RESEARCH PAPER

EVALUATION OF LAND SUITABILITY FOR *CUNNINGHAMIA KONISHII* HAYATA (CUPRESSACEAE) PLANTING IN VIETNAM

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Received: December 29th, 2020 / Accepted: May 25th, 2021 / Published: July 1st, 2021
https://DOI-10.24057/2071-9388-2020-218

ABSTRACT. The suitability of land for *C. konishii* was evaluated using the analytic hierarchy process (AHP) method, which included multiple criteria, such as elevation, soil, climate, and vegetation characteristics. 120 different sites of *C. konishii* were studied and the model approximations were verified by a confusion matrix. The subsistence of *C. konishii* was mainly affected by topographic features (elevation, slope) and soil (soil texture) conditions. 15 variables were selected for the ecological analysis and construction of the land suitability map. They were combined into four main groups for weights approximation. The weights obtained by AHP were calculated as follows: topographic features (65%), soil (21.3%), climate conditions (7.4%), and vegetation type (6.3%). The total area with the highest suitability was estimated at 4, 6, 2 and 8% of the province area in Son La, Ha Giang, Thanh Hoa, Nghe An, respectively. The suitable areas for planting were located in Mai Son, Muong La, Moc Chau, Sop Cop districts of Son La province; Hoang Su Phi, Xin Man districts of Ha Giang province; Muong Lat district of Thanh Hoa province; Que Phong, Ky Son, Tuong Duong, Con Cuong districts of Nghe An province. Nghe An province has the largest suitable area for planting. The estimated AHP accuracy was 91.6%, which indicates that the approach is reliable for forestry management. The current study will provide a ground to the local population for the selection of suitable lands, ensuring the sustainability of natural resources, sustainable use and quality forest production.

KEYWORDS: AHP, forest planting; GIS, land suitability evaluation

CITATION: Mai Phuong Pham, Dinh Duy Vu, Syed Noor Muhammad Shah, Quoc Khanh Nguyen, Thanh Tuan Nguyen, Hanh Tong Thi, Van Sinh Nguyen (2021). Evaluation of land suitability for Cunninghamia konishii Hayata (Cupressaceae) planting in Vietnam. Geography, Environment, Sustainability, Vol.14, No 2, p. 63-73 https://DOI-10.24057/2071-9388-2020-218

ACKNOWLEDGMENTS: The first author was supported by The Project «Application of geographic information method (GIS) and molecular biology for investigation, monitoring and development Cunninghamia konishii Hayata species of Vietnam» by Vietnam – Russia Tropical Centre (63 Nguyen Van Huyen street, Ha Noi, Vietnam) for 2020-2022. We are grateful to the laboratory of the Institute of Tropical Ecology of Vietnam – Russia Tropical Centre. We thank E. Sterling (New York) and K. Koy (Berkeley) for providing the map of Vietnam in Fig. 1. We appreciate Pu Hoat Nature Reserve – Nghe An province, Xuan Lien Nature Reserve – Thanh Hoa province, Xuan Nha Nature Reserve – Son La province, Hoang Su Phi protected forest – Ha Giang province for their support of the research. Special thanks to Mr Nguyen Van Manh, Mr Vi Van Tinh who have been working as forest managers at Pu Hoat Nature Reserve and some local people at Hanh Dich commune for their support of our survey.

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

Cunninghamia R. Br. ex. A.Rich. is a monotypic genus of the Cupressaceae family with only one known species, namely *Cunninghamia lanceolata* (Lamb.) Hook., distributed in South-Eastern Asia (Lu et al. 1999; Chung et al. 2004). *Cunninghamia lanceolate* var. konishii was first discovered in Taiwan, it was described as *Cunninghamia konishi*i Hayata and was later also found in Vietnam, Laos and continental China (Hayata 1908; Farjon 2010; Jagel 2014). *C. konishi*i is a large tree up to 40–50 m tall with monopodial growth and diameter at breast height reaching 3-4.5 m (DBH). In Vietnam it is mainly distributed in Ha Giang, Son La, Thanh Hoa and Nghe An provinces (Phan et al. 2009; Nguyen et al. 2017; Thai et al. 2015). It can be found at elevations of 1300 – 2800 m in Taiwan (Liang 2010), 1300 – 2000 m in China, 900 – 2200 m in Laos (Averyanov 2014), 1000 – 1600 m in Vietnam (Phan et al. 2017). It grows on deep, well-drained loams or loamy sand soil, but can also be found on weathered soils from granite or other silicate originated rocks. It requires a moderately cold and moist climate with precipitations above 4000 mm per year, and an average annual temperature of 13-19 °C but can tolerate up to 1.1-6.6 °C in some regions (Bigras 2001; Farjon 2010, Nguyen et al. 2004; Nguyen et al. 2009). The size of the natural population of *C. konishi*i in Vietnam is limited (Lu 2001; Lu et al. 2001; Nguyen 2009; Nguyen et al. 2009, 2012; Phan et al. 2013) due to its fragrance and outstanding durability in the timber industry (Cheng et al. 2012). The commercial exploitation of the species and cultivation is neglected to date (Farjon 2010). The natural population is declining due to the felling of primal forests, although some part of it is protected in nature reserves, and the species is treated as endangered (Farjon 2010; Thomas, Yang 2013; Nga et al. 2016). The species is included in the red list of IUCN threatened species and Vietnam red data book 2007 (Decree 06/2019/ND-CP of Vietnam Government). It is classified as an endangered, precious, and rare species. Therefore, the areas of distribution, ecology, natural active ingredients, phytochemicals and other possible resources of *C. konishi*i need to be explored for its conservation.

The anthropogenic pressure on natural forests is increasing every day due to the high demand for timber and leads to the reduction of forest area. To compensate for the high demand from limited resources, efficient use of land can play a significant role (Lubka 1982; Adeyoju 1983; Joyce 1981; Florence, Carron 1983). Trees can be planted and grown under different natural conditions; therefore, land evaluation is necessary. The data required to test land suitability for forest species depend on environmental parameters of exact tree species such as their soil, natural conditions and ecological requirements (FAO 1976, 1984). Olarieta et al. (2006) stated that soil factors have a major role in the growth of *Pinus radiata*. Dayawansa and Ekanayake (2003) also stated that climatic, topographic, and vegetation variables play important role in the identification of land for forest production (Dayawansa, Ekanayake 2003). Dengiz et al. (2010) estimated land suitability for forests by providing maps of suitability for each species. The researchers have also determined land potential by evaluating the ecological suitability criteria (Perpina et al. 2013). Suitability index and related criteria are determined using complex methods based on Geographic Information System (GIS) called Multi-Criteria Analysis (MCA) (Liu et al. 2007). This approach is implemented by applying a complex geographic information system (GIS) and the Analytic Hierarchy Process (AHP) for land suitability assessment through analysis of environmental parameters and provides support for species conservation (Chen et al. 2001; Draper et al. 2003). GIS can also be used in the qualitative assessment. Yüksel et al. (2001) studied the relationship between soils and land use units through the detailed soil map at Kenbag Nursery of Cankiri. The soil quality and climate are the main factors that influence productivity, among which, soil depth combined with elevation factor is the most important (Romanyà 2004). The current study was designed to evaluate the suitability of land in four provinces (Ha Giang, Son La, Thanh Hoa, Nghe An) of Vietnam for *C. konishi*i based on GIS and AHP and to optimize protected areas. The suitable lands on large scale for *C. konishi*i were mapped according to the ecological requirements including topography, climate, soil and vegetation characteristics.

MATERIALS AND METHODS

Study area

The study focuses on the provinces of Ha Giang, Son La, Thanh Hoa and Nghe An (Fig. 1), which include more than 50% of the forest area in Vietnam (Fig. 7, General Statistics Office of Vietnam 2019). Ha Giang province has a temperate monsoon climate, which is colder than in the Northeastern provinces of the country, but warmer than in the Northwestern ones. Son La province is known for its mountains characterized by a humid subtropical climate with cold and dry winters, hot and humid summers, and frequent heavy rainfalls. These areas have complex and deeply divided topography, forming many sub-climatic zones and special interzonal elements, which results in rich biodiversity and high agroforestry production.

Nghe An province is known for its tropical monsoon climate with two distinct summer and winter seasons and some climatic peculiarities. From April to August, the province is influenced by dry and hot southwest wind, while in winter the climate is cold and humid due to the northeast Pacific monsoon. Thanh Hoa province is situated in the middle of North and Central Vietnam, which is influenced by both regions including the «Laos Wind».

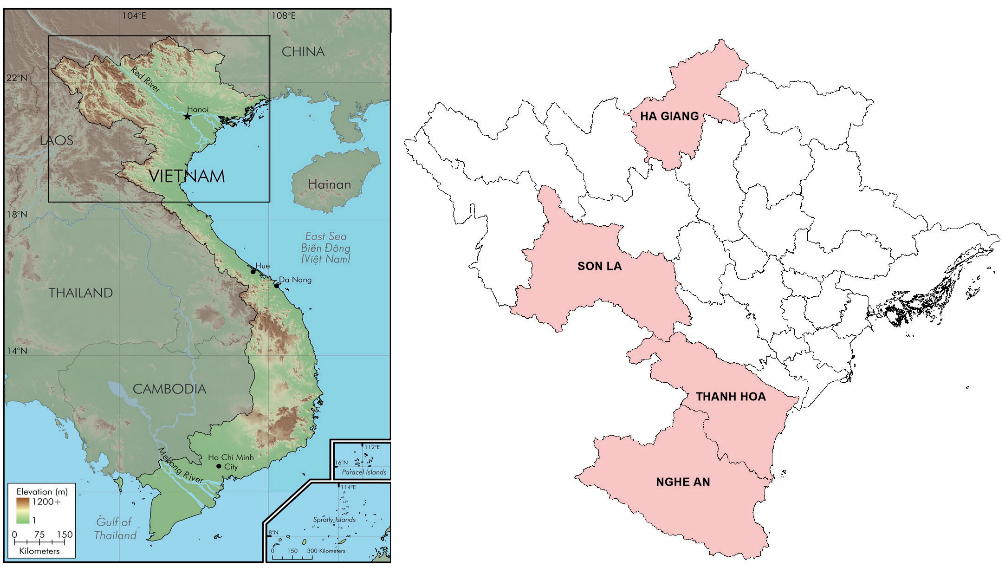

Fig. 1. Geographical location of the study areas

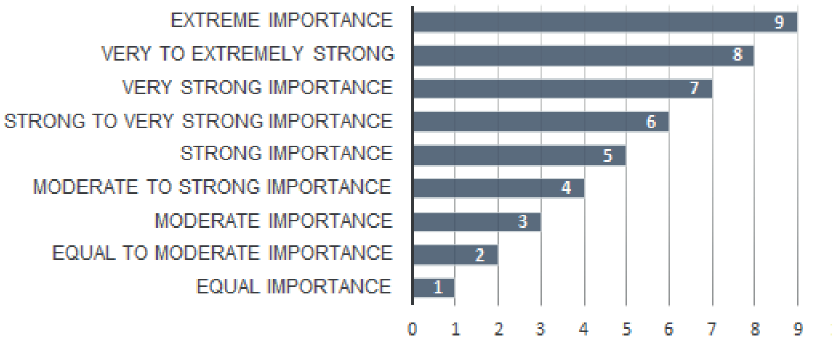

Fig. 2. The scale used for generation of the pairwise comparison matrix (Saaty 1980

Table 1. Categories of land suitability index

Categories of land suitability	Explanation	Index
Suitability index 1 (highly suitable)	Land unit is very favorable for *C. konishii* with no ecological limitations	>80
Suitability index 2 (moderately suitable)	Land unit is almost favorable for *C. konishii* with few ecological limitations	60-80
Suitability index 3 (marginally suitable)	Land unit is marginally favorable for *C. konishii* with severe ecological limitations	30-60
Suitability index N (unsuitable)	Land unit is almost unfavorable for *C. konishii* with severe ecological limitations	<30

Data collection

The distribution of *C. konishi*i was explored during July-August of 2020. The longitude and latitude of the studied 120 locations of the *C. konishi*i population were determined using a global positioning system (GPS). After that, the location data were incorporated into the geographic information system (GIS). The data on ecological factors were investigated during the field survey and determined using GIS. These factors included (1) topographic factors (elevation, slope, distance to nearest rivers and streams), (2) soil factors (soil type, texture and layer thickness), (3) general climate factors (mean diurnal and annual temperature range, annual precipitation, precipitation of the driest month and driest quarter and warmest quarter, sunshine duration of the growing month) and (4) vegetation factors (vegetation type, tree coverage). All of them were combined and considered as four main factors and 15 sub-factors (Table 2).

Table 2. Criteria for delineating land suitability of *C. konishii*

Criteria	Weight (W1)	CR	Sub- criteria	Categories				Weight (W2)	Overall weight (W1 xW2)	CR
				SI 1	SI 2	SI 3	N			
			Elevation	1100-2000m	900-1100m	800-900m	<800m	0.746	0.484	
Topography	0.650		Slope	$>45^0$	$30\text{-}45^0$	$25\text{-}30^0$	$<25^0$	0.134	0.087	0.022
			Distance to streams	200-400m	400-600m	600-800m	> 800, <200m	0.120	0.078	
			Soil type	A, Fs, Ha, Hq, Hs, Fk	Fa, Fj, Fq, Fv, Fe, Fu	Fp	Other land	0.090	0.019	
Soil	0.213		Soil texture	Loam	Sandy loam	Silty clay	Loamy sand, other soil types	0.556	0.119	0.068
			Soil layer thickness	> 100 cm	70-100 cm	50-70 cm	<50 cm	0.354	0.075	
			Mean diurnal range	$6.7\text{-}8.7^0$ C	5-6.6; $8.8\text{-}10^0$C	$10.1\text{-}12^0$C;	<4.9; $>12.1^0$ C	0.162	0.012	
		0.087	Annual temperature range	16.7-19.70 C	14-16.7; $19.8\text{-}22^0$ C	12-13.9; $22\text{-}24^0$C	<11.9; $>24.1^0$ C	0.039	0.003	
			Annual precipitation	1200-1700 mm	1000-1200; 1700-2000 mm	900-1000; 2000-2100 mm	<900; >2100 mm	0.058	0.004	
Climate	0.074		Precipitation of driest month	2-20 mm	1-2 mm	0.5-1 mm	<0.5 mm	0.199	0.015	0.081
			Precipitation of driest quarter	> 13 mm	10-13 mm	8-10 mm	<8 mm	0.129	0.009	
			Precipitation of warmest quarter	500-1000 mm	400-500; 1000-1200 mm	300-400; 1200-1300 mm	<300; >1300 mm	0.122	0.009	
			Sunshine duration of the growing month	130-160 (hours)	100-130; 160-180 (hours)	90-100; 180-200 (hours)	<90,> 200 (hours)	0.292	0.022	

Vegetation	0.063	0.087	Vegetation type	Protection forest on mountain	Production forest on mountain	Plantation forest on mountain	Other types of vegetation	0.167	0.011	
			Tree coverage	90%	80-90%	70-80%	<70%	0.833	0.053	

A: Humus on high mountains
Fs: Red and yellow soil on clay and metamorphic rocks
Ha: Red yellow humus on acid magma rock
Hq: Light yellow humus soil on sandstone
Hs: Yellow red loam on clay
Fk: Reddish-brown soil on neutral and basic magma
Fa: Red yellow soil on acid magma rock
Fq: Light yellow soil on sandstone
Fj: Yellow red soil on metamorphic rocks
Fv: Brown red soil on limestone
Fe: Purple brown soil on purple clay
Fu: Yellow brown soil on neutral and basic magma
Fp: Yellow brown soil on ancient alluvium

Topographic factor: Digital elevation model (DEM) data with resolution 30x30m were downloaded from http://srtm.csi.cgiar.org/ and included terrain elevation for the area from 103° 14' 14" N to 18° 30' 52" N and 105° 37' 40" E to 23° 31' 25.5" E by World Geodetic System 84. The surface analysis function in Arcgis 10.0 was used to build an elevation and slope map. The data on the *C. konishii* distribution along with updated river and streams data were used to determine the distances to the nearest river. Soil data (soil type, texture and layer thickness) were collected from the Soil map of the studied provinces (with a scale of 1:100.000) as provided by the Ministry of Natural Resources and Environment (MONRE). Climatic factors: 19 bio-climate parameters with a spatial resolution of 30s (1 km2) were collected from WorldClim-Global (ver.2) and were used to gather and analyze the actual ecological requirement factors for *C. konishii*. Vegetation data: The current map of land use of the studied provinces as available up to 2020 was provided by MONRE and used for the identification of vegetation types. Vegetation coverage data were obtained from www.globalforestwatch.org and calculated per pixel cell based on the canopy cover percentage for all vegetation higher than 5m (Hansen et al 2013).

Methods

AHP hierarchical model

In this study, a focus group discussion was implemented in which the participants including experts and local people were surveyed through a questionnaire. AHP is a structured technique for organizing and analysing complex decisions based on mathematics and psychology. It was developed by Thomas Saaty and Ernest Forman in the 1970s, implemented in Expert Choice in 1983 and has been extensively studied and advanced to date. It represents an accurate approach for quantifying the weights of decision criteria. Individual experts were brought to estimate the relative magnitudes of factors through pair-wise comparison. Initial AHP questionnaire has 1 to 9 scale (Saaty 1980; Li et al. 2019; Fig. 2). Each of our respondents had to compare the relative importance of the two items under a specially designed questionnaire.

The aim was to perform the analysis of land suitability for *C. konishii* planting in Vietnam along with the parameters which have to be involved in the process including soil, climate, and topographic characteristics. The weight of such parameters was obtained through pairwise comparison and statistically analyzed. Consistency Ratio (CR) (< 10 %) was used to check the accuracy of comparisons (Saaty 2000; Malczewski 1999; Maleki 2017; Bozdağ 2016).

Land suitability analysis using the integration of GIS and AHP

The FAO guidelines recommend using the scheme of suitability classification described in the Framework for Land Evaluation. The class level was chosen to evaluate the suitability of land in its current condition. The categories were described in the following way: highly suitable; moderately suitable; marginally suitable; not suitable. The FAO guidelines do not require the use of a specific methodology for assessment but provide a framework for whichever method the user wishes to apply (FAO 1976, Dengiz 2010). To evaluate the land suitability for the planting of *C. konishii*, the data of 15 variables were classified using 4 levels (SI 1, SI 2, SI 3, N). The purpose of this work was to create 15 component maps in raster form. AHP acquired weights of the variables were applied to all the raster layers, presented in the WGS84 Zone 48N coordinate system. The suitability of land for the species was mapped through overlay (superposition) of 15 raster component maps using ArcGIS 10.0 software. Finally, the map of land suitability for *C. konishii* was obtained and classified into 4 categories (Table 1).

Validation of the method

120 different sites of *C. konishii* were studied. During the assessment, the ratio between the number of correctly predicted scores and the total number of points in the test data set was calculated. The prediction accuracy was determined from the distribution of *C. konishii* scores (species occurrence, findings) obtained during the survey, which were attributed to a highly suitable class. Confusion matrix was used to compute accuracy (ACC), true positive rate (TPR) and true negative rate (TNR) from the following equations (Cabrera 2020; Singh, Singh 2017; Table 3).

Table 3. Confusion matrix to calculate the overall accuracy (ACC)

		Actual class	
		Positive	Negative
Predicted class	Positive	TP	FP
	Negative	FN	TN
		Actual class	
		Positive	Negative
Predicted class	Positive	93	9
	Negative	2	16
		ACC= 0.91; TPR=0.98; TNR=18	
TP: true positive; TN: true negative; FP: false positive; FN: false negative			

$$ACC = \frac{TP+TN}{P+N} = \frac{TP+TN}{TP+TN+FP+FN} \quad (1)$$

$$TPR = \frac{TP}{TP+FN} \quad (2)$$

$$TNR = \frac{TN}{TN+FP} \quad (3)$$

RESULTS AND DISCUSSION

AHP and GIS analysis

The results based on the experts pairwise comparisons showed that topography (0.65) has the highest values, followed by soil (0.213), climate (0.074) and vegetation (0.063) conditions (Table 2). Among the topographic criteria, elevation is prominent while the distance from streams has the lowest values. From the total soil sub-criteria, soil texture and soil types have the highest and lowest values, respectively. Similarly, among the climatic sub-criteria, the sunshine duration of the growing season have major roles in describing the land suitability for *C. konishi*i. The accuracy (ACC) was 91% for validation of the method, while true positive rate (TPR) and true negative rate (TNR) were 98% and 18%, respectively (Table 3). The consistency ratio (CR) of the matrix was 0.087 for the four main criteria. The CR of topographic, soil and climatic criteria were 0.022, 0.068, 0.081, respectively (Table 2).

We found that elevation and soil texture have a stronger impact on *C. konishi*i growth compared to any other studied criteria. It was found that in Nghe An province 8% (1244 km2) of the total area was suitable for *C. konishi*i planting, which is the largest potential area with a highly suitable index (73.39%) of all the provinces. The Son La and Ha Giang provinces had moderately and marginally suitable indexes covering 60% and 47% of the total area, respectively.

These results confirmed that the AHP methodology had high accuracy in the prediction of area suitability for the species. Our result also confirmed the previous studies (Huynh 2009; Lai et al 2002; Maleki et al 2017; Olarieta et al 2006), and the AHP method was found to be the best method for land suitability analysis. The elevation, shallow soil depth, steep slope, aspect trend and tough climatic conditions affect the land utilization type, which helped the local planners to reinstate the region by planting trees in proper ecological conditions (Gholizadeh 2019). Kooch and Najafi (2011) revealed the potential of an ecological zone of forest trees using soil analysis in Khanikan Forest in Iran.

In the study area, the land suitability evaluation is considered to be a vital link to the sustainability of ecosystems in terms of their productivity and environmental stability. The multi-criteria analysis has been used as an effective method as it may support the administration or decision-makers about the planning

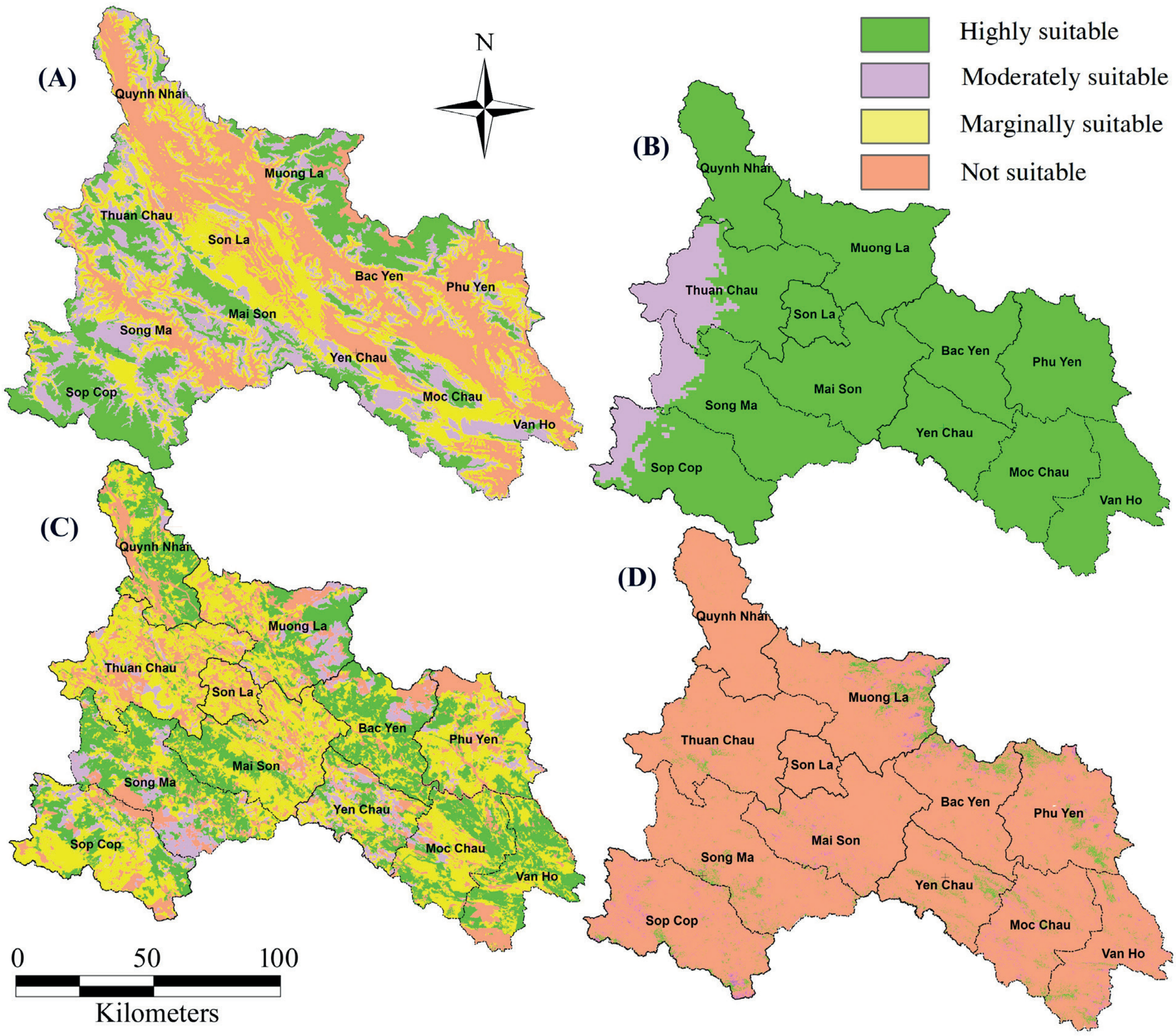

Fig. 3. Land suitability assessment for the main variables in Son La province; (A): Elevation, (B): Climate, (C): Soil; (D): Vegetation

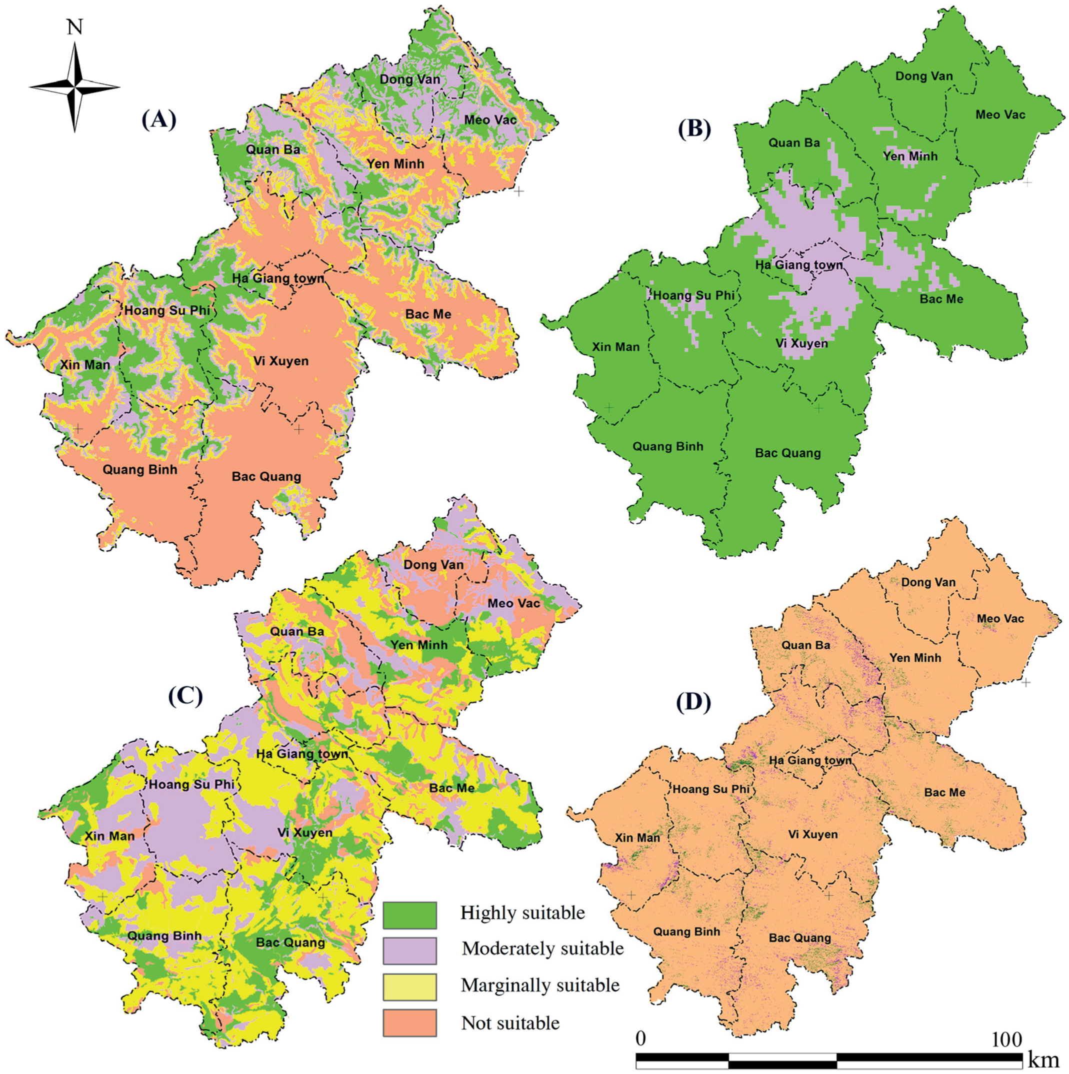

Fig. 4. Land suitability assessment for the main variables in Ha Giang province; (A): Elevation, (B): Climate, (C): Soil; (D): Vegetation

of reforestation programs. Spatial analysis methods are commonly used for land-use planning or land suitability selection studies but AHP has an advantage for decision-making compared to other proposed techniques. According to Lai et al. (2002), with AHP it is possible to measure the consistency of the decision maker's judgments.

During the study of the selected regions, elevation and climate criteria revealed that a wide range of areas is suitable to the ecological requirements of the species. Fig. 8 shows the difference among four provinces in the scuttering of land used for the regional programs of land suitability for *C. konishi*i planting. The land suitability map shows the area divided into highly suitable, moderately suitable, marginally suitable, and unsuitable class zone (Fig. 3, 4, 5, 6, 8). This subdivision had also been formerly applied in some evaluation studies for agriculture and forestry (Fao 1976; Huynh 2009; Ahmad et al. 2017a, 2017b).

Land suitability classes description

Highly suitable index (SI 1)

The highly suitable lands in Nghe An and Son La were broader than in Ha Giang and Thanh Hoa provinces, constituting about 73.39% of the total highly suitable area. The area of highly suitable class for Son La, Ha Giang, Thanh Hoa, and Nghe An comprised 4, 6, 2 and 8% of their total area, respectively (Table 4, 5). These areas are situated mainly in Mai Son, Muong La, Moc Chau, Sop Cop districts in Son La province; Hoang Su Phi, Xin Man districts in Ha Giang province; Muong Lat district in Thanh Hoa province and Que Phong, Ky Son, Tuong Duong, Con Cuong districts of Nghe An province. Based on our data, the highly suitable ecological conditions for *C. konishi*i may be described as: 1) Elevation of 1000-2000m, slope over 45° and distance to rivers/streams of 200-400m; 2) Soil condition: the presence of humus on high mountains, red and yellow clay soil and metamorphic rocks, red yellow humus on acid magma rock, light yellow humus soil on sandstone, yellow red loam on clay, reddish-brown soil on neutral and basic magma, loam soil, the thickness of soil layer of over 100 cm; 3) Climatic conditions: mean diurnal temperature range 6.7-8.7°C, annual temperature range 16.74-19.7°C; annual precipitation 1200-1700mm) precipitation of the driest month 2-20mm, precipitation of the driest quarter over 13mm, precipitation of the warmest quarter 500-1.000mm and sunshine exposition during the growing month from 130-160 hours; 4) Vegetation condition: the existence of forest protection on the mountain in the area and tree canopy coverage of 90% (Table 2).

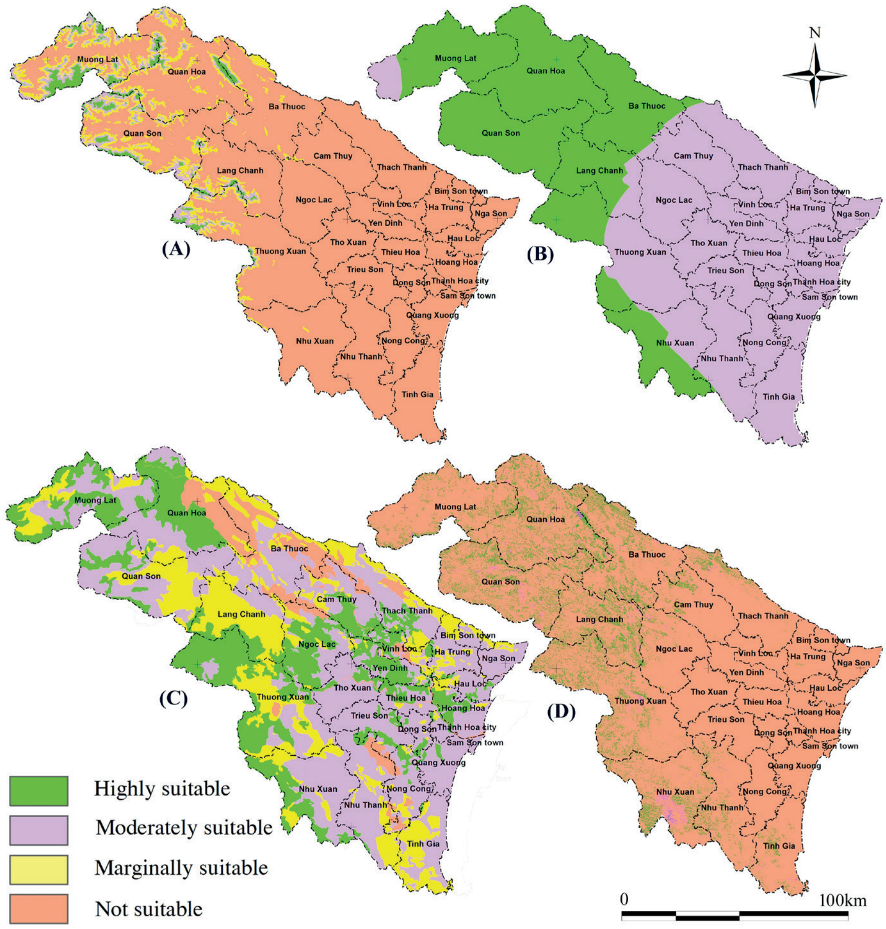

Fig. 5. Land suitability assessment for the main variables in Thanh Hoa province; (A): Elevation, (B): Climate, (C): Soil; (D): Vegetation

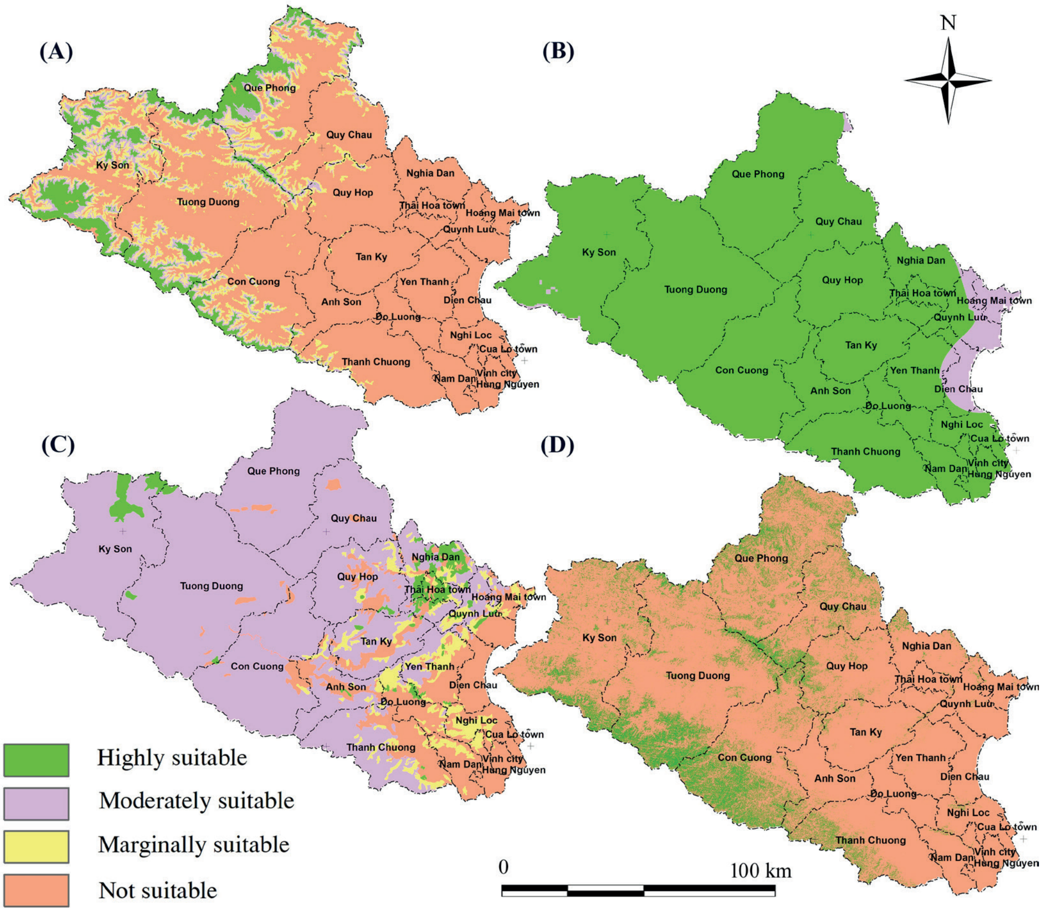

Fig. 6. Land suitability assessment for the main variables in Nghe An province; (A): Elevation, (B): Climate, (C): Soil; (D): Vegetation

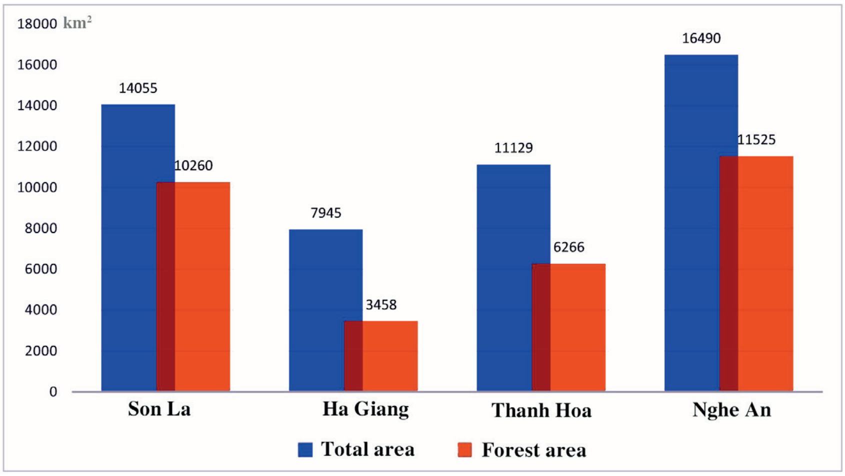

Fig. 7. Relative of total area and forest area of study provinces (km^2)

Moderately suitable index (SI 2)

Moderately suitable areas in Son La and Ha Giang were more spacious than in Nghe An and Thanh Hoa province as they combine for about 65.06% of the total moderately suitable land. The ratio of moderately suitable areas for Son La, Ha Giang, Thanh Hoa, and Nghe An provinces reach 23, 25, 8 and 12% of the total province area, respectively (Table 4, 5).

Marginally suitable index (SI 3)

Marginally suitable areas in Son La and Ha Giang were larger than in Nghe An and Thanh Hoa provinces. The former two combined for about 76.89% of the total marginally suitable land. The share of marginally suitable area for Son La, Ha Giang, Thanh Hoa, and Nghe An province reaches 47, 22, 10 and 9%, respectively (Table 4, 5). These results confirmed the high potential for the *C. konishii* growth in the western part of the studied area, especially in Ha Giang, Thanh Hoa and Nghe An province. These areas are restricted from human activities but the natural conditions are generally not too favorable and forest patches are largely fragmented by socio-economic activities.

Unsuitable (N) index

The unsuitable areas for C. lanceolata in Nghe An province were larger than in other provinces. The unsuitable lands in Son La, Ha Giang, Thanh Hoa, and Nghe An province were 25, 47, 81, 72%, respectively (Table 4, 5). Although for many places the climatic conditions were found suitable, in the eastern part, especially in Ha Giang, Thanh Hoa and Nghe An province, *C. konishii* cannot realize its natural potential, probably due to too low elevations and lower slopes. These results are also in line with Phan (2017) and Nga et al. (2017a, b), who mentioned that agricultural activities, development of rural and urban residential areas, elevation and slope may act as limiting factors for the *C. konishii* planting in the zones. There may be few single trees in scattered form in these kinds of areas, but not in clusters or concentrated parcels to develop any sustainable populations.

AHP can be accurately used in unstudied areas where species presence was detected. It is quite appropriate for our case study because many populations of the species have been destroyed and left untouched. In this study, we used a mixed approach (expert-based and species distribution). 120 species locations were determined during the survey to validate the results of the AHP analysis and confirmed its results with high accuracy. In addition, it has a very wide range of other applications such as planning and choosing any kind of decision among alternatives. It also relies on judgments, meaning that if experts are from different backgrounds, the evaluation can be done easily from different aspects.

CONCLUSIONS

The current study was designed for the *C. konishii* land suitability assessment based on GIS and AHP in four provinces (Ha Giang, Son La, Thanh Hoa, Nghe An) of Vietnam. The most influential ecological variables were used as a dataset for inclusion in the matrix comparison. The AHP results showed high accuracy. It was found, that elevation and soil condition affect the *C. konishii* growth more than any other factor. In the Nghe An province, 8% (1244 km^2) of the total area was found to be highly suitable for the *C. konishii* planting. It is the largest potential area with a highly suitable index (73.39%) of all the provinces. In

Table 4. Land suitability for *C. konishii* in each province

Land suitability index for *C. konishii*	Son La province (km^2)	Percentage (%)	Ha Giang province (km^2)	Percentage (%)	Thanh Hoa province (km^2)	Percentage (%)	Nghe An province (km^2)	Percentage (%)
SI 1	613	4	460	6	213	2	1244	8
SI 2	3228	23	1970	25	889	8	1902	12
SI 3	6638	47	1768	22	1060	10	1466	9
N	3576	25	3747	47	8967	81	11877	72
Total	14055	100	7945	100	11129	100	16490	100

Table 5. Distribution of area based on land suitability for *C. konishii*

Suitable index	Son La (km^2)	%	Ha Giang (km^2)	%	Thanh Hoa (km^2)	%	Nghe An (km^2)	%
Suitability area of topographic criteria								
SI 1	1666	12	1438	18	251	2	1275	8
SI 2	3288	23	1778	22	504	5	1179	7
SI 3	3660	26	959	12	717	6	1643	10
N	5441	39	3770	47	9657	87	12393	75
Suitability area of soil criteria								
SI 1	2226	16	1265	16	2731	25	491	3
SI 2	1301	9	2040	26	5138	46	12232	74
SI 3	6545	47	3282	41	2443	22	992	6
N	3983	28	1358	17	817	7	2775	17
Suitability area of climatic criteria								
SI 1	11952	85	7454	94	4734	43	15801	96
SI 2	2103	15	491	6	6395	57	689	4
Total	18038	100	9303	100	11946	100	16490	100
Suitability area of vegetation criteria								
SI 1	416	3	121	2	825	7	2088	13
SI 2	286	2	111	1	66	1		
SI 3	13353	95	7713	97	10238	92		
N							14402	87

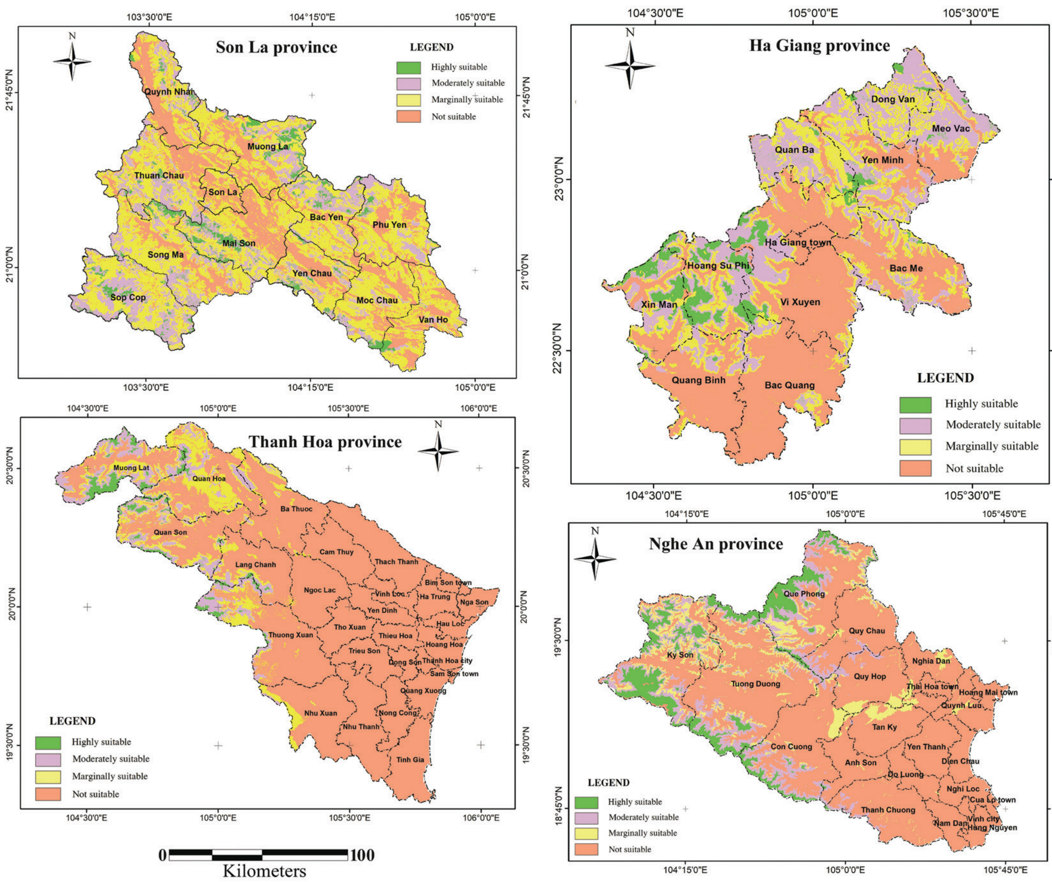

Fig. 8. Land suitability assessment map for *C. konishii* planting in Vietnam

Son La and Ha Giang provinces, the lands with moderately and marginally suitable indexes amounted to 60% and 47% of the total area, respectively.

The regional characteristics of different provinces affect the contribution of different factors. On the scale of a province, the records of environmental factors influencing the distribution of species population were not comparable with other provinces. Only data on forests and characteristics of tree layers showed variables characterizing the vegetation cover. It would be appropriate to describe the typological diversity of the vegetation for habitats of different suitability, which was not done within this study. The study will help in the development of *C. konishi*i forests on suitable land.

REFERENCES

Adeyoju S.K. (1983). Striking a balance in land-use planning. Unasylva, 35, 24-27.

Ahmad F., Goparaju L., Qayum A. (2017a). FAO guidelines and geospatial application for agroforestry suitability mapping. Case study of Ranchi, Jharkhand state of India. Agroforestry Systems, DOI: 10.1007/s10457-017-0145-y.

Ahmad F., Goparaju L., Qayum A. (2017b). Agroforestry suitability analysis based upon nutrient availability mapping. A GIS based suitability mapping. AIMS Agriculture and Food, 2(2). 201-220, DOI: 10.3934/agrfood.2017.2.201.

Averyanov L.V., Hiep N.T., Sinh K.N., Pham T.V., Lamxay V., Bounphanmy S., Lorphengsy S., Loc P.K., Lanorsavanh S., Chantthavongsa K. (2014). Gymnosperms of Laos. Nordic Journal of Botany, 32, 756-805.

Bigras F.J. and Colombo S.J. (2001). Conifer Cold Hardiness. Kluwer Academic Publishers. The Netherlands, 16-19.

Bozdağ A., Yavuz F., Günay A.S. (2016). AHP and GIS based land suitability analysis for Cihanbeyli (Turkey) County. Environmental Earth Sciences, 75(9), 813.

Cabrera J.S., Lee H.S. (2020). Flood risk assessment for Davao Oriental in the Philippines using geographic information system–based multi–criteria analysis and the maximum entropy model. Journal of Flood Risk Management, e12607.

Cheng S.S., Chung M.J., Lin C.Y., Wang Y.N., Chang S.T. (2012). Phytochemicals from Cunninghamia konishii Hayata act as antifungal agents. Journal of agricultural and food chemistry, 60(1), 124-128.

Chung J.D., Lin T.P., Tan Y.C., Lin M.Y., Hwang S.Y. (2004). Genetic diversity and biogeography of Cunninghamia konishii (Cupressaceae), an island species in Taiwan. A comparison with Cunninghamia lanceolata, a mainland species in China. Molecular Phylogenetics and Evolution, 33(3), 791-801.

Dayawansa N.D.K., Ekanayake G.K. (2003). Land suitability identification for a production forest through GIS techniques. Forestry and Biodiversity, Map India Conference, India.

Dengiz O., Gol C., Sario Lu F.E., Edi S. (2010). Parametric approach to land evaluation for forest plantation. A methodological study using GIS model. African Journal of Agricultural Research, 5(12), 1482-1496.

Decree No. 06/2019/ND-CP (2019). Management of endangered, precious and rare species of forest fauna and flora and observation of Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Draper D., Rosselló-Graell A., Garcia C., Gomes C.T., Sérgio C. (2003). Application of GIS in plant conservation programmes in Portugal. Biological Conservation, 113(3), 337-349.

FAO (1976). A framework for land evaluation. Soils Bulletin 32. Food and Agriculture Organization of the United Nations, Rome, Italy. ISBN 92-5-100111-1. http://www.fao.org/docrep/t0715e/ t0715e06.htm. Accessed November 10, 2017.

FAO (1984). Land evaluation for forestry, forestry paper 48. Rome, Italy. Food and Agriculture Organization of the United Nations.

Farjon A. (2010). A Handbook of the world's conifers, Brill Academic Publishers, Leiden, The Netherlands, 1112

Florence R.G., Carron L.T. (1983). Forest land use and environmental planning in Australia. Proc. Institute of Foresters of Australia 10th Triennial Conference, 16-21.

General Statistics Office of Vietnam (2019). Statistical Yearbook. Statistical publisher.

Gholizadeh A., Bagherzadeh, A., Keshavarzi A. (2019). Model application in evaluating land suitability for OAK and PINE forest plantations in Northeast of Iran. Geology, Ecology, and Landscapes, 1-15.

Hayata B. (1908). The Gardeners' Chronicle, ser. 3, 43, 194.

Hansen M.C., Potapov P.V., Moore R., Hancher M., Turubanova S.A., Tyukavina A., Thau D., Stehman S.V., Goetz S.J., Loveland T.R., Kommareddy A., Egorov A., Chini L., Justice C.O., and Townshend J.R.G. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change, Science 342, 850-53.

Huynh V.C. (2009). Multi-criteria soil suitability assessment for crops with GIS and AHP integrated. A case study in Huong Binh commune, Thua Thien Hue. Hue University Journal of Science, 50, 5-16.

IUCN 2020 (2020). The IUCN red list of threatened species, https://www.iucnredlist.org.

Joyce P.M. (1981). Forest management and land use planning. Proceedings of the 17th IUFRO World Congres, Japanese IUFRO Congress Committe, Ibaraki, Division 4, 363-374.

Kooch Y., Najafi A. (2011). Ecological potential assessment of forest groups using fuzzy set theory and regression analysis of soil characteristics (case study. Khanikan Forest, Chalus, north of Iran). Journal of Wood & Forest Science and Technology, 18(1).

Lai V., Wong B.K., Cheung W. (2002). Group decision making in a multiple criteria environment; a case using the AHP in the software selection. Eur. J. Oper. Res, 137(1), 134-144.

Li R.Y.M., Chau K.W., Zeng F.F. (2019). Ranking of risks for existing and new building works. Sustainability, 11(10), 2863.

Li H.L., Keng H. (1994). Taxodiaceae – In Flora of Taiwan, 2nd ed., Taiwan. 1. 582-585.

Liang W.Y. (2010). The cutting propagation technique and afforestation experiment of Cunninghamia konishii. Subtropical Agriculture Research, 6(4), 217-221.

Liu Y., Lv X., Qin X., Guo H., Yu Y., Wang J., Mao G. (2007). An integrated GIS-based analysis system for land-use management of lake areas in urban fringe. Landsc. Urban Plan, 82. 233-246.

Lu S.Y., Chiang T.Y., Hong K.H., Hu T.W. (1999). Re-examination of the taxonomic status of Cunninghamia konishii and C. lanceolata based on the RFLPs of a chloroplast trnD-trnT spacer. Taiwan Journal of Forest Science, 14, 13-19

Lu S.Y., Peng C.I., Cheng Y.P., Hong K.H., Chiang T.Y. (2001). Chloroplast DNA phylogeography of Cunninghamia konishii (Cupressaceae), an endemic conifer of Taiwan, Genome, 44, 797-807.

Lubka L. (1982). Role of the forester in land use planning. J. For., 80, 597-601.

Maleki F., Kazemi H., Siahmarguee A., Kamkar B. (2017). Development of a land use suitability model for saffron (Crocus sativus L.) cultivation by multi-criteria evaluation and spatial analysis. Ecological Engineering, 106, 140-153.

Malczewski J. (1999). GIS and multicriteria decision analysis. New York. Wiley.

Nguyen T.H., Phan K.L., Nguyen T.D.L., Thomas P.I., Farjon A., Averyanov L., Regalado J. (2004). Vietnamese conifers. Current status and conservation studies, Fauna & Flora International, 55-56.

Nga N.T.T., Dung N.A., Chung N.T., Thai T.H., Hung N.D. (2016). The distribution and some ecological characteristics, and essential oil of Cunninghamia konishii Hayata in Pu Hoat nature reserve, Nghe An province, Vietnam. Engineering and Applied Science Research, 43, 121-124.

Olarieta J.R., Besga G., Rodríguez–Ochoa R., Aizpurua A., Usón A. (2006). Land evaluation for forestry. a study of the land requirements for growing Pinus radiata D. Don in the Basque Country, northern Spain. Soil use and management, 22(3), 238-244.

Olson D.M., Dinerstein E., Wikramanayake E.D., Burgess N.D., Powell G.V.N., Underwood E.C., D'Amico J.A., Itoua I., Strand H.E., Morrison J.C., Loucks C.J., Allnutt T.F., Ricketts T.H., Kura Y., Lamoreux J.F., Wettengel W.W., Hedao P., Kassem K.R. (2001). Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51(11), 933-938.

Perpina C., Martinez-Llario J.C., Navarro A. (2013). Multi-criteria assessment in GIS environments for sitting biomass plants. Land Use Policy, 31, 326-335.

Phan K.L., Pham V.T., Phan K.L., Regalado J., Averyanov L.V., Maslin B. (2017). Native conifers of Vietnam – a review, Pak. J. Bot, 49(5), 2037-2068.

Phan K.L., Pham V.T., Nguyen S.K., Averyanov L.V. (2013). Conifers naturally growing in Vietnam – Updated 2013. Journal of Economy & Ecology, 45, 33-45.

Romanyà J., Vallejo V.R. (2004). Productivity of Pinus radiata plantations in Spain in response to climate and soil. Forest Ecology and Management, 195(1-2), 177-189.

Saaty T.L. (1980). The analytical hierarchy process. McGraw Hill, New York

Saaty T.L. (2000). Fundamentals of decision making and priority theory with the analytic hierarchy process. RWS Publications, Pittsburg.

Singh K.K., Singh A. (2017). Identification of flooded area from satellite images using hybrid Kohonen fuzzy C-means sigma classifier. Egyptian Journal of Remote Sensing and Space Sciences, 20. 147-155, DOI: 10.1016/J.EJRS.2016.04.003.

Thai T.H., Bazzali O., Hoi T.M., Minh D.T., Loc P.K., Nga N.T.T., Bighelli A. (2015). Chemical composition of the essential oil from Cunninghamia konishii Hayata growing wild in Vietnam. American Journal of Essential Oils and Natural Products, 2(3), 01-05.

Thomas P., Yang Y. (2013). Cunninghamia konishii. The IUCN Red List of Threatened Species.

Book V.R.D. (2007). Part II-Plants. Natural Science and Technology Publishing House, 133.