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Study on the ecological suitability and Medicinal component zoning of *Ardisia crenata* (Myrsinaceae) Based on ArcGIS and MaxEnt Model

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Abstract

Ardisia crenata Sims, a plant of considerable medicinal importance, exhibits notable geographical variation in the distribution of ecologically suitable habitats and the mechanisms underlying its medicinal quality. Our comprehensive analysis, utilizing 366 distribution points and 36 ecological factors, identified vegetation type as the primary constraint on its distribution both nationally and within Guizhou Province, with contribution rates of 48.1% and 28.9%, respectively. At the national scale, precipitation of coldest quarter (25.4%) and annual precipitation (10%) emerged as critical determinants of suitable habitats, with the model demonstrating high predictive accuracy (AUC = 0.941). In Guizhou Province, mean temperature of driest quarter (16.1%) and mean temperature of warmest quarter (10.3%) were identified as the principal limiting factors. Quantitative analysis of the bioactive components in *A. crenata*, conducted using high-performance liquid chromatography (HPLC) and spatial analysis via MaxEnt and ArcGIS, revealed a significant correlation between the accumulation of bioactive compounds and mean temperature of warmest quarter, mean diurnal range, and iso-thermality. Spatial analysis reveals that nationally suitable areas are predominantly located in the southeastern coastal regions and the middle-lower reaches of the Yangtze River. Within Guizhou Province, the distribution exhibits a "higher in the south, lower in the north" pattern. The primary suitable zones are identified in the three autonomous prefectures of Qianxinan, Qiandongnan, and Qiannan, as well as in Tongren City. Advanced co-kriging interpolation analysis has pinpointed Congjiang, Liping, Rongjiang, and Jianhe in Qiandongnan Prefecture; Songtao in Tongren City; and Libo in Qiannan Prefecture as optimal regions for the production of high-quality medicinal materials, attributed to their exceptional ecological suitability and favorable conditions for the accumulation of active components. These regions are recommended as priority sites for the establishment of standardized cultivation bases. This study elucidates the ecological factors influencing medicinal quality formation and provides a spatial decision-making framework for resource development.

1. Introduction

Ardisia crenata Sims, a member of the Myrsinaceae family, is an evergreen shrub predominantly found in regions such as Guizhou, Zhejiang, Sichuan, and Chongqing in China. It is also referred to as Hongluopan, Daluosan, and Bazhuajinlong, etc (Editorial committee of *Flora of China*., 2004; Yu et al., 2012). The roots of this plant are utilized in traditional medicine and serve as the primary source of the distinctive Miao medicine BaZhuaJinLong. This plant exhibits therapeutic properties, including heat-clearing and detoxification, wind-dispelling and dampness-removing, as well as blood circulation promotion and pain alleviation. It is frequently employed in the treatment of various ailments such as sore throat, tonsillitis, hemoptysis due to exhaustion, and rheumatoid bone pain, earning it the reputation of being an effective remedy for throat-related conditions (Guizhou Provincial Drug Administration., 2003). Contemporary research has identified that *A. crenata* contains a variety of compounds, including coumarins, which exhibit diverse pharmacological activities such as anti-tumor, anti-cough, and anti-inflammatory effects (Ye et al., 2022; Ren et al., 2024). Furthermore, the roots of *A. crenata* are utilized as primary raw materials in the formulation of "YangYingKouQiang Oral Liquid" and "KaiHouJian Spray" and other prescription medications. Bergenin, one of the principal active constituents of *A. crenata*, not only demonstrates pharmacological activities such as anti-cough, anti-inflammatory, and notable anti-tumor effects (Li et al., 2025; Zhu et al., 2023) but also serves as a crucial indicator for assessing the quality of the medicinal material due to its significant correlation with pharmacological efficacy.

At present, the procurement of *A. crenata* medicinal materials predominantly depends on wild harvesting. However, the escalating market demand coupled with ecologically harmful harvesting practices has led to a significant depletion of its wild resources, thereby severely hindering the advancement of associated industries. This depletion underscores the urgent need for systematic research into cultivation techniques. Identifying optimal cultivation zones is essential for commercial cultivation, necessitating a comprehensive understanding of the species' natural distribution, scientific prediction of ecologically suitable and high-quality production areas, and the identification of locations that effectively balance yield potential with growth suitability. These efforts are vital for ensuring both the sustainable development of the *A. crenata* cultivation industry and the conservation of its wild populations.

In the study of Traditional Chinese Medicine (TCM) resources, the integrated application of ecological niche modeling and geographic information systems (GIS) has become a crucial methodology. This approach not only facilitates the analysis of the current distribution patterns of medicinal plants but also identifies potential suitable zones and high-quality production areas, thereby providing a scientific foundation for site selection in the introduction and cultivation of medicinal plants (Jiang et al., 2025). In recent years, the MaxEnt model, in conjunction with ArcGIS, has been extensively utilized for predicting suitable areas and conducting quality zoning analyses of various Chinese herbal medicines (Li et al., 2024; Lin et al., 2023; Yu et al., 2023).

As an ethnomedicinal herb with considerable potential for development, *A. crenata* has been the subject of limited research concerning its resource distribution patterns and cultivation zoning. Existing studies primarily focus on its chemical composition, pharmacological effects, seed storage and quality, germination tests, horticultural propagation through cuttings, and basic introduction techniques (Tao et al., 2014; Cai et al., 2012; Hou et al., 2020; Zhao et al., 2023; Liao et al., 2023). Building upon this foundational knowledge, the present study employs the MaxEnt model and ArcGIS software to predict the ecologically suitable areas for *A. crenata*. This is achieved by integrating data on resource distribution, ecological climate factors, and the active ingredient bergenin. Consequently, a quality zoning model is established to provide scientific theoretical support and methodological guidance for the introduction and domestication of *A. crenata*, as well as the optimization of production sites.

2. Materials and Methods

2.1 Materials

2.1.1 A. crenata samples and distribution point data

The research team systematically collected all experimental samples from various locations across Guizhou Province between 2022 and 2023. These samples were authenticated as A. crenata by Professor Wei Shenghua from the Guizhou University of Traditional Chinese Medicine. Voucher specimens have been deposited at the Institute of Medicinal Plant Cultivation (Breeding) and Processing, Guizhou University of Traditional Chinese Medicine. Following the removal of impurities, the samples were shade-dried, pulverized, sieved through a 60-mesh screen, and stored in airtight containers for subsequent analysis. Distribution data for A. crenata were obtained through field surveys and supplemented with records from the Global Biodiversity Information Facility (https://doi.org/10.15468/dl.24fqa9), the National Specimen Information Infrastructure (http://www.nsii.org.cn/), and the Chinese Virtual Herbarium (http://www.cvh.org.cn). After consolidation and deduplication using Excel, a total of 366 non-redundant and representative occurrence points were selected for analysis.

2.1.2 Ecological factor data

The ecological data utilized in this study were sourced from the WorldClim database (http://www.worldclim.org/), the National Cryosphere Desert Data Center (http://www.ncdc.ac.cn), and the Harmonized World Soil Database v2.0 (HWSD2.0; https://www.fao.org/). These datasets encompass a total of 36 ecological factors, including 19 climatic variables, 3 topographic variables, and 14 soil variables.

2.1.3 Map data sources and processing

All geospatial vector data employed in this study, such as the base maps of China and Guizhou Province, along with their respective administrative division maps, were acquired from the Datav Data Visualization Platform (https://datav.aliyun.com/). These maps are associated with the official review number GS (2024) 1158. They were utilized exclusively as base layers for this study, with appropriate annotations added, and no further modifications were made.

2.2 Methods

2.2.1 Model construction and environmental factor screening

We employed the MaxEnt 3.4.4 model to simulate and predict the potential geographical distribution of *A. crenata*. First, 366 occurrence records of *A. crenata* and 36 environmental variables were imported. The occurrence data were partitioned with 25% allocated as the test set and 75% as the training set for model configuration. The maximum number of iterations was set to 1,000, and the Bootstrap resampling method was applied with 10 replicates. All other parameters retained their default values. Finally, the Jackknife test and receiver operating characteristic (ROC) curve were utilized for model evaluation and environmental variable screening (Wu et al., 2024).

2.2.2.Model performance assessment

The area under the ROC curve (AUC value), as a threshold-independent metric for evaluating the performance of the MaxEnt model, can objectively reflect the predictive accuracy of species distribution models. According to the range of AUC value, the accuracy of the model can be graded: when the AUC value is between 0.5 ~ 0.6, the prediction accuracy of the model is very poor ; the 0.6 ~ 0.7 interval represents that the prediction accuracy of the model is poor ; the 0.7 ~ 0.8 interval shows that the model has general prediction accuracy ; the range of 0.8 ~ 0.9 shows that the model prediction accuracy is good ; when the AUC value reaches 0.9 ~ 1.0, the model has excellent prediction accuracy and reliable results (Li et al., 2023).

2.2.3 Suitability classification

In ArcGIS 10.8, we post-processed the averaged results from 10 MaxEnt model runs through the following steps: first, the output data were converted to ASCII format files. Subsequently, raster data were reclassified using the equal interval classification method, with habitat suitability probability (*P*-value) categorized into four levels: non-suitability zones ($P < 0.2$), low-suitability zones ($0.2 \le P < 0.4$), moderate-suitability zones ($0.4 \le P < 0.6$), and high-suitability zones ($P \ge 0.6$). Finally, generate a spatial zoning map of suitability levels for the potential distribution area of *A. crenata*.

2.2.4 Quality zoning of *A. crenata*

This study determined the bergenin content in 31 batches of *A. crenata* samples from different origins, with each sample measured in triplicate, and the results were expressed as mean values. Then, the geographical coordinates of actual sampling sites were integrated with 36 environmental factors in ArcGIS to extract corresponding environmental data for each sampling point. Using SPSS 26.0 statistical software, a stepwise regression analysis was performed to establish a quantitative model between bergenin content and environmental factors. Finally, based on this regression model, spatial analysis tools in ArcGIS were employed to simulate and predict the spatial distribution pattern of bergenin content in *A. crenata* across Guizhou Province.

3. Results

3.1 MaxEnt models evaluation

The 10 simulation analyses based on the MaxEnt model for the geographical distribution of *A. crenata* and its environmental factors in Guizhou Province showed that the average AUC value of the model reached 0.941 (> 0.90) (Fig. 1). This demonstrates that the model has high reliability and excellent predictive performance, enabling precise simulation of the potential suitable zones for *A. crenata* and supporting its application in quality zoning research for this species.

3.2 Main ecological factor analysis

3.2.1 Ranking of contribution rates

During the modeling process, 10 key variables were selected from 36 candidate environmental factors for predicting the distribution of *A. crenata*, including vegetation type, precipitation of coldest quarter (bio19), annual precipitation (bio12), temperature annual range (bio7), soil basic saturation (t_bs), min temperature of coldest month (bio6), mean diurnal range (bio2), slope, altitude, and iso-thermality (bio3). As shown in Table 1, the contribution rates of these factors varied

significantly. Vegetation type exhibited the highest contribution rate (48.1%), followed by precipitation of coldest quarter (25.4%) and annual precipitation (10%).

Table 1
Analysis results of the contribution rate of main environmental factors affecting the distribution of *A. crenata*

Sequence number	Variable	Percent contribution	Permutation importance
1	vegetation	48.1	37.8
2	bio19	25.4	1.4
3	bio12	10	20
4	bio7	3.6	11
5	t_bs	3.4	1.9
6	bio6	2.4	14.7
7	bio2	2.1	0.7
8	slope	1.8	3.5
9	altitude	1.7	4.9
10	bio3	1.2	2.9

3.2.2 Jackknife test and response curve analysis

Based on the jackknife test results (Fig. 2) for evaluating environmental factor importance, we discovered the dominant factors affecting the distribution of *A. crenata* roots were vegetation, annual precipitation (bio12), min temperature of coldest month (bio6), soil base saturation (t_bs) and precipitation of coldest quarter (bio19), while the influence of temperature annual range (bio7) and mean diurnal range (bio2) was relatively small.

Response curve analysis (Figures. 3–4) revealed that *A. crenata* exhibits ecological optima under the following conditions: stable moderate temperatures with minimal diurnal variation, soil base saturation maintained at intermediate levels (20–40%), shrubland or open woodland vegetation types, and precipitation ranging between 200 and 400 mm. The comprehensive study demonstrates that this species shows a strong preference for warm-humid habitats (mean annual temperature 15–20°C) with low thermal variation (annual temperature range < 15°C), mild winter temperatures, shrubland habitats or forest-edge environments, and fertile soils.

3.3 Suitability level zoning of *A. crenata*

We employed the MaxEnt model to predict ecologically suitable areas for *A. crenata* across China and within Guizhou Province. The results were categorized into four levels of suitability, and the distribution areas for each level, as well as the suitable areas within selected Chinese provinces, were calculated. Figure 5 illustrates the potential distribution of *A. crenata* in China, while Fig. 6 presents its potential distribution in Guizhou Province. In these figures, white regions indicate non-suitable areas, green represents low-suitability zones, orange signifies moderate-suitability zones, and red denotes high-suitability zones. The nationwide predictions of potential suitability reveal that highly suitable areas encompass 6.16×10^4 km², constituting 0.66% of China's total land area. These high-suitability zones are predominantly located in Northeastern Sichuan, Southwestern Chongqing, Northeastern Yunnan, Central Guizhou, Northeastern Hunan, Northern and Central Jiangxi, Central and Southern Guangdong, coastal regions of Fujian and Taiwan, most areas of Zhejiang, and Southern Hainan Province. The moderately suitable area extends over 7.58×10^5 km², accounting for 8.16% of China's total land area. The statistical data of distribution areas by province are presented in Table 2.

The prediction results for Guizhou Province indicate that *A. crenata* finds its most suitable habitat in central Qianxinan Buyi and Miao Autonomous Prefecture (including Anlong County, Xingren City, central Ceheng County, and Wangmo County), the southwestern and northern parts of Anshun City (Xixiu District, Ziyun Miao and Buyi Autonomous County), the central and southern parts of Guiyang City (Baiyun District, Yunyan District, Guanshan Lake District, Nanming District, Huaxi District, Xiuwen County), The northeastern and southeastern of Qiannan Buyi and Miao Autonomous Prefecture (Duyun City, Dushan County, Libo County, Yudu Shui Autonomous County), Qiandongnan Miao and Dong Autonomous Prefecture (Kaili City, Rongjiang County, Congjiang County, Liping County, Jinping County, Tianzhu County, Jianhe County, Majiang County, Leishan County), Tongren City (Songtao Miao Autonomous County, Jiangkou County, Bijiang District, Dejiang County, Yanhe Tujia Autonomous County), Zunyi City (central Xishui County, Renhuai City, Honghuagang District and Huichuan District, Meitan County, Fenggang County) and other regions. Based on the suitable habitat distribution of *A. crenata* in Guizhou Province, our research team collected 31 batches of medicinal material samples from various counties and towns across the province for quality zoning analysis.

Table 2
Distribution area of 4 suitable zones in each administrative region

Administrative division	Non-suitability zones		Low-suitability zones		Moderate-suitability zones		High-suitability zones	
	Area/ km²	Proportion	Area/ km²	Proportion	Area/ km²	Proportion	Area/ km²	Proportion
Nationwide	7.18×10^{6}	77.32%	1.29×10^{6}	13.86%	7.58×10^{5}	8.16%	6.16×10^{4}	0.66%
Henan Province	1.46×10^{5}	87.94%	1.38×10^{4}	8.36%	5.11×10^{3}	3.09%	1.02×10^{3}	0.62%
Zhejiang Province	1.01×10^{4}	10.00%	5.57×10^{4}	54.80%	3.01×10^{4}	29.61%	5.68×10^{3}	5.59%
Hainan Province	8.73×10^{2}	2.60%	5.96×10^{3}	17.75%	2.51×10^{4}	74.66%	1.68×10^{3}	4.99%
Taiwan Province	1.13×10^{4}	31.60%	1.50×10^{4}	42.07%	6.39×10^{3}	17.88%	3.02×10^{3}	8.46%
Guangxi Zhuang Autonomous Region	1.05×10^{4}	4.44%	1.02×10^{5}	43.11%	1.20×10^{5}	50.79%	3.92×10^{3}	1.66%
Hubei Province	5.41×10^{4}	29.10%	8.66×10^{4}	46.57%	4.08×10^{4}	21.95%	4.43×10^{3}	2.38%
Jiangsu Province	8.29×10^{4}	81.71%	1.21×10^{4}	11.96%	4.78×10^{3}	4.71%	1.64×10^{3}	1.62%
Shandong Province	1.43×10^{5}	92.94%	6.31×10^{3}	4.08%	4.39×10^{3}	2.84%	2.08×10^{2}	0.13%
Tibet Autonomous Region	1.12×10^{6}	93.22%	7.84×10^{4}	6.52%	3.10×10^{3}	0.26%	0.26×10^{2}	——
Chongqing Province	4.28×10^{3}	5.19%	4.33×10^{4}	52.52%	3.28×10^{4}	39.82%	2.03×10^{3}	2.47%
Fujian Province	8.78×10^{3}	6.81%	6.74×10^{4}	52.27%	4.67×10^{4}	36.22%	6.06×10^{3}	4.70%
Guangdong Province	3.90×10^{3}	2.27%	9.67×10^{4}	56.28%	5.91×10^{4}	34.41%	1.21×10^{4}	7.04%
Jiangxi Province	0.49×10^{2}	0.03%	8.76×10^{4}	57.20%	6.20×10^{4}	40.48%	3.51×10^{3}	2.29%
Yunnan Province	3.03×10^{5}	51.51%	2.23×10^{5}	37.87%	5.89×10^{4}	10.00%	3.64×10^{3}	0.62%
Sichuan Province	7.87×10^{4}	30.11%	1.46×10^{5}	55.82%	3.22×10^{4}	12.32%	4.58×10^{3}	1.75%
Anhui Province	5.18×10^{4}	45.66%	4.52×10^{4}	39.87%	1.37×10^{4}	12.11%	2.67×10^{3}	2.36%
Hunan Province	1.76×10^{5}	46.98%	1.01×10^{5}	26.90%	9.46×10^{4}	25.21%	3.41×10^{3}	0.91%
Shanxi Province	1.83×10^{5}	86.14%	2.73×10^{4}	12.85%	1.66×10^{3}	0.78%	4.81×10^{2}	0.23%
Guizhou	——	——	5.72×10^{4}	33.19%	1.41×10^{5}	66.16%	1.11×10^{3}	0.65%

Administrative division	Non-suitability zones		Low-suitability zones		Moderate-suitability zones		High-suitability zones	
	Area/ km²	Proportion	Area/ km²	Proportion	Area/ km²	Proportion	Area/ km²	Proportion
Province								

3.4 Quality zoning analysis of *A. crenata*

3.4.1 Bergenin content in *A. crenata*

In this study, we selected bergenin as the core indicator for quality evaluation of *A. crenata* medicinal materials, and quantified its content in 31 wild-collected samples from different production areas in Guizhou Province. The results showed that the content of bergenin in samples from different regions showed obvious regional differences (Table 3). Among all samples, ZSG19 from Qiaowai Village (Yongle Town, Leishan County) and ZSG21 from Dapotou Village (Rongdu Town, Ceheng County) exhibited significantly higher bergenin content (≥ 3.00%) compared to other production areas.

Table 3

Bergenin content in *A. crenata* samples(*n*=3, $\overline{\varvec{x}}$)

Sample ID	Collection Site	Bergenin Content(%)
ZSG01	Zhuguan Village, Buyi and Miao Ethnic Township, Xixiu District	1.30
ZSG02	Kuankuoshui, Wangcao Town, Suiyang County	0.65
ZSG03	Shihuihe Village, Nangong Town, Taijiang County	2.05
ZSG04	Dishuitang, Yangxi Town, Daozhen County	1.10
ZSG05	Foding Mountain, Maxi Township, Shibing County	1.90
ZSG06	Laowo Village, Luwo Town, Xifeng County	0.35
ZSG07	Yuanping Village, Dalu Town, Songtao County	1.70
ZSG08	Litao Village, Longshan Town, Anlong County	1.45
ZSG09	Baoguan Village, Yunwu Town, Guiding County	0.70
ZSG10	Longla Village, Sanjiang Town, Jinping County	1.20
ZSG11	Litao Village, Daye Town, Wangmo County	0.25
ZSG12	Pingba Village, Lutun Town, Xingyi City	0.80
ZSG13	Shihuiyao Village, Longshan Town, Anlong County	1.10
ZSG14	Dapo Village, Puping Town, Anlong County	1.40
ZSG15	Baidao Village, Taiyong Town, Jianhe County	1.20
ZSG16	Baoli Village, Leli Town, Rongjiang County	1.65
ZSG17	Pingchang Village, Gaoniang Town, Tianzhu County	1.55
ZSG18	Jiefang Village, Pingle Town, Suiyang County	2.16
ZSG19	Qiaowai Village, Yongle Town, Leishan County	3.39
ZSG20	Longwang Village, Zaima Town, Rongjiang County	2.25
ZSG21	Dapotou Village, Rongdu Town, Ceheng County	3.52
ZSG22	Xinzhai Village, Baini Town, Yuqing County	0.53
ZSG23	Pingwang Village, Ganxi Township, Shiqian County	1.58
ZSG24	Zhanli Village, Gaoceng Township, Congjiang County	2.50
ZSG25	Zhounan Village, Zhouxi Town, Kaili City	2.62
ZSG26	Maoping Village, Xianyuan Town, Xishui County	1.88
ZSG27	Siping Village, Yangxi Town, Daozhen County	1.48
ZSG28	Dongyi Village, Nangong Township, Taijiang County	1.94
ZSG29	Shihuaping, Longshan Town, Anlong County	1.80
ZSG30	Pingba Village, Longchang Town, Zhenfeng County	2.70
ZSG31	Huilong Town, Xingren City	2.55

3.4.2 Modeling the relationship between bergenin content and environmental factors in *A. crenata*

We employed stepwise regression analysis to assess the influence of environmental factors on bergenin content in *A. crenata*, establishing a predictive model between bergenin (Y) and environmental factors (X). The derived regression equation is: $Y = -7.7676 + 0.0167 X_1 + 2.3816 X_2 - 0.6184 X_3$, Among them, X_1 is precipitation of warmest quarter (bio18), X_2 is mean diurnal range (bio2), and X_3 is iso-thermal (bio3). The F-test results for the regression equation showed $P = 0.0693$ and $R^2 = 0.2272$, indicating a statistically significant linear relationship between the dependent and independent variables, with the regression model demonstrating notable predictive efficacy. The results showed that suitable hydrothermal conditions could promote the growth of *A. crenata* and the accumulation of its index components, and the warm and humid climate conditions were particularly critical. This finding aligns with field observations demonstrating *A. crenata*'s sensitivity to temperature and humidity variations, confirming that stable thermal regimes, minimal diurnal temperature fluctuations, and adequate precipitation are critical environmental determinants of bergenin accumulation. Based on these factors, we performed cokriging spatial interpolation modeling with the three selected environmental variables (Zhao et al., 2023).

3.4.3 Quality zoning analysis based on bergenin content in *A. crenata*

Using the Fuzzy Overlay analysis tool in ArcGIS, we spatially integrated the quality zoning results of bergenin, ultimately generating a comprehensive quality zoning map for *A. crenata* in Guizhou Province (Fig. 7). The results showed that the high-quality producing areas of *A. crenata* were mainly concentrated in Qiandongnan Miao and Dong Autonomous Prefecture in eastern Guizhou (including Danqin County, Majiang County, Congjiang County, Rongjiang County, Liping County, Kaili City, Tianzhu County, Jianhe County, Taijiang County), as well as the northeastern and eastern regions of Tongren City in northeastern Guizhou (including Songtao Miao Autonomous County, Bijiang District, Jiangkou County, and Wanshan District), the southeastern Qiannan Buyi and Miao Autonomous Prefecture (encompassing Sandu Shui Autonomous County, Libo County, Dushan County, and Duyun City), and the southeastern Qianxinan Buyi and Miao Autonomous Prefecture (covering Anlong County, Ceheng County, and Zhenfeng County) and other regions. These areas not only benefit from favorable natural conditions for large-scale planting, but also exhibit significantly higher bergenin content in their medicinal materials compared to other regions. Among these, Congjiang County, Jianhe County, Jiangkou County, Dushan County, and Libo County are also traditional production areas of *A. crenata* medicinal materials (Guizhou Flora Editorial Committee., 1989).

4. Discussion

We integrated niche modeling with stoichiometry to achieve a spatial optimization analysis from ecological suitability to medicinal quality. It was found that the Qiandongnan Miao and Dong Autonomous Prefecture, Tongren City, as well as Qianxinan and Qiannan Prefectures are not only optimal habitats for *A. crenata* but also premium production zones with elevated bergenin content. These areas are recommended as priority zones for large-scale cultivation to ensure both high yield and superior quality of the medicinal material. The tripartite research framework of "ecological suitability—quality correlation—spatial optimization" established in this study provides a reference for the resource conservation of *A. crenata* and the selection of artificial cultivation bases. However, the study still has certain limitations. For instance, the selection of environmental factors may not fully cover all variables influencing the growth of *A. crenata.* Future research could consider incorporating more microecological factors (such as soil microbial communities) to improve model accuracy. Additionally, although bergenin is the primary active component, the medicinal efficacy of *A. crenata* may involve synergistic effects of multiple compounds. Follow-up studies could expand to a multi-component comprehensive evaluation.

5. Conclusion

In this study, we systematically analyzed the effects of ecological factors on *A. crenata* quality by combining MaxEnt modeling and ArcGIS geospatial analysis, integrating ecological niche modeling with chemometric approaches. Subsequently, we predicted both suitable distribution areas and quality zones across Guizhou Province. The results demonstrated that the ecological suitability of *A. crenata* is determined by four key factors: vegetation type (contributing 48.1%, the highest among all factors), annual precipitation, min temperature of coldest month, and base saturation of soil. These findings are consistent with the species' documented preference for warm-humid climates and fertile soils, further confirming the critical roles of hydrological and thermal conditions in its growth and secondary metabolite accumulation. In the quality zoning analysis, bergenin, the main active component of *A. crenata*, shows significant correlations with precipitation of warmest quarter, mean diurnal range, and iso-thermality, indicating that consistent water supply and stable thermal conditions are the key factors affecting bergenin accumulation. These findings provide a scientific basis for the selection of artificial cultivation sites and resource conservation of *A. crenata*, and offer methodological insights for ecological suitability and quality zoning studies of other medicinal herbs.

Declarations

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

P.Z.: Data curation (equal), Methodology (equal), Validation (equal), Software (equal), Writing – original draft (equal). S.W.: Methodology (equal), Resources (equal), Funding acquisition (equal), Conceptualization (equal), Project administration (equal), Supervision (equal), Validation (equal). H.X.: Data curation (equal), Investigation (equal). Y.L.: Investigation (equal), Methodology (equal). Y.J.: Investigation (equal). Z.W.: Conceptualization (equal), Resources (equal), Supervision (equal), Validation (equal). F.Y.: Conceptualization (equal), Funding acquisition (equal), Project administration (equal), Resources (equal), Supervision (equal), Validation (equal), Writing – review & editing (equal)

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Data Availability Statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the privacy policy of the organization.

References

1. Cai, J.Z., & Hu, Y.J., 2012. Advances in the chemistry and pharmacology of the saponin analogs of *Hypericum perforatum*. Natural Products Research and Development, 24(11), 1671–1679.
2. Editorial committee of flora of China, Chinese academy of sciences, 2004. Flora of China., Beijing:Science Press.
3. Guizhou Provincial Drug Administration, 2003. Quality standards for Chinese herbal medicines and ethnomedicinal herbs in Guizhou Province., Guizhou Science and Technology Press, 164.
4. Guizhou Flora Editorial Committee. Flora of Guizhou., 1989. Volume IX. Sichuan: Sichuan Minzu Publishing House, 340–342.
5. Hou, X.Y., Xie, Y.X., Yu, F.X., Ma, Y.T., & Lu, Y., 2020. Seed tissue culture and healing tissue induction in *A. crenata* Sims. Anhui Agricultural Bulletin,26(13),25–28.
6. Jiang, X., Zhao, J.X., Shi, P.P., Ping, L.L., Du, C.H., & Zhan H.X., 2011. Ecological suitability zoning of three *Scutellaria baicalensis* medicinal plants in Shanxi Province based on MaxEnt and ArcGIS. Journal of Ecology, 1–11.
7. Li, J.A., 2025. Study on the dynamic accumulation of the content of bergenin in *A. crenata* Sims. Chinese Ethnic and Folk Medicine,34(06),25–28.
8. Lin, L., Wei, J.Y., Jin, L., Li, C.Q., Kang, S.F., Zhao, L., & Yuan, S.X., 2024. Study on the suitability and quality zoning of Tibetan medicine *Gentiana lawrencei* var. based on ecological niche model. Chinese Journal of Traditional Chinese Medicine Information, 31(12), 1–7.
9. Lin, X., Li, C.Y., Wei, S., Zhou, R.J., Zhang, G., Xie, Y.H., & Liu, S.R., 2023. Habitat suitability evaluation of *Hedysarum polybotrys* Hand. based on MaxEnt model and ArcGIS. Proprietary Chinese Medicine, 45(12), 4005–4010.
10. Liao, B.L., 2023. Research on the seedling raising technology of *A. crenata* Sims cuttings. Anhui Agricultural Bulletin, 29(19), 60–63.
11. Li, Y.F., He, P., & Meng, F.Y., 2023. Analysis of quality change of *Epimedium* in Taohe River Basin of Southern Gansu Province based on MaxEnt model. Journal of Sichuan University (Natural Science Edition), 60(02), 156–162.
12. Ren, Q.L., Luo, Q., Liu, H.Q., Wu, I.V., He, Y.Q., Liu, J.G. & Wang, Q., 2024. Progress of anti-tumor effects of *A. crenata* Sims. Chinese Journal of Comparative Medicine,34(01),165–170.
13. Tao, M.C., Liao, B.L., & Luo, S.J., 2014. Technical procedures for seeding and nursery of *A. crenata* Sims Seeds,33(10),126–128.
14. Wu, D.Y., Qin, Q., Xu, L.L., Chen, M.M., Liu, M.G., Wu, Y.H., & Zhang, S.W., 2024. Analysis of the suitable area and quality zoning of the characteristic medicinal herb *Ligusticum chuanxiong* in Jiangxi. Chinese Materia Medica, 47(06), 1397–1402.
15. Yu, C.L., Song, L.K., Wu, S.S., Li, Z.H., Wang, S.N. & Wang, Y., 2012. Distribution of medicinal resources of *A. crenata* Sims and research progress. Anhui Agricultural Science, 40(28), 13793–13794 + 13924.
16. Ye, Q., Chen, J.P., Ling, Y., Liu, Y.M., Liu, Y., Gai, X.H… Chen,C.Q., 2022. Progress in the study of chemical composition and pharmacological effects of *A. crenata* Sims. Chinese Herbal Medicine, 53(09), 2851–2860.
17. Yu, M., Zhang, J.K., Sun, Z., Li, J.Y., Liu, Y.L., & Jing, Z.X., 2023. Ecological suitability and quality zoning of forest ginseng in Liaoning Province. Chinese Journal of Experimental Formulas,29(20),149–159.
18. Zhu, L., Luo, Q., Liu,H.Q., Jia T.Z., Liu, J.Q., & Wang, Q., 2023. Progress of anti-tumor effects and mechanism of bergenin and its derivatives. Chinese Journal of Pharmacology,58(22),2028–2032.
19. Zhao, C.B., Chen, M.M., Zhang, G.M., & AI X.M., 2023. Effects of different treatments on the germination of recalcitrant seeds of yellow-fruited *A. crenata* Sims. Zhejiang Agricultural Science,64(08),1931–1934.
20. Zhao, M.Y., Zhao, Y.X., Shen, T.Z., Shu Li, Yao, G.Y., Chen, Z.S., & Xu, Y., 2023. Collaborative kriging interpolation and high-resolution mapping of soil Mn and Zn pollution distribution based on in situ PXRF data. Environmental Science Research, 36(03), 599–609.

Figures

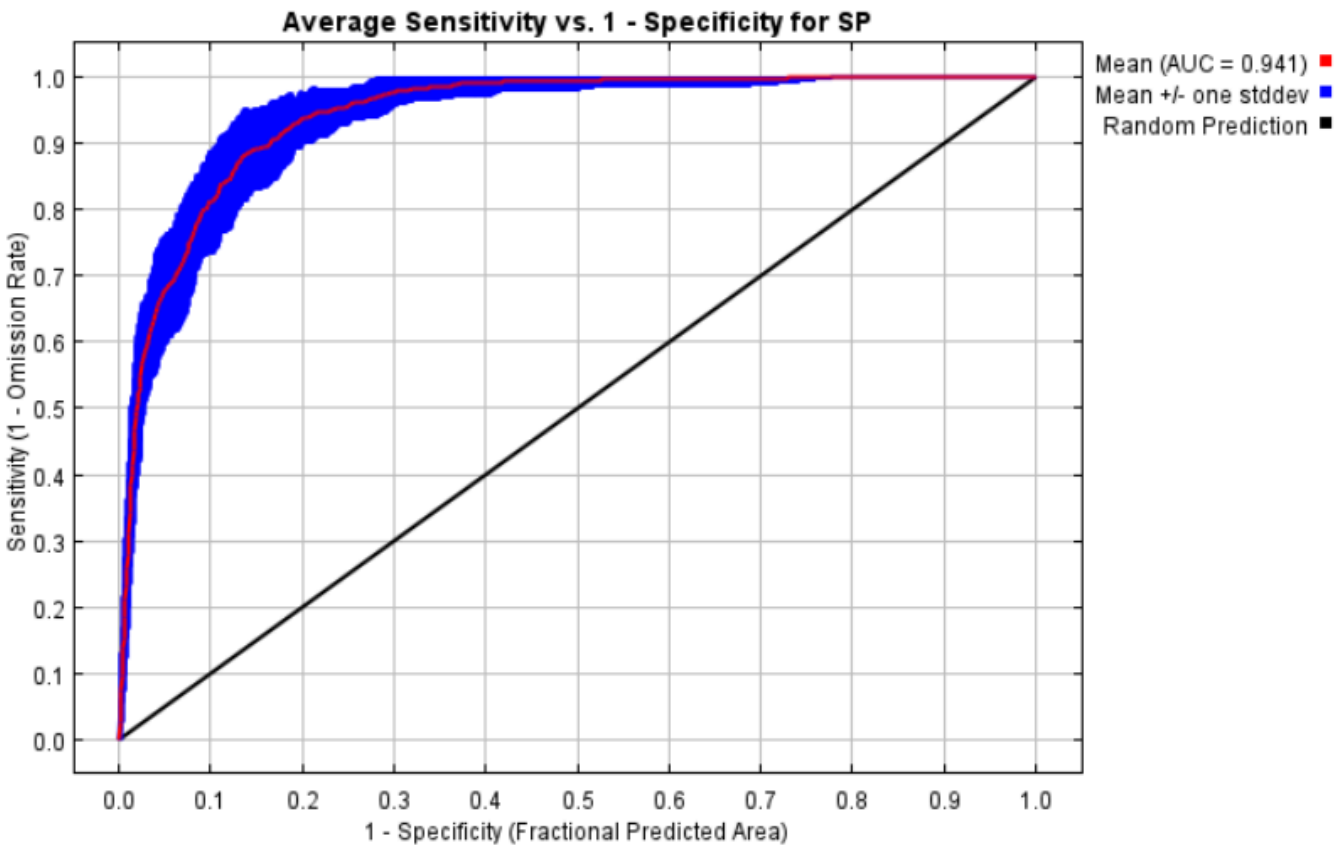


Figure 1

Analysis results of ROC curve of potential distribution prediction model of *A. crenata* in China

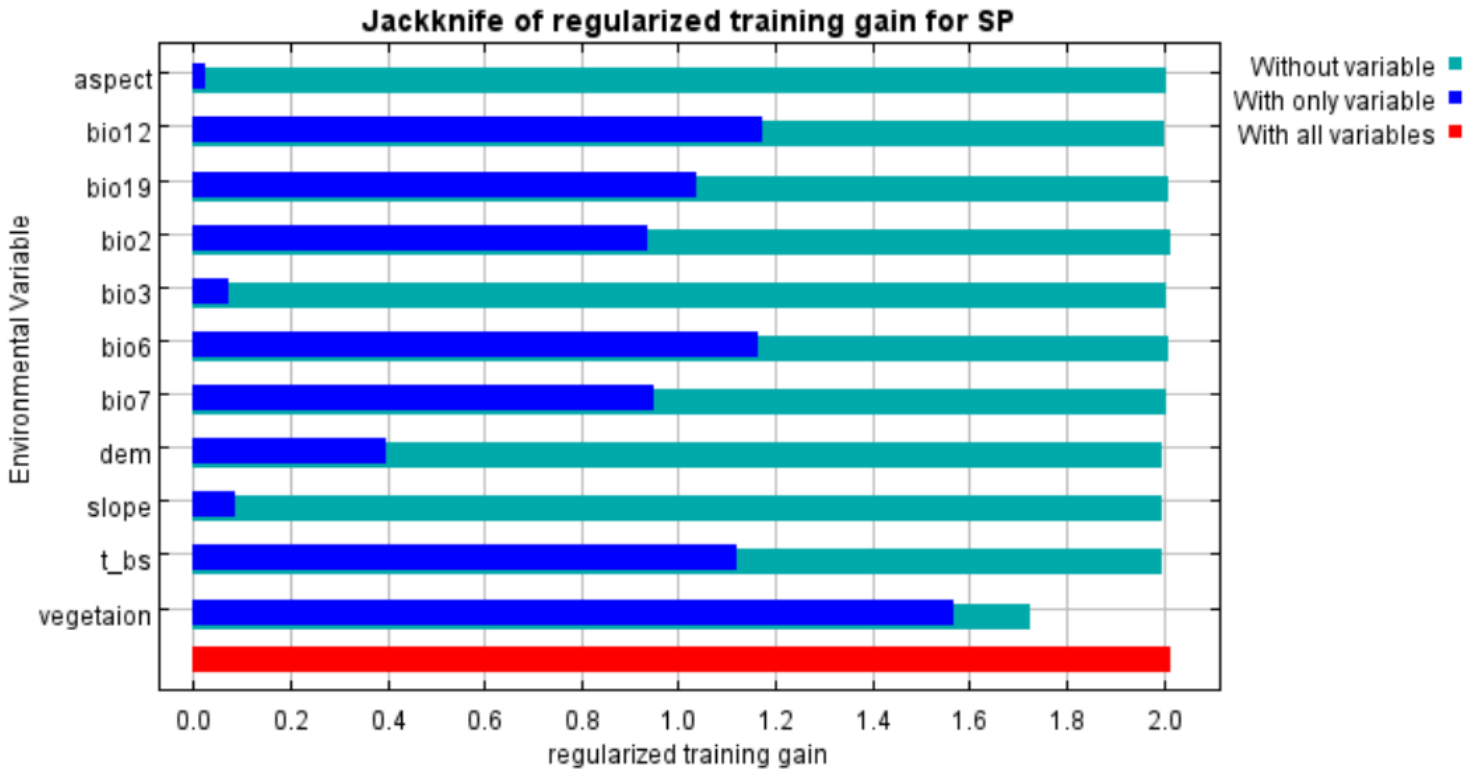


Figure 2

Results of the jackknife test analyzing environmental factors affecting *A. crenata* distribution.

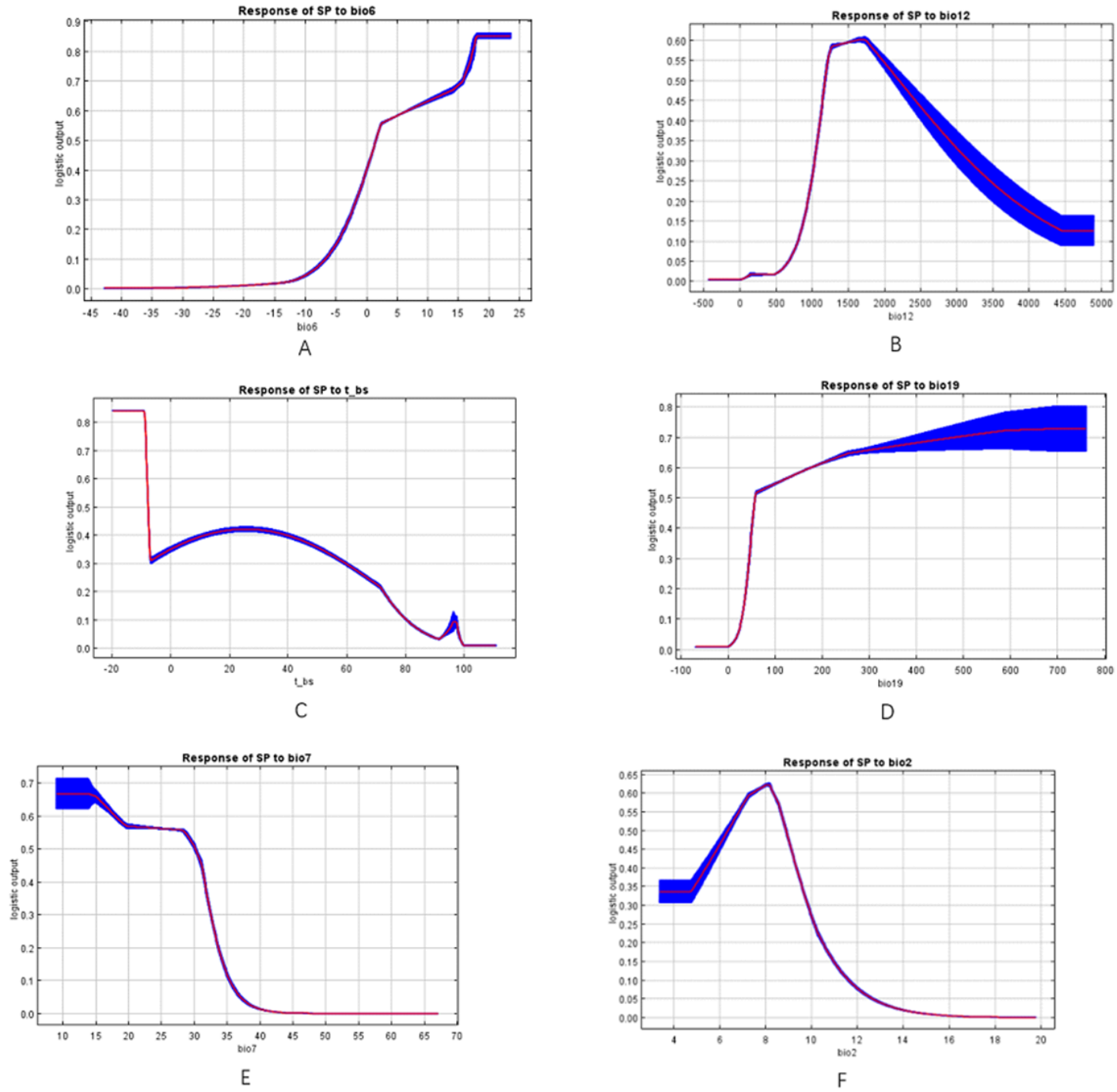


Figure 3

Response curves of key ecological factors for *A. crenata* habitat suitability;(A□bio6□B□bio12□C□t_bs□D□bio19□E□bio7□F□bio2)

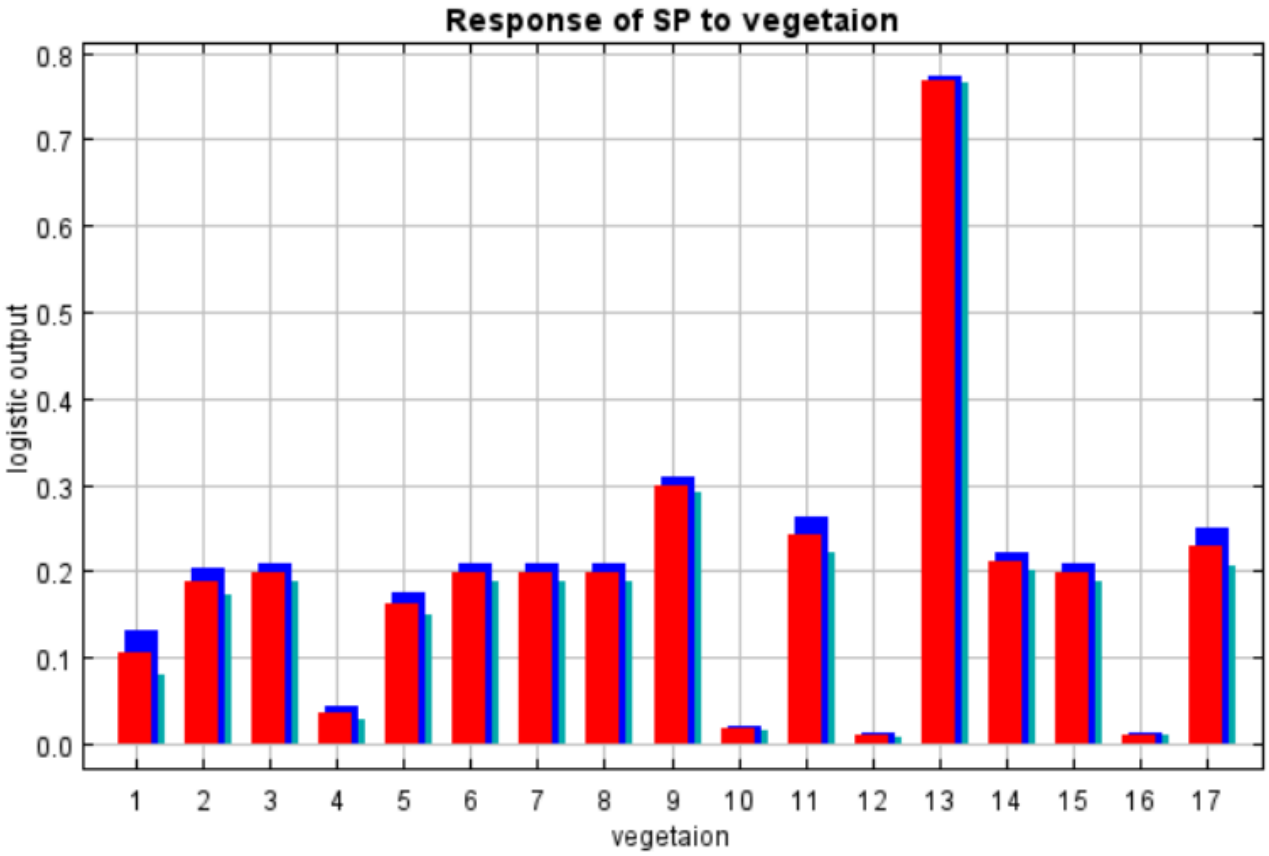


Figure 4

Analysis result of Vegetation response curve

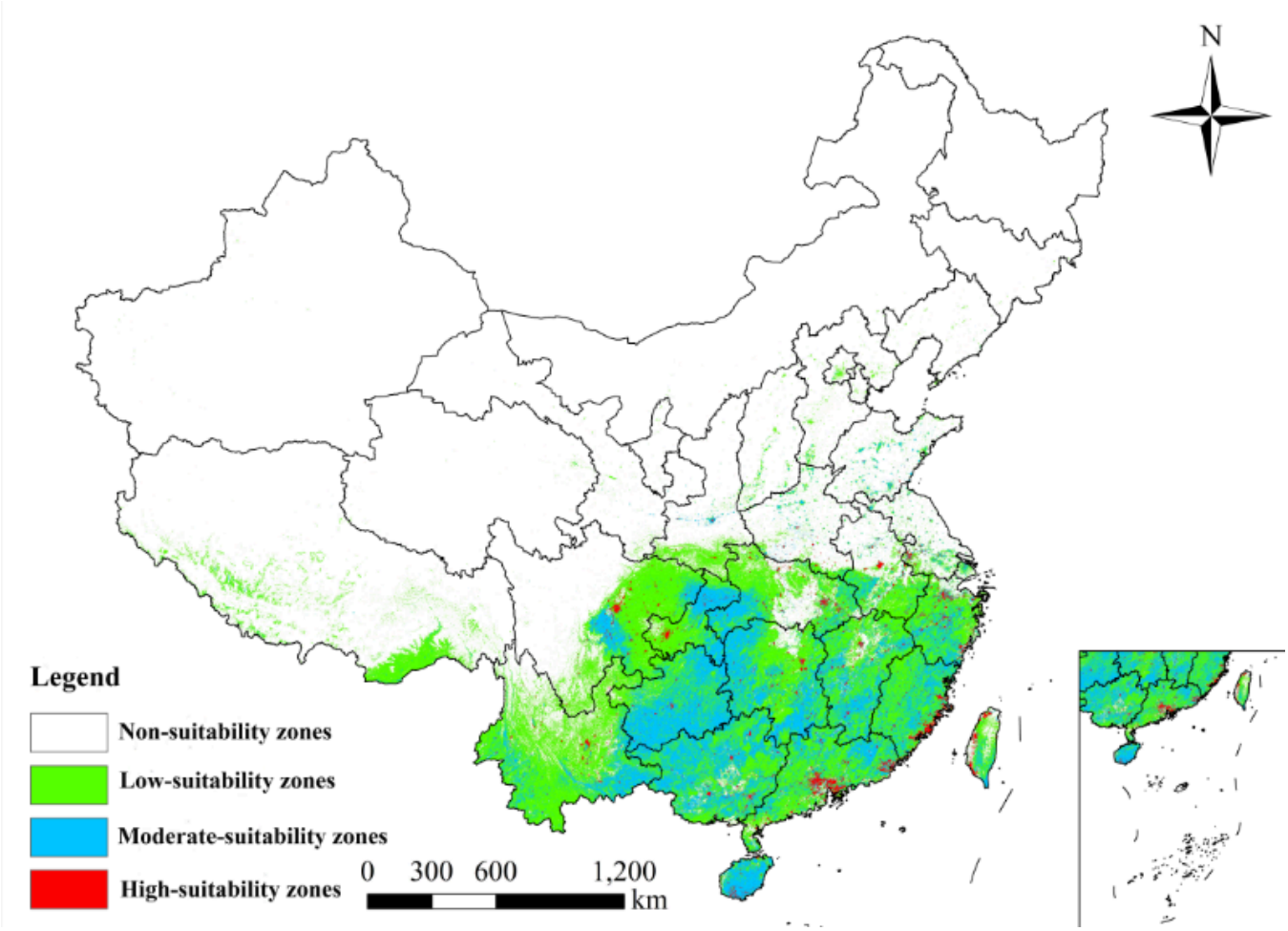


Figure 5

Predicted suitable habitat distribution of *A. crenata* in China

Note: This map is drawn based on the standard map from the Datav Data Visualization Platform [Review No.: GS(2024)1158], with unmodified base map boundaries. The same applies below.

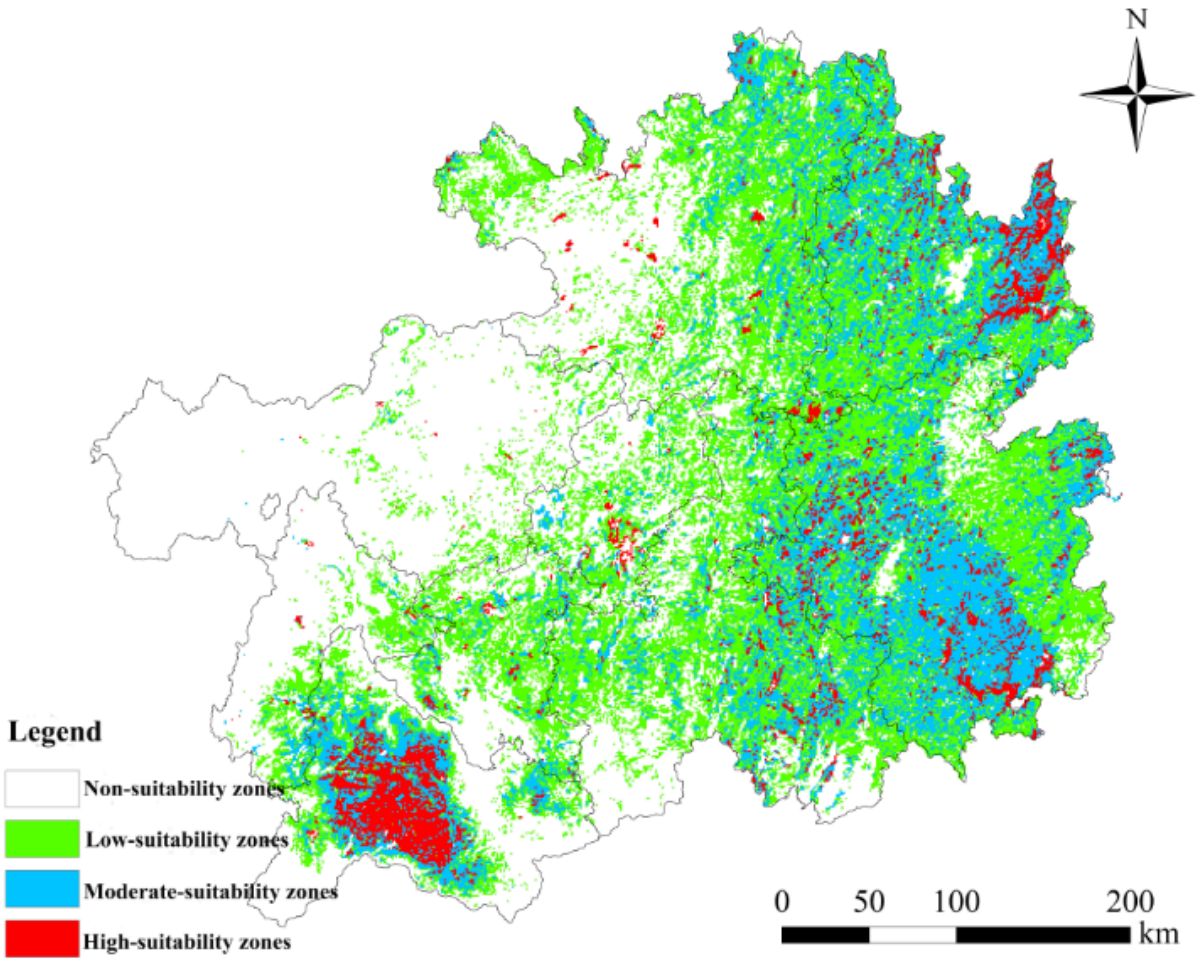


Figure 6

Predicted suitable habitat distribution of *A. crenata* in Guizhou Province