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Article

Species Distribution Modeling of Endemic *Jurinea* (Asteraceae) Species Shows Opportunistic Results for Their Conservation

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Abstract: Climate change is expected to alter the distribution patterns of endemic mountain flora, yet species-specific responses remain poorly understood in Central Asia. We modeled the current and future potential distributions of five endemic taxa under SSP1–2.6 and SSP5–8.5 climate scenarios for 2050 and 2070. The results revealed pronounced interspecific differences in climatic sensitivity. Three species (*J. asperifolia*, *J. sangardensis*, and *J. zakirovii*) showed substantial expansion of climatically suitable areas under both scenarios, with projected increases ranging from 90% to 180% relative to present conditions. In addition to the Pamir-Alay region, the western Tien Shan emerged as a potentially suitable area, suggesting additional climatic refugia. In contrast, *J. gracilis* exhibited severe habitat contraction across all projections, including complete loss of suitable area under SSP5–8.5 by 2070, indicating high extinction risk. *J. mariae* demonstrated moderate expansion and relative stability. These contrasting patterns highlight strong interspecific variation in climatic tolerance within a single genus. However, projected expansion does not necessarily guarantee realized range shifts, as dispersal limitation and habitat fragmentation may constrain colonization. Overall, the findings emphasize the need for species-specific conservation strategies to mitigate climate-driven biodiversity loss in endemic mountain ecosystems.

Keywords: Central Asia, Climate Change, Endemic Plants, Habitat Suitability, Species Distribution Modeling

Introduction

Mountain ecosystems of Central Asia represent important centers of plant endemism and diversification, yet many narrowly distributed species remain poorly studied in terms of their ecological requirements and future vulnerability[1]. Uzbekistan, located within the Irano-Turanian floristic region, harbors numerous endemic taxa restricted to isolated mountain systems and arid foothill habitats. Species with small geographic ranges and limited population sizes are particularly sensitive to environmental change, including climate warming and shifts in precipitation regimes

(Legg, 2021; Thuiller et al., 2005)[2]. Understanding the potential distribution and climatic suitability of such taxa is therefore essential for biodiversity conservation planning and long-term management[3].

Endemic species with few known occurrence records present a specific conservation challenge. Restricted distributions increase extinction risk due to habitat degradation, land-use change, and climate-driven shifts in suitable environments (Dirzo et al., 2014; Urban, 2015). In arid and semi-arid regions such as Uzbekistan, projected increases in temperature and changes in precipitation patterns are expected to intensify drought stress and alter habitat suitability, particularly in mountainous refugial systems (Legg, 2021). For taxa confined to specialized substrates or microclimatic niches, even modest climatic changes may result in significant range contractions[4].

Species distribution modelling (SDM) has become a widely used approach for estimating potential habitat suitability and forecasting range shifts under future climate scenarios (Elith & Leathwick, 2009; Phillips et al., 2006). Presence-only modelling techniques, especially the Maximum Entropy (MaxEnt) algorithm, are particularly suitable for rare or endemic species with limited occurrence data (Phillips et al., 2006; Hernandez et al., 2006). Although small sample sizes may increase model uncertainty, careful parameterization and regularization can reduce overfitting and provide useful ecological insights (Merow et al., 2013). When applied to climate change scenarios, SDMs allow the identification of potential range expansions, contractions, and shifts in habitat suitability, thereby informing conservation prioritization[5].

The present study focuses on five endemic plant species of Uzbekistan: *J. asperifolia*, *J. gracilis, J. mariae, J. sangardensis*, and *J. zakirovii*. These taxa are characterized by narrow geographic ranges and limited numbers of documented occurrences derived from herbarium materials and verified online records. Due to their restricted distributions and ecological specialization, these species represent suitable model objects for assessing climate-driven distributional change in Central Asian mountain systems[6].

The main objective of this study is to model the current and future potential distributions of these endemic species under the SSP1–2.6 climate scenario for mid-century (2041–2060) and late-century (2061–2080) periods. Specifically, we aim to (1) estimate present-day habitat suitability using bioclimatic predictors, (2) project future suitability under a moderate climate mitigation scenario, and (3) quantify changes in suitable habitat area over time[7]. The central research question is whether these narrowly distributed endemic species are likely to experience range contraction, stability, or expansion under projected climate conditions.

By integrating occurrence data with climatic predictors in a presence-only modelling framework, this study provides an assessment of climate sensitivity for endemic flora of Uzbekistan[8]. The results are expected to contribute to regional conservation planning and to improve understanding of how climate change may affect rare and range-restricted plant species in arid mountain ecosystems.

Materials and Methods

Data collection

We collected coordinates from herbarium materials and online sources for all study objects. In total, nine coordinates for *J. asperifolia*, seven coordinates for *J. gracilis*, five coordinates for *J. mariae*, sixteen coordinates for *J. sangardensis* and eight coordinates for *J. zakirovii* were collected. After that, we downloaded biovariables from worldclim database (Fick and Hijmans, 2017). Then according to the coordinates of species, we removed correlated variables per species using corrplot package (Wei et al. 2017) in R. For *J. asperifolia*, BIO18 (Precipitation of Warmest Quarter), BIO19 (Precipitation of Coldest Quarter), BIO8 (Mean Temperature of Wettest Quarter), and BIO9 (Mean Temperature of Driest Quarter) were used. For *J. gracilis*, BIO17 (Precipitation of Driest Quarter), BIO18 (Precipitation of Warmest Quarter), BIO8 (Mean Temperature of Wettest Quarter), and BIO10 (Mean Temperature of Warmest Quarter) were included. For *J. mariae*, BIO17 (Precipitation of Driest Quarter), BIO18 (Precipitation of Warmest Quarter), BIO8 (Mean Temperature of Wettest Quarter), and BIO11 (Mean Temperature of Coldest Quarter) were retained. For *J. sangardensis*, BIO6 (Minimum Temperature of Coldest Month), BIO11 (Mean Temperature of Coldest Quarter), BIO14 (Precipitation of Driest Month), BIO18 (Precipitation of Warmest Quarter), and BIO19 (Precipitation of Coldest Quarter) were selected.

For *J. zakirovii*, BIO13 (Precipitation of Wettest Month), BIO14 (Precipitation of Driest Month), and BIO16 (Precipitation of Wettest Quarter) were used in the final

Species distribution modelling was conducted using presence-only occurrence data and bioclimatic environmental predictors in R. Geographic coordinates of the target species were compiled from a CSV file and converted into spatial objects using the WGS84 geographic coordinate system (EPSG:4326). Administrative boundaries of Uzbekistan were incorporated for visualization purposes using a national shapefile. Current and future bioclimatic variables were obtained as raster layers in GeoTIFF format. Future projections corresponded to the SSP1-2.6 scenario for the periods 2041–2060 (2050) and 2061–2080 (2070). All raster layers were imported as multi-layer stacks and harmonized by aligning layer names across time periods to ensure consistency in predictor variables.

To define the accessible area for model calibration, a buffer was generated around all occurrence records and merged into a single spatial extent. Background points (n = 2000) were randomly sampled from the environmental layers within this buffered area while excluding missing values. Species distribution models were fitted using the Maximum Entropy algorithm implemented in the dismo package, with environmental predictors provided as raster stacks and occurrence and background coordinates supplied as spatial points. Model complexity was controlled by setting a regularization parameter (betamultiplier = 5.0) to reduce overfitting.

Habitat suitability was predicted for current and future climate scenarios. Future projections were resampled to match the spatial resolution and extent of the current prediction grid using bilinear interpolation. To generate binary suitability maps, a minimum training presence threshold was applied, defined as the lowest predicted suitability value among occurrence records. Continuous suitability maps were converted into binary rasters based on this threshold.

Habitat area was quantified by calculating the surface area of suitable cells in square kilometers using raster cell area computations. Total suitable area was estimated for current, 2050, and 2070 scenarios, and percentage change relative to current conditions was calculated. Visualization outputs included bar plots summarizing total suitable area and proportional change, as well as high-resolution maps of continuous habitat suitability and binary habitat distribution for all time periods. All spatial processing and statistical analyses were performed in R using the packages terra, raster, and dismo (Hijmans et al., 2015; 2017; 2023).

Results

Species distribution models revealed contrasting responses among the five endemic taxa under future climate scenarios. Substantial interspecific variation was observed in both the direction and magnitude of projected habitat change under SSP1–2.6 and SSP5–8.5 for mid-century (2050) and late-century (2070) periods[9].

J. asperifolia exhibited a pronounced expansion of suitable habitat under both climate scenarios (Fig. 1). Under SSP1–2.6, suitable area increased from 29,140.5 km² at present to 82,255.1 km² by 2050 (+182.3%), followed by a slight reduction to 75,774.0 km² in 2070, which nevertheless represented a 160.0% increase relative to current conditions[10]. Under SSP5–8.5, projected expansion was similarly strong, with suitable area reaching 80,830.9 km² in 2050 (+177.4%) and remaining high at 80,727.2 km² in 2070 (+177.0%). These results indicate consistent and substantial potential range expansion across both moderate and high-emission pathways.

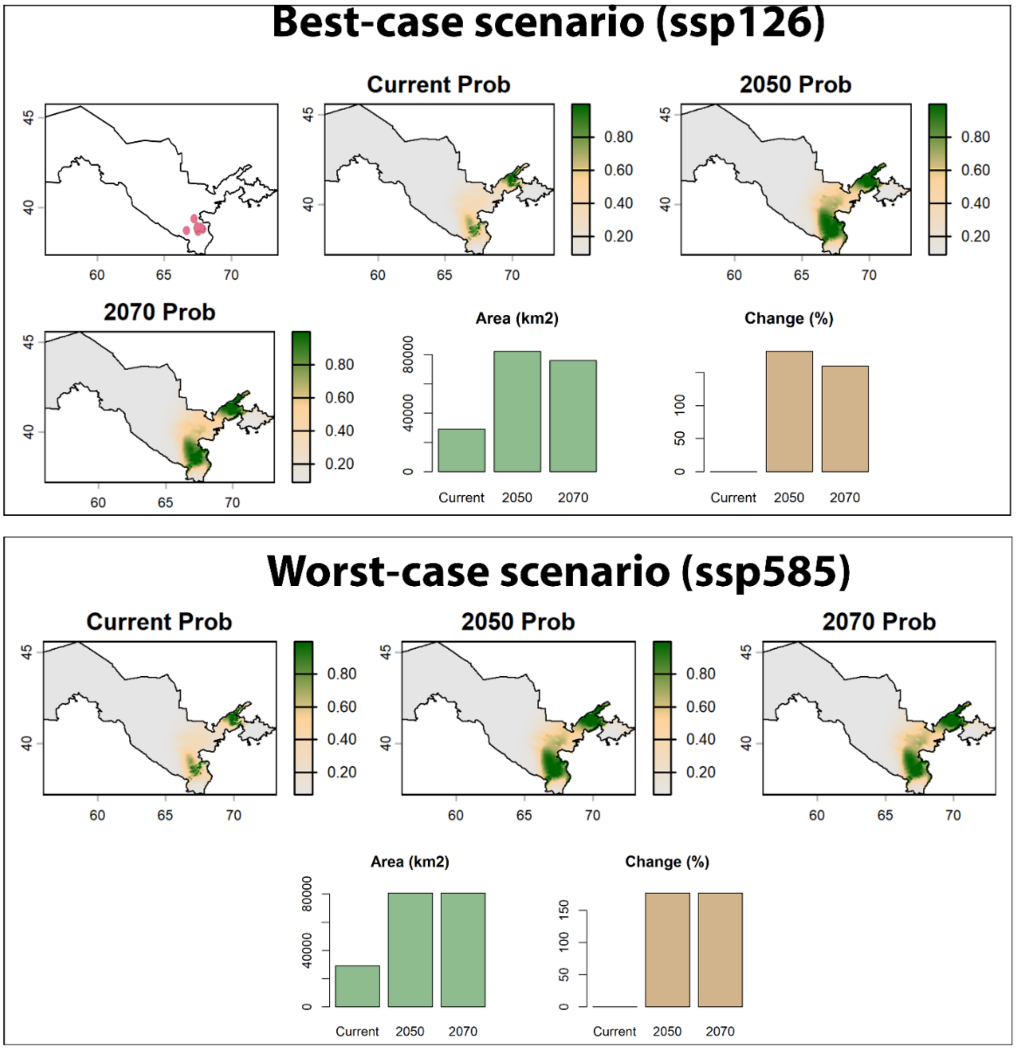

Figure 1. Overall species distribution model of J. asperifolia for current and future under best case (upper panel) and worst-case (lower panel) scenarios

In contrast, *J. gracilis* showed a dramatic contraction of suitable habitat under all future projections (Fig. 2)[11]. From a current area of approximately 21,251.3 km², suitable habitat declined to 299.1 km² in 2050 under SSP1–2.6 (−98.6%) and remained severely reduced at 856.9 km² in 2070 (−96.0%). Under SSP5–8.5, habitat suitability decreased even more sharply, falling to 148.0 km² in 2050 (−99.3%) and reaching complete loss (0 km²) by 2070 (−100%). These projections suggest extreme vulnerability of *J. gracilis* to future climatic conditions, particularly under the high-emission scenario[12].

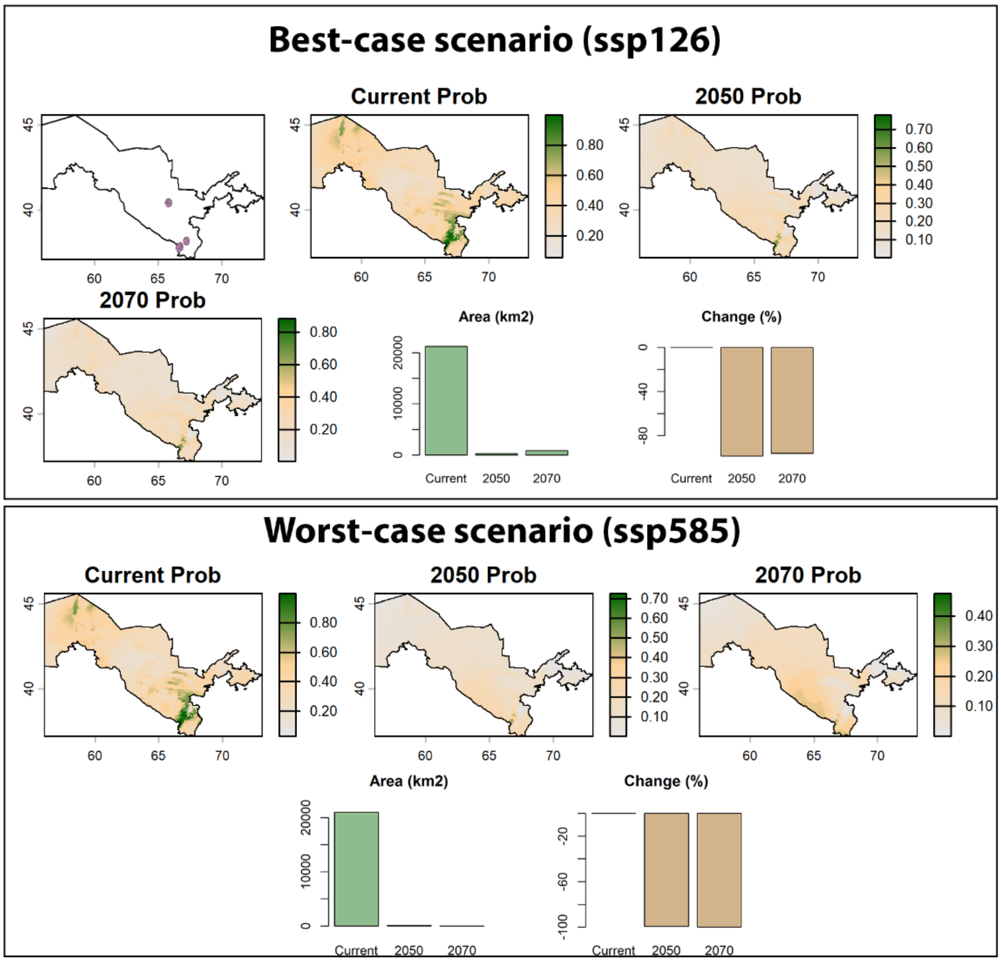

Figure 2. Overall species distribution model of J. gracilis for current and future under best case (upper panel) and worst-case (lower panel) scenarios

J. mariae demonstrated comparatively moderate changes (Fig. 3). From a present suitable area of 8,908.3 km², projections under SSP1–2.6 indicated expansion to 10,508.1 km² in 2050 (+18.0%) and 9,783.4 km² in 2070 (+9.8%). Under SSP5–8.5, the species showed a smaller increase to 9,664.7 km² in 2050 (+8.5%), while late-century projections were unavailable. Overall, *J. mariae* appears relatively stable, with modest potential gains in suitable habitat under both scenarios.

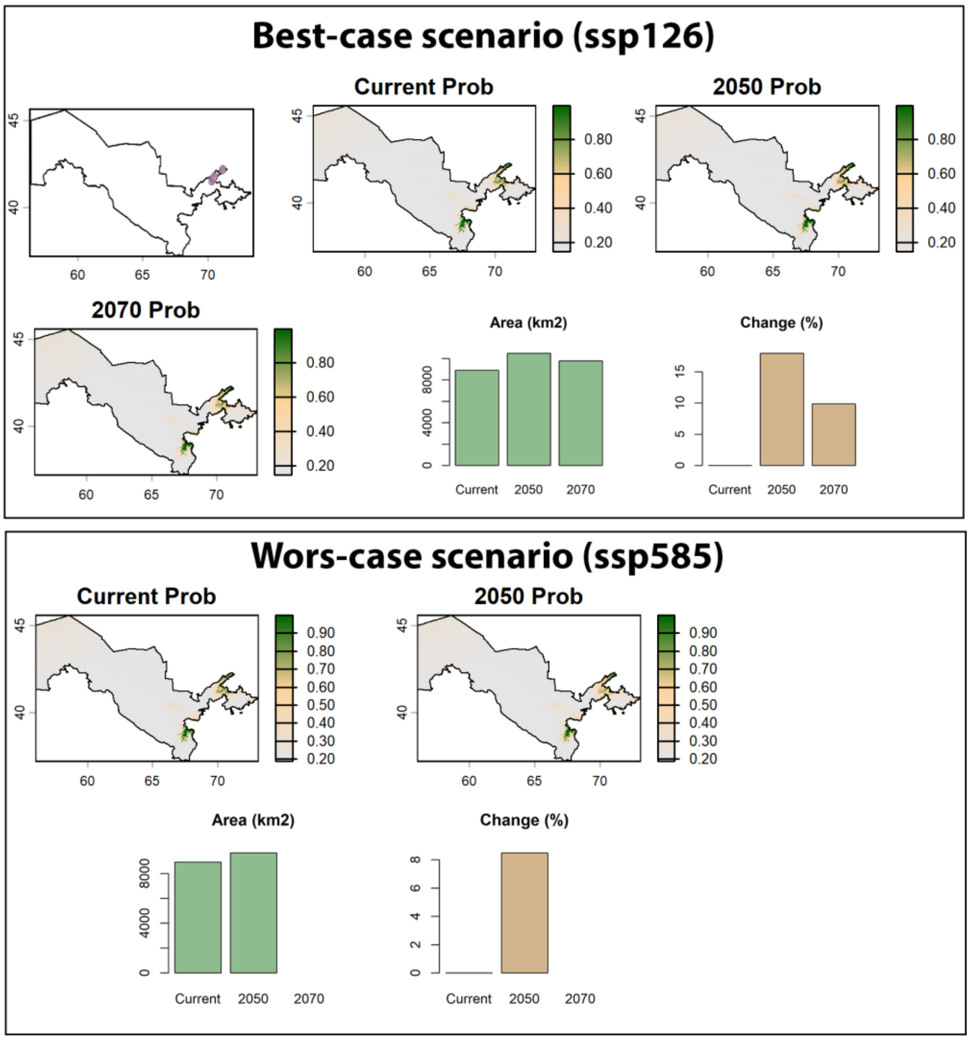

Figure 3. Overall species distribution model of J. mariae for current and future under best case (upper panel) and worst-case (lower panel) scenarios

J. sangardensis displayed strong potential expansion similar to *J. asperifolia* (Fig. 4). Current suitable area (approximately 45,128.1 km²) increased to 94,756.1 km² in 2050 under SSP1–2.6 (+110.0%) and remained high at 90,528.6 km² in 2070 (+100.6%). Under SSP5–8.5, suitable area expanded to 93,669.2 km² in 2050 (+105.8%), while late-century projections were not available. These findings indicate a marked increase in climatically suitable habitat for this species under both mitigation and high-emission pathways[13].

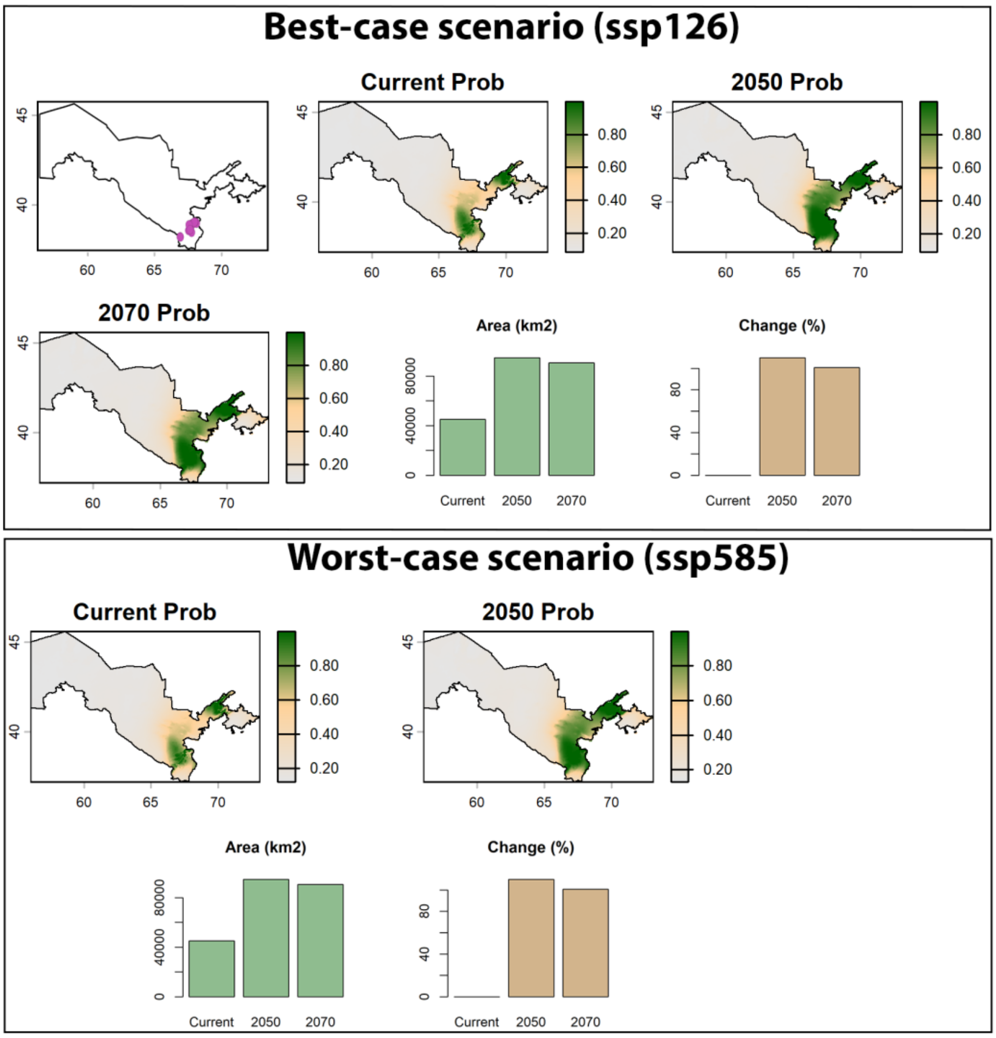

Figure 4. Overall species distribution model of J. sangardensis for current and future under best case (upper panel) and worst-case (lower panel) scenarios

J. zakirovii also exhibited consistent expansion across scenarios (Fig. 5). From a present distribution of 38,943.1 km^2, suitability increased to 89,782.5 km^2 in 2050 under SSP1–2.6 (+130.5%) and remained elevated at 84,713.4 km^2 in 2070 (+117.5%). Under SSP5–8.5, suitable area expanded to 75,754.6 km^2 in 2050 (+94.5%) and 69,783.8 km^2 in 2070 (+79.2%)[14]. Although gains were somewhat lower under the high-emission pathway by late century, projections consistently indicated substantial habitat expansion relative to present conditions.

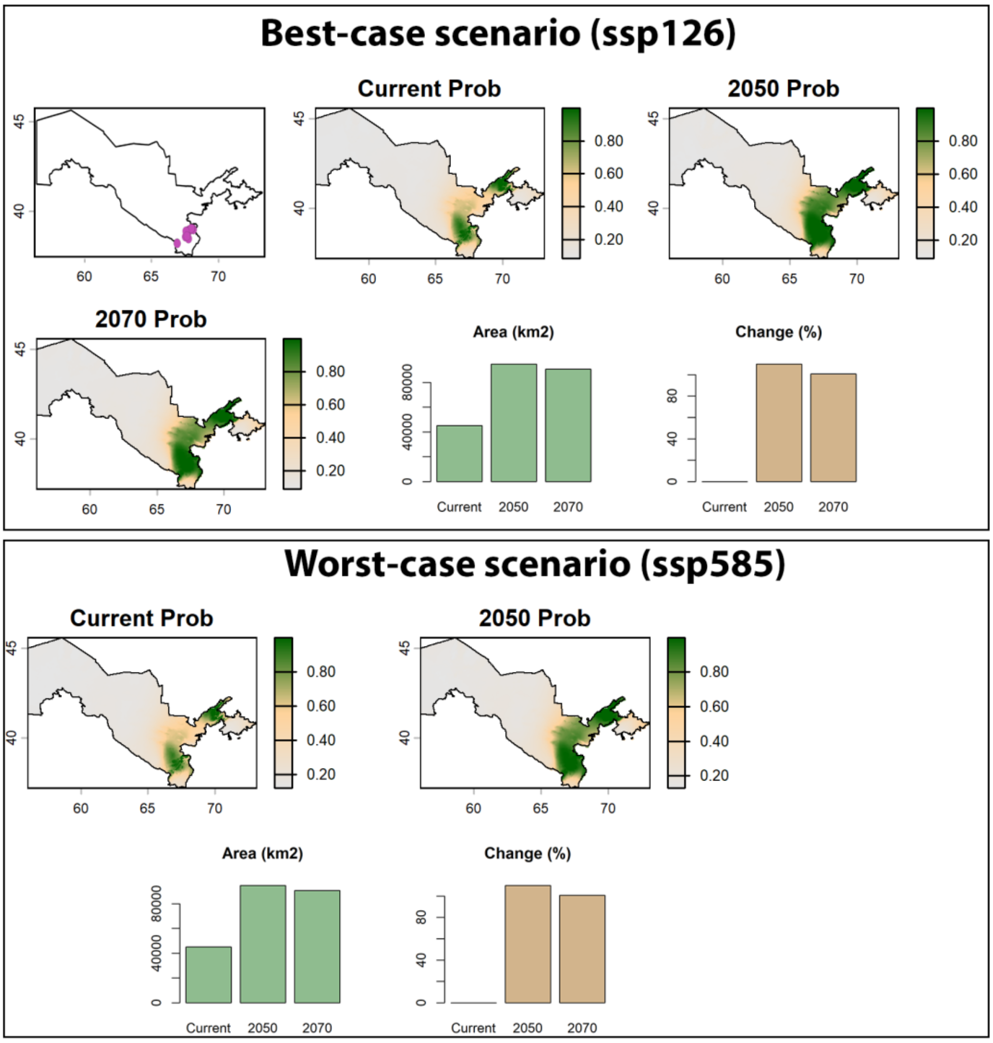

Figure 5. Overall species distribution model of J. zakirovii for current and future under best case (upper panel) and worst-case (lower panel) scenarios

Overall, three species (*J. asperifolia*, *J. sangardensis*, and *J. zakirovii*) showed strong projected increases in suitable habitat under both climate scenarios, while *J. mariae* exhibited moderate expansion and relative stability. In contrast, *J. gracilis* showed severe and progressive habitat loss, including complete disappearance of suitable area under SSP5–8.5 by 2070. These divergent responses highlight substantial interspecific differences in climatic sensitivity among endemic taxa and suggest that future climate change may simultaneously create expansion opportunities for some species while posing critical extinction risk for others[15].

Discussion

The projected distributional shifts revealed marked interspecific differences in climatic sensitivity among the five endemic taxa, underscoring the heterogeneous responses of closely related species to climate change[16]. Such contrasting patterns are consistent with previous studies demonstrating that even phylogenetically related or ecologically similar species may exhibit divergent responses due to differences in niche breadth, physiological tolerances, and microhabitat specialization (Thuiller et al., 2005; Elith & Leathwick, 2009)[17].

Three species (*J. asperifolia*, *J. sangardensis*, and *J. zakirovii*) showed substantial increases in climatically suitable area under both SSP1–2.6 and SSP5–8.5 scenarios. Although these species currently occur in or around the Pamir-Alay region of Uzbekistan, the models indicate that the western Tien Shan also provides climatically suitable habitat[18]. This suggests the presence of potential additional refugia that could be considered for conservation planning, including the possibility of carefully evaluated human-assisted migration. Range expansions under future warming have been widely documented for species adapted to arid or semi-arid environments, particularly where increased temperatures may reduce cold limitations and allow colonization of previously unsuitable habitats (Parmesan & Yohe, 2003; Chen et al., 2011). In mountainous and continental regions, warming can shift thermal envelopes upward or poleward, potentially enlarging suitable areas for taxa tolerant of increased aridity (Engler et al., 2011). The consistency of expansion across both moderate and high-emission pathways suggests that these species may possess broader climatic niches or greater ecological plasticity compared to the more vulnerable taxa examined[[19].

In contrast, *J. gracilis* exhibited a dramatic contraction in suitable habitat under all projections, including complete loss under SSP5–8.5 by 2070. Such extreme declines are characteristic of species with narrow ecological amplitudes or strong dependence on specific microclimatic conditions (Urban, 2015). In arid and semi-arid systems, increasing temperatures combined with reduced precipitation during critical growth periods may exceed physiological thresholds, leading to rapid habitat loss (Legg, 2021)[20]. The projected disappearance of suitable area under high-emission scenarios highlights the potential extinction risk for this species, emphasizing the vulnerability of narrow endemics to accelerating climate change (Dirzo et al., 2014).

J. mariae demonstrated moderate expansion and relative stability across scenarios. This pattern may reflect an intermediate climatic tolerance, where warming neither strongly enhances nor severely restricts habitat suitability. Species exhibiting such stability may benefit from moderate climatic shifts while remaining sensitive to more extreme conditions (Thuiller et al., 2005). The limited magnitude of projected change suggests that its distribution is constrained by a combination of temperature and precipitation variables rather than a single dominant climatic driver.

The divergent responses observed in this study illustrate a broader principle in climate impact research: species responses are highly idiosyncratic and cannot be generalized even within a single genus (Morin & Thuiller, 2009). Importantly, expansion of climatically suitable area does not necessarily translate into realized range expansion. Dispersal limitations, soil specificity, biotic interactions, and anthropogenic barriers may prevent colonization of newly suitable habitats (Svenning & Sandel, 2013). For narrowly distributed endemics, limited seed dispersal capacity and habitat fragmentation may further constrain range shifts despite favorable climatic projections.

Moreover, species distribution models estimate potential climatic suitability rather than demographic performance. Factors such as population size, genetic diversity, and adaptive capacity ultimately determine long-term persistence (Urban et al., 2016). For species projected to expand, monitoring will be necessary to determine whether predicted gains are realized in situ. Conversely, for *J. gracilis*, immediate conservation attention may be warranted, particularly under high-emission trajectories.

Overall, the results indicate that future climate change may generate both opportunities and risks for endemic flora. While some taxa may benefit from shifting climatic envelopes, others may face severe range contraction or extinction. These findings reinforce the importance of species-specific assessments in conservation planning and highlight the need to integrate climatic projections with ecological and demographic data to develop robust management strategies.

Conclusion

The findings of this study underscore the highly heterogeneous responses of endemic J species to projected climate change, reflecting substantial interspecific variation in climatic sensitivity, ecological plasticity, and niche breadth. While species such as J. asperifolia, J. sangardensis, and J. zakirovii are projected to experience expansions in climatically suitable areas, potentially benefiting from broader ecological tolerance, J. gracilis faces dramatic habitat contraction and potential extinction under high-emission scenarios, highlighting the vulnerability of narrow endemics to accelerating environmental change. J. mariae exhibits moderate stability, indicating intermediate climatic tolerance. These divergent outcomes emphasize that species responses cannot be generalized even within a single genus and that projected climatic suitability does not automatically translate into realized range shifts due to dispersal limitations, microhabitat specificity, and anthropogenic barriers. Consequently, conservation planning must adopt a species-specific approach, integrating climatic projections with ecological, demographic, and genetic data to identify priority taxa, potential refugia, and appropriate management interventions.

Overall, climate change presents both opportunities and risks for endemic flora, reinforcing the need for proactive monitoring, targeted conservation strategies, and adaptive management to safeguard biodiversity under rapidly changing environmental conditions.

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