

## Geographical Distribution Modeling and Comparative Analysis of Ecological Characteristics of *Cerasus cerasoides* and *Cerasus campanulata*: A Postprint

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### Abstract

### Full Text

### Preamble

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**Modeling Geographical Distribution and Comparative Analysis of Ecological Characteristics between *Cerasus cerasoides* and *C. campanulata***

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### Abstract

This study investigates the ecological niche divergence between *Cerasus cerasoides* and its allied species *C. campanulata*. By collecting geographical coordinates of their actual distributions, we employed the BIOCLIM model to simulate modern suitable habitat ranges and predict potential distribution changes under future climate scenarios (CCM3, 2100). Principal component analysis and correlation analysis were used to identify dominant climatic factors, and differences in climate limiting factors between the two species were compared. Model predictive performance was evaluated using receiver operating characteristic (ROC) curves. The results demonstrated that: (1) Both *C. cerasoides* and *C. campanulata* are primarily distributed across most provinces south of the Yangtze River in China, with contemporary distribution centers located in the Yunnan-Guizhou Plateau, Wuyi Mountains, and Nanling Mountains. (2) Under

future climate change scenarios (CCM3), the suitable ranges for both species will contract. The suitable habitat in southwestern China for *C. cerasoides* and in southeastern China for *C. campanulata* may decrease substantially, while suitable areas for *C. campanulata* in western Hunan may increase. (3) Principal component analysis (PCA) and correlation analysis revealed that annual precipitation (bio12), precipitation in the wettest quarter (bio16), precipitation in the warmest quarter (bio18), and temperature seasonality (bio4) are the primary climatic factors influencing the current suitable habitats of both species, with “temperature variability magnitude” being the most important environmental factor causing distributional differences between them. (4) The AUC values for *C. campanulata* (0.816) and *C. cerasoides* (0.799) both exceeded the random test value (0.500), indicating that the BIOCLIM model accurately predicts the distributions of both species. This research provides important guidance for resource conservation, species identification, and phylogeographic studies of *C. cerasoides* and *C. campanulata*.

**Keywords:** *Cerasus cerasoides*, *Cerasus campanulata*, geographical distribution, climatic limiting factors, BIOCLIM model

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## Introduction

*Cerasus cerasoides* and *C. campanulata* are subtropical tree species in the genus *Cerasus* characterized by rose-red flower color, early flowering periods, and strong resistance to pests and diseases. These excellent traits significantly broaden the flowering period and color spectrum of ornamental cherry blossoms. *Cerasus cerasoides*, also known as Yunnan winter cherry, typically grows in dense valley forests at elevations of 1300–2200 m and was discovered as a new species by Don David in 1825. *Cerasus campanulata*, also known as Fujian mountain cherry, usually occurs in valley forests and forest margins at elevations of 100–600 m and was described as a new species by Maximowicz in 1883 (Yu & Li, 1984, 1986). However, since their discovery, the taxonomic status of these two species has remained controversial. For instance, in 1910 Koidzumi treated *C. campanulata* as a variety of *C. cerasoides*, naming it *Prunus cerasoides* var.

*campanulata*. Wang (1993) published a taxonomic revision of *Cerasus* and considered *C. campanulata* to be an eastern variety of *C. cerasoides*. The English edition of *Flora of China* (2003) recognized them as two distinct species. Although clear habitat differentiation exists between *C. cerasoides* and *C. campanulata* along elevational and latitudinal gradients, the environmental factors determining their ecological niche differentiation remain unclear. Identifying and analyzing their geographical distribution patterns and ecological factor differences can help elucidate the causes of phenotypic variation and speciation (Mallet, 2005).

Vegetation serves as a sensitive indicator of global climate change, with climatic conditions being the primary abiotic factor determining vegetation phenology, productivity, distribution patterns, and their dynamic changes (Jiao et al., 2018). The relationship between plants and climate, as well as the simulation and prediction of geographical distribution patterns, constitute important tools in basic ecology and biogeography research (Elith et al., 2006). With continuous development in computer and geographical sciences, ecological niche models have been widely applied in simulating and predicting plant geographical distribution patterns. Commonly used models include MaxEnt, GARP, BIOCLIM, and DOMAIN, each with distinct advantages and disadvantages due to their different algorithms and principles (Li & Cheng, 2007; Xu et al., 2015). As one of the classic models for predicting species suitable habitats, BIOCLIM has achieved satisfactory results in biodiversity conservation (Zhang et al., 2012; Wang et al., 2013; Jiang et al., 2014), climate change impacts on species distribution (Li et al., 2014; Liu et al., 2017; Qiu et al., 2018), and risk assessment of invasive alien plants (Maidina, 2017). Even with small sample sizes, BIOCLIM can achieve satisfactory predictive performance (Shao et al., 2009).

BIOCLIM modeling is primarily based on DIVA-GIS software, which offers simple operation, strong versatility, and intuitive results (Hijmans et al., 2001; Xie, 2011; Zhu et al., 2017). Additionally, the DIVA-GIS website provides free access to a complete set of global climate data at different resolutions, as well as climate data packages generated by different atmospheric circulation models. Based on DIVA-GIS, climate data for actual distribution points can be rapidly obtained and future climate information can be extracted for prediction (Tian et al., 2015). In this study, we obtained climate data and actual geographical distribution maps for *C. cerasoides* and *C. campanulata* using DIVA-GIS software, predicted their current and future suitable ranges using the BIOCLIM model, and conducted current abundance analysis. By comparing their climate response patterns at regional scales, we aimed to clarify differences in geographical distribution patterns and ecological characteristics between the two species, providing important insights for species identification, molecular phylogeographic analysis, and effective conservation and utilization of wild resources.

## 1. Materials and Methods

### 1.1 Species Distribution Data Collection and Mapping

Distribution point information was obtained from the National Specimen Information Infrastructure (<http://www.nsii.org.cn/>), the Plant Photo Bank of China (PPBC; <http://www.plantphoto.cn/>), the Chinese Field Herbarium (CFH; <http://www.cfh.ac.cn/>), and relevant published literature (Chen et al., 1999; Lü, 2006; Su, 2007). After deleting erroneous and ambiguous records and excluding cultivated and artificially introduced specimens, we compiled a final dataset of 186 precise distribution points, comprising 82 records for *C. cerasoides* and 104 records for *C. campanulata*. Geographic coordinates (latitude and longitude) for each distribution point were obtained using the Baidu coordinate picker system and Google Earth, then entered into Excel 2013 and converted to text format. Using DIVA-GIS (Version 7.5) software (<http://www.diva-gis.org>) with Chinese provincial administrative vector maps (downloaded from the National Fundamental Geographic Information System website <http://nfgis.nsd.gov.cn/>) as base maps, we imported the geographical distribution data for both species to generate actual distribution maps.

**Note:** Different colors represent different altitude ranges (m).

[Figure 1: see original paper] Actual geographic distribution of *Cerasus cerasoides* and *C. campanulata*

### 1.2 Model Establishment and Climate Data Analysis

The global climate data on the DIVA-GIS website originates from WorldClim (<http://www.worldclim.org/>). We selected climate data at 2.5 resolution for both current conditions and future CCM3 scenarios for 2100, imported them into DIVA-GIS software, and extracted 19 climate variable values corresponding to actual effective distribution points. Using the BIOCLIM model coupled with DIVA-GIS, we completed simulation and prediction of current and future suitable habitats for both species, including suitability classification and current abundance analysis. First, we performed principal component analysis (PCA) on the obtained climate variable data using PAST3 (Version 3.14) software (<http://folk.uio.no/ohammer/past/>) to examine variation in different climate factors across distribution points and select candidate dominant climate factors with larger variance contributions. Subsequently, correlation analysis was conducted to retain only climate variables with low correlation ( $r > 0.8$ ) as the main climate factors limiting the current geographical distributions of *C. cerasoides* and *C. campanulata*. Additionally, PCA distribution maps for both species were generated based on the identified dominant climate factors. PAST3 was also used to create frequency distribution histograms for both species with normal curve fitting to compare differences in climate limiting factors.

### 1.3 Model Accuracy Assessment

The receiver operating characteristic (ROC) curve is a commonly used method for model performance evaluation. The ROC curve plots the true positive rate (sensitivity) against the false positive rate (1-specificity). The area under the curve (AUC) is calculated by summing the areas of small trapezoids formed by connecting adjacent points on the curve with straight lines and the horizontal axis:  $AUC = S_1 + S_2 + \dots + S_n$ . Larger AUC values indicate greater distance from random distribution and stronger correlation between environmental variables and the predicted species distribution model, thus reflecting better model predictive performance (Cui & Wei, 2016).

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## 2. Results

### 2.1 Geographical Distribution Patterns

The BIOCLIM model predictions of potential distribution were classified into six suitability levels: non-suitable (0), low suitability (0–2.5%), moderate suitability (2.5%–5%), high suitability (5%–10%), very high suitability (10%–20%), and optimal suitability (20%–37%). According to *Flora of China*, *C. cerasoides* is mainly distributed in southern Tibet and northwestern Yunnan, while *C. campanulata* occurs primarily in Fujian, Guangdong, Guangxi, Hainan, Hunan, Taiwan, and Zhejiang. Actual distribution points and predictive results (Figure 2A and 2B) revealed that both species are mainly distributed in subtropical regions, covering nearly all provinces south of the Yangtze River (Figure 2A). *Cerasus cerasoides* is distributed between 21.58°–29.15°N and 94.37°–105.83°E, covering southeastern Tibet, most of Yunnan, and southern Sichuan. *Cerasus campanulata* ranges from 21.91°–30.32°N and 105.78°–121.55°E; in addition to the distribution areas recorded in *Flora of China*, Jiangxi is also part of its range, while no distribution points were recorded in Hainan. Furthermore, southwestern and southeastern Hubei, southeastern Guizhou, and southern Anhui represent potential distribution areas for *C. campanulata*. Abundance analysis was used for hierarchical assessment of distribution points, with each location representing one plant community presence. Variant richness was counted within 1° × 1° grids, and integrated with current suitable habitat predictions to indicate that the modern distribution center of *C. cerasoides* is located in the Yunnan-Guizhou Plateau, while that of *C. campanulata* is in the Wuyi and Nanling Mountains (Figure 2C).

Under future climate change scenarios, comparison of Figures 2A and 2B shows that the overall distribution patterns of both species remain relatively similar, but the transition from dark to light colors in predicted suitability probability indicates that suitable areas for both *C. cerasoides* and *C. campanulata* will shrink, with habitats becoming fragmented. In central Yunnan, the suitable range for *C. cerasoides* will decrease significantly. For *C. campanulata*, the original suitable range may be substantially reduced in central Fujian, south-

western Zhejiang, southwestern and southeastern Jiangxi, and northern Guangdong. However, under the CCM3 scenario, western Hunan may see the addition of large new suitable areas for *C. campanulata*.

**Note:** A. Potential distribution range and suitability levels under current climate scenarios; B. Future potential spatial distribution and suitability levels; C. Current abundance analysis.

[Figure 2: see original paper] Geographical distribution pattern and suitability analysis of *Cerasus cerasoides* and *C. campanulata*

## 2.2 Analysis of Dominant Climate Factors

Because the 19 climate factors may exhibit certain correlations, we used PCA and correlation analysis to screen for dominant climate factors with low correlation but rich variation across distribution points (Liu et al., 2018). The results identified annual precipitation (bio12), precipitation in the wettest quarter (bio16), precipitation in the warmest quarter (bio18), and temperature seasonality (bio4) as the dominant climate factors limiting the current suitable habitats of both species. The fluctuation ranges of these four dominant climate factors at distribution sites were 660–2019 (1223–2233) mm, 380–1173 (578–1119) mm, 380–1173 (446–1119) mm, and 326–565 (488–924) (standard deviation  $\times$  100) for *C. cerasoides* (*C. campanulata*), respectively. Subsequent PCA based on these four dominant climate factors revealed that principal components 1 and 2 (PC1 and PC2) explained 96.61% of the variation. Classification analysis of distribution points for both species based on PC1 and PC2 (Figure 3) showed that distribution points were generally divided into two groups: one primarily comprising *C. cerasoides* points and the other mainly *C. campanulata* points, indicating distinct habitat characteristics between the two species' current ranges. Comparative analysis of frequency histograms for limiting environmental factors and their normal distribution fitting (Figure 4) demonstrated that the optimal annual precipitation (bio12) range is 900–1050 mm for *C. cerasoides* and 1500–1650 mm for *C. campanulata*; optimal precipitation in the wettest quarter (bio16) is 800–900 mm for *C. cerasoides* and 700–800 mm for *C. campanulata*; optimal precipitation in the warmest quarter (bio18) is 600–700 mm for *C. cerasoides* and 500–600 mm for *C. campanulata*; and optimal temperature seasonality (bio4) is 390–420 (standard deviation  $\times$  100) for *C. cerasoides* and 660–720 (standard deviation  $\times$  100) for *C. campanulata*. These results reflect the influence of “moisture factors” and “temperature variability magnitude,” with the latter being the most important environmental factor causing distributional differences between the two species (Figure 4).

**Note:** bio12. Annual precipitation; bio16. Precipitation in the wettest season; bio18. Precipitation in the warmest season; bio4. Variance of seasonal temperature change. The percentage of variance explained by each factor is indicated in parentheses.

[Figure 3: see original paper] Distribution of *Cerasus cerasoides* and *C. cam-*

*panulata* based on factors PC1 and PC2 calculated by PCA

**Note:** bio12. Annual precipitation; bio16. Precipitation in the wettest season; bio18. Precipitation in the warmest season; bio4. Variance of seasonal temperature change.

[Figure 4: see original paper] Frequency histogram of limiting environmental factors for *C. cerasoides* and *C. campanulata*

### 2.3 Model Validation

As shown in Figure 5, the ROC curves demonstrated excellent predictive performance for both species. The AUC value reached 0.799 for *C. cerasoides* and 0.816 for *C. campanulata*, both significantly higher than the random test AUC value of 0.500, indicating that the BIOCLIM model performed well and can accurately predict the distributions of both species.

**Note:** A. *C. cerasoides*; B. *C. campanulata*.

[Figure 5: see original paper] ROC curve validation based on AUC values for *C. cerasoides* (AUC=0.799) and *C. campanulata* (AUC=0.816)

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## 3. Discussion

### 3.1 Comparison of Ecological Factors and Species Identification

Based on extensive examination of herbarium specimens, Wang (1993) found that the main differences between *C. cerasoides* and *C. campanulata* lie only in calyx shape and flowering phenology, with morphological variations potentially related to local microclimate and altitude. For example, Chen (2008) discovered that floral phenotypic traits in *C. campanulata* showed significant or highly significant correlations with latitude, longitude, altitude, and annual precipitation, while flowering phenology was significantly correlated with annual sunshine hours. Li et al. (2014) found that the distribution of *Cerasus serrulata* was strongly influenced by temperature. Our analysis of dominant climate factors revealed that the average temperature seasonality (bio4) differed by 285 (standard deviation  $\times$  100) between the two species, representing the most important environmental factor causing their distributional differences. *Cerasus cerasoides* occurs in the cold and dry Sino-Himalayan subregion west of 105°E, primarily influenced by the Indian monsoon, whereas *C. campanulata* is found in the warm and humid Sino-Japanese subregion east of 105°E, mainly affected by the Pacific monsoon. The gradient in altitude and different monsoon environments from west to east likely create heterogeneous environments that drive adaptive differentiation in plants (Ye et al., 2017a). Therefore, we hypothesize that morphological differences (such as calyx traits and flowering phenology) are most likely caused by temperature differences between the two regions.

Wang (1992a, 1992b) proposed that plants in China's subtropical region may have originated in southwestern China and subsequently dispersed eastward along three routes: the Qinling-Daba Mountains in the north, the Dalou-Wuling Mountains in the central region, and the Nanling Mountains in the south. However, this hypothesis has received limited validation. Based on haplotype geographic distribution, Li (2009) inferred that the distribution center of subgenus *Cerasus* had already formed before the Quaternary glaciation and subsequently experienced migration from the Yunnan-Guizhou Plateau to central China mountains and then to Jiangnan Hills in eastern China. The modern distribution centers of *C. cerasoides* and *C. campanulata* in the Yunnan-Guizhou Plateau, Wuyi Mountains, and Nanling Mountains served as important southern refugia during glacial periods. Long-term isolation during glacial and interglacial periods maintained high levels of inter-population genetic diversity and differentiation (Ye et al., 2017b). Our study reveals substantial differences in environmental factors between the two species' distribution points and clear distinctions in their natural ranges, suggesting that they have undergone significant differentiation during evolution due to climatic and other factors. However, whether they constitute one species or two varieties, whether their specific migration routes conform to the above hypotheses, and whether *C. campanulata* represents a speciation event following eastward migration of *C. cerasoides* to adapt to local climatic conditions remain questions that require integration with fossil, pollen, and phylogeographic evidence.

### 3.2 Conservation and Utilization Recommendations

As typical subtropical tree species, *C. cerasoides* and *C. campanulata* perform poorly north of the Qinling-Huaihe line, showing no flowering or delayed flowering. Only a few improved varieties of *C. campanulata*, such as *C.* 'Youkou' and *C.*  $\times$  *kanzakura* 'Kawazu-zakura', perform well in these regions. Although China has numerous native cherry species, most remain undeveloped, and breeding technology lags far behind Japan. Records indicate that more than 13 cultivars under the *C. campanulata* lineage are currently on the market, almost all developed by Japanese researchers (Wang, 2014; Wang et al., 2014). Although wild distribution of *C. campanulata* is recorded in Japan's Ryukyu Peninsula, it is highly likely that these represent naturalized introductions from Taiwan. While some *C. cerasoides* cultivars are recorded in Yunnan, these are basically selected from natural variations in wild populations and are limited to promotion and use in southwestern China. Both species typically grow in forest margins or secondary forests with significant disturbance, and their wild resources have been severely damaged (Duan et al., 2004; Wang et al., 2006). Therefore, we propose the following recommendations for conservation and rational development of *C. cerasoides* and *C. campanulata* resources: (1) Increase the scale of new cultivar selection through natural selection, artificial hybridization, and chemical mutagenesis to develop new cherry cultivars with greater ornamental value and national representation. (2) Under the influence of global warming, the potential distribution area will shrink in several southern provinces at the southern

edge of their ranges, while new distribution areas will emerge in higher-latitude western Hunan, reflecting an overall northward expansion trend. This indicates that high concentrations of greenhouse gas emissions will severely impact the habitats of both species, causing habitat fragmentation, reduced biodiversity, and other serious consequences. Therefore, to protect their habitats, all sectors of society should adopt effective measures such as afforestation, energy conservation, emission reduction, and new energy development to strictly control greenhouse gas emissions. (3) To strengthen protection of existing resources, nature reserves in central Fujian, southwestern Zhejiang, southwestern and southeastern Jiangxi, and northern Guangdong should be designated as key conservation units for both species, and their potential distribution areas should be incorporated into new conservation efforts. Redistribution of the species should be promoted through transplantation and grafting techniques.

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

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