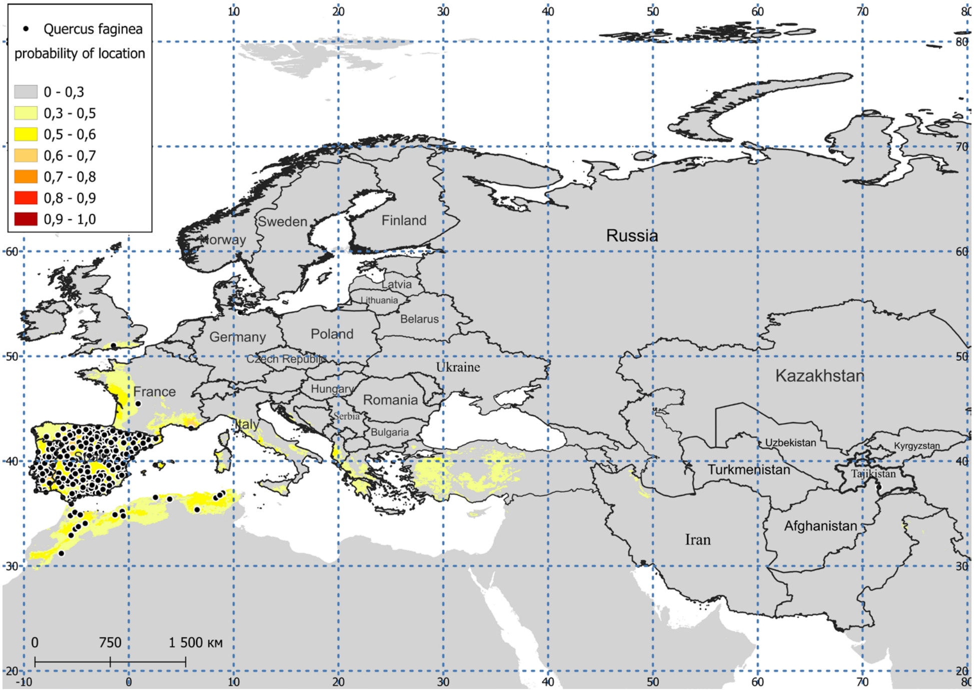

Figure 11. General predictive distribution and location points of *Q. faginea*.

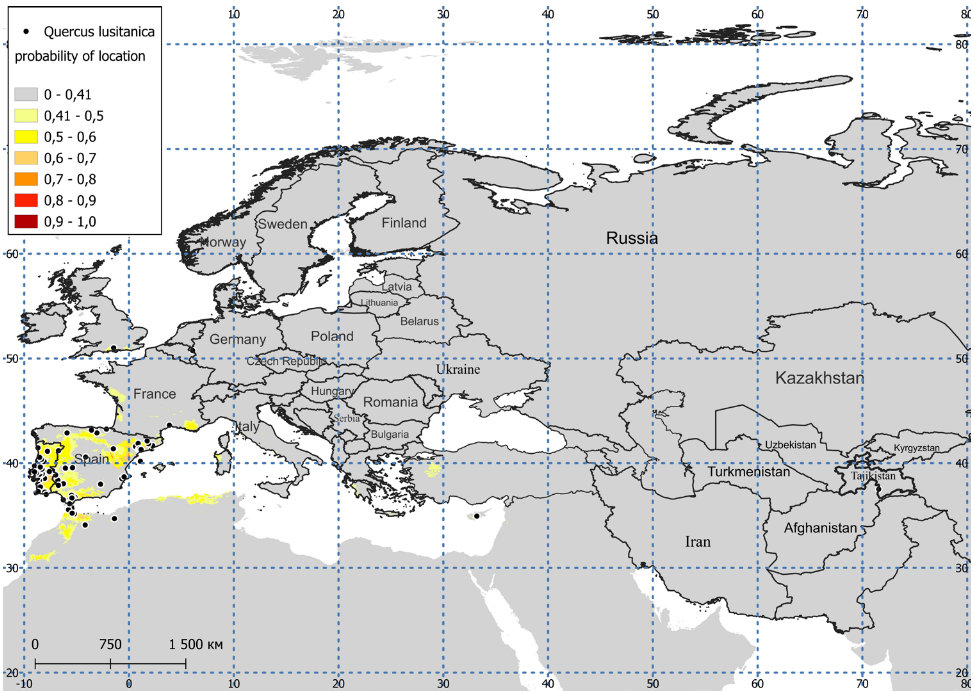

Figure 12. General predictive distribution and location points of *Q. lusitanica*.

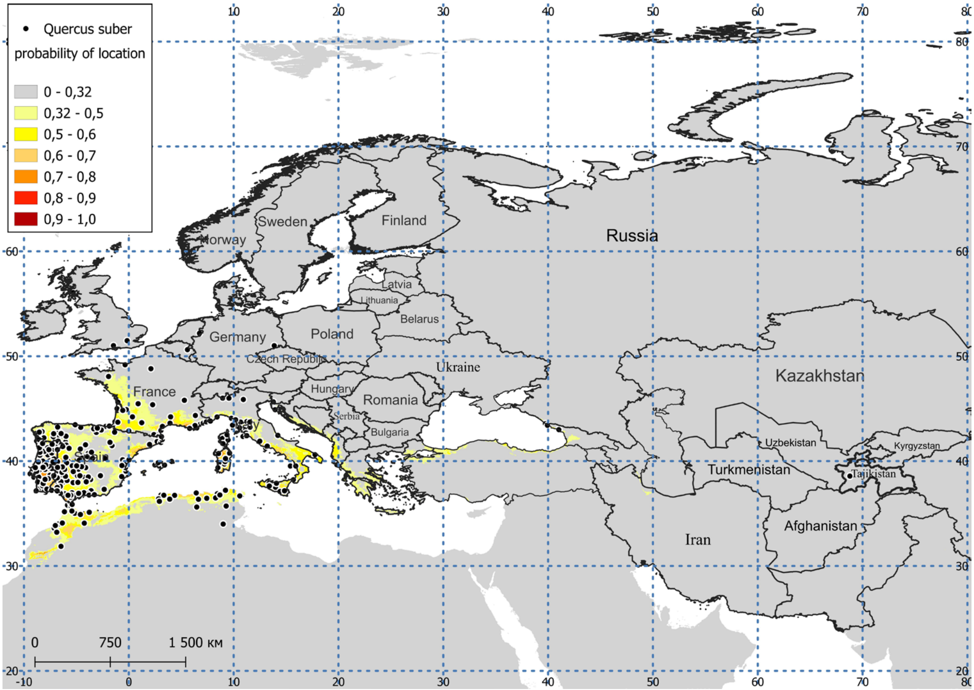

Figure 13. General predictive distribution and location points of *Q. suber*.

Conclusion

This study provides a comprehensive evaluation of the introduction, current distribution, and climatic suitability of eight *Quercus* species in Tajikistan using ecological niche modeling. The results demonstrate that while 13 oak species have been historically introduced into the country, their utilization in urban greening and forestry remains fragmented.

The predictive models exhibited excellent accuracy (AUC > 0.90) across all evaluated species, confirming the reliability of the bioclimatic variables in determining their potential distribution. Temperature regimes, particularly Annual Mean Temperature (BIO1) and the Mean Temperature of the Coldest Quarter (BIO11), were identified as the most critical limiting factors for the genus in the region. For Mediterranean taxa, winter precipitation (BIO19) emerged as an equally vital constraint.

Based on the spatial predictions and field observations, we conclude the following:

Highly Recommended Species: *Quercus robur*, *Quercus castaneifolia*, and *Quercus macranthera* exhibit the highest climatic suitability and proven phenological adaptability in Tajikistan. These species should be prioritized for expanded use in urban landscaping, shelterbelts, and afforestation projects, particularly in the Districts of Republican Subordination and the Sughd Region.

Conditionally Suitable Species: *Quercus coccifera* and *Quercus ilex* show high potential but are strictly limited by winter cold and require specific microclimates, such as the areas west of Dushanbe, to avoid frost damage.

Suboptimal Species: *Quercus faginea*, *Q. lusitanica*, and *Q. suber* are not recommended for widespread introduction, as the climatic models indicate that the territory of Tajikistan falls outside their optimal ecological niches.

While climate modeling provides a robust framework for predicting species distribution, it represents only a partial picture of ecological viability. Future research and practical introduction efforts must integrate edaphic (soil) analyses, hydrological data, and assessments of biotic interactions to ensure the successful, long-term establishment of *Quercus* species in Tajikistan's changing environmental landscape.

Acknowledgements

The study was supported by the Ministry of Science and Higher Education of the Russian Federation (project No FZMW-2026-0006).

References

Cord AF, Klein D, Gernandt DS, Perez JA, Dech S (2014) Remote sensing data can improve predictions of species richness by stacked species distribution models: a case study for Mexican pines. Biogeography 41(4): 736–748. https://doi.org/10.1111/jbi.12225

Davlatzoda SKh, Ibragimov A, Bobokalonov JM, Baikova EV (2024) Assessment and identification of the main species of trees and shrubs for greening in Bokhtar. The Plant World of Asian Russia 4: 327–337. https://doi.org/10.15372/RMAR20240406 [In Russian]

Dobrowski SZ, Safford HD, Cheng YB, Ustin SL (2008) Mapping mountain vegetation using species distribution modeling, image-based texture analysis, and object-based classification. Applied Vegetation Science 11: 499–508. https://doi.org/10.3170/2008-7-18560

Dudov SV (2016) Modeling of species distribution using topography and remote sensing data, with vascular plants of the Tukhuringra Range low mountain belt (Zeya 181 Nature Reserve, Amur Region) as a case study. Journal of General Biology 7(1): 16–28. https://doi.org/10.1134/S2079086417030021 [In Russian]

Elith J, Leathwick JR (2009) Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution and Systematics 40: 677–697. https://doi.org/10.1146/annurev.ecolsys.110308.120159

Gursky AV, Zapryagaeva VI, Koroleva AS, Ryabova TI (1953) Greening of cities and villages in Tajikistan. Publishing House of the Academy of Sciences of the Tajikistan SSR, Stalinabad, 139 pp. [In Russian]

Ibragimov AKh (2025) History of study and distribution of some species of the genus *Quercus* L. in the Republic of Tajikistan (Bokhtar zone). The Light of Science Higher Attestation Commission under the President of the Republic of Tajikistan. Shine of Science 4(08): 158–164. [In Russian]

Lisovsky AA, Dudov SV, Obolenskaya EV (2020) Advantages and limitations of methods for ecological modeling areas. 1. Common approaches. Journal of General Biology 81(2): 123–134. https://doi.org/10.31857/S0044459620020037 [In Russian]

Lisovsky AA, Dudov SV (2020) Advantages and limitations of methods for ecological modeling areas. 2. MAXENT. Journal of General Biology 81(2): 135–146. https://doi.org/10.31857/S0044459620020049 [In Russian]

Peterson EB (2005) Estimating cover of an invasive grass (*Bromus tectorum*) using tobit regression and phenology derived from two dates of Landsat ETM plus data. International Journal of Remote Sensing 26: 2491–2507. https://doi.org/10.1080/01431160500127815

Phillips SJ, Dudik M (2008) Modeling of species distributions with MaxEnt: new extensions and a comprehensive evaluation. Ecography 31: 161–175. https://doi.org/10.1111/j.0906-7590.2008.5203.x

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BF, De Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, Van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL, Williams SE (2004) Extinction risk from climate change. Nature 427: 145–148. https://doi.org/10.1038/nature02121

Tsulaya VI (1961) Results of the introduction of tree and shrub species in the Vakhsh Valley. Bulletin of the Main Botanical Garden 40: 17–23. [In Russian]

Zapryagaeva VI, Vilisova VV, Zelyaeva ZR, Rokochaya EK, Temberg YaG (1986) Plants for ornamental gardening in Tajikistan. Nauka, Moscow, 493 pp. [In Russian]

Zimmermann H, Wehrden H, Damascos MA, Bran D, Welk E, Renison D, Hensen I (2011) Habitat invasion risk assessment based on Landsat 5 data, exemplified by the shrub *Rosa rubiginosa* in southern Argentina. Austral Ecology 36(7): 870–880. https://doi.org/10.1111/j.1442-9993.2010.02230.x