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Ecological characteristics and suitable habitat of threatened species Madhuca pasquieri (Dubard) H.Ja in Thai Nguyen province, Viet Nam

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ABSTRACT

Planning for the protection, resource use, and cultivation of species at various levels requires an assessment of the influence of important environmental conditions on habitat suitability. Madhuca pasquieri Berg (M. pasquieri) has been known in Vietnam, is suffering from negative effects on habitat such as illegal logging, conversion of forest land into agriculture land resulting in forest cover decrease. The research aims to study the ecological characteristics of M. pasquieri and the relationship between species and the habitat conditions to distribution of M. pasquieri species. The research employed the MaxEnt approach to forecast the species distribution of M. pasquieri species in order to model suitable environments. The research results showed that M. pasquieri is found and the dominating species in six out of the total of 18 plots. The height gradient increased both the stem density and the stand variables. With a value of 63,1% (Permutation significance), land cover has the biggest effect on M. pasquieri distribution, followed by the altitude factor's contribution ratio (36,9%). The identification of three acceptable classes including highly suitable habitat, moderately suitable habitat, and unsuitable environment, which offers a fundamental scientific foundation for the in-situ and ex-situ conservation of species by local governments and stakeholders, contributing to the sustainable forest management.

Keywords: Ecological characteristic; distribution; MaxEnt; suitable habitat, endangered species

INTRODUCTION

Viet Nam is known for having a high level of biodiversity. A detailed understanding of the ecology of individual species is important for conservation, especially for endangered or rare species (Fitter and Peat, 1994). *M. pasquieri* is one of the most threatened species in Northern of Vietnam (listed as VU in IUCN Red List; listed as EN in Vietnam Red-book list). Due to its high values such as valuable timber (Bui at al., 2005; Van and Cochard, 2017) and 30% edible oil have been found in seeds used in the chemical industry, it is threatened by habitat loss and over-harvesting over the last decades. However, due to the less of research on conservation of *M. pasquieri*.

According to Chan and Huyen (2000), *M. pasquieri* is a large tree, reaching a height of 35-40 meters and a diameter of 80-120 meters or more, with a dense, dark green canopy. It has a straight trunk, cylindrical in shape, and branches out late. The bark is dark brown, and when young, the leaves are pink or pale red. It produces white resin that flows when cut.

M. pasquieri is one of the most threatened species in Northern of Vietnam (listed as VU in IUCN Red List; listed as EN in Vietnam Red-book list). Due to its high values such as valuable timber and oil have been found in seeds used in the chemical industry, it is threatened by habitat loss and over-harvesting over the last decades. *M. pasquieri* is an endemic tree species of Vietnam, primarily found in provinces from Hue province to

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provinces in the northern, Vienam. It is concentrated in several provinces, including Son la (Phi at al., 2022), Lao Cai, Yen Bai, Phu Tho, Vinh Phuc, Ha Bac, Thanh Hoa, Nghe An, and Ha Tinh, Thai Nguyen and Bac Kan as well (Cong et al., 2015; Hang and Ly, 2013). According to Le et al (2015), alkaloids extracted from the leaves of the *M. pasquieri* have demonstrated anti-cancer properties. The seeds contain 20-30% fatty oil, which is used in the food and pharmaceutical industries. A previous study conducted by Nguyen (1997) measured the oil content in the seeds of 20 Madhuca pasquieri trees of different ages in Tam Qui. The research showed that the oil content in the seeds ranged from 30% to 46% of the seed's weight and was not dependent on the age of the trees.

By promoting sustainable and discreet gathering of medicinal plants from throughout the world, knowledge on the distribution and biological characteristics of the plants helps prevent overexploitation of threatened species (Bhattacharya and Sharma, 2008). *M. pasquieri*'s ecological properties and distribution in study area and Vietnam have not yet been discussed. A common method for predicting the geographic range of a species is species distribution modeling (SDM) (Poloczanska et al., 2008). In order to assess suitable habitats and predict dispersion in uncharted areas, this model creates statistics based on information on the locations where a species occurs and environmental characteristics (Hijmans et al., 2005). SDM is a favored method for mapping the distribution of data since it is extremely effective, even with a small input.

By promoting sustainable and discreet gathering of endangered species from throughout the world, knowledge on the distribution and ecological characteristics of the plant spcies helps prevent overexploitation of threatened species (Bhattacharya and Sharma, 2008). Ecological properties of *M. pasquieri*, distribution, and capacity for regeneration in Vietnam have not yet been discussed. A common method for predicting the geographic range of a species is species distribution modeling (SDM) (Poloczanska et al., 2008). In order to assess suitable habitats and predict dispersion in uncharted areas, this model creates statistics based on information on the locations where a species occurs and environmental characteristics (Hijmans et al., 2005). SDM is a favored method for mapping the distribution of data since it is extremely effective, even with a small input.The results of the research provide valuable information about biological characteristics, ecological characteristics, distribution, and suitable habitat of *M. pasquieri* in the study area. The scientific findings along with a map of habitat suitability are scientific basics to develop technical guides and identify ex-situ areas for long-term conservation.

MATERIALS AND METHODS

Data collection

Thai Nguyen is a province located in the Northeast region of Vietnam. The geographical coordinate stretches across from 20^{o}20’ to 22^{o}25’North and 105^{o}25’ to 106^{o}16’ East, where *M. pasquieri* has been found. For data collection on species: occurrence and distribution using field surveys carried out from november, 2022 to September, 2023. The sampling sites were selected in four regions including Vo Nhai, Dinh Hoa, Dai Tu and Dong Hy District where *M. pasquieri* are distributed. For each location, the survey transects for entire areas went through different types of habitat and forest status.

M. pasquieri information was collected in a total of eighteen temporary sample plots (40 x 25 m), sample plots were laid out where this species occurring. Handy GPS and GPS RTK was used to record 90 distribution position of *M. pasquieri*. The data was saved in an Excel file and visualized in ArcGIS® 10.3 platform. In sample plots of 1000 m^2 all trees with a diameter of ≥ 6 cm at breast height were measured and recorded. Natural regeneration of tree species (seedlings and saplings) with the dbh < 6 cm were measured and recorded in 25 m^2 (5 x 5 m) subplots located in the middle and corners of each plot.

The name of species was recorded in local/Vietnamese name. Forest inventory team comprised of a dendrologist (from Thai Nguyen University of Agriculture and forestry, Vietnam). In case of a species that was not identified during the inventory, a photo and specimen of the species were taken, and assessed by other dendrologists (from Institute of ecology and biological resources, Vietnam). The relative ecological significance

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of each woody species in forests is expressed the importance value index (IVI) as the sum of the relative density and relative basal area (Curtis 1959) for species in one plot.

Modeling species distribution

To evaluate the potential distribution at present of *M. pasquieri* in the study area, this study has developed a species distribution model with 5 variables including: land cover, altitude, slope, precipitation, soil type by Maximum Entropy (MaxEnt) software.

Data on the climate regime (mean annual precipitation): The Vietnam Institute of Meteorology, Hydrology, and Climate Change (http://www.imh.ac.vn) contributed the climate data. Based on observations made over a 15-year period (from 2008 to 2022) at three weather stations and 11 rainfall stations, rainfall information was gathered. Applying the Kriging/Cokriging method in the ArcGIS® 10.3 platform (ESRI, Redlands, CA, USA) provided for the spatial interpolation of mean annual rainfall based on DEM.

Data on topography (elevation, slope) was provided by the Consortium for Spatial Information (CSI) as a digital elevation model (DEM) with a resolution of 30 x 30 m from the Shuttle Radar Topographic Mission (SRTM). Using GPS, the longitude and latitude of each sample plot were recorded.

Data on Soil properties (soil type, soil depth): Soil properties were derived from the digital soil map provided by the Vietnam Academy of Agriculture Sciences (VAAS). The map was created in 2005 about soil type information. According to the FAO-UNESCO-based soil classification system in 1998, the major soil groups are Acrisols /Ferralsols, and 5 subgroups consisting of Fluvisols, Haplic acrisols, Luvisols, Ferralsols and Dystric gleysols. In specific, according to the information derived from the soil map, soil types classified into 12 classes: (1) Fs: Yellowish red soil on metamorphic and sedimentary rock; (2) Fha: Humic ferralsols developed on acid magma rock; (3) Fa: Ferralic Acrisols, is Yellowish red soil developed on acid magma, formed by the feralite process; (4) Fk: Rhodic Ferralsols developed on bases and acid magma rock; (5) Fv: Rhodic Ferrasols developed on Limestone; (6) Fq: Yellowish red soil developed on sandstone; (8) Fp: Ferralic Acrisols formed by the feralite process is ancient alluvial soil; (9) Fl: Plinthic Acrisols and yellowish red soil formed by cultivation; (10): K2: Karst; (11) P: fluvisols; (12) Rk: Chrimic luvisols.

Additionally, the Copernicus Global Land Operations https://land.copernicus.eu/ map of the Land Cover layer was used. Using Google Earth Engine, the Dynamic Land Cover map at 100 m spatial resolution (CGLS-LC100) was obtained. For each type of land cover, the product delivers proportional estimates of the vegetation and ground cover. Using a Sentinel time-series and the PROBA-V 100 m, the Land Cover maps (v3.0.1) for the year 2019 are presented for the entire globe (Buchhorn, Lesiv, et al., 2020). For the species distribution modeling, a 30 arc-second raster soil record from the Harmonized World Soil record (Nachtergaele et al. 2009) was also extracted and included. Lan cover classified into 14 classes: (1) Shrubs; (2) Herbaceous vegetation; (3) Cultivated and managed vegetation/agriculture (cropland); (4) Urban / built up; (5) Bare / sparse vegetation; (6) Permanent water bodies; (7) Herbaceous wetland; (8) Closed forest, evergreen needle lea; (9) Closed forest, evergreen, broad leaf; (10) Closed forest, deciduous broad leaf; (11) Closed forest, mixed; (12) Closed forest, unknown; (13) Open forest, evergreen broad leaf; (14) Open forest, unknown;

This study employed MaxEnt (3.4.4), a popular and practical machine learning technique (Pimm et al., 1995), to model suitable habitats. Because of its precision and usefulness, MaxEnt is undoubtedly one of the most widely used techniques for showing species distribution (Phillips et al., 2006). For a number of reasons, including the selective use of species information, adaptability in natural information processing - including both sequential and intermittent elements, and the capacity to accommodate complex responses to ecological factors, MaxEnt is a very reasonable option for displaying species distributions (Pearson, 2010; Wei et al., 2018). MaxEnt is a favored model for all test sample sizes since, in particular, its size checking sensitivity is low (Phillips et al., 2008). MaxEnt is appropriate for anticipating species dispersion in information destitute locale like Vietnam (Truong at al., 2017; Phillips et al. 2006). The comes about of the MaxEnt show are assessed based on the AUC (Region Beneath the recipient working characteristic Bend) list (Almadrones-Reyes and Dagamac, 2018). The AUC esteem ranges from 0 to 1. A esteem underneath 0.5 shows that the expectation show fizzled, whereas an AUC of 1 demonstrates that the

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demonstrate has supreme exactness. Models with AUC values from 0.7 to 0.9 were considered to have a good fit (Remya et al., 2015). The show was run 10 times autonomously to induce the cruel of 10 runs.

In spite of the fact that changes in nature do not happen in discrete interims, for conceptualization and simple elucidation of the comes about of the Maxent show, the prescient comes about were regrouped and plotted into four levels based on Jenks' common breaks: unacceptable territory (0–0.1), appropriate environment (0.1–0.3), direct appropriate territory (0.3–0.5), tall reasonable living space (0.5–1). This model has been broadly utilized in species dispersion models (Arabameri et al. 2020; Li et al. 2019; Zhao et al. 2021). The output map of the MaxEnt model is designed in ArcGIS. Criteria for classifying areas with suitable/unsuitable conditions are as follows: unsuitable area ($P < 0.1$), low suitable area ($0.1 \le P < 0.4$), moderate suitable area ($0.4 \le P < 0.6$) and high suitable area ($P \ge 0.6$) (Beane et al., 2013, Khafaga et al., 2011).

RESULTS AND DISCUSSION

Ecological characteristics

The results have shown that *M. pasquieri* was found between 190 - 910 m above sea level. The highest elevation was recorded to appear in 910 m above sea level in Dai Tu district, whereas the lowest value 190 m above sea level was observed in Dinh Hoa and Vo Nhai district. The findings of the previous researches (Qu et al., 2018; Flora of China, 2021) reported the same result and observed the occurrence of M. pasquieri at the altitude from 0 to 1100 m above sea level. *M. pasquieri* in the study area was also recorded at the slope from 15 - 30^o and the forest cover percentage of 60 - 70%. The species mainly distributed in evergreen brodleaved forests on soil mountain (Closed forest), however, there are 15 individuals in Vo Nhai district distributed in evergreen brodleaved forests on rocky mountain (Closed forest). *M. pasquieri* was found in forest soil type of Fs, Fk, Fa and rocky mountain. M. pasquieri individuals were mainly found in areas with annual rainfall ranging from 1375mm/year to 2155mm/year.

Forest composition

The majority of *M. pasquieri* individuals were found (90 individuals) and eighteen plots were laid out in evergreen brodleaved forests. Number of stems ranged from 170stems /ha - 960stems /ha, Average diameter at breast height ranged from 11.4cm to 21.2cm, from 8.7m – 14.2m for height of forest stands. *M. pasquieri* individuals are distributed in closed forests including evergreen broadleaved forest on soil mountain and rocky mountain with average stand volume ranging from 11.3m^3/ha to 110.3m^3/ha (Table 1).

Table 1. Stand variables and Importance Value Index of the species

Plot alt. (m)	No. (Stem/ha)	DBH (cm)	Height (m)	Stand volume (m^3/ha)	Importance Value Index (IVI%)
907	440	15.0	12.2	42,79	29.78 Machilus grandifolia +20.74 Madhuca pasquieri +11.5 Lithocarpus fissus +6.87 Knema conferta +31.09 others
902	450	17.8	10.5	52.8	35.7 Machilus grandifolia +16.2 Madhuca pasquieri +48.1 others
410	620	17.7	10.7	73.7	18.03 Engelhardtia roxburgliana+9.89 Machilus grandifolia +7.30 Alangium chinense +7.18Sp3+5.1 Castanopsis indica +47.4 others
456	480	18.1	11.4	63.7	14,98 Madhuca pasquieri + 8,55 Castanopsis indica + 7,85 Sterculia lanceolata + 5,82 Deutzianthus tonkinensis

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					+ 5,40 Elaeocarpus grandiflorus + 5,07 Endospermun chinense + 52,32 others
430	590	19.7	10.9	89.1	7,32 Cinnamomum iners + 6,58 Ormosia balansae + 5,22 Lithocarpus bacgiangensis + 80,88 others
449	420	14.3	8.7	26.2	29,22 Streblus macrophyllus + 12,93 Cephalomappa sinensis+ 11,15 Diospyros eriantha+ 10,43 Madhuca pasquieri + 36,27 others
462	550	17.9	10.3	63.5	22.72 Madhuca pasquieri +9.71 Castanopsis chinensis +7,70 Syzygium cinereum +6.31 Cinnamomum iners +47.33 others
631	320	16.6	10.4	32.1	18.79 Vatica odorata +14.41Polyalthia nemoralis+12.21Choerospondias axillaris +11.78Lithocarpus fissus +42.79 others
600	210	15.9	10.5	19.50	27.09 Madhuca pasquieri+19.84Syzygium levinei +18.09Podocarpus neriifolius+9.36Schima superba+25.59 others
632	250	21.2	13.9	55.2	21.66 Polyalthia suberrosa +19.244 Vatica odorata +15.31 Nephelium chryseum +11.73 Parashorea chinensis +32.04 others
655	250	19.9	14.2	79.2	32.11 Polyalthia clemensorum +22.05 Syzygium levinei +19.87 Vatica odorata + 22.96 others
349	960	15.8	9.9	83.6	14,88 Cryptocarya metcalfiana +7,99 Choerospondias axillaris +5,95 Machilus grandifolia +5,91 Pterospermum heterophyllum +64,85 others
449	840	17.8	11.8	110.3	35,37 Lithocarpus fissus +12,66 Cryptocarya concinna +7,30 Machilus grandifolia +5,20 Cryptocarya metcalfiana +39,47 others
190	400	14.0	10.4	28.5	33,53 Streblus macrophyllus + 12,15 Dendrocnide urentissima + 11,77 Diospyros + 7,71 Machilus odoratissima + 7,57 Madhuca pasquieri + 7,06 Arenga saccharifera + 20,21 others
190	520	11.4	9.8	23.7	47,57 Streblus macrophyllus + 16,75 Diospyros + 10,17 Dendrocnide urentissima + 5,56 Cassia + 5,40 Macaranga denticulata + 5,05 Madhuca pasquieri + 9,54 others
340	170	13.4	10.5	11.3	23,29 Castanopsis chinensis + 22,33 Syzygium cuminii + 17,55 Canarium tonkinense + 17,39 Machilus odoratissima

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					+ 9,77 Syzygium cuminii + 5,54 Styrax tonkinensis + 4,14 others
190	500	13.3	10.4	32.5	12,08 Cratoxylon pruniflorum + 8,49 Castanopsis chinensis + 7,42 Machilus odoratissima + 7,35 Sterculia lanceolata + 6,41 Ficus + 58,25 others
290	470	15.6	10.8	43.4	16,66 Machilus Bonii + 9,84 Streblus + 7,33 Pterospermum heterophyllum+ 7,06 Schefflera + 7,00 Hexaneurocarpon + 6,74 Ficus Hispida + 6,14 Polyalthia nemoralis+ 5,78 Canarium album + 5,13 Streblus macrophyllus+ 5,03 Dendrocnide urentissima + 23,29 others

According to the importance value results of forests where *M. pasquieri* occuring *Machilus grandifolia, Engelhardtia roxburgliana, Streblus macrophyllus, Polyalthia suberrosa, Lithocarpus fissus, Streblus macrophyllus, Castanopsis chinensis* are the dominant species, folowwed by *Lithocarpus fissus, Knema conferta, Machilus grandifolia, Alangium chinense, Castanopsis indica, Sterculia lanceolata, Deutzianthus tonkinensis, Elaeocarpus grandiflorus, Endospermun chinense, Ormosia balansae, Lithocarpus bacgiangensis, Cephalomappa sinensis, Diospyros eriantha, Machilus odoratissima, Syzygium cinereum, Cinnamomum iners, Sterculia lanceolata, Pterospermum heterophyllum, Ficus Hispida, Dendrocnide urentissima….* As a result of the research performed in the field, *M. pasquieri* appears and is dominant species in 6 out of the total 18 plots.

The increase of the species richness causes the increase of species diversity, number of species per site ranged from 7-36. Previous research indicated that altitude gradient has a relation with the species composition and stand variables (Sahu et al., 2008; Nepali et al., 2021; Lou et al., 2023). The results indicated that stem density ands stand variables increased by altitude gradient. In the research area, the forests are less affected by human activity when they are located at higher elevations. In areas of altitude of less than 400 m above the sea level, stem density, diameter at breast height, height of forest stands and stand volume are lower in comparison with areas of altitude of higher than 400 m above the sea level. Information of forest composition and stand variables enable forest managers to comprehensively understand the managed forests and effectively improve protection and management.

Suitable habitat of M. pasquieri

By analyzing the distribution of *M. pasquieri* species by Maxent model, the results show that the AUC for the *M. pasquieri* distribution model is 0.917 (Figure. 1), higher than that of the random model with a value of 0.5. The value indicates that the model is in "very good" condition (Pimm et al., 1995) and the model is reliable and can reflect the species distribution according to the factors.

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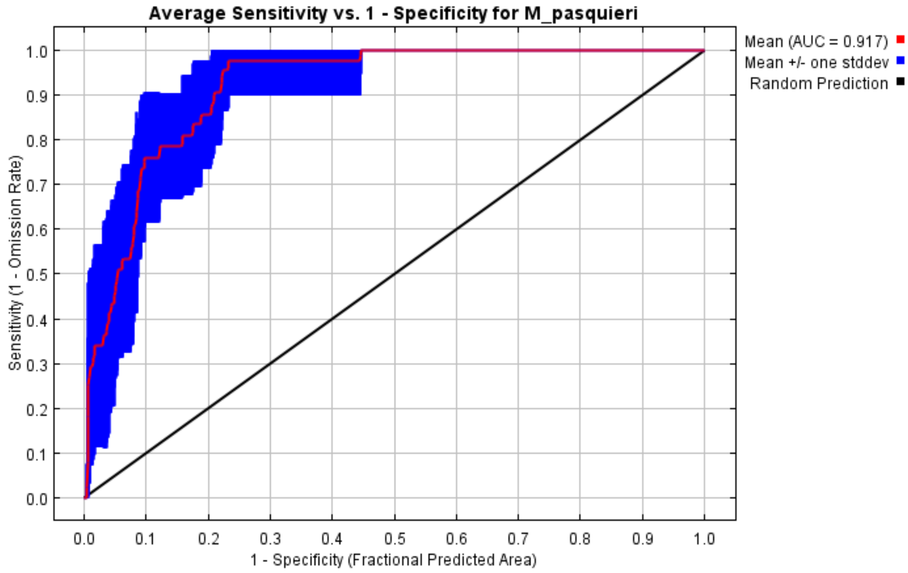

Figure. 1. Model performance (AUC) of *M. pasquieri*

The results of the jackknife test and the percent of significance of the variables (Figure. 2) showed that land cover has the greatest impact on *M. pasquieri* with a value of 63,1% (Permutation importance), followed by the contribution ratio of altitude factor (36.9%). Soil type, slope and annual precipitation factors have insignificant impact on species distribution.

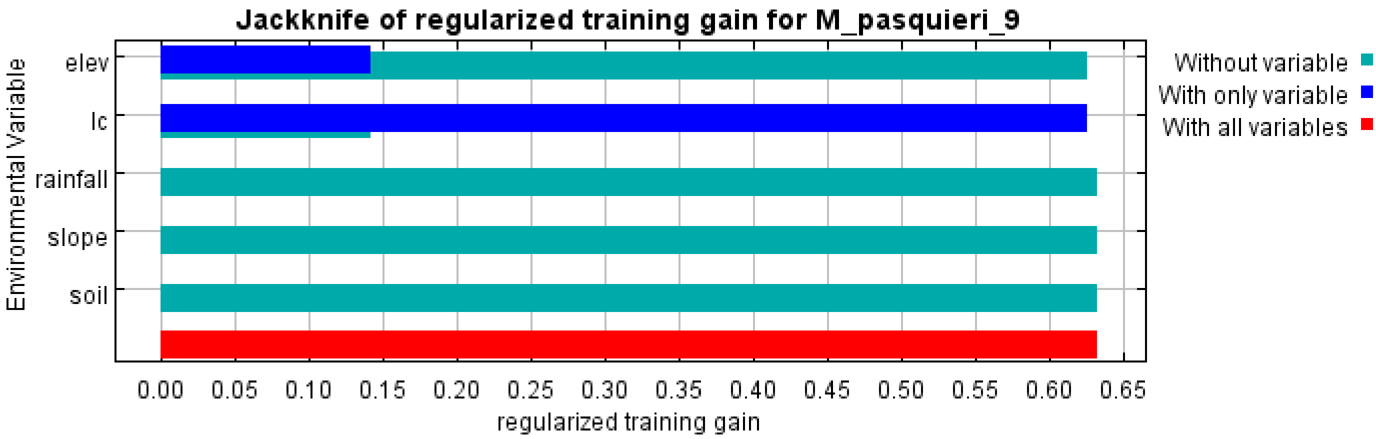

Figure.2. Jack-knife test evaluating the relative importance of variables on the distribution of *M. pasquieri*

The result shows that the suitable areas (0.6–1) for the distribution of *M. pasquieri* are those where the forest state is closed forests including evergreen brodleaved forests on soil mountain and evergreen brodleaved forests on rocky mountain. In terms of Altitude, areas of high suitability range from 500m to 1100m.

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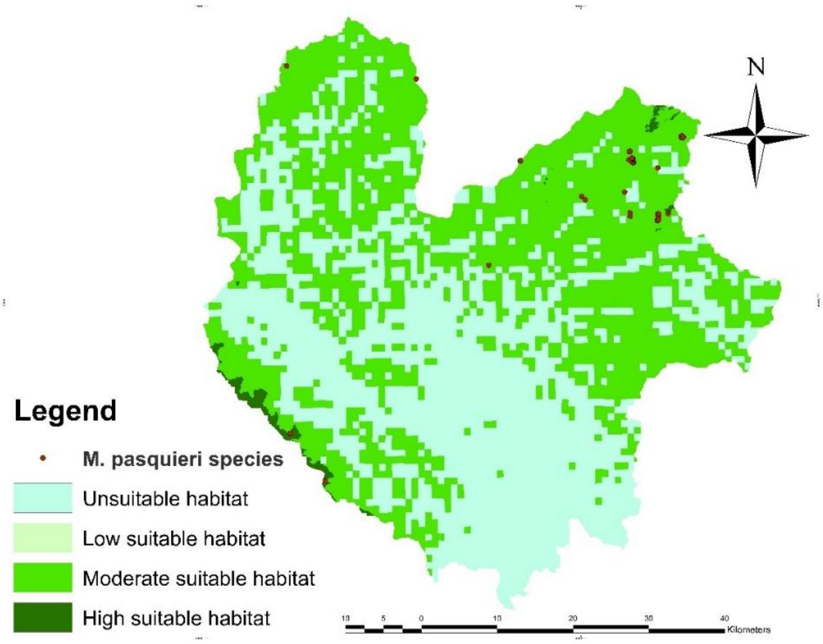

Figure. 3. Map showing suitable habitat for *M. pasquieri*

A map of suitable habitat for *M. pasquieri* is predicted and represented in Figure. 3. The predictive results were regrouped and plotted into three classes including high suitable habitat, moderate suitable habitat and unsuitable environment with areas of 2934,91ha (0.8%), 159593.1ha (43.3%), 189668ha (53.9%) respectively. Ther area of potential low suitable habitat is not recognized in the study area. The results suggest that *M. pasquieri* can be planted in suitable places, especially under the forest canopy of closed forests, which is a very important scientific basis for local government and stakeholder carry out in-situ and ex-situ conservation activities of species, contributing to biodiversity conservation and sustainable forest management.

The map of suitable habitat for *M. pasquieri* may be regarded as an important reference for determining promising locations for in-situ and ex-situ conservation efforts directed in Thai Nguyen province. In study area, major disturbances like illegall loging, deforestation and cultivation expansion which destroy the closed forests. In-situ and ex-situ conservation are effective approaches for protecting the species (Wang et al., 2017, Qu et al., 2018). In Vietnam, the loss of the remaining closed forest will threatens the survival of many species in the region, many national parks and nature reserves have been established for conservation of threatened plant species such as *M. pasquieri* species. Identification of *Madhuca pasquieri* species distribution is a necessary step to conserve existing individual species and is a scientific basis to select potential suitable habitat for growing the species, which significantly contributes to decision-making processes of the sustainable forest management.

The limited *M. pasquieri* population is endangered by disturbances and habitat loss. For the region's biodiversity to be conserved, it is crucial to identify the geographical distribution of vulnerable species (Khoi and Murayama, 2010). The composition and number of plant species were significantly affected, in particular, by cultivation within restricted forest regions. The prediction maps of suitable habitat for threatened and vulnerable species can assist in the long-term sustainable management of forests by assisting managers of protected areas in determining where conservation and forest management efforts should be concentrated.

CONCLUSION

Individuals of *M. pasquieri* are found in closed forests including evergreen broadleaved forest on soil mountain and rocky mountain. In six of the total 18 plots, *M. pasquieri* is present and the dominant species. The stem density ands stand variables increased by altitude gradient. Suitable distribution of *M. pasquieri* between 500m to 1100m and closed forests. Three suitable classes including high suitable habitat, moderate suitable habitat and unsuitable environment were identified, which provides a crucial scientific basic for the in-situ and ex-situ protection of species by local governments and stakeholders.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

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