Diffusion Risk of *Galinsoga quadriradiata* on the Qinghai-Tibet Plateau under Climate Change: Postprint

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Abstract

Galinsoga quadriradiata is an agricultural invasive species with a wide ecological amplitude and rapid spread. Predicting its potential suitable habitat distribution on the Qinghai-Tibet Plateau under future climate change scenarios can provide a scientific basis for preventing its expansion and formulating control strategies. Based on the current distribution of G. quadriradiata on the Qinghai-Tibet Plateau and 10 related environmental factors, an ensemble model was constructed using Biomod2 software integrating 12 single models, and, in combination with ArcGIS and R software, its suitable habitat distribution and centroid shift trajectories were predicted under current and future (2050s, 2070s) climate conditions (SSP126, SSP245, SSP585). The results showed that the AUC and TSS values of the ensemble model were 0.989 and 0.928, respectively, indicating a high predictive performance of the model; elevation (elev) and human footprint (hf) were the dominant environmental factors. Under current climate conditions, G. quadriradiata is mainly distributed in eastern Qinghai, southeastern Gansu, southeastern Sichuan, northwestern Yunnan, southeastern and central Tibet, and southwestern Xinjiang. Under future climate scenarios, suitable habitats show an overall expansion trend, with the centroid shifting generally toward the southeast. The suitable habitat of G. quadriradiata will expand significantly under future climate conditions, posing a threat to food security of crops and ecological security on the Qinghai-Tibet Plateau, and preventive and control measures should be taken as early as possible.

Full Text

Dispersal Risk of Galinsoga quadriradiata on the Qinghai-Xizang Plateau under Climate Change

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Abstract

Galinsoga quadriradiata is a widely adapted and rapidly spreading invasive agricultural weed. Predicting its potential suitable habitat distribution on the Qinghai-Xizang Plateau under future climate change conditions provides a scientific basis for preventing its expansion and developing control strategies. Based on current distribution data for G. quadriradiata on the Qinghai-Xizang Plateau and 10 relevant environmental variables, we constructed an ensemble model using 12 individual models with the Biomod2 package, and analyzed suitable habitat distribution and centroid migration trajectories under current and future climate scenarios (2050s and 2070s) based on SSP126, SSP245, and SSP585. The ensemble model demonstrated excellent predictive performance, with AUC and TSS values of 0.989 and 0.928, respectively. Elevation (elev) and the Human Footprint Index (hf) were identified as the dominant environmental factors influencing species distribution. Under current climatic conditions, G. quadriradiata is mainly distributed in eastern Qinghai, southeastern Gansu, southeastern Sichuan, northwestern Yunnan, southeastern and central Xizang, and southwestern Xinjiang. Under future climate scenarios, suitable habitat areas show an expansion trend, with the centroid generally shifting toward the southeast. The suitable habitat for G. quadriradiata will significantly expand under future climate conditions, threatening food security and ecological safety on the Qinghai-Xizang Plateau. Preventive and management measures should be implemented as soon as possible.

Keywords: invasive plant; Galinsoga quadriradiata; species distribution models; suitable habitat; Qinghai-Xizang Plateau

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Introduction

With the rapid development of international trade and economy, China has become one of the countries most severely affected by invasive alien plants [1]. Invasive plants can alter natural community composition and represent a key obstacle to native ecosystem restoration [2]. Furthermore, research indicates that some invasive alien plants increasingly threaten human health [3]. Species

Distribution Models (SDMs) are widely used to simulate potential species distributions, assess climate change impacts on biodiversity, and analyze complex relationships between species and environmental factors [4-6].

Galinsoga quadriradiata, commonly known as "eyelash galinsoga" or "spicy grass," is an annual herb in the Asteraceae family and a globally distributed agricultural weed [7]. Native to Latin America, it has invaded most regions worldwide and is a typical cosmopolitan weed. Introduced to China in the mid-20th century with horticultural plants, it was first discovered in Chengdu, Sichuan, and is now widely distributed in Yunnan, Guizhou, Liaoning, and other provinces [8-10]. According to Flora of Qinghai and Flora of China, G. quadriradiata is rarely distributed on the Qinghai-Xizang Plateau [11,12], though Wei et al. [13] first reported its distribution in Qinghai. G. quadriradiata exhibits strong competitiveness and reproductive capacity, with high seed production and dispersal ability. In invaded areas, it often forms monodominant communities, significantly reducing local plant diversity. Its impact on agricultural production is particularly severe, with crop yield losses reaching up to 70% in heavily invaded areas [14]. Given its wide distribution and potential economic damage, G. quadriradiata is considered one of the most invasive species requiring effective management and control [15].

Current research on G. quadriradiata primarily focuses on seed morphology and germination characteristics [16], population dynamics [17], adaptability and genetic differentiation [18], with relatively few studies predicting its potential suitable habitats on the Qinghai-Xizang Plateau, particularly using ensemble models to enhance prediction robustness. Therefore, this study, based on field survey data of G. quadriradiata distribution, uses the Biomod2 package to construct an ensemble model from 12 individual models to systematically predict suitable habitat distribution for G. quadriradiata on the Qinghai-Xizang Plateau under climate change scenarios, analyze changes in suitable habitats, and track centroid migration trajectories. The results reveal significant spatial expansion and migration trends of G. quadriradiata suitable habitats on the Qinghai-Xizang Plateau, clarifying its potential invasion risk. These findings provide crucial evidence for developing scientific control strategies to curb population expansion and offer new empirical cases and theoretical support for predicting suitable habitats of invasive alien plants on the Qinghai-Xizang Plateau.

1. Materials and Methods

1.1 Species Data Collection and Screening Species occurrence data for G. quadriradiata were primarily obtained from field surveys conducted in Qinghai Province in 2023, yielding 95 population data points (Table 1). Additional distribution points on the Qinghai-Xizang Plateau were obtained from literature searches [13,19,20]. Global distribution data were retrieved from the Global Biodiversity Information Facility (GBIF, https://doi.org/10.15468/dl.fcqaun) and the Chinese Virtual Herbarium (CVH, http://www.cvh.ac.cn/). Using ArcGIS 10.8 software, we extracted distribution points on the Qinghai-Xizang Plateau.

To minimize clustering effects during modeling, we applied a spatial filtering approach using the spThin package with a 10 km radius, retaining only one occurrence point within each 10 km radius. This process yielded 54 G. quadriradiata population distribution points on the Qinghai-Xizang Plateau (Figure 1).

1.2 Environmental Data Acquisition and Processing Environmental variables included 10 bioclimatic factors, 3 topographic factors, and the Human Footprint Index. Current climate data (1970-2000 averages) were obtained from WorldClim 2.1 at 2.5 arc-minute resolution [21]. Future climate projections used the ACCESS-CM2 model, which performs well in simulating climate over the Qinghai-Xizang Plateau [22], for periods representing the 2050s (2041-2060) and 2070s (2061-2080) under three Shared Socioeconomic Pathways (SSP126, SSP245, SSP585) representing low, medium, and high greenhouse gas emission scenarios [23]. All climate data had a spatial resolution of 2.5 arc-minutes. Topographic data (elevation, slope, and aspect) were derived from the Qinghai-Xizang Plateau terrain dataset [24], with elevation data extracted from SRTM DEM 90 m data. The Human Footprint Index was obtained from the 2018 global human influence geographic data (2009 Human Footprint, Version 3) from NASA' s Socioeconomic Data and Applications Center (SEDAC) [25], originally at 1 km resolution. All environmental layers were resampled to 2.5 arc-minute resolution using bilinear interpolation in ArcGIS' s Spatial Analyst Resample tool to match the climate data.

To mitigate multicollinearity effects on prediction accuracy, we performed Pearson correlation analysis and Variance Inflation Factor (VIF) assessment on all environmental variables using the "usdm" package. Variables with Pearson correlation coefficients < 0.8 and VIF < 10 were retained (Figures 2-3). This screening yielded 10 environmental variables for final model prediction: 7 climate factors, 2 topographic factors, and the Human Footprint Index (Table 1).

1.3 Ensemble Model Construction and Evaluation This study used the latest Biomod2 package (version 4.2-4) in R 4.4.1 for all modeling analyses. The BIOMOD_{FormatingData} function formatted occurrence and environmental data. To reduce uncertainty, we employed a 10-fold cross-validation strategy, conducting 10 individual modeling runs. Pseudo-absence generation was controlled using the "PA.nb.rep" parameter with a random strategy (PA.strategy = "random"), creating 10 pseudo-absence datasets with the same number of points as G. quadriradiata occurrences, repeated 10 times to improve simulation accuracy.

The BIOMOD_{Modeling} function was used to construct 12 individual models: Generalized Linear Model (GLM), Classification Tree Analysis (CTA), Surface Range Envelope (SRE), Multivariate Adaptive Regression Splines (MARS), Maximum Entropy Model (MaxEnt.Phillips), Generalized Additive

Model (GAM), Generalized Boosted Model (GBM), Artificial Neural Network (ANN), Flexible Discriminant Analysis (FDA), Random Forest (RF), MaxNet, and eXtreme Gradient Boosting (XGBOOST). Model parameters used the software' s recommended "Bigboss" parameter optimization to avoid subjective preset parameters while ensuring fair comparison across models [26,27]. Randomly selected 70% of occurrence points were used for training, with the remaining 30% for testing.

Model performance was evaluated using True Skill Statistic (TSS) and Area Under the Receiver Operating Characteristic Curve (AUC). AUC > 0.90 and TSS > 0.75 indicated strong predictive performance, while values below 0.5 suggested random predictions [28]. After selecting individual models with AUC > 0.90 and TSS > 0.75, we used BIOMOD_{EnsembleModeling} to construct ensemble models using four methods: EMmean (based on prediction averages), EMmedian (based on prediction medians), EMwmean (weighted average), and EMcv (binary voting based on cross-validation results). The optimal ensemble model was selected based on evaluation metrics (AUC, TSS, etc.), and BIOMOD_{EnsembleForecasting} was used to predict suitable habitats under current and future climate scenarios.

1.4 Analysis of Suitable Habitat Changes and Centroid Migration The BIOMOD_{EnsembleForecasting} function generated prediction results with original suitability values ranging from 0 to 1000, where higher values indicate greater habitat suitability. To ensure scientific and comparable classification, we applied the natural breaks method to classify suitable habitats into four categories based on current climate predictions: non-suitable (0-125), low-suitable (126-294), medium-suitable (295-553), and high-suitable (554-951) [29]. This classification was applied to future scenarios. Habitat areas were calculated by adding area fields in attribute tables and using raster calculators based on pixel size. Centroid migration was analyzed by calculating geometric centers under different climate scenarios [30], and migration distances were computed using the "dists" function in R 4.4.1.

2. Results

2.1 Model Reliability After 10 repeated runs, individual model evaluation showed XGBOOST had the highest average AUC (0.987) and TSS (0.912) values, while SRE had the lowest values but still indicated good overall performance. For ensemble modeling, we selected individual models with AUC and TSS values above 0.90. Among the four successful ensemble methods (Figure 4), EMmean performed best with average AUC and TSS values of 0.989 and 0.928, respectively, demonstrating high prediction accuracy and stability.

2.2 Environmental Variable Importance Based on variable weights from the ensemble model, elevation (elev) and Human Footprint Index (hf) were the most important factors, contributing 42.79% and 22.52% respectively (Figure 5).

Response curves (Figure 6) showed a significant negative correlation between elevation and species distribution: predicted suitability decreased rapidly above 2700 m, indicating high elevations limit the species. Conversely, hf showed a positive correlation: suitability increased when hf > 20, suggesting G. quadriradiata prefers areas with intensive human activity.

2.3 Suitable Habitat Distribution Under Current and Future Climate Scenarios Under current climate conditions, the ensemble model predicted G. quadriradiata's high-suitable habitats are mainly distributed in eastern Qinghai, southeastern Gansu, southeastern Sichuan, northwestern Yunnan (the southern Hengduan Mountains transition zone to the Yunnan-Guizhou Plateau), southeastern and central Xizang, and southwestern Xinjiang (Kunlun Mountains near Kashgar), covering 10.31$×10^{4}$ km^{2}. Other suitable habitats extend from high-suitable areas toward the plateau interior, mainly in Sichuan, Yunnan, central-eastern Gansu and Qinghai, and central-eastern Xizang, totaling 56.36$×10^{4}$ km^{2} (Figure 7).

Under future climate scenarios (Figure 8), suitable habitat areas increase across all categories, with medium- and low-suitable areas expanding more than high-suitable areas—likely due to elevation constraints. The SSP585 scenario in the 2070s shows the largest expansion, with total suitable habitat reaching 99.63$×10^{4}$ km^{2} (39.15% of the Qinghai-Xizang Plateau area). High-suitable habitat expansion is relatively small, occurring near current high-suitable areas and parts of central-eastern Xizang. Medium- and low-suitable habitats expand substantially, concentrating in central Xizang, northern Qinghai, and northwestern Xinjiang (Kunlun and Altun Mountains) (Figure 9).

2.4 Centroid Migration Analysis Under current climate, the suitable habitat centroid is located at 31.8859°N, 96.2164°E, at the border between Nangqian County (Yushu City, Qinghai) and Leiwuqi County (Changdu City, Xizang). Under future scenarios, the centroid migrates with increasing CO_2 concentrations (Figure 10). In the SSP126 2050s scenario, the centroid shifts 3.52 km southwest to 31.8652°N, 96.1964°E. By the 2070s, it shifts further southeast 30.15 km to 31.6462°N, 96.3764°E in Chamdo City, Xizang. In SSP245, the centroid shifts 31.94 km northeast to 31.7657°N, 96.5465°E in the 2050s, then 3.28 km southeast to 31.7465°N, 96.5664°E in the 2070s. In SSP585, the centroid shifts 34.5 km southeast to 31.9461°N, 96.4664°E in the 2050s, then turns northward 21.3 km to 32.0572°N, 96.3765°E in the 2070s, landing in Nangqian County, Yushu City, Qinghai (Figure 10).

3. Discussion

As a highly invasive alien plant, G. quadriradiata poses significant ecological threats across China, mainly in southwestern and northeastern regions [8,10]. However, reports of its distribution in Qinghai remain limited [13]. This study obtained 95 precise village-level distribution records for Qinghai through field surveys. Data quality was improved by verifying coordinates and applying spatial filtering, providing reliable support for distribution modeling. To enhance prediction accuracy and reliability, we used 12 individual models to construct an ensemble model. We employed both MaxEnt and MaxNet models, which share theoretical principles but differ in algorithmic implementation—MaxEnt has been widely applied while MaxNet offers more flexible modeling through the glmnet package [31]. Due to differences in feature selection and regularization, their performance varies in AUC and TSS metrics, which is reasonable. Including both enriches model diversity and enhances prediction robustness. During individual model construction, 10 repeated runs with 10-fold cross-validation optimized model performance. The ensemble model achieved AUC and TSS values of 0.989 and 0.928, respectively, demonstrating excellent predictive capability and stability.

Environmental variable importance analysis revealed that the Human Footprint Index (hf) significantly influences G. quadriradiata distribution, consistent with findings that climate change and intensifying human activities significantly impact Qinghai-Xizang Plateau vegetation [32]. Field surveys found G. quadriradiata mainly in orchards, farmland, residential areas, and waste sites with strong human disturbance. Increasing human activities and global climate change may facilitate alien species expansion to higher elevations [33]. However, Chen et al. [16] found G. quadriradiata' s reproductive capacity and seed dispersal ability decrease significantly at high altitudes, consistent with our finding that predicted suitability declines above 2700 m. Thus, while climate change and human activity may positively influence expansion, high-altitude spread may be limited by biological characteristics.

This study reveals significant centroid migration trends for G. quadriradiata under future climate scenarios. Results show the centroid generally shifts southeast across scenarios, with SSP585 showing the most substantial migration. This directional shift likely reflects the species' response to temperature and precipitation pattern changes—southeastern regions are warmer and more humid, matching its growth requirements. Climate warming typically drives invasive plants toward warmer, wetter areas [34], and the southeastern Qinghai-Xizang Plateau' s unique topography and abundant hydrothermal conditions provide ideal environments for potential expansion. Additionally, centroid migration may correlate with human activity corridors. The southeastern plateau has well-developed transportation infrastructure and frequent agricultural activity, creating typical "invasion corridor effects" that facilitate spread along roads, farmland edges, and residential areas [35]. Therefore, southeastward migration reflects both climate responses and interactions between climate change and human disturbance. This finding is significant for understanding invasion mechanisms in plateau environments and suggests that risk assessment should not only consider static suitable area changes but also dynamic migration directions and potential dispersal corridors revealed by centroid shifts. This provides scientific basis for targeted monitoring and control, such as establishing early warning networks in potential corridor areas along migration paths.

We found that suitable habitat areas for G. quadriradiata on the Qinghai-Xizang Plateau will expand under all future climate scenarios, with total suitable area increasing by 32.96$×10^{4}$ km^2 in the SSP585 2070s scenario compared to current conditions. This has important implications for biodiversity conservation and weed control strategies. In high-risk suitable areas, especially along migration directions, long-term monitoring networks should be established, focusing on highly disturbed habitats like roadsides, farmland edges, residential points, and abandoned lands to detect and eradicate new invasions early. In already-invaded areas, ecological restoration measures (reestablishing native dominant species, increasing vegetation cover) should be combined to reduce reinvasion potential. At suitable habitat edges and potential dispersal corridors, quarantine and biosecurity measures should be implemented to strictly control spread through transportation and agricultural product movement. Finally, integrating results with regional land-use planning and ecological conservation redlines will help decision-makers identify priority control areas and improve resource allocation efficiency.

This study has limitations. Future climate scenarios (especially SSP585) have inherent uncertainties, and regional-scale depiction of local environmental changes remains biased, potentially affecting predictions. The 2018 Human Footprint data used are static, implicitly assuming unchanged spatial distribution in future scenarios, which cannot reflect dynamic changes in land-use transformation, infrastructure development, and socioeconomic growth. Future research should incorporate high spatiotemporal resolution dynamic human activity data and more ecological processes to improve prediction accuracy.

4. Conclusion

Under current climate conditions, G. quadriradiata' s suitable habitat on the Qinghai-Xizang Plateau covers 66.67$×10^{4}$ km^2, with high-suitable habitats mainly in eastern Qinghai, southeastern Gansu, southeastern Sichuan, northwestern Yunnan, southeastern Xizang, and southwestern Xinjiang. Under future climate scenarios, suitable habitats show expansion trends. In the SSP585 2070s scenario, total suitable habitat reaches 99.63$×10^{4}$ km^2, with medium- and low-suitable habitats expanding most in central Xizang, northern Qinghai, and northwestern Xinjiang. The distribution center generally shifts eastward. Environmental variable importance analysis shows elevation (elev) and Human Footprint Index (hf) are key factors affecting G. quadriradiata distribution on the Qinghai-Xizang Plateau. Predicted suitability decreases with elevation above 2700 m (negative correlation) and increases with hf (positive correlation).

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Note: Figure translations are in progress. See original paper for figures.