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Blue footprint: Distribution and use of indigo-yielding plant species *Strobilanthes cusia* (Nees) Kuntze

Libin Zhang [a,b], Huizhao Yang [a,b,c], Yanan Wang [a], Huifu Zhuang [a], Wenyun Chen [a], Zihong Lin [a], Jianchu Xu [a,c,d,*], Yuhua Wang [a,*]

[a] Department of Economic Plants and Biotechnology, Yunnan Key Laboratory for Wild Plant Resources, Kunming Institute of Botany, Chinese Academy of Sciences, Kunming 650201, Yunnan, China
[b] University of the Chinese Academy of Sciences, Beijing 100049, China
[c] Centre for Mountain Futures (CMF), Kunming Institute of Botany, Kunming 650201, Yunnan, China
[d] East and Central Asia Regional Office, World Agroforestry (ICRAF), Kunming 650201, Yunnan, China

A R T I C L E I N F O

Keywords:
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A B S T R A C T

Background: Strobilanthes cusia (Nees) Kuntze is an important medicinal, edible, and indigo-yielding plant species. It has been cultivated for centuries and it is often the only natural dye still used in many places of East and Southeast Asia. Although *S. cisia* is extensively cultivated and widely used, the ecological factors of its environmental demands are poorly understood. Moreover, with the increasing demand and growing habitat degradation, its wild populations are in sharp decline. It is therefore imperative to understand the socio-ecological interactions of this species regarding its climatic niche, ethnobotanical importance, and human relations in order to meet its demand.

Methods: We first collected *S. cusia* occurrences from plant species databases, literatures and ethnobotanical surveys. 244 wild occurrences and 10 variables were used to predict its suitable habitats using the MaxEnt model. Furthermore, for a better understanding of socio-ecological interactions regarding its distribution and use, we also collected use reports and calculated the relative importance level (RIL).

Results: Strobilanthes cusia is valued for many reasons, as it contains numerous health benefits as a medicinal plant and use in tea alongside its indigo dying and tattooing properties. Indigo dye, Southern Banlangen, and Indigo Naturalis are its most important usages. Its suitable habitats are chiefly located in Western and Central Himalayas, Southern China, and Southern Japan. The 'temperature seasonality (standard deviation × 100)' (bio4), the 'precipitation of coldest quarter' (bio19), and the human footprint index showed the strongest association with the relative contributions of 38.5%, 32.4%, and 9.1%, respectively.

1. Introduction

Traditional Chinese herbal medicine (TCM) is regarded as an integral part of health care in Asia and it has been extensively documented for nearly 2000 years (Kumagai et al., 2016; Brand et al., 2017). *Strobilanthes cusia* (Nees) Kuntze is an important plant species of TCM with a long medicinal history of approximately 1000 years (Liau et al., 2007). *S. cusia* is a perennial shrub form the

* Correspondence to: Kunming Institute of Botany, Chinese Academy of Sciences, 132 Lanhei Road, Kunming 650201, China.
E-mail addresses: jxu@mail.kib.ac.cn (J. Xu), wangyuhua@mail.kib.ac.cn (Y. Wang).

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family Acanthaceae (Fig. 1). It is distributed across China (Fujian, Guangdong, Guangxi, Guizhou, Hainan, Hunan, Sichuan, Taiwan, Tibet, Yunnan, and Zhejiang Province), Bangladesh, Bhutan, India, Laos, Myanmar, Thailand, and Vietnam. It usually occurs in moist wooded places, sometimes cultivated, at elevations from 100 m to 2000 m (Flore of China, 2011).

To date, a total of 42 medicines have been patented form *S. cusia* (Yu et al., 2021). Southern Banlangen, Southern Daqingye, and Indigo Naturalis are three frequently-used TCMs from this species, which are usually used to treat viral hepatitis, influenza, cold, pneumonia, and inflammation (Gu et al., 2014). Pharmacological activities such as antimicrobial, antiviral, antitumor, and anti-inflammatory effects have been confirmed in this plant and its herbal medicines (Gu et al., 2014; Yu et al., 2021). Further, the leave of *S. cusia* is also indigenously used in Northern Thailand to treat diarrhea by the Mien (Yao) people (Panyaphua et al., 2011). In Japan, its fresh juice is locally used to treat Athlete's foot and an antifungal component is isolated from it (Honda and Tabata, 1979).

In addition to its medicinal value, *S. cusia* is of cultural importance to the people of various ethnic minorities in East and Southeast Asia. In these regions, *S. cusia* has been extensively cultivated for centuries and is likely the only natural dye still used at the present time (Balfour-Paul, 2011; Cardon, 2007). Unlike food crops, the cultivation of *S. cusia* has mainly been driven by cultural values instilled in indigo-dyed textiles. This is because ethnic minorities imbue the color blue with spiritual meaning. The indigo dyes for traditional textiles have been central to the cultural identities of ethnic minorities such as Landian Yao (literally "blue clothes Yao", Mien language group) (Li et al., 2019). As the main indigo source, *S. cusia* has the highest indigo yields when compared with other indigo-yielding plant species (Chanayath et al., 2002). Furthermore, increasing evidence reveals that *S. cusia* has serious potential for sustainable indigo production in the future (Zhang et al., 2019). Consequently, through history, *S. cusia* has been cultivated in many counties for indigo production.

Although *S. cusia* is extensively cultivated and widely used, the ecological factors of its environmental demands are poorly understood. Furthermore, with increasing demand and growing habitat degradation, its wild populations are in sharp decline because people prefer to harvest wild plants for medicinal purposes (Yang et al., 2012); Du, 2008; Wang and Lin, 2013). It is therefore imperative to understand the socio-ecological interactions of this species regarding its climatic niche, ethnobotanical importance, and human relations in order to responsibly meet its rising demand. Thus, the present study attempts to consolidate knowledge on the distribution and use of *S. cusia* to guide its sustainable cultivation and comprehensive utilization.

2. Material and methods

In general, we used both qualitative and quantitative methods to collect and analyze primary and secondary data. We adopted qualitative method to collect voucher specimens and indigenous knowledge of human use of *S. cusia*, and used a quantitative method to map the distribution of *S. cusia*.

2.1. Ethnobotanical field surveys

In order to collect occurrence records and different usages of *S. cusia*, we carried out ethnobotanical field surveys from October 2017 to January 2020. During the field surveys, snowball sampling methods (Blernacki and Waldorf, 1981) and semi-structured

Fig. 1. *Strobilanthes cusia* and its products. Legend: A) *S. cusia* in the forest. The image was downloaded from the GBIF and photographed by Ueda (2021). B) Southern Banlangen from TCM mill of Guangxi Province, China. C) Herbal tea of *S. cusia* seeds and fruits. D) Indigo Naturalis from indigo mill in Guizhou Province, China. E) Indigo paste extracting from *S. cusia*.

interviews (Longhurst, 2009) were employed to collect primary data. A total of 29 villages, 5 markets and 12 mills were visited (Fig. 2, Appendix A). Prior informed consent (Rosenthal, 2006) was obtained verbally from all respondents before documenting their indigenous knowledge on various usages of *S.cusia*. We mainly focused on the different usages, parts used and indigo extracting methods during the semi-structured interviews (Zhang et al., 2019). In addition, voucher specimens collected in the field surveys were deposited at the herbarium of the Kunming Institute of Botany (KUN).

2.2. Review, data analysis and GIS mapping

A literature review was performed to collect the occurrences and usages of *S. cusia*. We reviewed 85 articles related to its distribution and use (Appendix B). In order to qualitatively assess knowledge and find the most important usages of *S. cusia*, we calculated the relative importance level (RIL) of *S. cusia*. Kunwar (2020) defined the RIL as representing the importance of each use type. The formula of RIL is as follows:

$$RIL = FCu/\ FCt\ (0 < RIL < 1).$$

Where FCu is the number of studies citing particular use type of *S. cusia*, and FCt is the total number of all use types recorded in this study. The RIL ranges from 0 to 1, with values of "1" indicating full importance of *S. cusia* for a particular use type (Kunwar et al., 2020). After identifying the districts of *S. cusia*'s use, we overlaid a map of occurrence records, field surveys, and use record regions by ArcGIS 10.2.1 (Fig. 2).

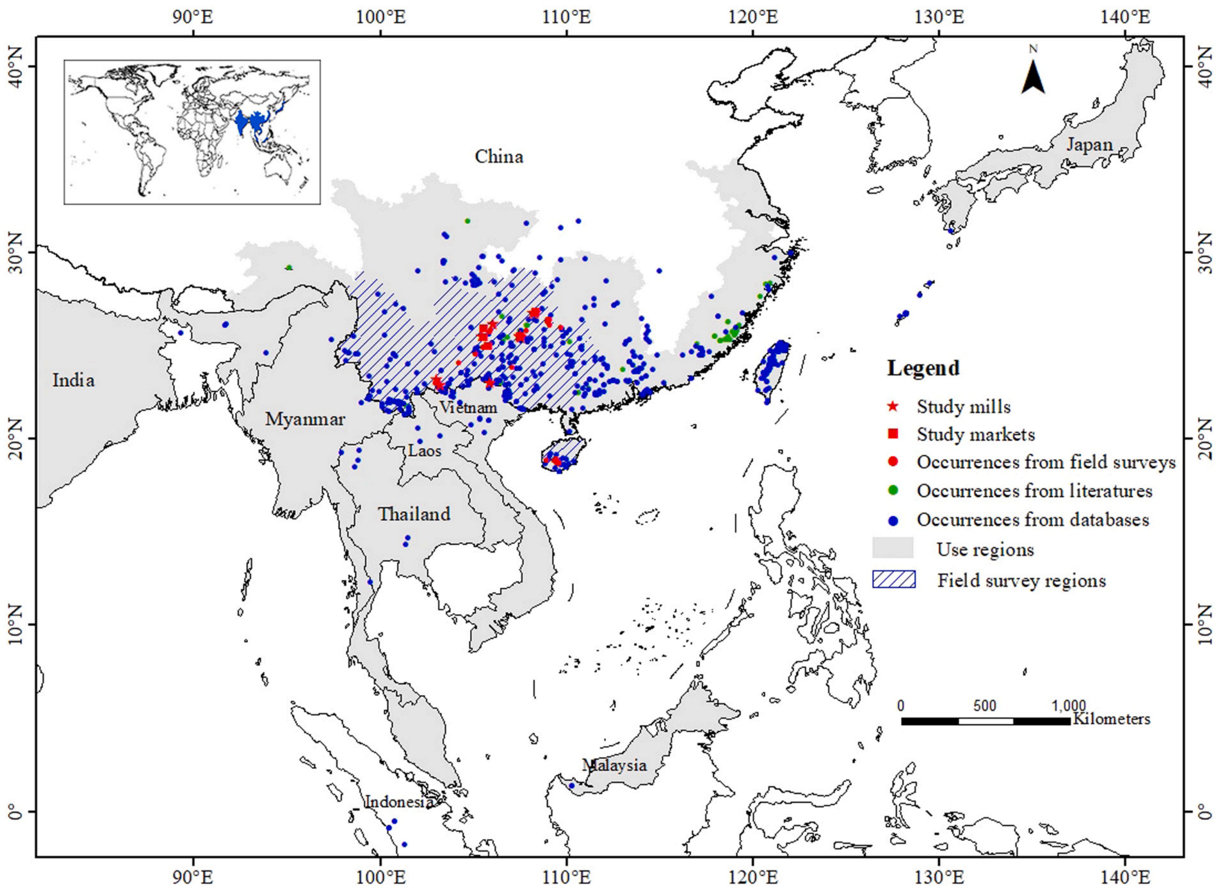

Fig. 2. Occurrences, use and field surveys map of *Strobilanthes cusia* (n = 766). Legend: red pentagram, study mills; red square, study markets; red dots, voucher specimens from the filed surveys; green dots, occurrences from literature view; blue dots, occurrences from the open source plant species databases; gray shaded region, use regions from literature review, we note that the use regions of China are displayed at the provincial level, and other countries are displayed at the national level because of the limited use information of *S. cusia*; blue slash region, field survey regions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.3. Species distribution modeling

2.3.1. Selection of species presence and pseudo-absence data

Besides the occurrence records from the ethnobotanical field surveys and literatures, we also collected occurrence records from the open source plant species databases, including the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/), the Global Plants on JSTOR (JSTOR, https://plants.jstor.org/), the Chinese Virtual Herbarium (CVH, http://www.cvh.ac.cn/), and the National Specimen Information Infrastructure (NSII, http://www.nsii.org.cn). The following records were removed from the data set: the duplicated records with the same collector and collection number; specimens with obvious identification error; and specimens with geo-coding errors. For the specimens without latitude and longitude data, we performed geographic correction using the location descriptions of the label information (Zhang et al., 2012). After these processes, 766 *S. cusia* occurrences remained in the data set (Appendix A).

The nature of the occurrence records affects the modeling. Species in cultivation are less sensitive to environmental variables than wild ones. Accordingly, we selected 386 wild and 92 cultivated occurrences out of 766 occurrences. The remaining 288 occurrences were unclear as to whether they were wild or cultivated because of vague habitat descriptions (see selection criteria in Appendix A). Wild occurrences were used to predict suitable habitats of *S. cusia*. For presence points, we removed duplicate records within a spatial resolution of 10 km to reduce spatial autocorrelation (Ranjitkar et al., 2014a). For background points, 10,000 random background points were selected within an area of 500 km radius from the wild occurrence points as a center. We performed Moran's I test for spatial autocorrelation by using R-package 'spdep' (Bivand et al., 2009, 2014). Finally, 244 wild occurrences were selected for modeling (the Moran's I index was 0.216, $p = 0.0003 < 0.001$).

2.3.2. Selection of study area

Through combing the literature on *S. cusia* occurrences, we found that *S. cusia* grows in China, India, Thailand, Laos, Myanmar, Japan, Malaysia and Indonesia (Fig. 2). Further, according to Flora of China*S. cusia* is mainly distributed in the south of China and Southeast Asia. Accordingly, we chose East Asia, South Asia and Southeast Asia to predict the suitable habitats for the sustainable cultivation of *S. cusia*. These areas include the known countries of distribution for *S. cusia* globally. Latitude and longitude approximately range from 10° S to 53° N and 61–145° E, respectively.

2.3.3. Selection of environmental variables

In this study, we selected four bioclimatic variables, three indicators of human activities, and three topographic variables for modeling (see descriptions and sources in Table 1). Since species habitat suitability is strongly determined by climate (Ranjitkar et al., 2014b), we chose bioclimatic variables as predictor variables. 19 bioclimatic variables (version 2.1 climate data for 1970–2000) were downloaded from the Worldclim (https://www.worldclim.org). Moreover, a study of Xu et al. (2019) has proved that human activities have opposing effects on distributions of narrow-ranged and widespread plant species in China. *S. cusia* is widely used, and we assumed that human activities also play a role in its occurrence. We adopted three indicators of human activities including the human footprint index (HFP), human population density (HPD), and cropland as predictor variables (Xu et al., 2019). In addition, topographic variables (elevation, aspect, and slope) were also used for modeling.

All the environmental variables were standardized to the same resolution as the climatic layers ($0.0083° \times 0.0083°$, approximately 1 km^2) using the same coordinate system (WGS1984). We used Pearson's correlations to detect collinearity between two variables and variance inflation factors (VIFs) to detect multicollinearity among several variables. Pearson's correlations and VIFs were calculated by R-package 'usdm' (Naimi et al., 2014; Dormann et al., 2012). The variables with a Pearson's correlation < 0.7 and a VIF < 5 were selected (Ranjitkar et al., 2014b). Finally, aspect, mean diurnal range (bio2), temperature seasonality (bio4), mean temperature of wettest quarter (bio8), precipitation of warmest and coldest quarter (bio18 and bio19), cropland, elevation, HFP, and HPD were selected for modeling (see details in Appendix C).

2.3.4. Modeling and model accuracy evaluation

Maximum entropy software (MaxEnt, version 3.4.1), a machine-learning program for species distribution modeling (SDM) (Phillips

Table 1
The environmental variables used in MaxEnt for evaluating the preferred associations with *Strobilanthes cusia* occurrence.

Variables	Abbreviation	Resolution	Source	Citation of description
19 Bioclimatic variables	Bioclimate	1 km	https://www.worldclim.org/data/worldclim21.html	(Fick and Hijmans, 2017)
Human footprint	HFP	1 km	https://sedac.ciesin.columbia.edu/data/collection/wildareas-v3	(Venter et, al, 2016)
Human population density	HPD	30″	https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11	SEDAC
Cropland	Cropland	5′	https://sedac.ciesin.columbia.edu/data/set/aglands-croplands-2000	(Ramankutty et al., 2008)
Elevation	Elevation	1 km	https://www.worldclim.org/data/worldclim21.html	(Fick and Hijmans, 2017)
Aspect	Aspect	1 km	Derived from the elevation data	
Slop	Slop	1 km	Derived from the elevation data	

et al., 2006; Phillips and Dudík, 2008), was used to project the distribution of *S. cusia*. MaxEnt is one of the most widely used SDMs for present-only data, and it has been shown to perform well in predicting habitat suitability (Phillips et al., 2006; Elith et al., 2006; Pearson et al., 2007). We used the SWD (sample with data, csv file) format for both presence and background points to run the model. 75% of the occurrence records were used as training model, and the remaining 25% for validating the MaxEnt model. In addition, the set features included Linear, Quadratic, Product and Hinge, and other default model settings.

For model accuracy evaluation, we used three measures, area under the curve values (AUC), max Kappa, and true skill statistic (TSS). AUC is a threshold-independent model evaluation indicator; models with values above 0.75 are considered potentially useful, and values from 0.85 to 1 are good (Phillips, 2008; Swets, 1988). Kappa and TSS are threshold-dependent model evaluation indicators, values below 0.4 are poor, 0.4–0.8 are useful, and above 0.8 are excellent (Kumar et al., 2017). The values of Kappa and TSS were calculated using the R-package (https://github.com/KarlssonCatharina/MaxEnt_TSS_calculations). For the MaxEnt output data, we reclassified it into four classes of habitat suitability. The different classes of habitat suitability were defined as: no suitability (0–0.2), low suitability (0.2–0.4), medium suitability (0.4–0.6), and high suitability (0.6–1) (Meng et al., 2019).

3. Results

3.1. Indigenous knowledge of S. cusia

We found 137 use repots and 83 occurrence records of *S. cusia* in the course of our literature review (Appendix A and B). We found that *S. cusia*'s use reports were recorded in seven countries, including Japan, India, Thailand, Laos, Myanmar, Malaysia, and China (Fujian, Guangdong, Guangxi, Guizhou, Hunan, Hainan, Jiangsu, Sichuan, Taiwan, Tibet, Yunnan, and Zhejiang Province) (Fig. 2). Indigo dye and Southern Banlangen were the most important usages for *S. cusia*. Both of the relative importance levels (RILs) were 0.28, next followed by Indigo Naturalis and Southern Daqingye, with the RILs of 0.23 and 0.18, respectively (Table 2).

In the field surveys, we documented five usages of *S. cusia*, including indigo dye, Southern Banlangen, Indigo Naturalis, herbal tea, and tattooing (Fig. 1). Among them, indigo dye was most widely used because ethnic minorities imbue the color blue with spiritual meaning and enjoy dressing in indigo-dyed blue clothing. The indigo dye was called *landian* (蓝靛) (translation: indigo paste) in Chinese. The *landian* was made from the fresh leaves and stems of *S. cusia* (Fig. 3B). According to our informants, the price of *landian* ranged from 10 to 26 yuan per kilogram depending on its quality (Fig. 3C). For local farmers, the profits of indigo dye were almost three times that of maize. Besides *landian*, the fresh leaves and stems of *S. cusia* were also traded, with a price of 0.5–1.0 yuan per kilogram (Fig. 3D). Consequently, *S. cusia* has been extensively cultivated to produce indigo in Yunnan, Guizhou, and Guangxi Province, China.

3.2. Model accuracy and S. cusia suitable habitats

The MaxEnt modeling successfully delineated the potential distribution range of *S. cusia* . The average AUC of ten replications was 0.886, which indicates that the selected variables better describe the model. The average max Kappa and TSS (ten replications) were 0.743 and 0.681 respectively. Both values were above 0.4 indicating the accuracy of predicting the *S. cusia* distribution by MaxEnt software.

Currently the suitable habitats were chiefly located in Western and Central Himalayas, Southern China, and Southern Japan with an area of approximately 1.14×10^6 km^2 (Fig. 4). Latitude and longitude approximately range from 16° to 38° N and 73 to 140° E, respectively. The areas of high, medium, and low suitable habitats were approximately 9.21×10^5 km^2, 1.93×10^5 km^2, and 2.79×10^4 km^2, respectively. Northern India, Nepal, Vietnam, Southern China (Yunnan, Guizhou, Sichuan, Chongqing, Guangxi,

Table 2
Use reports, use types, and parts used of *Strobilanthese cusia* recorded in articles.

Use type	Total use reports (FCu)	RIL	Part used	% Part used
Athlete's foot	1	0.01	fresh juice	1
Diarrhea	1	0.01	leaf	1
			stem	1
Edible vegetable	1	0.01	shoot	1
Herbal tea	1	0.01	leaf	1
Indigo dye	39	0.28	leaf	90
			stem	64
			aerial portion	8
Indigo Naturalis	31	0.23	leaf	97
			stem	97
			aerial portion	3
Southern Banlangen	38	0.28	root	95
			rhizome	53
			stem	3
Southern Daqingye	25	0.18	leaf	92
			stem	32
			aerial portion	4
FCt	**137**			

Fig. 3. Usages and trade of *S. cusia* collected during the field surveys. Legend: A) *S. cusia* cultivation in Dushan County, Guizhou Province, China. B) Indigo pigment extraction in Guangxi Province, China. C) Indigo paste trade through middleman in Shidong market, Guizhou Province, China. D) Fresh leaves and stems of *S. cusia* were traded in the village of Miao nationality, Guizhou Province, China.

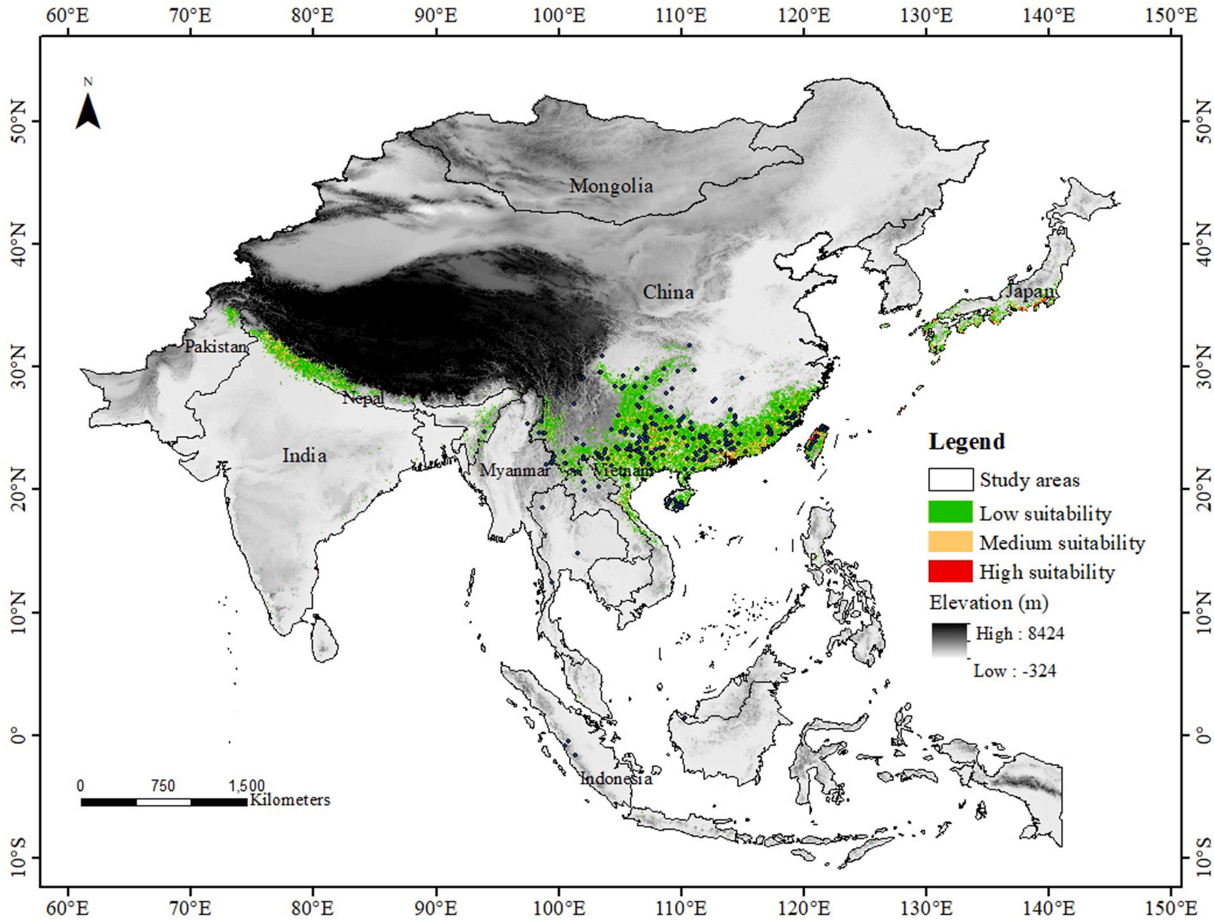

Fig. 4. The MaxEnt probability map of *S. cusia* occurrence in East Asia, South Asia and Southeast Asia. The data of *S. cusia* occurrences were from 1867 to 2020 (n = 244). Legend: blue dots, *S. cusia* occurrences used in the molding; green region, low suitability (0.2–0.4) with the areas of 9.21×10^5 km^2; orange region, medium suitability (0.4–0.6) with the areas of 1.93×10^5 km^2; and red region, high suitability (0.6–1) with the areas of 2.79×10^4 km^2 (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Guangdong, Fujian, Zhejiang, Hainan, and Taiwan Province), and Southern Japan (Kyushu, Shikoku, Chugoku, and Kanto Region) were predicted to be highly suitable for *S. cusia* cultivation.

3.3. Key variables related to distribution

For the environmental variables used in the model, the occurrence of *S. cusia* showed strong associations with the 10 environmental variables (Table 3). The 'temperature seasonality (standard deviation × 100)' (bio4) showed the strongest association (positive) with a relative contribution of 38.5%. This was followed by the 'precipitation of coldest quarter' (bio19) (32.4%). The human footprint index (HFP), slope, and 'precipitation of warmest quarter' (bio18) also played roles in its occurrence with the relative contributions of 9.1%, 5.2%, and 4.8%, respectively. Furthermore, as shown in Fig. 5, the highest suitability (≥ 0.6) for *S. cusia* occurs in the areas where 'temperature seasonality (standard deviation × 100)' (bio4) ranges from 3000 to 6500 (namely, the difference in temperature between the different seasons ranges from 30 ℃ to 65 ℃), "precipitation of coldest quarter" (bio19) ranges from 50 mm to 350 mm, and human footprint index (HFP) ranges from 7 to 50 (Fig. 5).

4. Discussion

Unlike food crops, the cultivation of *S. cusia* is mainly driven by its various medicinal usages and cultural values including indigo dye, edible vegetable, herbal tea, and tattooing. Known as 'Assam indigo', *S. cusia* is extensively cultivated for indigo production in East and Southeast Asia (Balfour-Paul, 2011). Especially in China, it is estimated that the cultivation areas of *S. cusia* in Yunnan Province reach approximately 5000 ha, with a total yield of approximately 13,100 tons, which creates approximately 108.75 million yuan for local communities (Ma et al., 2020). During our field surveys, we also found *S. cusia* was extensively cultivated in Guizhou and Guangxi Province for indigo production. Further, *S. cusia* is easy to propagate by cuttings and harvesting occurs two to three times annually (Balfour-Paul, 2011). This species thus of considerable economic potential for sustainable indigo production. In addition, both *S. cusia* and its products (e.g. indigo dye) were traded in the field survey areas, but its trade value remains unclear. Greater attention should be paid to the trade value of *S. cusia* to aid rural economic development.

In general, the suitable habitats of *S. cusia* predicted by MaxEnt were consistent with the distribution description recorded in Flore of China (2011). The model accuracy evaluation also showed a good fit with the values of AUC (0.886), max Kappa (0.743), and TSS (0.681). However, we failed to find the wild occurrence records in Northern India, Nepal, and Japan, but suitability is predicted in those location using MaxEnt model (Fig. 4). This might be because the suitable habitats predicted by MaxEnt are in regions that have similar environmental conditions to where the species is known to occur, and not as predicting actual limits to the range of a species (Pearson and Dawson, 2003; Phillips et al., 2006). Further, Balfour-Paul (2011) recorded that *S. cusia* was cultivated in Japan and its cultivation areas in Ryūkyū Island were up to 4.8 ha. Thus, in those locations, there is a higher possibility of *S. cusia* occurrence or they are climatically suitable for its cultivation.

Climate is vital in the determination of species distribution (Ranjitkar et al., 2014b). Our model predicted that temperature and precipitation had the maximum contributions for *S. cusia* occurrences (Table 3). Temperature and precipitation are the most direct and important factors for plant growth (Cui and Shi, 2010). The probability of *S. cusia* occurrence is relatively higher (≥ 0.6) when the difference in temperature between the different seasons ranges from 30 ℃ to 65 ℃ and the 'precipitation of coldest quarter' (bio19) ranges from 50 mm to 350 mm. It can be found in South Asia, Indo-China Peninsula and most provinces of China because of its tolerance to different climatic conditions and soil pH levels (Hoang, 2009). Accordingly, the subtropical monsoon climate and tropical monsoon climates, which are hot and rainy in summer as well as warm and humid in winter, are suitable for *S. cusia*. Therefore, cultivation in the climatic suitable areas predicted by MaxEnt is a good way to meet its rising demand.

In addition to climatic factors, the human footprint index (HFP) also played a role in *S. cusia* occurrences. The highest suitability (≥ 0.6) of *S. cusia* occurs in areas where the HFP ranges from 7 to 50, which means its occurrence is in high human pressure areas, since indices above 4 indicate high human pressure (Marco et al., 2018). The HFP (range from 0 to 50) provides an integrated value representing impacts of human population density, land transformation, accessibility, and electrical power infrastructure on the land of the world (Venter et al., 2016). It has been shown to affect the species geographic range (Xu et al., 2019) and extinction risk trends (Marco et al., 2018). For *S. cusia* occurrence, human impacts may chiefly lie in its diverse usages. Local communities use *S. cusia* and diversify its repertoire, resulting in diverse use-types and indigenous knowledges of this plant. Such indigenous knowledges are useful in the comprehensive development and utilization of this plant.

5. Conclusions

Strobilanthes cusia has enormous value via maintaining health and cultural values, including indigo dye, edible vegetable, herbal tea, and tattooing. Our MaxEnt results revealed that the suitable habitats of *S. cusia* were chiefly located in Western and Central Himalayas, Southern China, and Southern Japan, with an area of approximately 1.14×10^6 km^2. The 'temperature seasonality (standard deviation × 100)' (bio4), the 'precipitation of coldest quarter' (bio19), and the human footprint index (HFP) showed the strongest association (positive) with the relative contributions of 38.5%, 32.4%, and 9.1%, respectively. Proper understanding of its climatic niche, ethnobotanical importance, and role in human relations will be useful in sustainable cultivation and comprehensive utilization of this plant to meet its ever-growing demand.

Table 3
Relative contributions of the environmental variables to *Strobilanthese cusia* occurrences estimated using MaxEnt.

Variable	% Contribution
Bio4: Temperature Seasonality (standard deviation × 100)	38.5
Bio19: Precipitation of Coldest Quarter	32.4
Human Footprint Index (HFP)	9.1
Slope	5.2
Bio18: Precipitation of Warmest Quarter	4.8
Human Population density (HPD)	2.5
Elevation	2.2
Cropland	2.2
Bio2: Mean Diurnal Range (Mean of monthly (max temp – min temp))	1.8
Aspect	1.1

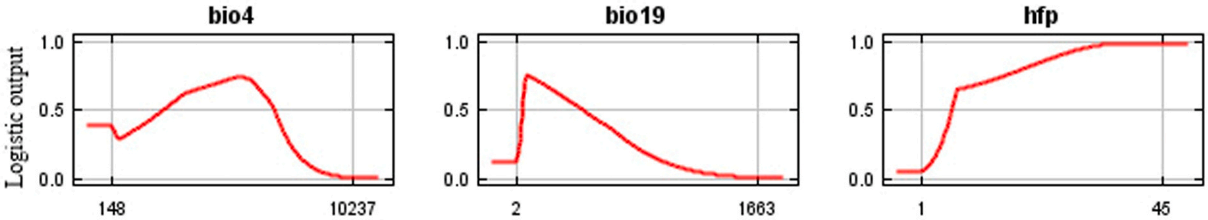

Fig. 5. Response curves of the selected significant predictive variables for *S. cusia* occurrence. Legend: bio4, temperature seasonality (standard deviation × 100). bio19, precipitation of coldest quarter. hfp, human footprint index (ranges from 0 to 50).

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Author contributions

YHW and JCX designed the study, supervised the research, and critically reviewed manuscript. LBZ and HZY carried out the field surveys, performed the MaxEnt molding, and wrote the manuscript. YNW and HFZ downloaded the species data, and performed the literature view. WYC and ZHL performed the GIS layers, and participated in the field surveys.

Declaration of Competing Interest

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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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2021.e01795.

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