

Environment tolerance of *Cunninghamia konishii* Hayata in northern of Vietnam

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Abstract: *Cunninghamia konishii* Hayata is one of the rarest timber trees in Vietnam, that have a high scientific and commercial value for timber and essential oil. According to the IUCN, the species is treated as Endangered (EN)-A2cd; B2ab (ii, iii, v) (IUCN), and Near Threatened (VU) - A1a, d, c1 according to Vietnam Red Data Book. We conducted research on the environment tolerance of the this species to determine the key climatic, soil, and topographic threshold that limits species occurrence in order to find scientific basis for ecosystem management. A survey in northern Vietnam was implemented to determine the natural distribution and damage to *C. konishii* by human interactions, and local cultivation. Fourteen social-environmental factors were investigated within five committee authorities focus group discussions (FGDs) from the document of questionnaire completed by nine commune heads. The result showed the highest sustainable index (SI) was focused in the Que Phong (A3), Ky Son (A1), communes. This suggests that SI was related to soil erosion (F_i).

1 Introduction

Environmental tolerance of a species is a key factor in the area of distribution, and is a result of the evolutionary process and environmental adaptations [1-2]. A theory for expression of a population's response to density-independent gradients of environmental factors is derived for the case of asexuality, the potential utility of this methodology for the analysis of standard data for environmental assessment [3]. The physiological limitations of a species are directly influenced by environmental conditions, however species also influenced by human activity. Environmental variables and social status interact in complex ways to influence species occurrence, in their survival and reproduction rates [1].

Cunninghamia konishii Hayata, known in Vietnam, under its vernacular name Sa Moc Dau, Sa Mu Dau, May Lung Linh, and May Lang Lenh [4-5], belongs to Cupressaceae family found in north and central Taiwan, China (Fujian), north of Laos and Vietnam (Son La, Ha Giang, Thanh Hoa, Nghe An province). *C. konishii* is light, aromatic, and strong timber that have high commercial value. According to the IUCN (2013), the species is treated as Endangered (EN)-A2cd; B2ab (ii, iii, v) [6], or Near Threatened (VU) - A1a, d, c1 according to Vietnam Red Data Book [7]. Almost all populations of *C. konshii* are protected in nature

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forest reserves, but the species still under threats of extinction due to rural development and agriculture land expansion. The largest population of the species distributed is in the East of Nghe An, a province of Vietnam, because of low human contact due to high mountain range.

This species has limited number of individuals and a small population in the nature [8-12]. *C. konishii* species are scattered in small clusters, mixed with evergreen primary forest growth within monsoon tropical climate that have average annual temperature of 13-19°C, rainfall level over 1,500 mm, on weathered soil from granite or other silicate rocks at an altitude of 960 – 2,000 m above sea level [13-15].

Resource management methods using GIS are widely used as GIS is capable of handling extremely large amounts of data and diverse information. In the Nature Reserve management database, information on species distribution is important data, specially for the threatened fauna and flora species. Furthermore, application AHP method by GIS was used to determine the importance and influence of individual ecological factors on the species based on expert knowledge [16-19]. Study of species distribution can help to improve population of wild trees [20-21]. Biological records of wild species based on the species distribution within the indicated area described their environmental variables. In addition, the ranges and limits of environmental tolerance of this species was untouched by research on small areas. Therefore, the objective of the present work is to unveil the limits of *C. konishii* distribution in Vietnam, as well as identify its climatic, soil and topographic tolerance limits. Status of sustainability also was determined using the AHP (analytic hierarchy process), a multi-criteria decision analysis is instrumental to evaluate the influence of social- environmental factors to the species sustainable index. The data provide a basis for scientific suggestions for development of *C. konishii* in Vietnam provinces. The results of this publication are just the first step for further deep advanced studies for entire ecoregion.

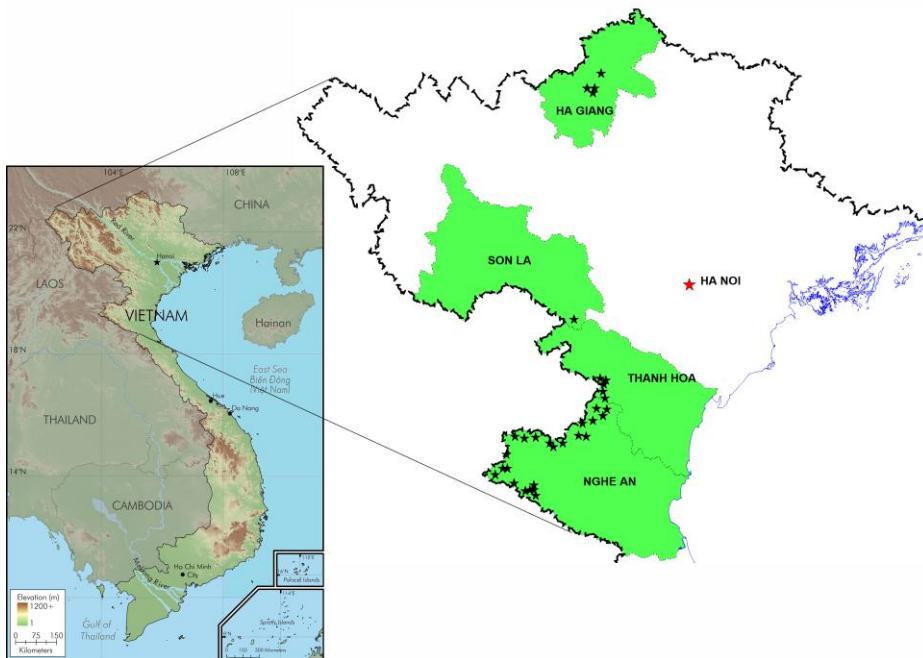


Fig 1. Location of study area and *C. konishii* population in Vietnam

2 Materials and methods

2.1 Data collection

We used the linear survey method, combined with a coordinate locator (GPS) to determine the position of *C. konishii* trees (Fig.1). We also used horizontal survey method to determine the cover of the forest canopy [22]. In addition, we studied soil properties as implemented by Thimo et al. [23]. We investigated and interview directly forest rangers, forest owners and local people to collect information of the species occurrence. Climatic data were obtained via WorldClim (1950-2000) at a spatial resolution of 5 arc-minutes (~10 km) [24]. Data on altitudes were gathered from a global digital elevation model at a spatial resolution of 5 arc-minutes (~10 km). Topographic variables were obtained by download DEM on SRTM web site (<http://srtm.csi.cgiar.org>). Slope and aspect from the DEM data were derived by using ArcGIS 10.0. The distance to river layer extracted from the National river and stream map (<https://www.bandovn.vn/>). Land use data was retrieved from survey. Tree cover collected from Global Forest Watch database (<http://globalforestwatch.org>).

To describe the environmental variables that *C. konishii* can tolerate in Vietnam and therefore that determine their habitat, species occurrences (longitude and latitude) were imported to Geography Information System (GIS). Therefore, environmental variables of each population distribution were showed by overlay of composite map of environmental variables. The results were analyzed for Means, maximum (largest value), minimum (smallest value) over a number of values were calculated by SPSS v20.

2.2 AHP technique

AHP uses a basic 9-point scale to represent importance of factors (F_i) according to expert assessment (table 1) [25-26], n was the 14 factors involved in the process (Table 5). Some *C. konishii* experts (9 commune heads in Ky Son, Con Cuong, Que Phong, Tuong Duong, Quy Chau, Muong Lat, Thuong Xuan, Hoang Su Phi, Moc Chau communes of Song Chinh district of Phu Yen province) were invited to fill a pairwise comparison table of the factors investigated during field survey to evaluation the level of importance of the factors and relations between them. The matrix format in pair comparison is described as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

Where: a_{ij} : the elements in the weight matrix, w : the weight; $a_{ii} = 1$ và $a_{ij} = 1/a_{ji}$. The results form a vector of weights: $W = [w_1, w_2, w_3, \dots, w_n]$. a_{ij} is calculated based on Saaty's eigenvector method. The eigenvector is normalized by equation (2) and then the weights are calculated using equation (3).

$$a_{ij} = \frac{a_{ij}}{\sum_{j=1}^n a_{ij}} \quad i, j = 1, 2, 3, \dots, n \quad (2)$$

$$w_{ij} = \frac{\sum_{j=1}^n a_{ij}}{n} \quad i, j = 1, 2, 3, \dots, n \quad (3)$$

Table 1. The Fundamental scale for pairwise comparisons

Intensity of importance	Judgments of verbal attribute labels
9	Absolute importance
7	Very strongly importance or preferred
5	Strong importance or strongly preferred
3	Weak importance, moderately important or preferred
2, 4, 6, 8	Intermediate values between adjacent judgments the two
1	Equally preferred more important or preferred

Source: Saaty, 2008

With the AHP algorithm, weights are calculated according to the standardized method of the matrix following the steps: (1) Sum the each column value of the pair comparison matrix; (2) Divide each component in the pair comparison matrix with the corresponding column total (the result is normalized by the pair comparison matrix); (3) Sum each row of the normalized matrix; (4) Divide the sum of each row by the sum of all rows given the corresponding weighted set for the factor. The final, the weight of factors for evaluation from experts through statistical analysis in Microsoft Excel 2016. The weighting accuracy was verified by the consistency ratio (CR) according to the formula (4):

$$CR = \frac{CI}{RI} \quad (4)$$

In which: CI: consistency index, which measures the degree of consistent deviation, determined by formula (5):

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (5)$$

λ_{\max} is the mean value of the consistent vector and n is the number of criteria.

$$\lambda_{\max} = \frac{1}{n} \cdot \left(\frac{\sum_{j=1}^n a_{1j} \cdot w_{11}}{w_{11}} + \frac{\sum_{j=1}^n a_{2j} \cdot w_{22}}{w_{22}} + \dots + \frac{\sum_{j=1}^n a_{nj} \cdot w_{nn}}{w_{nn}} \right) \quad (6)$$

RI is a random index, or mean value of CI, depending on the number of indicators to be compared (Table 2).

Table 2. RI value according to different indicators

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49	1.52	1.54	1.56	1.58	1.59

In the AHP, the CR shows the level of consistency among the expert's opinions during discussion. If CR is less than <0.1 or 10% (less than 0.1% to 10%) this proves that the correlation matrix between selected ecological factors is threatened as reliable [27-31]. Therefore, the weights of the factors influencing the sustainable of the species are accepted to add in the GIS layers to calculate the sustainable index (CI) for *C. konishii* in the study area.

2.3 Multi-criteria decision analysis instrument

Score for each factor i on Table 5 was (X_i) on each commune unit was determined base on the interview commune leader, the importance of factor i are converted to factor weights (W_i), i rang from 1 to m , where m was the total number of factor involved in the process. The weighted linear combination of (W_i) and (X_i) give sustainable index (SI) for each commune unit. Score of each level variable computed for each sustainable unit. These values are combined with the above mentioned overall weight to provide value for each sustainable unit. This process applying using the formula in Eq (7).

$$SI = \sum_{i=1}^m (W_i \cdot X_i) \quad (7)$$

3 Results and Discussion

3.1 Searching for *C. konishii* occurrences

Previous studies were analysed for identification of natural distribution of *C. konishii* in Vietnam [4, 12, 32]. Special survey was also implemented in August-November of 2020, the species was recorded as indicated in Table 3.

Table 3. Location of *C. konishii* distribution

Province	District	Commune	Elevation (m)	Number of individuals
Nghe An	Ky Son (A ₁)	Na Ngoi	1637-1908	280
		Tay Son	1900	65
		Muong Tip	1556	5
		Muong Ai	2000	2
		My Ly	1500-2000	<i>undefined</i>
		Nam Can	2000-2500	2
	Con Cuong (A ₂)	Chau Khe	800-1000	120
		Mon Son	800-1000	<i>undefined</i>
		Lang Khê	800-1000	<i>undefined</i>
	Que Phong (A ₃)	Hanh Dich	1500-2000	222
		Thong Thu	1300-1800	5
		Nam Giai	1300-1700	50
		Hanh Dich	1300-1800	970
		Tri Le	1200-1800	40
		Quang Phong	1060-1185	4
	Tương Duong (A ₄)	Tam Hop	65-75	2
		Tam Quang	65-80	<i>undefined</i>
		Nhon Mai	70	1
		Mai Son	N.a	<i>undefined</i>
		Nga My	100	<i>undefined</i>
Quy Chau (A ₅)		200	<i>undefined</i>	
	Chau Hoan	100-200	<i>undefined</i>	
		100-200	<i>undefined</i>	
	Dien Lam	1237	<i>undefined</i>	
Thanh Hoa	Muong Lat (A ₆)	Pu Hu	700-1200	2
	Thuong Xuan (A ₇)	Bat Mot	1300-1400	31
Ha Giang	Hoang Su Phi (A ₈)	Tung San	1212	2
Son La	Moc Châu (A ₉)	Chieng Xuan	1500-1600	1

3.2 Environmental tolerance

A environment tolerance is the ranger of conditions within which the species can live and its degree of abundance to conditions within the scope of the natural environmental condition (Table 4).

Table 4. Environmental variables

Variab les	Environment al predictors	Code	Unit	Data type	Min	Max	Mean
Topogra phy	Aspect	Topo1	Degree	<i>Continuous</i>	0	360	45
	Slope	Topo2	Degree	<i>Continuous</i>	20	50	45
	Elevation	Topo3	meter	<i>Continuous</i>	950	2500	1500
	Distance to river	Topo4	meter	<i>Continuous</i>	100	1000	100
Soil	Soil type	SOIL		<i>Categorical</i>	Ferralic Acrisols; Humic Acrisols		
	pH	pH		<i>Continuous</i>	5	5.5	5.2
	N _{total}	N	%	<i>Continuous</i>	0.2	0.27	0.25
	Humidity	Humi	%	<i>Continuous</i>	1.5	3	1.7
Land use	Forest cover	Cover	Percent	<i>Continuous</i>	80	100	
	Land use type	Land		<i>Categorical</i>	Protect forest (Evergreen broad leaved mixed forest)		
Climate	Annual Mean Temperature	C1	Celsius degree	<i>Continuous</i>	11.4 4	24.63	20
	Mean Diurnal Temperature Range	C2	Celsius degree	<i>Continuous</i>	5.3	9.55	7
	Temperature Seasonality	C3		<i>Continuous</i>	285. 32	501.4 7	400
	Temperature Annual Range	C4	Celsius degree	<i>Continuous</i>	16.4	21.1	18
	Annual Precipitation	C5	Millimeter	<i>Continuous</i>	117 8	2335	2000
	Precipitation of the Driest Month	C6	Millimeter	<i>Continuous</i>	0	9	7
	Precipitation Seasonality	C7		<i>Continuous</i>	78.2 7	107.1 8	93

The topography variables reveal that the level of tolerance to elevations were above 1000 m, while tolerance to slopes were above 25 degrees, tolerance to aspect were from 0-50 degree of northeast. The tolerance to distance to river also reveals that species optimum is above 1 km of distance. In agreement with data presented by other researchers, species are found from 1.000 – 1.500 m, slope from 15 – 45 [8-15]. Fig 2 was a representation of *C. konishii* population's common distribution for most influencing environmental factors, no individuals were recorded with value outside this range.

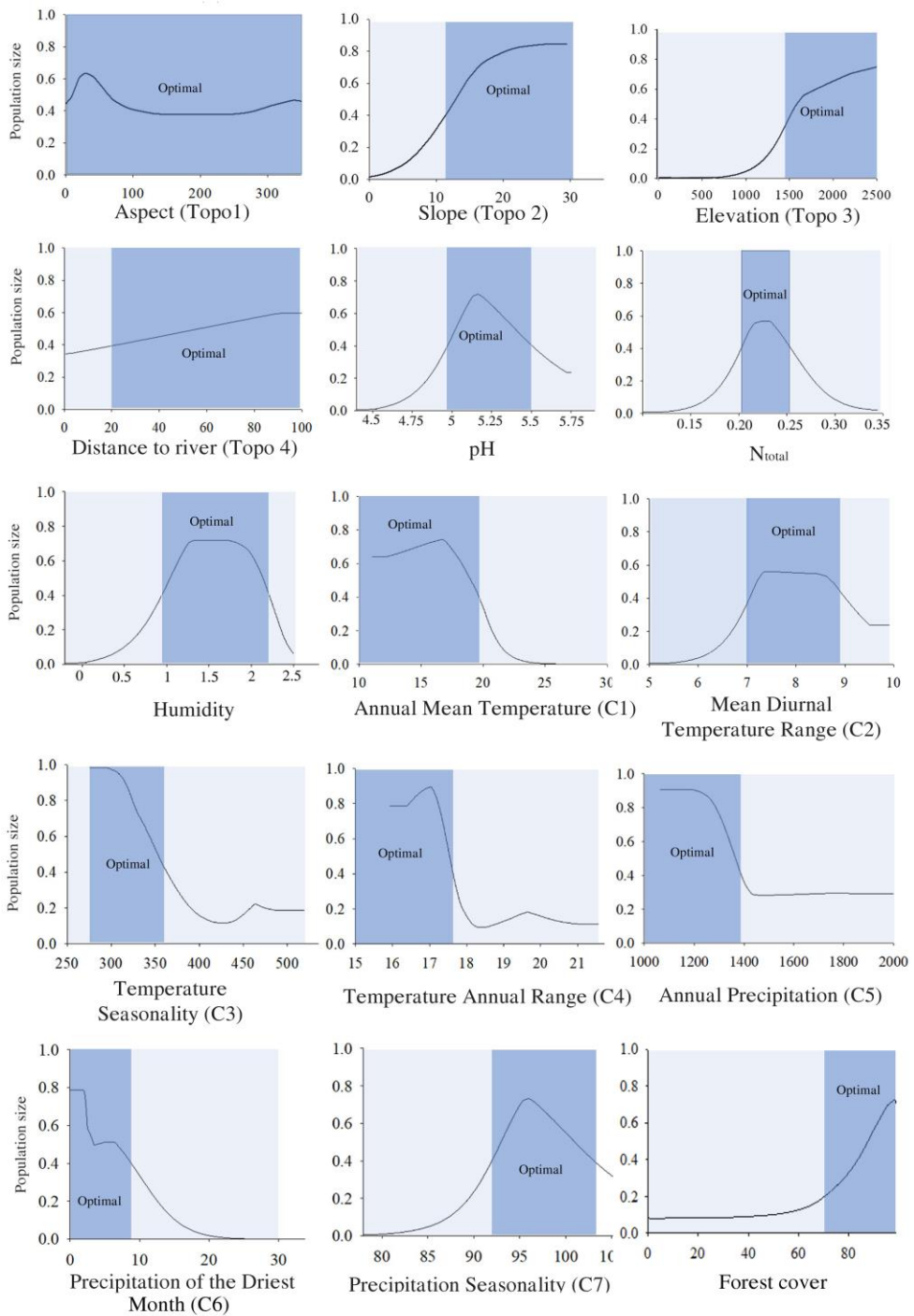


Fig 2. Optimal zone of environmental variables for *C. konishii*

3.4 Factors influencing to the area of *C. konishii* population in Vietnam

Analysis of the environmental performance of land use is the part of the content of environmental impact assessments for land use options. Environmental efficiency analysis is an important content to ensure the sustainable development of the land use type [33]. This study aimed to assess the environmental efficiency on commune units with agriculture land use. The impact of such land use on the environment included both two groups of factors: direct impact on the environment in the study area and indirect impact on the environment outside the study area (Table 5). However, it also effects on species population was thought that existed in the watershed of protected forests which agricultural activities are located around.

The table 5 comprise factor F_i from F_1 to F_{14} ($m=14$) were discovered from focus group discussions (FGDs) based on the Instruction for land evaluation TCVN 8409:2012 that was regulation of Ministry of Science and Technology of Vietnam [33]. Category of environmental impact assessments were divided on 3 category (Unsustainable, Less sustainable, Sustainable) correspond to score (X : 1, 2, 3). The document of questionnaire to weight (W) the importance of each factors were completed by 9 commune heads in Ky Son, Con Cuong, Que Phong, Tuong Duong, Quy Chau, Muong Lat, Thuong Xuan, Hoang Su Phi, Moc Chau communes of Song Chinh district, Phu Yen province, Vietnam.

Table 5. Category of environmental impact assessments

Factors	Level	Category	Score (X)
F ₁ : Soil erosion	Strong erosion	Unsustainable	1
	Moderate erosion	Less sustainable	2
	Weak erosion	Sustainable	3
F ₂ : Productivity of the land	High production capacity	Unsustainable	1
	Average production capacity	Less sustainable	2
	Low production capacity	Sustainable	3
F ₃ : Flow characteristics in streams	Overflow after rain	Unsustainable	1
	Drought in the summer	Less sustainable	2
	Flowing steadily	Sustainable	3
F ₄ : The occurrence of flooding and drought	Usually happens	Unsustainable	1
	Medium occurrence	Less sustainable	2
	Less happening	Sustainable	3
F ₅ : Water quality	Poor quality (turbidity, polluted)	Unsustainable	1
	Average quality	Less sustainable	2
	Good quality (clean, no pollution)	Sustainable	3
F ₆ : Number and area of protection forest area	Bad condition (deforestation, forest fire)	Unsustainable	1
	Average condition	Less sustainable	2
	The forest is intact	Sustainable	3
F ₇ : Forest tree species	Few species	Unsustainable	1
	Average number of species (commercial crops)	Less sustainable	2
	Multi-species, multi-layer	Sustainable	3
F ₈ : Wild animals	Few species	Unsustainable	1
	Moderate species	Less sustainable	2
	Species diversity	Sustainable	3
F ₉ : Mining and hunting methods	Destruction	Unsustainable	1
	Selectively	Less sustainable	2
	Protection	Sustainable	3
	Mainly rain water	Unsustainable	1

F ₁₀ : Water sources for agriculture	Rain water is essential and with additional irrigation	Less sustainable	2
	Big dam, deep well	Sustainable	3
F ₁₁ : Control weeds and pests	Use chemicals	Unsustainable	1
	Using mechanical and mechanical methods	Less sustainable	2
	Biology, crop structure and management	Sustainable	3
F ₁₂ : Plant system	Single culture farming, market-oriented	Unsustainable	1
	Many species on repeat crops	Less sustainable	2
	Crop rotation and polyculture	Sustainable	3
F ₁₃ : Labor	Out of the community	Unsustainable	1
	Family, cooperative	Less sustainable	2
	Family and community hire	Sustainable	3
F ₁₄ : Financial resources	External sources	Unsustainable	1
	Family, cooperative	Less sustainable	2
	Credit institutions (cooperatives, private enterprises, families)	Sustainable	3

Recently, assessment of the factors affected on the land use become more popular, especially there was instruction for production land evaluation that was implemented for all type of land use for agricultural production. The forest is a place strongly affected by human activities, so when the agricultural, forestry activities and economic development are not stable, it will lead to the risks of forest destruction. At that time, species populations are therefore affected through habitat loss or soil habitat degradation, erosion, flora and fauna loss. Results of the questionnaire have clarified exact important factors affecting the environment tolerance of the species population through the assessment of the sustainability of the local agricultural and forestry land. Soil erosion (F₁) was the top ranking of 14 factors involved in process with the weight was 21.1%, followed by (F₇: 7.22%) (F₈: 6.75%), (F₅: 6.23%), (F₁₃: 5.59%), (F₉: 4.99%). Consistency CR was: 0.02, this shows the reliability of the questionnaire results. Sustainable index (SI) showed that the highest SI was concentrated in the Que Phong (A₃), Ky Son (A₁), followed by Con Cuong (A₂), Tuong Duong (A₄), Quy Chau (A₅), Muong Lat (A₆), Thuong Xuan (A₇), Hoang Su Phi (A₈), Moc Chau (A₉) communes of Song Hinh district of Phu Yen province. This suggests that high SI is related to population size (A₃ and A₁ were the area found the large number of individual species) and soil erosion (F₁) that considered as an indicator for sustainable management of agricultural land resources in the buffer zones around reserves or protected forest.

4 Conclusions

The environmental tolerance of a *C. konishii* determined to a great extent its area of distribution for the expression of a population's response to density-independent gradients of environmental factors. The physiological limitations of species are directly influenced by environmental conditions, their occurrences also reflect the variability of many of these environmental parameters. Our survey was implemented in all locations where the species were recorded on previous researches, thesis, report, internet source, publications and interviews. Therefore, we are confident that this result is quite complete for surveying the distribution of species in Vietnam. The environmental data collected was determined by Geography Information System (GIS) through hundreds of species populations localities recorded. Twenty environmental tolerance factors have been established. The results show that species adapt to cold climate on high mountains, high temperature amplitude, and small amount of raining. On the other hand, FGDs with the participation of commune leaders was

implemented. Soil erosion (F_1) was important factor affecting the environment tolerance of the species population through the assessment of the sustainability of the local agricultural area (buffer zones around reserves or protected forest), followed by forest tree species (F_7), wild animals (F_8), water quality (F_5). Que Phong (A_3), Ky Son (A_1) were indicated high sustainable index than other alternatives.

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