

Global Warming Will Drive Spatial Expansion of *Prunus mira* Koehn in Alpine Areas of Southeast Qinghai–Tibet Plateau

Guoyong Tang

tangguoyong1980@gmail.com

Chinese Academy of Forestry <https://orcid.org/0000-0002-5618-6866>

Jinkai GU

Institute of Plateau Forestry, Chinese Academy of Forestry Sciences

Qiang HE

Institute of Xizang Plateau Ecology, Xizang Agricultural & Animal Husbandry University

Qiangwan LI

Institute of Plateau Forestry, Chinese Academy of Forestry Sciences

Shengjian XIANG

Institute of Plateau Forestry, Chinese Academy of Forestry Sciences

Wanchi LI

Institute of Plateau Forestry, Chinese Academy of Forestry Sciences

Aohang JIN

Xizang Agriculture & Animal Husbandry University

Qinglin LI

International Rivers and Ecological Security Research Institute of Yunnan University

Shunbin WANG

Institute of Plateau Forestry, Chinese Academy of Forestry Sciences

Article

Keywords: *Prunus mira* Koehn, suitable habitat, species distribution, global warming,

Posted Date: August 19th, 2024

DOI: <https://doi.org/10.21203/rs.3.rs-4792908/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Additional Declarations: There is **NO** Competing Interest.

Abstract

Global climate change exerts great effort for plants distributions. However the response of *Prunus mira* Koehn, one of the most important species for ecological protection in the southeast of Qinghai-Tibet Plateau, to climate change remains unclear. To explore the ecological factors on the distribution of *Prunus mira* Koehn in context of global climate change, the MaxENT model is used to predict the suitable habitats for *Prunus mira* Koehn. Our study indicated that the distribution of *Prunus mira* Koehn is primarily influenced by temperature rather than precipitation, warming can facilitate the growth of *Prunus mira* Koehn. When the temperature seasonality (bio4) ranges from 134 to 576 and the mean temperature of coldest quarter (bio11) ranges from -2.6°C to 2.7°C , it is most conducive to the growth of *Prunus mira* Koehn. Among the four climate scenarios, the optimal habitat for *Prunus mira* Koehn is predominantly concentrated in river valley areas and is expected to expand into higher altitude regions, particularly in the north and southeast. SSP245 and SSP370 climate pathways are conducive to the growth and spatial expansion of *Prunus mira* Koehn. Our findings highlight the significant impact of temperature not precipitation on the distribution of *Prunus mira* Koehn, and this insight is crucial for the stability and conservation of this ecologically significant plant species.

1. Introduction

Since the 20th century, the global climate has changed significantly, and the fifth assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) points out that climate warming is an indisputable fact[1]. In this case, global warming and changes in precipitation patterns have caused an increase in extreme weather phenomena[2], which will not only affect plant growth and geographical distribution[3, 4], but also lead to the disappearance of the phytoclimates[5], posing a great challenge to ecosystem structure and biodiversity. The changes of temperature and precipitation caused by climate change will affect the tolerance of species to the environment. When the climate change exceeds the tolerance threshold of species, species will evolve or change their distribution range to find suitable habitats[6]. For species with small ranges, habitat loss due to future climate change has become a serious threat to their survival, increasing their risk of extinction[7].

Species Distribution Modeling (SDM) mainly predict the potential distribution of species based on the relationship between the ecological environment of species distribution and climate factors[8]. At present, the main models used to predict the distribution of potential species are Maximum Entropy Model(MaxEnt)[9], ecological niche factor analysis model (ENFA)[10], genetic algorithmic model (GARP)[11], bioclimate analysis and prediction system (BIOCLIM)[12], as well as Domain Models (DOMAIN)[13]. As one of the most important species prediction models, MaxEnt model is widely used because it is easy to operate and can provide reliable prediction in the case of limited number of samples[14, 15]. In recent years, MaxEnt model has been widely used in alien species invasion, animal and plant protection, disease transmission and species response to climate change[16–20].

P. mira is a plant species of the Rosaceae family, indigenous to the Qinghai-Xizang Plateau and also found in the provinces of Sichuan and Yunnan[21]. Compared to other varieties of peaches, the *P. mira* is designated as *P. mira* due to its smooth pit[22]. *P. mira*, as one of the most ancient and widely distributed endemic tree species on the Xizangan plateau, exhibits exceptional resistance to cold, drought, barren conditions, and diseases, with a potential lifespan spanning thousands of years.[23, 24]. It is called the "Living Fossil Group" of peach resources in the world[25]. *P. mira* is of great value for ornamental, culinary, and medicinal[25–27]. In recent years, the natural habitat of *P. mira* has been shrinking due to environmental changes, human activities, and social development. The traditional Xizangan lifestyle includes feeding livestock with fruit, making it challenging to preserve the fruit as a breeding medium, and resulting in serious aging of the tree species.[26–28].

The current research on *P. mira* has primarily emphasized the physiological and genetic aspects.[28, 29], the appropriate distribution area and environmental driving variables under the context of climate change remain uncertain. However, acknowledging the impact of climate change on the suitable growth areas of *P. mira* is crucial for understanding the distribution mechanism of the *P. mira* population and providing a vital foundation for the rational development, utilization, and scientific protection of *P. mira*.

We predict the suitable habitable area of *P. mira* on the Nyingchi in different periods by the MaxENT. The main objectives of our study include the following: (1) to study the current spatial distribution pattern of *P. mira* and the main environmental variables affecting its distribution; (2) to predict the distribution pattern of *P. mira* and its response to key variables under different climate scenarios in the future; (3) to analyze the expansion characteristics of *P. mira* under the background of climate change. This study can provide scientific reference value for the development, utilization and protection of *P. mira* under the future climate change.

2. Methods and Materials

2.1. Study Area

Nyingchi municipality is located in the southeast of Qinghai-Tibet Plateau, in the middle and lower reaches of the Yarlung Zangbo River. Geographically, it extends from $92^{\circ}09'$ E to $98^{\circ}18'$ E in longitude and from $27^{\circ}33'$ N to $30^{\circ}40'$ N in latitude. The terrain inclines from northwest to southeast, with an average elevation of 3000 m, the highest point of 7782 m and the lowest point of 152 m[30]. It is the largest vertical drop area in the world. Nyingchi municipality has jurisdiction over seven counties (districts and cities), including Bayi District, Gongbujiangda County, Milin City, Motuo County, Bomi County, Chayu County and Lang County[31]. It is adjacent to Changdu City of Xizang and Diqing Xizangan Autonomous Prefecture of Yunnan in the east, Lhasa City and Shannan City in the west, Nagqu City in the north, and Myanmar and India in the south. Nyingchi's dimensions stretch to 646.7 km from east to west and span 353.2 km from north to south. Situated in marine monsoon climate zone, with an annual average temperature of $6-17^{\circ}\text{C}$, the coldest average temperature is 0.2°C , and the hottest average temperature is 20°C . The Yarlung Zangbo River and Niyang River run through the city, with an average annual rainfall of about 750 mm[32]. It is known as "the snowy Jiangnan". Nyingchi, with its unique climatic and geographical conditions, is highly suitable for the growth of *P. mira*. The varying

altitudinal ranges create distinct microclimates, which help in understanding the species' adaptability to different climatic conditions and elevations. Furthermore, Nyingchi's rich biodiversity and relatively undisturbed natural environment make it an ideal area for studying the distribution patterns of *P. mira*.

2.2. Data Collection and Processing

The boundary of the Nyingchi was downloaded from the Department of Natural Resources of the Xizang Autonomous Region (<http://zrzyt.xizang.gov.cn/fw/zyxz/> (visited on 22 October 2023)). The natuer distribution point data of *P. mira* was received from the Global Biodiversity Information Network (GBIF:<http://www.gbif.org> (visited on 2 December 2023)), the Digita Herbarium of China (CVH:<http://www.cvh.ac.cn> (visited on 2 December 2023)) and field survey data. Data without an exact location in the GBIF were first removed, and then latitude and longitude were acquired based on the geographic location of the species. Next, invalid data and duplicate data were removed using the ENMTools. We set up a 1km×1km (30s) grid buffer and one geographic point was kept for every grid. The data of 35 effective distribution points were finally obtained and convert distribution point data to CSV format.

Table 1
environment factors

Category	Variable	Description	Unit	Category	Variable	Description	Unit
Climate	bio1	Annual Mean Temperature	°C		t-CaSO4	Topsoil Gypsum	%weight
	bio2	Mean Diurnal Range	°C		t-cec-clay	Topsoil CEC (clay)	cmol/kg
	bio3	Isothermality	%		t-cec-soil	Topsoil CEC (soil)	cmol/kg
	bio4	Temperature Seasonality	/		t-clay	Topsoil Clay Fraction	%wt
	bio5	Max Temperature of Warmest Month	°C		t-esp	Topsoil Sodicity (ESP)	%
	bio6	Min Temperature of Coldest Month	°C		t-gravel	Topsoil Gravel Content	%vol
	bio7	Temperature Annual Range	°C		t-sand	Topsoil Sand Fraction	%wt
	bio8	Mean Temperature of Wettest Quarter	°C		t-silt	Topsoil Silt Fraction	%wt
	bio9	Mean Temperature of Driest Quarter	°C		t-teb	Topsoil TEB	cmol/kg
	bio10	Mean Temperature of Warmest Quarter	°C		t-usda-tex-clay	Topsoil USDA Texture Classification	/
	bio11	Mean Temperature of Coldest Quarter	°C		t-bs	Topsoil Base Saturation	%
	bio12	Annual Precipitation	mm		t-ref-bulk	Topsoil Reference Bulk Density	kg/dm3
	bio13	Precipitation of Wettest Month	mm		t-ece	Topsoil Salinity (Elco)	dS/m
	bio14	Precipitation of Driest Month	mm		t-oc	Topsoil Organic Carbon	%wt
	bio15	Precipitation Seasonality	/		t-ph-H2O	Topsoil pH (H ₂ O)	_log(H+)
	bio16	Precipitation of Wettest Quarter	mm	Topography	Ele	Elevation	m
	bio17	Precipitation of Driest Quarter	mm		Asp	Aspect	°
	bio18	Precipitation of Warmest Quarter	mm		Slo	Slop	°
	bio19	Precipitation of Coldest Quarter	mm	Vegetation	NDVI	Normalized Difference Vegetation Index	/
	D-index	Dryness Index	/		V_type	Vegetation Type	/
	Su-sym90	Soil Unit Symbol	/	River	D_river	Distance to River	km
	t-CaCO3	Topsoil Calcium Carbonate	%weight				

According to the growth habit of *P. mira*[33], this study used 43 environmental variables (Table 1), including climatic, soil factors, terrain, vegetation and river factors. The current climate factors were acquired from the WorldClim 2.1 version (<http://www.woldclim.org/> (visited on 23 December 2023)). Current climate factors are 19 average bioclimatic variables from 1970–2000. The future climate factors were acquired from the WorldClim 2.1 version (<http://www.woldclim.org/> (visited on 23 December 2023)), which in every scenario includes 19 average bioclimatic factors. We used the future climate prediction date from CMIP6 to predict the future distribution of *P. mira*. Future climate data are bioclimatic variables under different carbon emission scenarios and shared socio-economic pathways (SSPs) reflect future climate change, including sustainable development path limited to 2°C (SSP126),

moderate development path limited to 3°C (SSP245), local development path limited to 4.1°C (SSP370) and conventional development path limited to 5°C (SSP585). So as to avoid error and uncertainty, we selected four bioclimatic variables (SSP126, SSP245, SSP370, SSP585) under the future climate scenario during 2021–2100. Terrain factors were acquired from the WorldClim 2.1 version (<http://www.worldclim.org/> (visited on 23 December 2023)). Soil factors were acquired from the Soil Data base (<http://www.iiasa.ac.at/web/home/research/researchPrograms/water/HWSD.html> (visited on 25 December 2023)). NDVI and vegetation type factors were acquired from the Resource and Environment Science and Data Center (<http://www.resdc.cn> (visited on 13 December 2023)). Dryness index was downloaded from the National Data Centre for the Xizangan Plateau (<https://data.tpdc.ac.cn/home> (visited on 13 December 2023)). The spatial resolution of each of the 43 environmental variables is 30s.

Table 2
Select environmental factors for model

Category	Variable	Description	Unit
Climate	bio3	Isothermality	%
	bio4	Temperature Seasonality	/
	bio11	Mean Temperature of Coldest Quarter	°C
	bio12	Annual Precipitation	mm
	D-index	Dryness Index	/
Topography	Ele	Elevation	m
	Slo	Slope	°
	Asp	Aspect	°
Soil	Su-sym90	Soil Unit Symbol	/
	T-bs	Topsoil Base Saturation	%
	T_silt	Topsoil Silt Fraction	%wt
Vegetation	V-type	Vegetation Type	/
	NDVI	Normalized Difference Vegetation Index	/
River	D-river	Distance to River	km

2.3. Selecting of Environmental Variables

Strong correlations between environmental variables can affect the accuracy of species potential distribution and MaxEnt results. The species distribution data and 43 environmental factors used in this study were first imported into the MaxEnt model for simulation, and the contribution rate was calculated using the Jackknife method in MaxEnt software, and screened for environmental factors with percentage contributions $\geq 1\%$ [34]. Next we calculate the correlation between environmental variables by using the SPSS 27.0 software (Fig. 2). If the correlation coefficients of both variables were greater than 0.8, only the environmental variables that had a significant impact on the distribution of *P. mira* was retained[35]. Finally, we select 14 mutual independence environmental factors to construct a predictive model of the suitable distribution of *P. mira*. (Table 2).

2.4. Model Parameter Optimization and Establishment

The default parameters of the model run will also lead to over-fitting of the model and affect the authenticity of the prediction results. The accuracy and goodness of fit of MaxEnt are closely related to the regularization coefficient (Regularization multiplier, RM) and the Feature combinations (FC), which are Linear (L), Quadratic (Q), Product (P), Hinge (H), Threshold (T). By using the kuenm data package of R language to optimize the MaxEnt model, the detailed calibration, parameter selection, model evaluation and final model establishment of the MaxEnt model are realized. In the optimization process, the RM value is set to be 0.1–4.0, the initial regularization and control frequency is 0.1, the regularization and control frequency is increased by 0.1 in each modeling, and 40 regularization and control frequencies are set in total. At the same time, 29 feature combinations FC of five features, including Linear (L), Quadratic (Q), Product (P), Hinge (H), Threshold (T), are selected for testing. Specifically include L, Q, P, T, H, LQ, LP, LT, LH, QP, QT, QH, PT, PH, TH, LQP, LQT, LQH, LPT, LPH, QPT, QPH, QTH, PTH, LQPT, LQPH, LQTH, LPTH, LQPTH. Finally, the kuenm package is used to test the above 1160 candidate models, and the complexity of the model is determined according to the 5% training omission rate and Delta AICc value of each model, and finally the model with Delta AICc = 0 is selected as the optimal model[36]. The default parameter RM-3.5 is obtained through optimization, and the delta AICc is equal to 0 when FC-QPT is used; At this time, the model is the optimal model.

Distribution data (CSV format) and environmental data (ASC format) were imported into the MaxEnt model, and the Jackknife method was used to determine and construct the response curve. In the MaxEnt model, 75% of the distribution points are used as the training set of the model, and the remaining 25% of the distribution points are used as the test set for validation. To improve the reliability of the results, 10 replicates were performed in this study. In this study, the contribution of each environmental variable was evaluated using the Jackknife test. The accuracy of the results was assessed according to the area under the curve (AUC) values of the working characteristics (ROC) of the subjects. AUC values ranged from 0 to 1, and the larger the AUC value, the better the prediction of MaxEnt model. An AUC value greater than 0.9 indicates perfect prediction[37].

2.5. Classification of Suitable Habitats

The ASC file of the model prediction results was imported into ArcGIS10.8 software, and the suitable areas of *P. mira* in different periods were visualized. Based on the natural discontinuous classification method and Rclass method of ArcGIS10.8 software and actual distribution of *P. mira*, the suitable areas were divided into four criteria: Not suitable ($p \leq 0.2$), Minimally suitable ($0.2 < p \leq 0.4$), Moderately suitable ($0.4 < p \leq 0.6$) and Highly suitable ($0.6 < p \leq 1$) [37, 38], and calculating the area of each suitable area.

2.6. Analysis of the dominant environmental factors

The importance value of environmental variables was used by jackknife method, which could quantitatively analyze the impact of environmental factors on the distribution of *Prunus mira* Koeh, so as to screen out the dominant environmental factors. In the jackknife method, the higher value of the regularization training gain for “only including this variable” demonstrate higher the prediction accuracy of the species distribution. In this study, the contribution rate and jackknife method were used to evaluate the environmental variables affecting species distribution, and the importance of environmental variables was analyzed. According to the classification standard of suitable area, when the response curve of environmental variables is greater than 0.6, the range of ecological variables was most suitable for species growth.

2.7. Change in Suitable Habitat under different climatic conditions

After defining the suitable and unsuitable habitats of *P. mira*, the spatial pattern of suitable areas under various climate scenarios in the future was analyzed by using the grid processing tool in ArcGIS (10.8). The future changes in suitable habitat were calculated based on current conditions. Under different climate paths in the future, the change from the suitable area to the unsuitable area is considered as the contraction area, the change from the unsuitable area to the suitable area is regarded as the expansion area, and the other changes are regarded as the stability area.

3. Results

3.1. Model Accuracy Evaluation

Through the optimization of parameter, the complexity of the model was reduced, making it more suitable for modeling in different period. The AUC value of *P. mira* was obtained by simulation training under the parameters of the optimal model. The ROC curve validation results for the *P. mira* showed that the average AUC values from 10 replicates were 0.992, 0.992, 0.991, 0.991, 0.992 (Table 3), all of which were greater than 0.990 and close to 1.0, indicating that the model with a high prediction accuracy.

Table 3
The AUC values of MaxEnt model for *Prunus mira* under different climatic backgrounds

Period	Current	SSP126	SSP245	SSP370	SSP585
Average AUC Values	0.992	0.992	0.991	0.991	0.992

3.2. Current Distribution Pattern of *P. mira* and Key Environment Variables

According to the classification of suitable habitats from the results (Fig. 3), highly suitable area of *P. mira* was mainly situated in the central and northern parts of Nyingchi, namely, along river valley. The not suitable area accounting for 62.70% of the total area of Nyingzhi, the minimally suitable area accounting for 14.13% of the total area, the moderately suitable area accounting for 12.31%, and the highly suitable area for 10.86%, the area of suitable habits account for 37.30% of the Nyingchi (Table 4).

Table 4
Area and proportion of current suitable for *P.mira*

Suitable level	Area//km ²	Proportion
Minimally suitable	16206.61	14.13%
Moderately suitable	14118.98	12.31%
Highly suitable	12450.84	10.86%
Suitable	42776.43	37.30%
Not suitable	71916.82	62.70%

The result from the analysis of factors contribution in the MaxEnt model (Table 5) show that the most critical factor affecting the distribution of *P. mira* was temperature seasonality (bio4, 30.1%), followed by mean temperature of coldest quarter (bio11, 25.6%), isothermality (bio3, 12.6%), soil unit symbol (su_sym90, 8.8%) and elevation (ele, 8.2%). The cumulative contribution of these five environment factors reached 85.3%, with climate variables being the most significant influencing factors and all related to temperature (68.3%), followed by the soil variables (8.8%) and the topography variables (8.2%).

Table 5
Select environmental factors and their rate of contribution importance

Category	Variable	Description	Unite	Percent contribution/%
Climate	bio3	Isothermality	%	12.6
	bio4	Temperature Seasonality	/	30.1
	bio11	Mean Temperature of Coldest Quarter	°C	25.6
	bio12	Annual Precipitation	mm	2.4
	d-index	Dryness Index	/	0
Topography	ele	Elevation	m	8.2
	slo	Slope	°	3.3
	asp	Aspect	°	1.7
Soil	su-sym90	Soil Unit Symbol	/	10.4
	t-bs	Topsoil Base Saturation	%	2.2
	t-silt	Topsoil Silt Fraction	%wt	0.1
Vegetation	v-type	Type	/	0.4
	ndvi	Normalized Difference Vegetation Index	/	1.2
River	d-river	Distance to River	km	1.8

According to the results of regularized training gain with only variable (Fig. 4), the regularized training of the temperature seasonality (bio4) was biggest, followed by the mean temperature of coldest quarter (bio11), isothermality (bio3), and elevation (ele), indicating that the temperature seasonality (bio4) was the key variable influencing the geographic distribution of the *P. mira*.

Based on the environmental variables response curves (Fig. 5), it can be concluded that the suitability of *P. mira* was negatively associated with temperature seasonality, the substantial fluctuations in temperature throughout the seasons are not favorable for its growth. The highest degree of suitability occurs when the temperature seasonality falls within the range of 134–576. The optimal average temperature range for the mean temperature of coldest quarter to pecan growth is -2.6°C to 2.7°C, and the optimum value was 0°C. The optimal range for the isothermality to *P. mira* growth is 43–57. The elevation of 2783–4089 m was the most suitable for the growth of *P. mira*.

3.3. Potential Distribution Areas for *P. mira* under Future Climate Conditions

Under the four time periods of SSP126 pathway, the area of not suitable area of *P. mira* was mainly distributed in the southern region of Nyingchi and the area was largest, followed by the minimally suitable, the moderately suitable and the highly suitable area. The highly suitable area would be concentrated in the Yarlung Zangbo Valley, the Niyang Valley and the southeast region, the minimally and moderately suitable would be concentrated in the central and eastern regions (Fig. 6). From 2021 to 2100, the unsuitable habitat of *P. mira* will continue to expand, the area of minimally and highly suitable habitat will continue to decrease, and the area of moderately suitable habitat will first decrease and then increase (Table 6). Compared with the current distribution range (Table 4), the areas of not suitable will be reduced, minimally suitable and moderately suitable will be expanded, and the areas of highly suitable will begin to shrink from 2061, the suitable area will reach the minimum in 2081–2100, according to 9.54%. From 2021 to 2100, the suitable area will continue to decrease.

Table 6
Area and proportion of future suitable for *Prunus mira*

Climate	Year	Not suitable		Minimally suitable		Moderately suitable		Highly suitable		Suitable
		Area//km ²	Proportion/%	Area//km ²	Proportion/%	Area//km ²	Proportion/%	Area//km ²	Proportion/%	Area//km ²
SSP126	2021–2040	60355.87	52.62%	21459.00	18.71%	17619.33	15.48%	15259.05	13.30%	54337.38
	2041–2060	63726.64	55.56%	20349.64	17.74%	15434.33	13.56%	15182.64	13.24%	50966.61
	2061–2080	67417.24	58.78%	19799.08	17.26%	15920.47	13.99%	11556.46	10.08%	47276.01
	2081–2100	70616.46	61.57%	16611.85	14.48%	16524.21	14.52%	10940.73	9.54%	44076.79
SSP245	2021–2040	60013.55	52.33%	20939.16	18.26%	16273.27	14.30%	17467.27	15.23%	54679.7
	2041–2060	66364.07	57.86%	19202.83	16.74%	17771.39	15.62%	11354.96	9.90%	48329.18
	2061–2080	66178.30	57.70%	20149.64	17.57%	16321.22	14.34%	12044.09	10.50%	48514.95
	2081–2100	60190.33	52.48%	21723.42	18.94%	18243.29	16.03%	14536.21	12.67%	54502.92
SSP370	2021–2040	57695.22	50.30%	20279.98	17.68%	17318.96	15.22%	19399.09	16.91%	56998.03
	2041–2060	62555.85	54.54%	20181.85	17.60%	15811.11	13.89%	16144.44	14.08%	52137.4
	2061–2080	68125.85	59.40%	19475.49	16.98%	14141.46	12.43%	12950.45	11.29%	46567.4
	2081–2100	63692.18	55.53%	18766.88	16.36%	14052.32	12.35%	18181.87	15.85%	51001.07
SSP585	2021–2040	65197.78	56.85%	18650.03	16.26%	16540.69	14.53%	14304.75	12.47%	49495.47
	2041–2060	60126.66	52.42%	20230.54	17.64%	16486.01	14.49%	17580.04	15.33%	54296.59
	2061–2080	66672.68	58.13%	18730.18	16.33%	14885.26	13.08%	14405.13	12.56%	48020.57
	2081–2100	69653.92	60.73%	16880.01	14.72%	13595.39	11.95%	14563.93	12.70%	45039.33

Under the SSP245 pathway, the suitable growth areas of *P. mira* are mainly concentrated in most areas except the southern part. The proportion of suitable area was followed by the not suitable area, minimally suitable area, moderately suitable area, and highly suitable area, (Table 6). From 2021 to 2100, the suitable area decreased first and then increased. Except for the not suitable and the highly suitable area, the minimally suitable and the moderately suitable area showed an overall increasing trend, from 2081 to 2100, the area of minimally and moderately suitable areas reached the maximum. Compared with the current distribution range (Table 4), the areas of not suitable will be reduced, minimally and moderately suitability will be expanded, and the areas of highly suitability will be reduced from 2041 to 2080.

Under the SSP370 pathway, the highly suitable habitat area of *P. mira* decreased from 2021 to 2080 and increased from 2081 to 2100. The not suitable habitat area reached the maximum from 2061 to 2080, the minimally suitable area decreased, the moderately suitable habitat area and the highly suitable habitat area decreased first and then increased (Table 6). Compared with the current distribution range (Table 4), the area of the not suitable area will be reduced, and the area of the minimally suitable, moderately area and highly area will be enlarged.

Under the SSP585 pathway, the area of the not suitable area still occupies the largest proportion, and the area of the not suited area decreases first and then increases from 2021 to 2100. The area of the moderately suitable area reaches the lowest in 2081–2100, and the area of the suitable area reaches the largest in 2041–2060. Under the four different future climate pathways, the suitable habitat area of *P. mira* will reach its maximum value, accounting for 49.70% of the total area under the 2021–2040 SSP370 climate, the suitable habitat area of *P. mira* will reach its minimum value under the 2081–2100 SSP126 climate, accounting for 38.43% of the total area. Compared with the current distribution (Table 4), the suitable habitat for *P. mira* is projected to increase, while the unsuitable habitat will decrease. Overall, the future growth and expansion of *P. mira* will be most favorable under the moderate temperature rise scenarios of SSP245 and SSP370.

3.4. Future Spatial Pattern of *P. mira*

According to Fig. 7 and Table 7, the suitable habitats of *P. mira* under the four future climate scenarios are in a trend of expansion, the areas of expansion of *P. mira* are significantly larger than the areas of contraction. The contraction area is mainly concentrated in the south-central part, and the expansion area is primarily concentrated at high elevations in the north and southeast. Under the SSP126 climate condition, the expansion area is larger than the contraction

area. In this climate condition, the *P. mira* expand is the smallest in 2081–2100, accounting for 5.71% of the area of Nyingchi, and the expansion area is slightly larger than the contraction area, it indicates a weak expansion towards the Nyingchi. Under the 2021–2040 SSP245 and 2021–2040 SSP370 climate scenarios, the *P. mira* of expand the largest, accounting for 13.43% and 12.26% of Nyingchi area, respectively. Under the 2081–2100 SSP245 and 2021–2040 SSP370 climate scenarios, the contraction area of *P. mira* is the smallest, accounting for 1.03% and 0.94% of Nyingchi area, respectively. Under the 2061–2080 SSP370 and 2081–2100 SSP585 climate scenarios, the contraction area of *P. mira* is the largest, accounting for 5.77% and 5.19% of Nyingchi area, respectively. On the whole, under the SSP245 and SSP370 climate scenarios are more suitable for the expansion of *P. mira*.

Table 7
Change of distribution areas and proportion of *P. mira* under the 4 climate pathway

Climate	Year	Stability		expansion		contraction	
		Area//km ²	Proportion/%	Area//km ²	Proportion/%	Area//km ²	Proportion/%
SSP126	2021–2040	41382.98	36.36%	13047.02	11.46%	1393.99	1.22%
	2041–2060	39928.32	35.08%	11112.21	9.76%	2841.91	2.50%
	2061–2080	38341.82	33.69%	8979.66	7.89%	4430.65	3.89%
	2081–2100	37544.08	32.99%	6495.80	5.71%	5224.65	4.59%
SSP245	2021–2040	40839.91	35.89%	13948.13	12.26%	1931.81	1.70%
	2041–2060	39245.93	34.48%	9178.91	8.07%	3524.3	3.10%
	2061–2080	38707.36	34.01%	9850.81	8.66%	4061.37	3.57%
	2081–2100	41595.71	36.55%	12957.13	11.39%	1177.51	1.03%
SSP370	2021–2040	41707.32	36.65%	15288.19	13.43%	1064.41	0.94%
	2041–2060	40685.61	35.75%	11517.45	10.12%	2081.662	1.83%
	2061–2080	36207.02	31.81%	10199.87	8.96%	6561.71	5.77%
	2081–2100	39394.24	34.61%	11560.90	10.16%	3375.24	2.97%
SSP585	2021–2040	39556.79	34.76%	9930.96	8.73%	3213.44	2.82%
	2041–2060	41362.01	36.34%	13267.24	11.66%	1408.97	1.24%
	2061–2080	38257.18	33.62%	9703.99	8.53%	4511.55	3.96%
	2081–2100	36857.20	32.39%	8089.03	7.11%	5910.78	5.19%

4. Discussion

In this study, we used MaxENT model to predict the potential distribution area of *P. mira* under current and future climate scenarios. MaxENT model has been widely used in species distribution models because of its unique advantages, but the model itself is sensitive to sampling bias and the default parameter setting is easy to cause over-fitting of the results and affect the final prediction results[39, 40]. The model constructed by using ENMeval data package to adjust the combination of various parameters can improve the prediction accuracy of the model and accurately reflect the impact of environmental factors on species distribution[36]. In order to avoid the multi-linear problem of environmental variables, the correlation analysis combined with jackknife method is used to eliminate the environmental factors with lower influencing factors; in order to avoid the over-fitting problem of the model, the regulation frequency and characteristic parameters of the model are optimized. After the optimization of the model, the correlation of each environmental factor is low, and the average AUC value of the final model in each period is greater than 0.99, which achieved high accuracy and precision in predicting the suitability, this study can accurately predict the suitable habitat of *P. mira* in different periods.

The current distribution area of *P. mira* is mainly concentrated in the central and northern parts of Nyingchi, along the Yarlung Zangbo River and Niyang River basins, and the suitable distribution area accounts for 37.30% of the total area of the region. This result is consistent with the results of the investigation and research of *P. mira*[28, 41]. Through the jackknife method and the regularization training gain, the temperature seasonality (bio4), the mean temperature of

coldest quarter (bio11), isothermality (bio3), and elevation (ele) are the main impact factor. The first three variables are all related to temperature, indicating that temperature had a greater impact on the distribution of *P. mira*, especially bio4 (temperature seasonality), the contribution rate reached 30.1%. During the growth period, it is not suitable to live in areas where the seasonal change of temperature is too large. When the temperature seasonality (bio4) was 134–576, it was the most suitable for the growth of *P. mira*, indicating that during the growth period the seasonal change of temperature should not be too large. Except the temperature seasonality, when the mean temperature of coldest quarter (bio11) was -2.6°C – 2.7°C , the isothermality (bio3) range was 43–57, and the elevation was 2783–4089 m, it was also suitable for the growth of *P. mira*. According to the growth characteristics of *P. mira*[22], the suitable altitude and climate of Nyingchi provide unique growth conditions for its growth[30–32], it can be conclude that the area of Nyingchi is suitable for *P. mira* growth under the current climate.

Over the past 60 years, the problem of warming in the Qinghai-Xizang Plateau has become increasingly prominent, and the temperature has shown a trend of continuous increase[42]. In this case, the frequency of extreme weather has increased, and climate instability has intensified, the species composition and community structure of the plateau have changed, and then have an impact on the reorganization and replacement of vegetation communities, but the diversity of regional vegetation does not necessarily decrease[43]. Previous studies have shown that global warming will lead to an increase in species diversity[44]. In this study, compared with the current suitable area, the suitable area of *P. mira* will increase under the future four climate scenarios. Under the 2021–2040 SSP370 climate pathway the suitable habitat area of *P. mira* will reach its maximum value, accounting for 49.70% of the total area. On the whole, Moderate warming is the most suitable for the growth of *P. mira*, while it was not suitable for the growth of *P. mira* under high warming. In the case of climate warming in the future, the high temperature will increase the seasonal difference of temperature, which may limit its growth and development.

Compared with the current situation, in the case of climate warming in the future, the suitable growth area of *P. mira* will expand, and the expansion area is greater than the contraction area, so the distribution area of *P. mira* will be greatly affected by climate change. Under the low level of climate warming pathway, the expansion range of *P. mira* decreased continuously, and it was the most suitable for *P. mira* to expand under the moderate warming path. From the spatial pattern of expansion, the high altitude areas in the north and south of Nyingchi are the main areas of expansion, aligning with the migration trend of temperate tree species to higher altitudes under climate warming conditions.[45]. The Nyingchi region is influenced by the Indian Ocean monsoon, with moisture advancing northward along the Yarlung Zangbo River Gorge, resulting in abundant precipitation. Additionally, the region's numerous rivers and substantial meltwater from snow and ice provide ample water for plant growth. Therefore, water is not a limiting factor for the growth of *P. mira* in Nyingchi.

In this study, the contribution rate of soil factors reached 10.4%, but the contribution rate in regularization training was not high, which may be due to the complex terrain and soil types in Nyingchi area, which made the demand for soil for *P. mira* growth not high, but the relationship between soil and its distribution still needs further study. In addition to climate, topography, soil, land use and other factors, there are some factors not taken into account in this study, such as human activities. The operation of MaxENT model is limited by the data of species existence, and the acquisition of some data in Nyingchi area is limited due to the special regional location. In future studies, we should strive to collect more comprehensive and timely data, incorporate more factors and geographical distribution data into the model prediction, and more accurately predict the suitable area of *P. mira* distribution. In addition, the combination of species dispersal ability, land use change, the competition between different species and the impact of human activities on species distribution, the expansion of spatial coverage of data and the combination of more advanced modeling technology to achieve more reliable prediction will help to further deepen the impact of climate change on species distribution, and provide new ideas for scientific protection and rational utilization of *P. mira*.

5. Conclusion

Based on MaxENT model, our study analyzed the suitable distribution pattern of Nyingchi *P. mira* and the ecological factors affecting its distribution. The results showed that: (1) the AUC values of MaxENT model were greater than 0.99, which accurately predicted the geographical distribution of *P. mira*; (2) the main environmental factors affecting the potential distribution of *P. mira* were bio4, bio3, bio11 and ele, and temperature was the most important environmental factor affecting its distribution; (3) Under the current and future climate paths, the suitable area of *P. mira* was mainly concentrated within river valley. Under the four different climate paths in the future, the suitable area of *P. mira* is increasing compared with the current distribution, and the moderate warming is the most suitable for the growth and expansion of *P. mira*; (4) In the case of climate warming in the future, the average temperature increase will conducive to the spatial expansion of *P. mira* particularly in the north and southeast. Understanding the future distribution and expansion trends of *P. mira* under the context of global warming is crucial for ecological sustainability, as well as for the conservation and stability of the species.

References

1. Alexander LV et al (2013) Climate change 2013: The physical science basis, in contribution of Working Group I (WGI) to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). computational geometry
2. Coumou D and S Rahmstorf(2012)A Decade of Weather Extremes. Nat Clim Change. <https://doi.org/10.1038/nclimate1452>
3. Girardin MP, Hogg EH, Bernier PY et al (2016) Negative impacts of high temperatures on growth of black spruce forests intensify with the anticipated climate warming. Glob Change Biol. <https://doi.org/10.1111/gcb.13072>
4. Alberto FJ (2013) Potential for evolutionary responses to climate change-evidence from tree populations. Glob Change Biol. <https://doi.org/10.1111/gcb.12181>
5. Conradi T, Eggli U, Kreft H et al (2024) Reassessment of the risks of climate change for terrestrial ecosystems. Nat Ecol Evol. <https://doi.org/10.1038/s41559-024-02333-8>
6. McHenry J, Welch H, Lester SL, Saba V (2019) Projecting marine species range shifts from only temperature can mask climate vulnerability. Glob Change Biol. <https://doi.org/10.1111/gcb.14828>

7. Prieto-Torres DA, Navarro-Sigüenza AG, Santiago-Alarcon G et al (2016) Response of the endangered tropical dry forests to climate change and the role of Mexican Protected Areas for their conservation. *Glob Change Biol*. <https://doi.org/10.1111/gcb.13090>
8. Soberon J and A.T (2005) Peterson, Interpretation of Models of Fundamental Ecological Niches and Species' Distributional Areas. <https://doi.org/10.17161/bi.v2i0.4>. *Biodiversity Informatics*
9. Hosseini N, Ghorbanpour M, Mostafavi H (2024) Habitat potential modelling and the effect of climate change on the current and future distribution of three *Thymus* species in Iran using MaxEnt. *Sci Rep*. <https://doi.org/10.1038/s41598-024-53405-5>
10. Hassanvand A, Radnezhad H et al (2018) Potential distribution of persian gazelle (*Gazella subgutturosa subgutturosa*) in bamoo national park, Shiraz, Iran: A presence-only model approach. *Applied Ecology and Environmental Research*http://dx.doi.org/10.15666/aeer/1601_305319
11. Robert P, Daniel L et al (2003) Evaluating predictive models of species' distributions: criteria for selecting optimal models. *Ecol Model*. [https://doi.org/10.1016/S0304-3800\(02\)00349-6](https://doi.org/10.1016/S0304-3800(02)00349-6)
12. Honig MA, Cowling RM, Richardson DM (1992) The invasive potential of Australian banksias in South African fynbos: A comparison of the reproductive potential of *Banksia ericifolia* and *Leucadendron laurum*. *Aust J Ecol*. <https://doi.org/10.1111/j.1442-9993.1992.tb00812.x>
13. Carpenter G, Gillison AN, J Winter (1993) DOMAIN: a flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity & Conservation*. <https://doi.org/10.1007/BF00051966>
14. Follak S, Dullinger S, Kleinbauer I et al (2013) Invasion dynamics of three allergenic invasive Asteraceae (*Ambrosia trifida*, *Artemisia annua*, *Iva xanthiifolia*) in central and eastern Europe. *Preslia* 85:41–61. <http://www.ibot.cas.cz/preslia/P131Follak.pdf>
15. Shi X, Wang J, Zhang L et al (2023) Prediction of the potentially suitable areas of *Litsea cubeba* in China based on future climate change using the optimized MaxEnt model. *Ecol Ind*. <https://doi.org/10.1016/j.ecolind.2023.110093>
16. Liu T, Liu H et al (2024) Staying on the current niche: consensus model reveals the habitat loss of a critically endangered dragonfly *Libellula angelina* under climate changes. *J Insect Conserv*. <https://doi.org/10.1007/s10841-024-00564-5>
17. Abrha H, Dodiomon S, Ongoma V et al (2024) Response of plant species to impact of climate change in Hugumbrda Grat-Kahsu forest, Tigray, Ethiopia: Implications for domestication and climate change mitigation. *Trees, Forests and People*. <https://doi.org/10.1016/j.tfp.2023.100487>
18. Kim I, Nam Y, Park S et al (2024) Enhancing pest control interventions by linking species distribution model prediction and population density assessment of pine wilt disease vectors in South Korea. *Frontiers in Ecology and Evolution*. <https://doi.org/10.3389/fevo.2023.1305573>
19. Downs J, Chakraborty S et al (2024) Effects of land use/land cover, bioclimatic, and topographic variables on the seasonal occurrence of eastern equine encephalitis virus in Florida. *J Land Use Sci*. <https://doi.org/10.1080/1747423X.2024.2321398>
20. Feng B, Tao Y, Xie X et al (2024) Identification of Suitable Mangrove Distribution Areas and Estimation of Carbon Stocks for Mangrove Protection and Restoration Action Plan in China. *JOURNAL OF MARINE SCIENCE AND ENGINEERING*. <https://doi.org/10.3390/jmse12030445>
21. Dong GZ (1991) Investigation of *Amygdalus mira* in Xizang. *Quarterly of Forest By-product and Specialty*. <https://doi.org/10.13268/j.cnki.fbsic.1991.03.024>
22. Zhang J, Chen W, Sun W et al (2022) *P. mira* in Sichuan, China: Recorded History as a Medicine and Food, Modern Applications, Distribution, and Ethnobotanical Investigations. *Front Pharmacol*. <https://doi.org/10.3389/fphar.2022.826712>
23. Zhou Y, Zhang J, Chen W et al (2022) Identification of Hair Growth Promoting Components in the Kernels of *P. mira* and Their Mechanism of Action. <https://doi.org/10.3390/molecules27165242>. *MOLECULES*
24. Zhang J, Chen W, Sun W et al (2022) *P. mira* in Sichuan, China: Recorded History as a Medicine and Food, Modern Applications, Distribution, and Ethnobotanical Investigations. *FRONTIERS IN PHARMACOLOGY*. <https://doi.org/10.3389/fphar.2022.826712>
25. Tan J, Zeng X, Liao M (2012) Genetic diversity of natural *Prunus mira* populations detected by SRAP. *Acta Prataculturae Sinica* 21:213–220. <http://cyxb.magtech.com.cn/EN/Y2012/V21/I6/213>
26. Tian Y, Xing C, Cao Y et al (2015) Evaluation of genetic diversity on *P. mira* by using ISSR and RAPD markers. *Biotechnol Biotechnol Equip*. <https://doi.org/10.1080/13102818.2015.1064780>
27. Jiang-Ping F, Zheng-Chang Z (2008) The Age Structure of Xizangan *P. mira* Kov et.Kpsl Population in Xizang Linzhi Region. *China Forestry Sci Technol* 1:53–56. <https://kns.cnki.net/kcms2/article/abstract>
28. Guan FC, Wang SP, Li RQ et al (2014) Genetic Diversity of Wild Peach (*P. mira* kov et. kpst) from Different Altitudes in the Xizangan Plateau by Pollen Morphous and RAPD Markers. *HortScience* 49(8):1017–1022. <http://dx.doi.org/10.2307/2052416>
29. Li J, Zhang S et al (2024) The Nascent Polypeptide-Associated Complex Subunit Alpha-Like Protein 1 (PmNACA1) Enhances Drought Tolerance by Scavenging ROS in *Prunus mira* Koehne. *J Plant Biology*. <https://doi.org/10.1007/s12374-023-09418-0>
30. Hao W, An HX, Wang ZY et al (2022) Importance Evaluation of Ecological Protection and Ecological Function Zoning in Nyingchi City. *Sci Technol Dev* 18:686–695. <https://doi.org/10.11842/chips.20220702001>
31. Yi M et al (2021) Comprehensive traffic advantage degree and its spatial characteristics at the prefecture level on the Qinghai-Xizang Plateau: A case study of Linzhi City. *Progress Geogr* 40:1332–1343. <https://doi.org/10.18306/dlkxjz.2021.08.007>
32. Hua Y, Xu Y, Wang JL et al (2023) Evaluation method and empirical application of construction land suitability and arable land suitability in alpine-gorgeregion of Qinghai-Xizang Plateau: A case study of Nyingchi city. *J Nat Resour* 38:1283–1299. <https://doi.org/10.31497/zrzyxb.20230511>
33. Zhang SS, Deng L, Zen XL (2016) Research Progress and Prospects of *Amygdalus mira* (Koehne). *J Agric* 6(02):88–91. <https://kns.cnki.net/kcms2/article>
34. An X, Huang T, Zhang H et al (2023) Prediction of Potential Distribution Patterns of Three *Larix* Species on Qinghai-Xizang Plateau under Future Climate Scenarios. <https://doi.org/10.3390/f14051058>. *FORESTS*

35. Parolo G, Rossi G, Ferrarini A (2008) Toward improved species niche modelling:: *Arnica montana* in the Alps as a case study. <https://doi.org/10.1111/j.1365-2664.2008.01516.x>. JOURNAL OF APPLIED ECOLOGY
36. Cobos ME, Townsend Peterson A et al (2019) n R package for detailed development of ecological niche models using Maxent. <https://doi.org/10.7717/peerj.6281>. PEERJ
37. Yang XQ, Kushwaha SPS, Saran S et al (2013) Maxent modeling for predicting the potential distribution of medicinal plant, *Justicia adhatoda* L. in Lesser Himalayan foothills. Ecol Eng 51:83–87. <https://doi.org/10.1016/j.ecoleng.2012.12.004>
38. Li J, Gang F, Yang H (2020) Predicting the current and future distribution of three Coptis herbs in China under climate change conditions, using the MaxEnt model and chemical analysis. Sci Total Environ 698:134141. <https://doi.org/10.1016/j.scitotenv.2019.134141>
39. Warren DL, Amber N, Wright et al (2014) Incorporating model complexity and spatial sampling bias into ecological niche models of climate change risks faced by 90 California vertebrate species of concern. Divers Distrib 20:334–343. <https://doi.org/10.1111/ddi.12160>
40. Peterson AT, Papes M, J Soberón (2008) Rethinking receiver operating characteristic analysis applications in ecological niche modeling. Ecol Model 213:63–72. <https://doi.org/10.1016/j.ecolmodel.2007.11.008>
41. Bao W, Wu YT, Li TZ et al (2017) Genetic diversity and population structure of *Prunus mira* (Koehne) from the Xizang plateau in China and recommended conservation strategies. PLoS ONE. <https://doi.org/10.1371/journal.pone.0188685>
42. Duan A (2015) Z Xiao Does the climate warming hiatus exist over the Xizangan Plateau? Scientific Reports. <https://doi.org/10.1038/srep13711>
43. Zhou JJ, Xiang J, Wang L et al (2019) The Impacts of Groundwater Chemistry on Wetland Vegetation Distribution in the Northern Qinghai-Xizang Plateau. <https://doi.org/10.3390/su11185022>. SUSTAINABILITY
44. Mohammad A, Wang X, Xu XT et al (2013) Drought and spring cooling induced recent decrease in vegetation growth in Inner Asia. Agric For Meteorol 178:21–30. <https://doi.org/10.1016/j.agrformet.2012.09.014>
45. Ye XZ, Zhao GH, Zhang MZ et al (2020) Distribution Pattern of Endangered Plant *Semiliquidambar cathayensis* (Hamamelidaceae) in Response to Climate Change after the Last Interglacial Period. FORESTS. <https://doi.org/10.3390/f11040434>

Figures

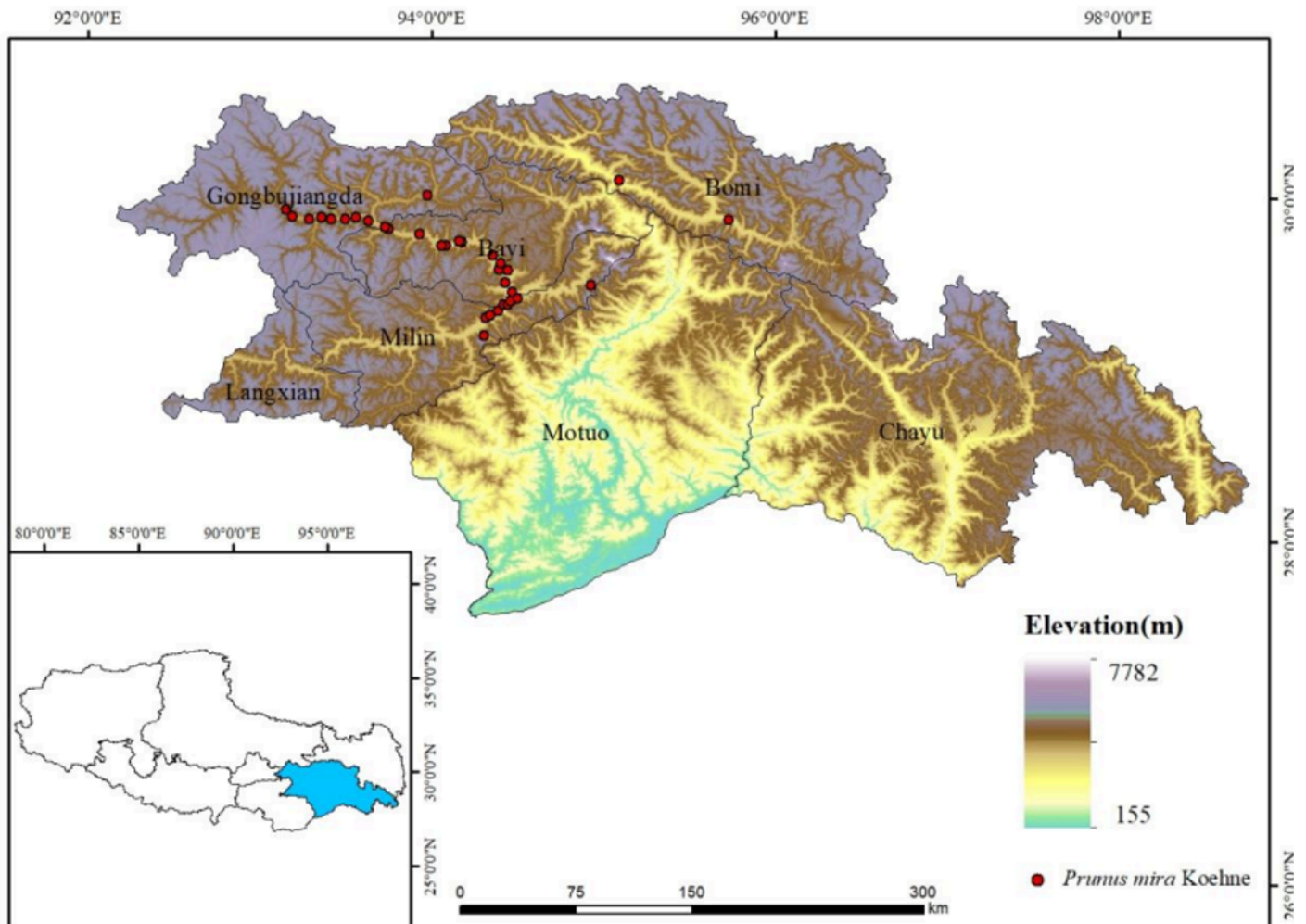


Figure 1

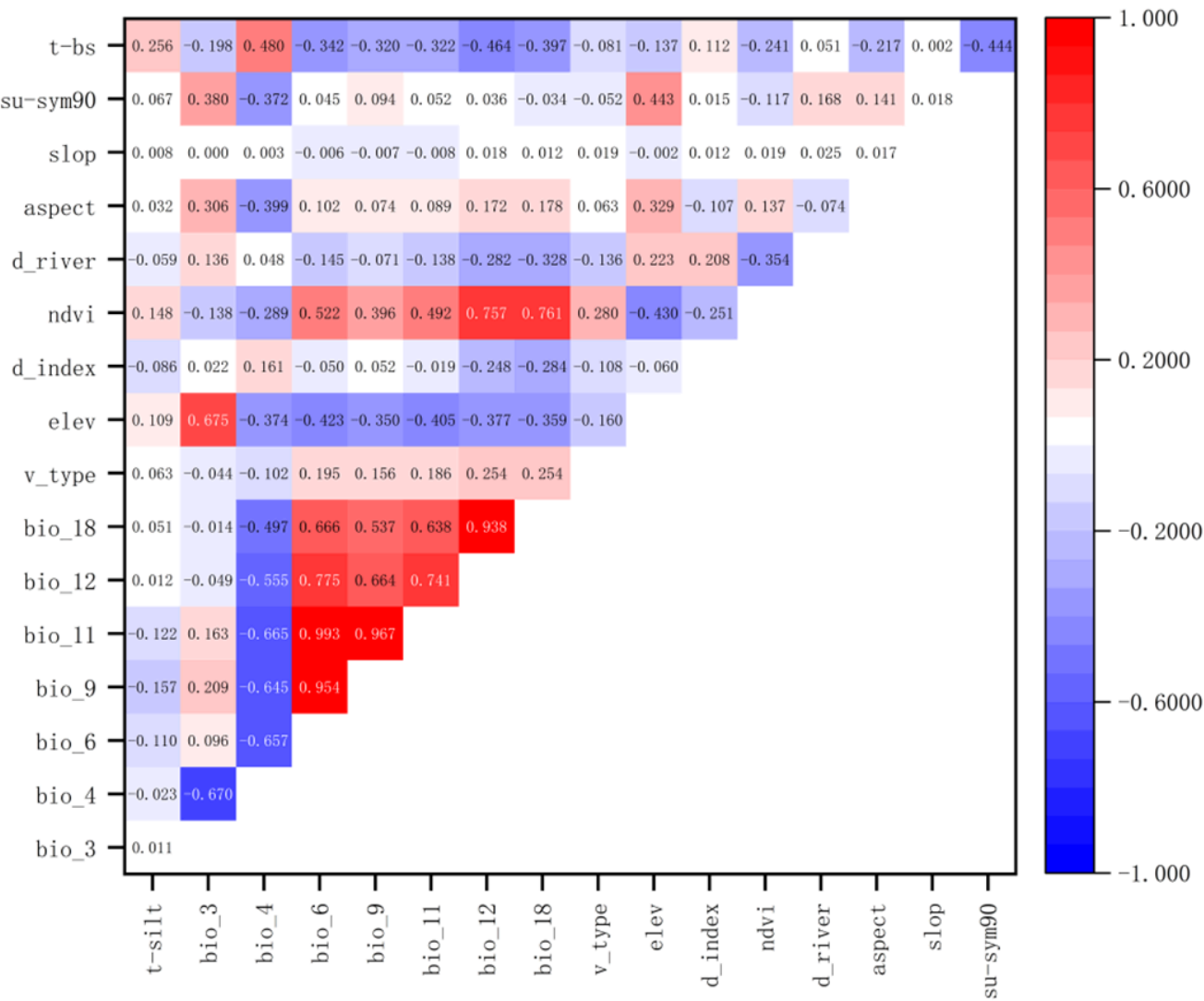


Figure 2
Correlation heat map of environment factors

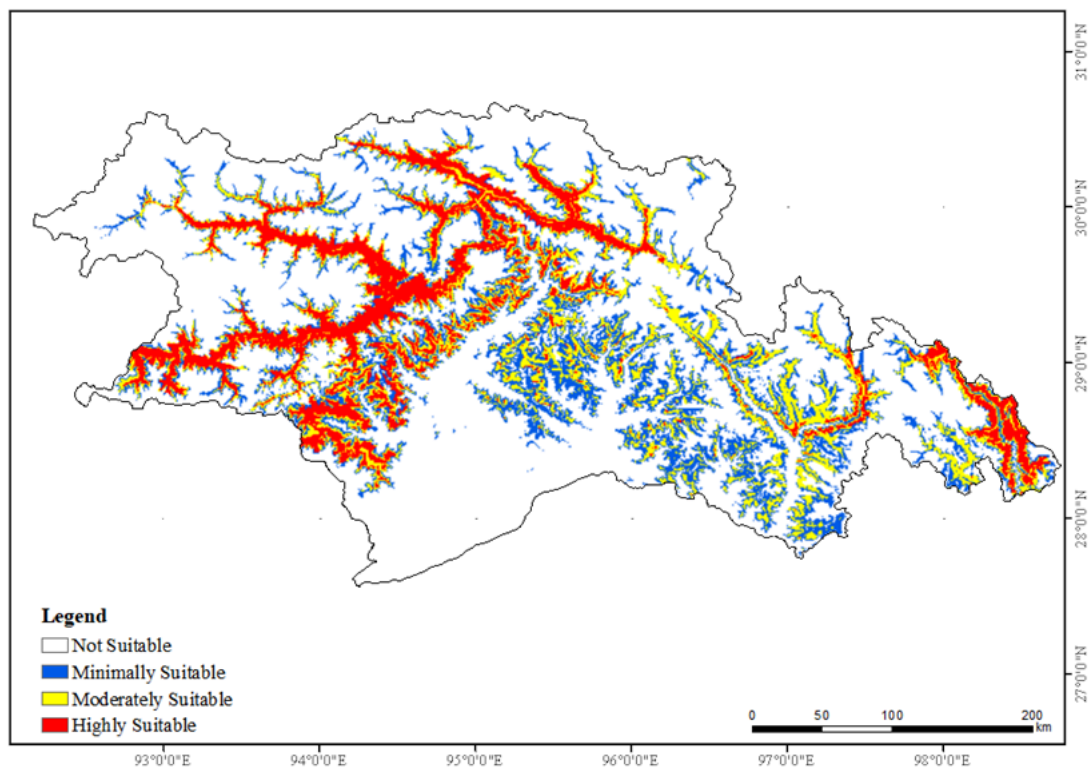


Figure 3

Current suitable distribution of *Prunus mira*



Figure 4

Regularized training gain with only variable

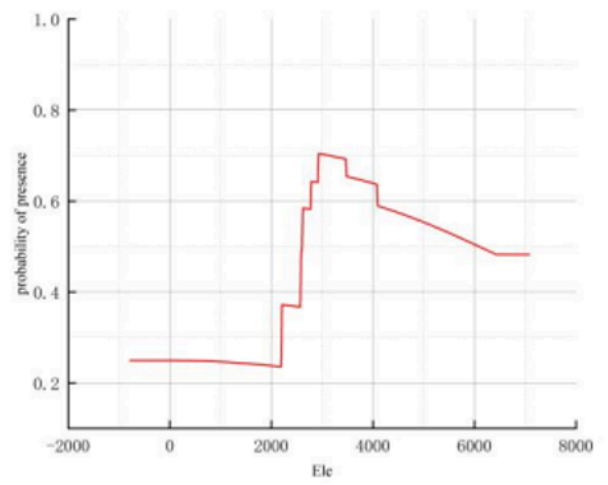
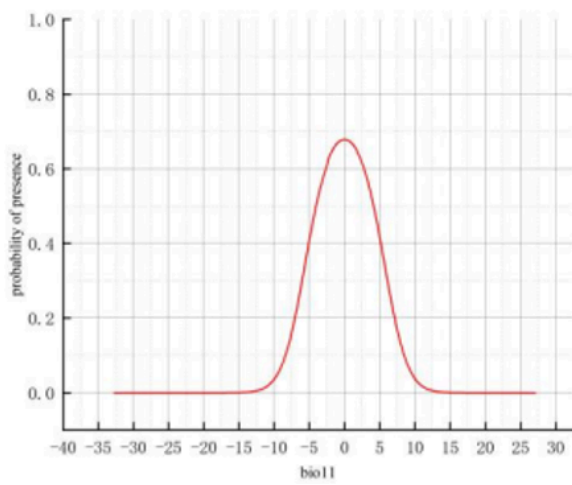
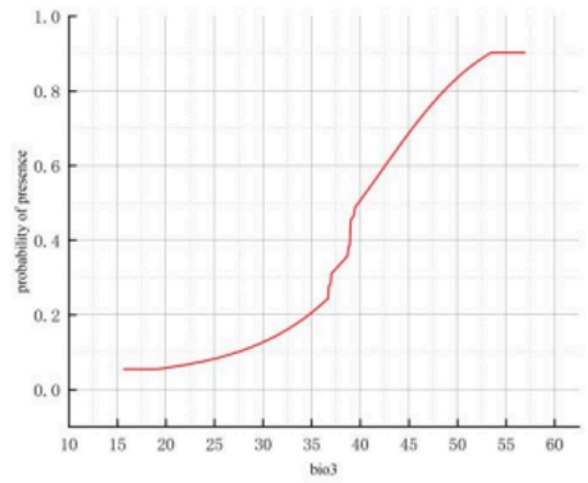
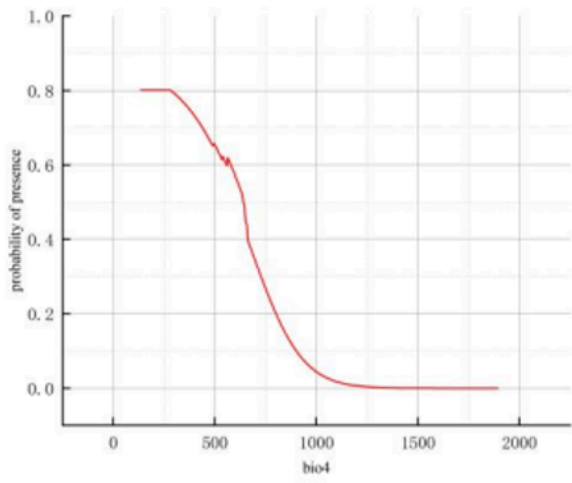


Figure 5

Response curves of *Prunus mira*

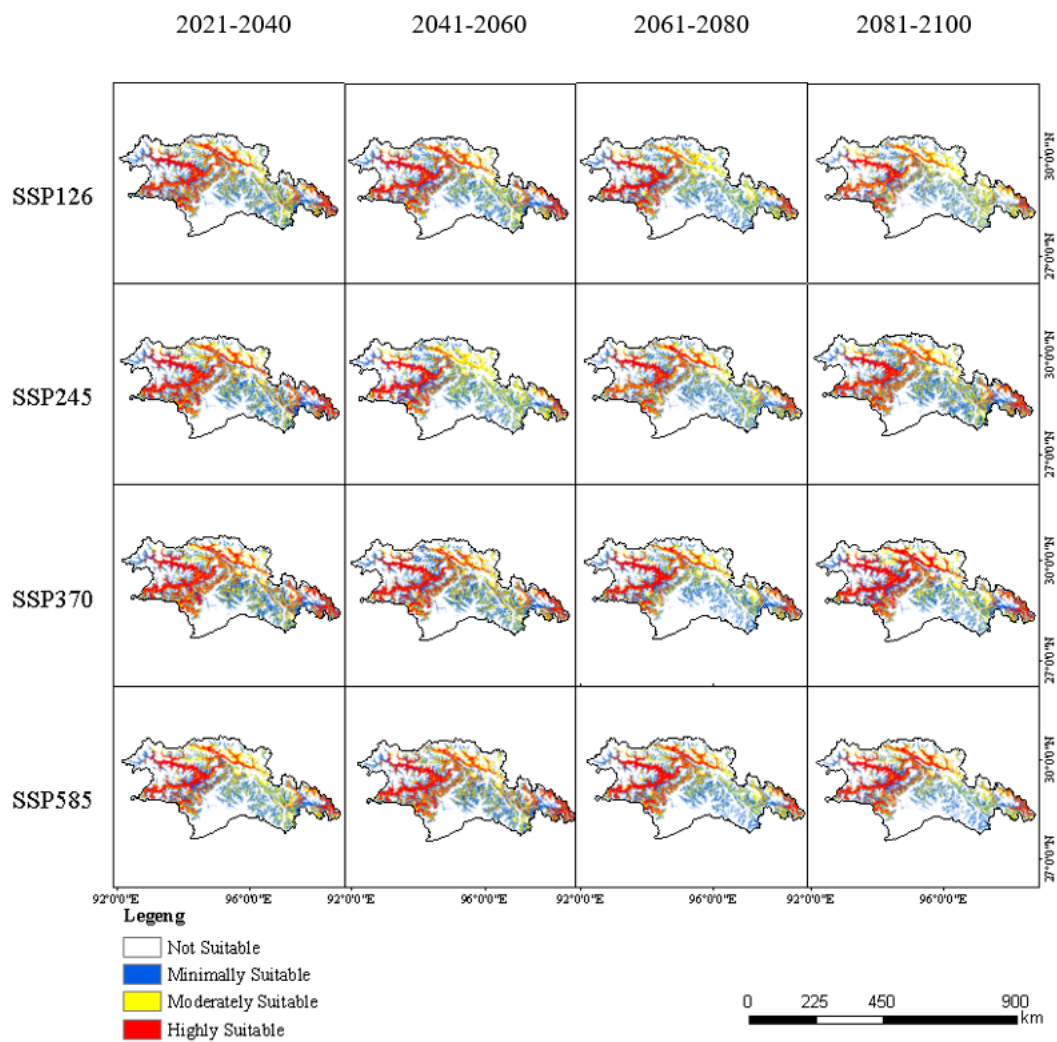


Figure 6

Distribution of suitable habits under the 4 climate pathway

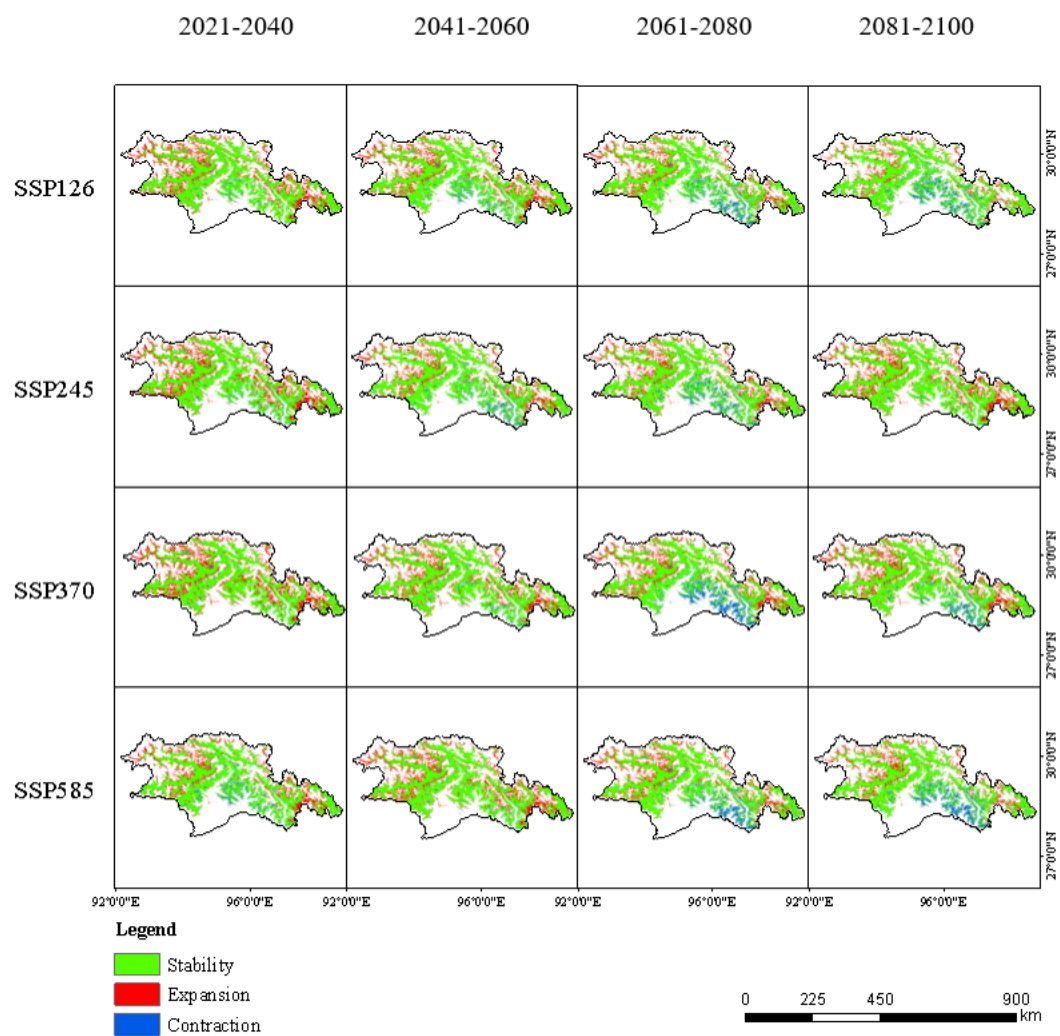


Figure 7
Change of Spatial Pattern under the 4 climate pathway