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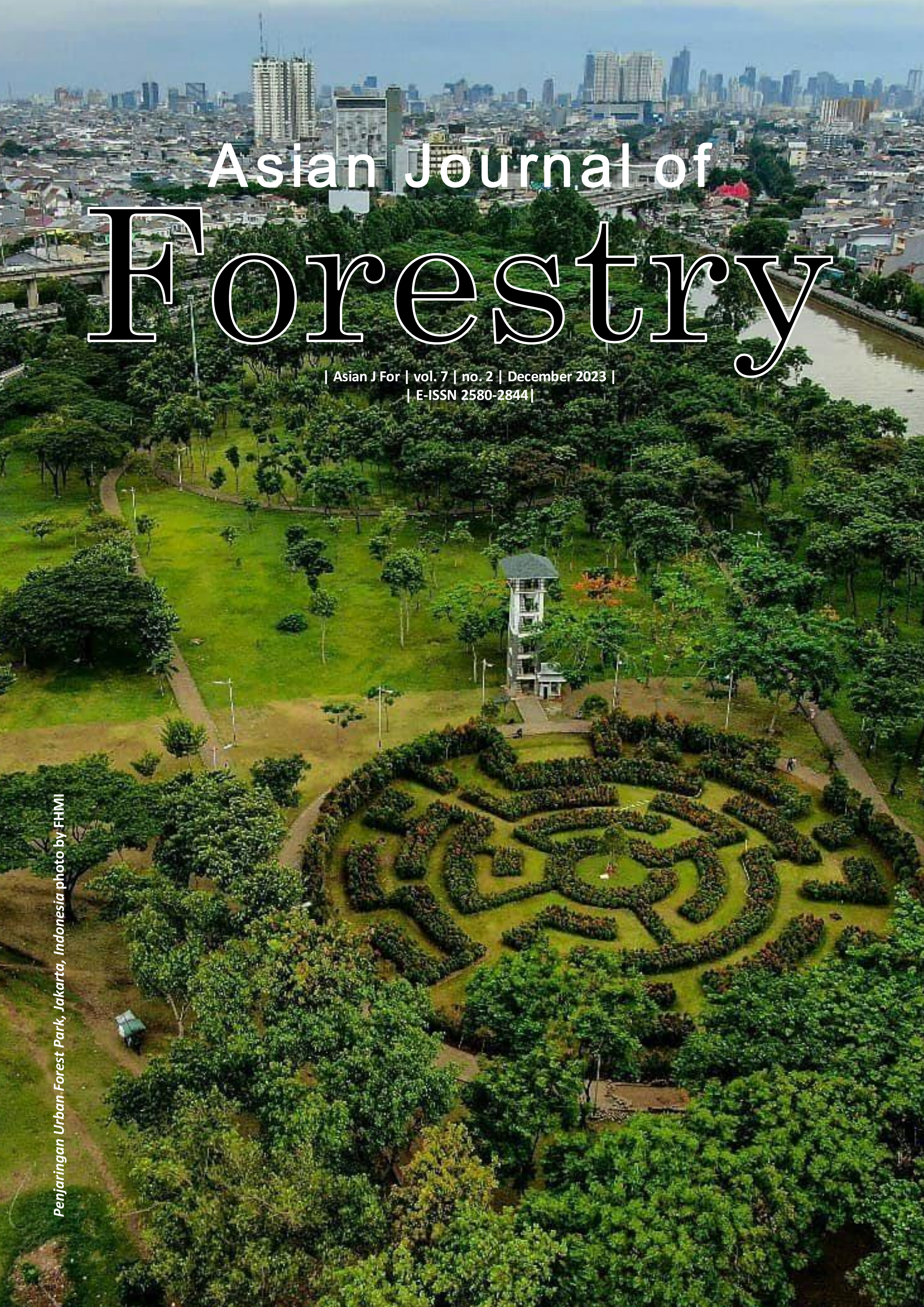

Penjaringan Urban Forest Park, Jakarta, Indonesia photo by FHMI

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Introduction is about 600 words, covering the aims of the research and provide an adequate background, avoiding a detailed literature survey or a summary of the results. **Materials and Methods** should emphasize on the procedures and data analysis. **Results and Discussion** should be written as a series of connecting sentences, however, for a manuscript with long discussion should be divided into subtitles. Thorough discussion represents the causal effect mainly explains why and how the results of the research were taken place, and do not only re-express the mentioned results in the form of sentences. **Concluding** sentence should be given at the end of the discussion. **Acknowledgements** are expressed in a brief; all sources of institutional, private and corporate financial support for the work must be fully acknowledged, and any potential conflicts of interest are noted.

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Journal:

Saharjo BH, Nurhayati AD. 2006. Domination and composition structure change at hemic peat natural regeneration following burning; a case study in Pelalawan, Riau Province. Biodiversitas 7: 154-158. DOI: 10.13057/biodiv/d070213.

The usage of "et al." in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in the book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from the internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. DOI: 10.1038/msb.2008.24. www.molecularsystembiology.com.

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Modeling understory shrub diversity related to environmental gradients using Akaike Information Criterion (AIC) in an urban forest in Jakarta, Indonesia

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Abstract. *Kirana GR, Wibowo AA, Nurdin E, Wardhana W, Basukriadi A. 2023. Modeling understory shrub diversity related to environmental gradients using Akaike Information Criterion (AIC) in an urban forest in Jakarta, Indonesia. Asian J For 7: 75-81.* The urban forest is one form of human-made ecosystem in urban environments. One of the most important components of urban forest ecosystem is understory shrubs. The sustainability of understory shrub community is supported by environmental variables suitable to its growth. Nonetheless, there has been limited information on how environmental variables contribute to the presence of shrubs in particular urban settings. This study aims to model the relationships between understory shrub diversity and environmental covariates, including air temperature, humidity, light intensity and wind speed, using the Akaike Information Criterion (AIC) in Srengseng Urban Forest, Jakarta, Indonesia. The result showed that there were 20 species and 12 families with the most common shrub species being *Rivina humilis,* followed by *Acalypha siamensis*, *Cordyline fruticosa*, *Syzigium paniculatum* and *Caesalpinia pulcherrima.* The average Shannon-Wiener diversity index was 0.671 (95% CI: 0.441, 0.901). The AIC models showed that understory shrub diversity was negatively correlated with humidity and positively correlated with light gradients with AIC values of 38.696 and 41.679, respectively. The diversity of understory shrubs in urban forests was significantly supported by sufficient light intensity (R^2 = 0.29) and limited by an increase in air humidity (R^2 =-0.44). The humidity and light intensity combinations also affect the understory shrub diversity (AIC = 38.900, R^2 = 0.256). The results of these studies can help urban forest managers manage urban forests if aiming for biodiversity conservation, especially understory shrub species.

Keywords: AIC, correlation, light intensity, *Rivina humilis,* urban

INTRODUCTION

The increasing trend of urbanization drives the development of cities across the world, resulting in the fast expansion of urban areas, which has an impact on many aspects of the ecosystem, including vegetation diversity (Theodorou et al. 2020). Despite the human-made ecosystem, urban areas are known to have distinct and unique vegetation diversities (Clemants and Moore 2003). Urban ecosystems, such as parks, gardens and urban forests, are extensively used for leisure and physical activity in urban settings to enhance human health and well-being. Through the planning and management of urban ecosystems, including social, cultural, and economic elements, they play a vital role in conserving world biodiversity.

Among the vegetation occurring in urban ecosystems, understory shrubs are an essential component which forms the lower layer of vegetation with various ecological and socio-cultural functions, from mitigating the risk of erosion to enhancing landscape beauty. Because of the small stature, understory shrubs in urban ecosystems can consist of relatively a large number of biodiversity within a limited urban space, compared to, for example, trees. Understory shrubs have also been widely utilized to assess and define community and ecosystem conservation status (Pyšek et al. 2012), as well as to understand future responses to climate change (Foxcroft et al. 2017).

The functionality and ecological integrity of understory shrubs in an urban ecosystem can be inferred from various parameters. Species diversity, vegetation structure and composition, and biological indices are most commonly used biological parameters crucial for species conservation at the community (Jeschke et al. 2014) and ecosystem levels (Tobin 2018). These parameters provide information regarding community dynamics, dispersion adaptation, and even the potential of understory shrubs to compete for establishment (Birch and Wachter 2011). Understanding the understory shrub spatial distribution patterns in urban forests through the application of biological indices including Shannon-Wiener diversity index (H') (Downey and Richardson 2016) is critical for the creation and execution of understory shrub management and conservation plans (Guiaşu and Tindale 2018). More recently, Akaike Information Criterion (AIC) has been used to model the correlations between environmental gradients with plant diversity. According to Barajas et al. (2020), environmental gradients, such as elevation and temperature, are collinear. Among the environmental gradient covariates, climatic heterogeneity has the strongest effect on plant species richness and elevational heterogeneity on plant species endemism.

Understanding the association between understory shrub diversity and environmental factors requires statistical analyses. In diversity-environmental factor relationships, researchers typically employ observational studies containing a high number of explanatory environmental factors to explain a particular pattern of diversity. Researchers have traditionally relied on hypothesis testing to include or exclude environmental factors in regression models to illustrate such associations, albeit the outcomes typically depend on the approach utilized based on forward, backward, and stepwise selection. Even though improved tools became available in the mid-1970s, they are still neglected in several domains, particularly in plant ecology studies. This is the case with the Akaike Information Criterion (AIC), which outperforms hypothesis-based approaches in model selection (i.e., variable selection). In comparison to current statistical analyses, AIC is straightforward to compute and understand, but more crucially, it gives a measure of the strength of evidence for each model that represents a reasonable biological hypothesis relative to the whole collection of models investigated for a given data set. Using this method, a weighted average of the estimate and standard error for any given environmental factor of interest over all models investigated can be computed. This method, known as model-averaging or multimodel inference, produces precise and robust estimates to elaborate the association between environmental factors with the understory shrub diversity in this study. As a result, plant ecology studies have used AIC to elaborate environmental gradient impacts on plant community including temperature (Parain et al. 2018) and total N, available K, available P, and soil organic matter (Hou et al. 2019)

In Jakarta Province, Indonesia, Srengseng Urban Forest is one of important urban ecosystems. The vegetation in this urban forest, particularly tree diversity, has been studied by Sari et al. (2022). Nonetheless, there is still a limited information about the understory shrub diversity and its environment determinant factors. This study aims to estimate the diversity of understory shrubs in the Srengseng Urban Forest in Jakarta Province. The novelty of this research lies in the use of AIC model to assess the link between environmental variables with the understory shrub diversity. The results of these efforts, as mentioned by English et al. (2022), can aid urban forest managers in supporting urban forest management and the conservation of biodiversity. Promoting understory shrub biodiversity in the Srengseng Urban Forest can be a potential conservation priority given the unique potential of the understory shrubs.

MATERIALS AND METHODS

Study area and period

The study was located at Srengseng Urban Forest in West Jakarta City, Jakarta Province, Indonesia (Figure 1). The geographical coordinates for Srengseng Urban Forest were 106.7616^0-106.7664^0 E and 6.2080^0-6.2136^0 S. This forest has an extent of 104,461 m^2 with elevation of 7 m above sea level. The monthly rainfall ranges 35.8 – 604.4 mm^3. The study was conducted from October to November 2022.

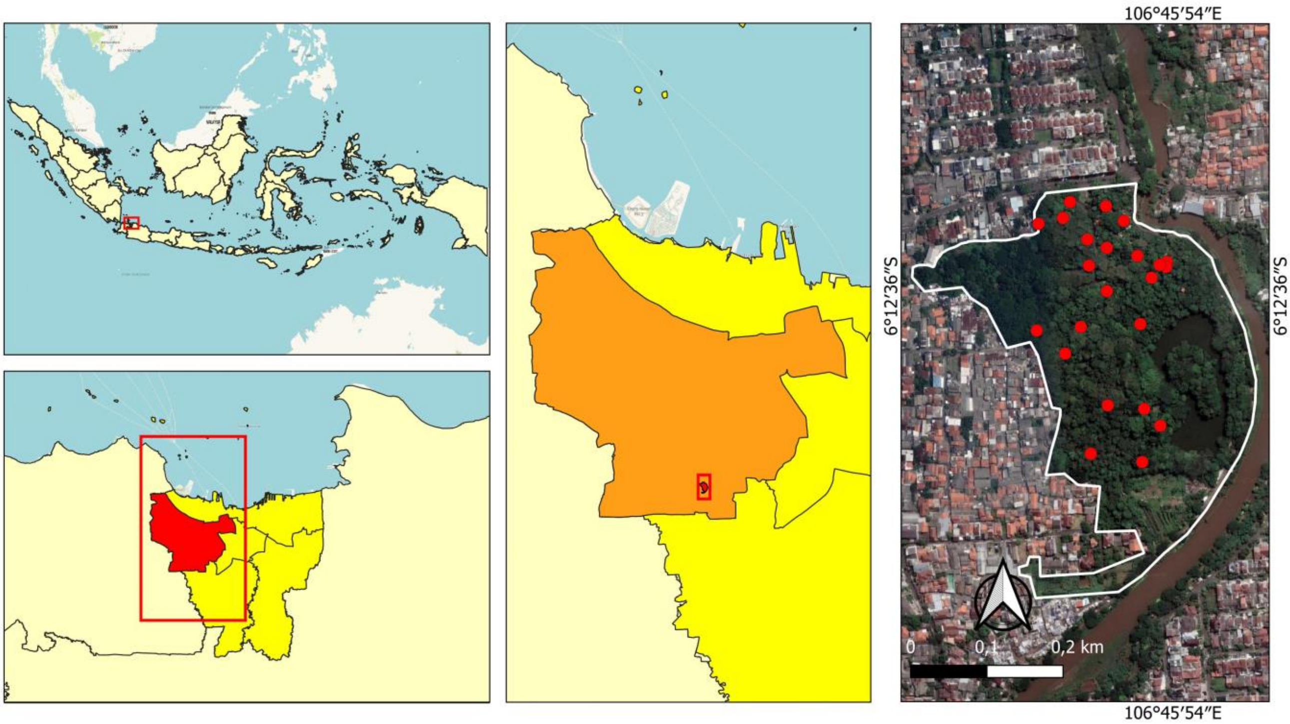

Figure 1. Map of study area and sampling points at Srengseng Urban Forest in West Jakarta City, Jakarta Province, Indonesia

Procedures

Understory shrub survey

The survey of understory shrub followed methods by Pourbabaei and Haghgooy (2012), Siregar et al. (2020), and Khan et al. (2021). An understory shrub survey at sampling locations was implemented using grids sized 2x2 m. Those sampling points were distributed randomly across the study area, resulting a total sampling points of 24. Within the sampling points, all shrub species were observed, collected, and counted for the number of individuals. The geocoordinates of sampling points were recorded using a Global Positioning System (GPS) Garmin Etrex handheld. The recorded geocoordinate data was then tabulated in a table.

Environmental variable survey

Environmental variables were measured directly in the field in the 24 sampling points. The environmental variables included air temperature (^{0}C), relative humidity/RH (%), wind (m/s), and light intensity (lux).

Data analysis

Data analysis included the calculation of diversity using Shannon-Wiener index and modeled using Akaike Information Criterion (AIC). Other quantifications of data were presented as histogram graphics and tabular presentations. Correlations were performed using Pearson correlation values as R^2.

Diversity analysis

The diversity of understory shrub (Matius et al. 2018) in Srengseng Urban Forest was indicated by Shannon-Wiener index (Bhat et al. 2014) and calculated using the equation as follows:

$$H' = \sum (p_i) (\log_2 p_i)$$

Where:

H' : Shannon-Wiener index of diversity;

p_i : proportion of the total sample belonging to i-th species

Understory shrub diversity model

The correlations between understory shrub diversity and environmental gradient covariates, including air temperature, humidity, light intensity and wind, were modeled using Akaike Information Criterion (AIC). The AIC was developed using linear regression with straight line fit equations of $y_i = b_0 + b_1x_i + \varepsilon_i$. The ε_i represents the residuals from the straight line fit. If the ε_i is considered to be independent and identically distributed (IID) Gaussian with zero mean, the model contains three parameters: b_0, b_1, and the Gaussian distributions' variance. As a result, we should use k = 3 when calculating the AIC value of this model. In general, the variance of the residuals' distributions should be counted as one of the parameters in any least squares model using IID Gaussian residuals. The measured parameters included in AIC, residual standard error, R-squared, F and P values. To build the model, environmental gradient covariates correlating with understory shrub diversity were included in the analysis to develop the model. The best model was selected based on the model that has the lowest AIC values. The AIC model tested was presented in Table 1 in which there were 4 models with 4 independent environmental variables as single model and 6 models involving combined independent environmental variables.

RESULTS AND DISCUSSION

Species and family diversities

In total, there were 828 individuals of understory shrub collected. Those individuals belong to 20 species and 12 families (Table 2). The most abundant species were in the following order of *Rivina humilis* > *Acalypha siamensis* > *Cordyline fruticosa* > *Syzigium paniculatum* > *Caesalpinia pulcherrima*. While, there were understory shrub species that were very rare in term of number of individuals in the Srengseng Urban Forest, including *Xhantostemon* sp., *Abelmoschus esculentus*, *Morus alba*, *Gardenia jasminoides*, and *Glycosmis pentaphyla*.

Families with the highest number of species found in the studied area were Solanaceae (4 species) > Myrtaceae and Euphorbiaceae (3 species) > Rubiaceae (2 species). While in term of number of individuals of each family, Euphorbiaceae and Petiveriaceae had the highest (Figure 2).

Understory shrub diversity and environmental variables

The results of understory shrub diversity measured as Shannon-Wiener diversity index and environmental variables are presented in Table 3. All measured values were presented with standard deviation and 95% confidence intervals. The Shannon-Wiener diversity index was 0.671. The air temperature was 25.886 ^{0}C since the research was conducted at rainy seasons while the humidity was quite high at 74.243%. The wind speed was low at 0.428 m/s because the urban forest was protected from the wind due to the presence of buildings nearby. While, the light intensity was measured at 20.313 due to the presences of tree canopy and cloud considering this research was implemented during the rainy season.

Table 1. Models used to test the relationships between shrub diversity and environmental gradient covariates

Variables		Model types	Model numbers
Dependent	Independent		
Diversity	Temperature	Single	1
Diversity	Humidity	Single	2
Diversity	Wind	Single	3
Diversity	Light intensity	Single	4
Diversity	Temperature, humidity	Combination	5
Diversity	Temperature, wind	Combination	6
Diversity	Temperature, light intensity	Combination	7
Diversity	Wind, humidity	Combination	8
Diversity	Wind, light intensity	Combination	9
Diversity	Humidity, light intensity	Combination	10

Table 2. Understory shrub species, families, and number of individuals in Srengseng Urban Forest, West Jakarta City, Jakarta Province

Species	Family	No. of ind.	Percent. (%)
Xhantostemon sp.	Myrtaceae	1	0.12
Syzigium paniculatum	Myrtaceae	110	13.28
Syzigium oleana	Myrtaceae	51	6.15
Glycosmis pentaphyla	Rutaceae	4	0.48
Capsicum annuum	Solanaceae	34	4.1
Capsicum chinense	Solanaceae	8	0.96
Solanum diphyllum	Solanaceae	17	2.05
Solanum bahamense	Solanaceae	5	0.6
Cordyline fruticosa	Asparagaceae	120	14.49
Exocaria cochinensis	Euphorbiaceae	26	3.14
Acalypha siamensis	Euphorbiaceae	126	15.12
Codiaeum variegatum	Euphorbiaceae	10	1.2
Tabernaemontana sp.	Apocynaceae	30	3.62
Abelmoschus esculentus	Malvaceae	1	0.12
Coffea canephora	Rubiaceae	10	1.2
Gardenia jasminoides	Rubiaceae	4	0.48
Morus alba	Moraceae	2	0.24
Caesalpinia pulcherrima	Fabaceae	84	10.14
Rivina humilis	Petiveriaceae	132	15.94
Pseuderanthenum carruthersi	Acanthaceae	53	6.4
Total		828	100

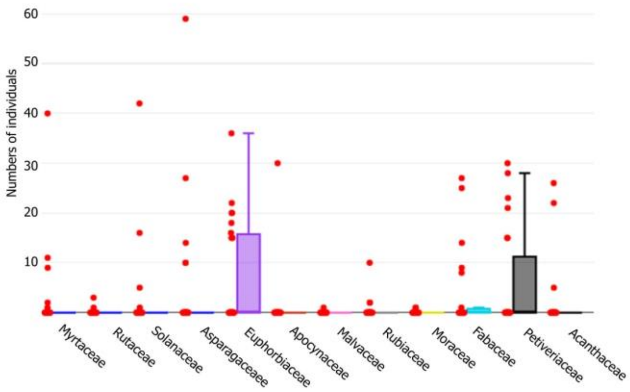

Figure 2. Boxplots of numbers of individuals based on understory shrub families in Srengseng Urban Forest, West Jakarta City, Jakarta Province. Red dots are the data points

Correlations between diversity and environmental variables

The correlations between understory shrub diversity and environmental variables were presented in Figure 3. There are positive and negative correlations. The positive correlations occurred between understory shrub diversity and temperature and light intensity. While the negative correlations were observed for humidity and wind. Figure 4 depicts the Pearson correlation values. The correlation value for understory shrub diversity and light intensity gradients was 0.29 while the value for diversity and humidity gradients was-0.44.

AIC models

Table 4 depicts the AIC values for each model. For the singular model involving only single environmental variable, the best model was shown for understory shrub diversity with humidity followed by diversity with light intensity with AIC values of 38.696 and 41.679, respectively. While for combination models, the combined humidity and light intensity had the most significant effect to the understory shrub diversity since it had the lowest AIC value of 38.900, followed by combined wind and light intensity with AIC value of 39.245. The other environmental covariates including temperature and wind speeds were considered have less contribution to the understory shrub diversity. This is because the AIC values for temperature and wind speed were 43.630 and 42.259 which are larger than humidity and light intensity covariates.

Table 3. Diversity index and environmental variables in Srengseng Urban Forest, West Jakarta City, Jakarta Province

Unit	Shannon-Wiener index (H')	Temperature (^{0}C)	Humidity (%RH)	Wind (m/s)	Light intensity (lux)
Mean	0.671	25.886	74.243	0.428	20.313
Standard deviation	0.561	0.895	4.303	0.124	1.329
95% Confidence intervals	0.441, 0.901	25.5, 26.3	72.5, 76	0.378, 0.479	19.8, 20.9

Table 4. AIC values of each model showing the correlations between Shannon-Wiener diversity index of understory shrub (H') and air temperature (Temp), humidity (Humid), wind (Wind), and light intensity (Lux) variables

Model	AIC	P	Residual standard error	R^2	F
H'~Temp	43.630	0.780	0.573	0.003	0.079
H'~Humid	38.696[a]	0.034	0.515	0.196	5.123
H'~Wind	42.259	0.254	0.557	0.061	1.374
H'~Lux	41.679[b]	0.177	0.55	0.084	1.946
H'~Temp+Humid	40.696	0.112	0.528	0.196	2.44
H'~Temp+Wind	44.202	0.517	0.57	0.063	0.680
H'~Temp+Lux	43.651	0.407	0.563	0.085	0.939
H'~Wind+Humid	39.295	0.061	0.512	0.243	3.221
H'~Wind+Lux	39.245[b]	0.059	0.511	0.245	3.249
H'~Lux+Humid	38.900[a]	0.051	0.508	0.256	3.449

Note: [a]the first best model, [b]the second best model,

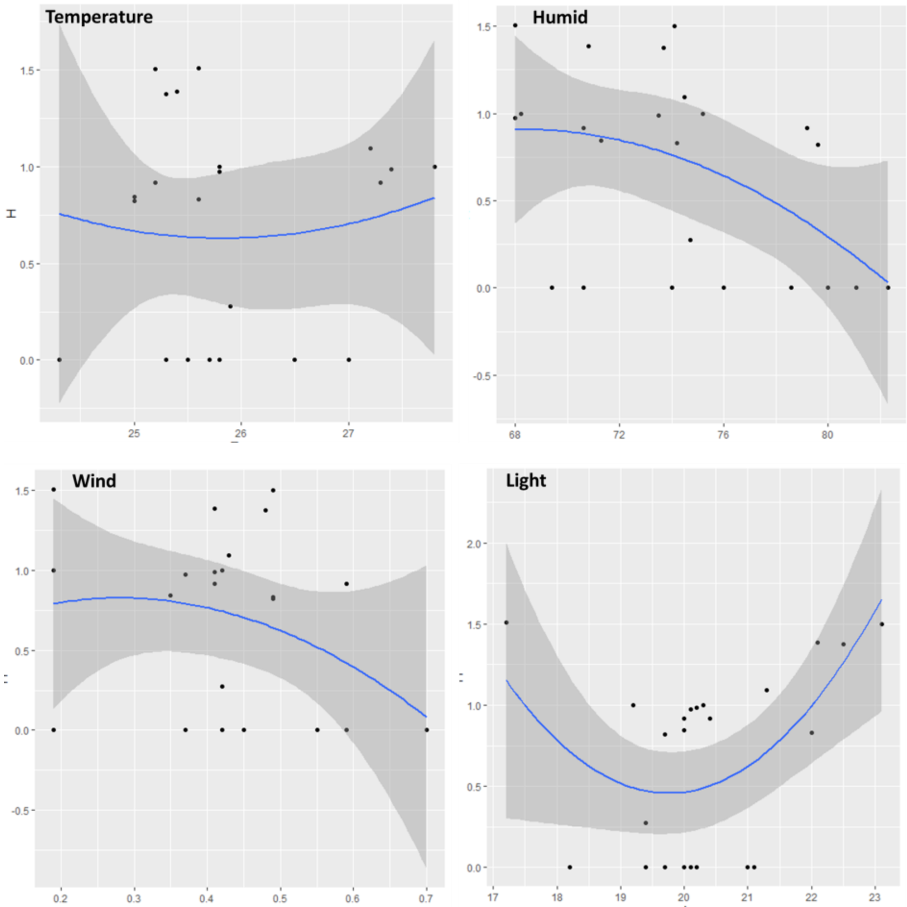

Figure 3. Correlations between Shannon-Wiener index (H') of understory shrub diversity (Y axis) and air temperature, humidity, wind, and light intensity (X axis). Note: Shaded grey shows 95% CI

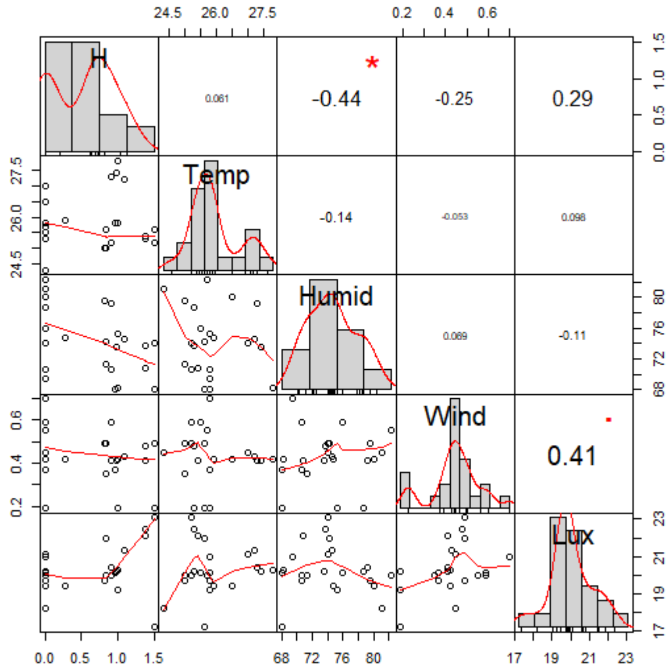

Figure 4. Pearson correlation values (R^2) between Shannon-Wiener diversity index (H’) of understory shrub and air temperature (Temp), humidity (Humid), wind (Wind), and light intensity (Lux) variables

Table 5. Comparisons of understory shrub diversities from other urban forests

Locations	H' value ranges	No. of species ranges	Sources
Metro Cebu, Philippines	0.774-2.775	11-85	Flores et al. (2020)
Cilegon, Banten	-	7-58	Muhlisin et al. (2021)
Cemoro Sewu, Magetan	-	5-9	Hidayah and Roziaty (2022)
Rajolelo, Bengkulu Tengah	1.059-1.282	21	Sihaloho and Pariyanto (2022).
Srengseng, Jakarta	0.000-1.508	20	This study

Discussion

The diversity of understory shrub species recorded in this study is compared with other urban forests at regional scales at South East Asia and national levels as presented in Table 5. It indicates that Srengseng Urban Forest has the potentials to support the biodiversity of particular understory shrub species. This study employed AIC to estimate and determine the environmental covariates that contribute mostly to the species diversity. This approach is in agreement with previous study by Monteiro et al. (2022) which used AIC and have confirmed that the near-infrared green ratio in spring obtained from Sentinel-2 satellite scene (NIR/green spring) and ratio of change between spring and summer scenes (NIR/green change) are predictor variables related negatively to species richness.

In this study, as confirmed by the AIC model, humidity was the limiting factor affecting the understory shrub diversity. According to Chia and Lim (2022), relative humidity of ambient air is a critical parameter for vegetation as it influences the water balance and photosynthesis process in the plants.

When relative humidity level is too high or there is a lack of air circulation, a plant cannot make water evaporate as a part of the transpiration process or draw nutrients from the soil (Gubanova and Paliy 2022). The humidity impacts the amount of water evaporating through the plant's leaves. When this occurs for a prolonged period, humid air directly contributes to problems such as foliar and root diseases, slow drying of the growing medium, plant stress, and slow growth. As a result, a plant might rot, causing a decline in number of individuals and decreasing diversity eventually (Chowdhury et al. 2021).

Among environmental covariates, light intensity was a primary supporting covariate for shrub community as indicated by significant AIC values. There was competition between tree stands and understory shrubs to obtain light. A large tree canopy may hinder the sunlight penetration that was required critically by shrub community below to carry out photosynthesis and grow. Result in this study was in agreement with a previous study by Dormann et al. (2020) which confirmed positive effect of light heterogeneity on plant species richness with R^2 values of 0.82. This explains a sharp increase in shrub diversity when light intensity was increasing as recorded in this study.

Wind speed was another environmental factor that significantly fit the model and limited shrub diversity. The negative value of Pearson correlation indicates that an increase in wind speed would cause a decline in shrub diversity. Our result is in agreement with a previous study by Bang et al. (2010), in which Wan et al. (2017) confirm that wind has a negative effect on the habitat distribution of invasive plants in tropical and subtropical moist biomes. Our study was an urban forest located in tropical moist biomes, and this explains the inverse association of shrub diversity with the wind gradients. The wind speed significantly affects the seed dispersal that determines the distribution of plants, including shrubs. For shrubs, regulated wind speed had a greater impact on short-distance shrub seed dispersal than on long-distance dispersal (Fu et al. 2021).

In conclusion, the diversity of understory shrub was supported significantly by sufficient light intensity and limited by the increase in humidity and air temperature. The combinations of humidity and light gradients will also affect the understory shrub diversity.

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Determining the causal factors affecting the survival of young plantations in Udayapur, Nepal

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Abstract. *Ayer S, Bhandari Y, Gautam A, Gautam J. 2023. Determining the causal factors affecting the survival of young plantations in Udayapur, Nepal. Asian J For 7: 82-88.* The plantation is a form of land management and rehabilitation to reverse land degradation, and the survival rate of seedlings is a critical factor for a successful plantation. This study aimed to investigate the survival rate of seedlings in ten plantation sites in Udayapur District, Nepal and identify the major causes of seedling mortality and stunted growth. Planting was done in April/May of 2020 and the total count of the seedlings was done in January/February 2021. Square plots of 5m x 5m each were used for inventory using systematic random sampling with 0.1% sampling intensity. Direct field observation and interviews with officials, *heralu*, and community forest users were conducted to identify reasons behind seedling mortality and stunted growth. The results showed that the overall survival rate of seedlings in the study site was 36.02%. However, site-wise survival rates varied significantly, with Paluwatar CF having the highest survival rate of 87.73% and Sunkoshi CF having the lowest survival rate of 10.76%. Species-wise survival rates also varied, with *Syzygium cumini* having the highest survival rate of 80% and *Cassia siamea* having the lowest survival rate of 5.55%. The major causes of seedling mortality were found to be soil composition and quality (38%), drought (27%), and plant diseases (12%). In addition, carelessness during handling, transportation, and after plantation (21%) were identified as the major causes of stunted growth. This study provides valuable insights into the factors affecting seedling survival and growth in a plantation site, which can be used to guide future plantation efforts. However, further research is needed to understand the complex interactions between different factors better and develop effective strategies for improving seedling survival and growth.

Keywords: Growth, mortality, plantation, seedlings, survival

INTRODUCTION

At the global, local, and regional levels, forests produce various ecosystem services, including providing food, lumber and medicinal plants, freshwater regulation, erosion control, carbon sequestration, ecotourism and so on (MEA 2005; Morgan et al. 2022; Nur et al. 2022). However, growing human population, conversion of forest areas to farmland, and progressive deterioration due to unsustainable agricultural practices have all contributed to worldwide land degradation (Singh et al. 2020; Morgan et al. 2022). Around 60% of the world's land surface is subjected to the degradation process (Pimentel 2006). In recent years, the restoration of degraded areas through plantations has been at the forefront of forest resource management (Abrha et al. 2020). Even though several studies have revealed low levels of biodiversity in plantations (Matthews et al. 2002; Barlow et al. 2007; Makino et al. 2007), other research suggests that plantations can play a significant role in biodiversity conservation, wood production, soil and water conservation, carbon sequestration (Rudel et al. 2005), restoration of forest species (Brockerhoff et al. 2008), provides critical habitat for endangered species (Pejchar et al. 2005; Arrieta and Suárez 2006) and also acts as wildlife corridors (Lindenmayer and Hobbs 2004). Therefore, various sectors like government, private individuals and communities plant seedlings to restore degraded landscapes through afforestation and reforestation programs and mitigate climate change's adverse effects (World Vision 2020).

Land degradation due to deforestation and forest degradation are serious environmental problems affecting Nepal's economy and natural ecosystem, mostly in Terai and Chure Region (Chaudhary et al. 2016; Chalise et al. 2019). More than 28% (3.262 million ha) of land area of Nepal is considered to be degraded (MoEST 2008). Population growth, illegal harvesting, unsustainable harvesting, encroachment, overgrazing, and infrastructure development are some major drivers of deforestation and forest degradation in Nepal, resulting in unpredicted erosion, landslide, lowland flooding and sedimentation (Jha et al. 2013; Chaudhary et al. 2016). Therefore, afforestation and reforestation programs have been prioritized in Nepal's Terai and Chure Region (DFRS 2015). Large-scale plantations in the hilly regions of Nepal were initiated in the early 1980s (Gilmour et al. 1990) to restore the forest. Terai Community Forestry Program has done extensive plantation in Terai Regions using local plant species Sissoo (*Dalbergia sissoo*) and other fast-growing exotic species such as Teak (*Tectona grandis*), Eucalyptus (*Eucalyptus camaldulensis*), Poplar (*Populus deltoides*) etc in the late eighty's (MoFSC 2015). However, poor survival rate is usually recorded due to different factors such as immature seedlings, harsh conditions of plantation sites and improper species-site selection (Paudel and Acharya 2018). Therefore, identifying these factors through survival count is important so that actions can be directed for either enrichment or replacement plantation based on the survival status (World Vision 2020).

Seedling's survival count means checking the existence of planted seedlings in the field, whether they are alive, dead or missed (World Vision 2020). The seedlings survival count guideline by World Vision (2020) states that if the survival rate is above 80%, the planted seedlings are performing well and only require protection and other management actions for fast growth and better quality, while if the survival rate is below 80%, replanting is required. Mortality and stunted growth of seedlings in plantation sites are common problems that can greatly affect the success of reforestation efforts (Fargione et al. 2021). The loss of seedlings can be costly and time-consuming, requiring additional resources and effort to replant and maintain the site (Le et al. 2012). Furthermore, stunted growth can lead to decreased productivity, reducing the overall yield of the plantation (Bhadouria et al. 2016). Therefore, it is important to identify the factors that contribute to these issues and develop effective strategies to prevent or mitigate them. Every year, millions of seedlings have been planted in Nepal, and a huge budget is spent on seedling development and plantation (Paudel and Acharya 2018). For the fiscal year 2016/17, the Government of Nepal allocated around NRs. 170 million (1.29 million USD) to the Departments of Forests to produce around 23 million seedlings (DoF 2016). Nevertheless, in many cases, the seedling status is not assessed, so the need for replanting is not realized, resulting in the failure of plantation programs (Paudel and Acharya 2018).

Very few studies (e.g., Paudel and Acharya 2018; Khanal et al. 2021) have been done to assess survival status of plantations. Furthermore, assessment and comparison of survival status of seedlings among various plantation sites are still lacking. This paper thus aims to assess survival status and causes of mortality and stunted growth of seedlings in various plantation sites in Katari Municipality of Udayapur District. The information gathered from this study will provide valuable insights for the forestry sector to understand the causes of mortality better and develop strategies to improve planting success in the future. Furthermore, by identifying the challenges faced in plantation sites and suggesting ways to overcome them, this study may contribute to sustainable forestry development in Udayapur District.

MATERIALS AND METHODS

Study area

The study areas lies in Katari and Tapli municipality (26° 57′ 0″ N, 86° 22′ 12″ E) of Udayapur District in eastern Nepal Figure 1).

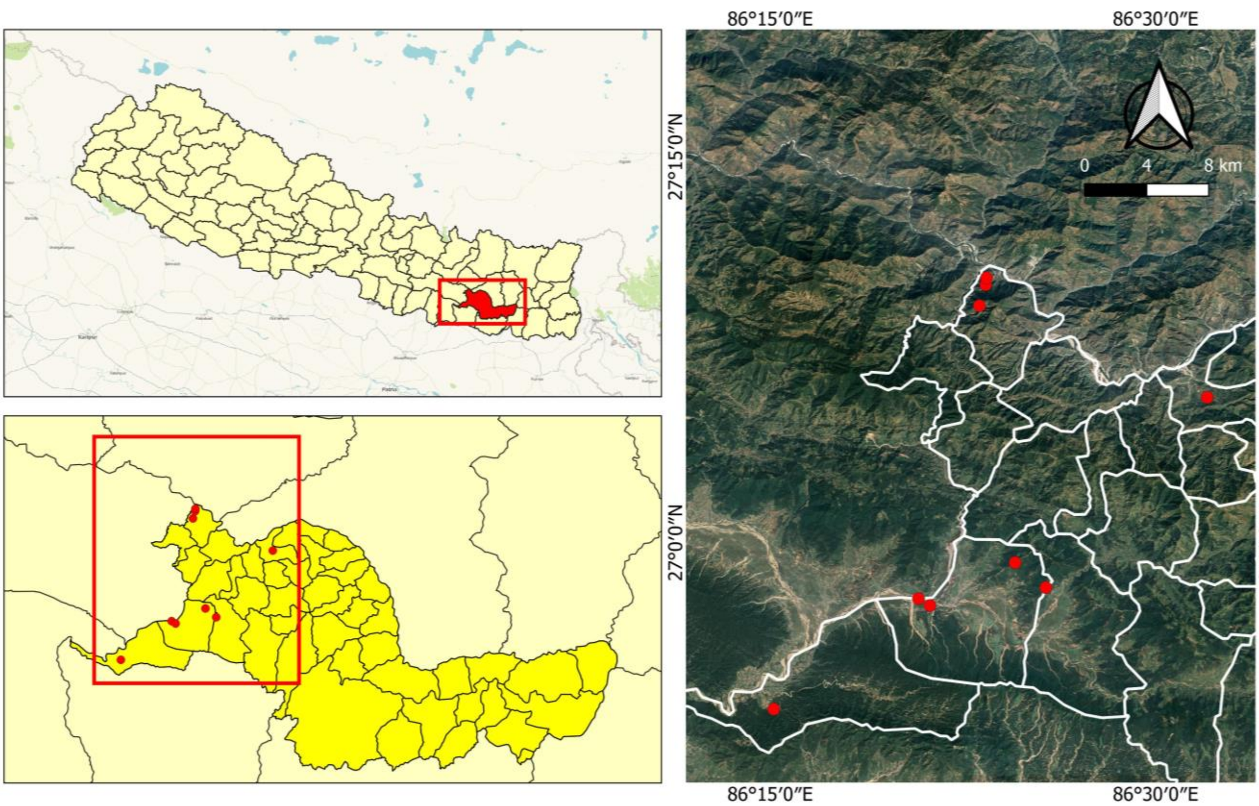

Figure 1. Map of study area and location of the sampled plantations in Udayapur District, Nepal

Table 1. Details about plantation sites in Udayapur District, Nepal examined in this study

Name of plantation site	Elevation (m asl.)	Location	Area (ha)	No. of sample plots	Species planted
Kalikhadi CFUG	210	Katari-5	4	5	Teak, Khair, Masala, Khamari, Siso, Amala
Lekhani (Bare land)	390	Katari-14	30	12	Teak, Khair, Masala, Salla
Kalikhola CFUG	220	Katari-1	4.5	5	Teak, Khair, Mahogony, Amala
Paluwatar CFUG	180	Katari-3	15	6	Teak, Khair, Masala, Khamari, Siso, Amala, Gulmohar, Jamun, Khanyu
Baliya khahare Tawakhola	180	Katari-3	5	5	Khair, Siso, Amala
Sisaghari CFUG	200	Katari-5	10	5	Katahar, Khair, Masala, Khamari, Amala, Salla, Casia simea
Solubhir CFUG	325	Katari-14	59.3	23	Teak, Khair, Masala, Khamari, Siso, Amala, Ambak, Mahogony, Kimbu, Thingure Salla, Laligurans, Ipil Ipil
Solubhir Bhangbhari CFUG	320	Katari-14	14.24	6	Masala, Khamari, Mahogony, Siso, Ipil ipil, Khair
Sunkoshi CFUG	350	Katari-14	14	6	Masala, Ambak, Khamari, Khair, Salla, Mahagony, Amala
Tapli CFUG	390	Tapli-5	15	6	Ambak, Masala, Siso, Mahogony, Khair

Note: Amala: *Phyllanthus emblica,* Casia simea: *Cassia siamea,* Ambak: *Psidium guajava,* Gulmohar: *Delonix regia,* Ipil ipil: *Leucaena leucocephala,* Jamun: *Syzygium cumini,* Katahar: *Artocarpus heterophyllu*s, Khair: *Senegalia catechu,* Khamari: *Gmelina arborea,* Khanyu: *Ficus semicordata*, Kimbu: *Morus alba*, Laligurans: *Rhododendron arboreum,* Mahogony: *Swietenia mahagoni,* Masala: *Eucalyptus camaldulensis*, Salla: *Pinus roxburghii,* Siso: *Dalbergia sissoo*, Teak: *Tectona grandis*, Thingure Salla: *Tsuga dumosa*

The study area encompasses a broad range of elevations (300-3000 m asl). Due to the unique geographical features and various climatic conditions (from lower tropical to temperate), the area is endowed with excellent habitats for diverse flora and fauna. Different topography, geology, and altitude have established three distinct physiographic zones i.e., Inner Terai, Churia, and Mahabharat range. The forest types include tropical evergreen forests to Alder forests. More than 80% area is in high-temperature zone. The rest of the areas have temperate climates. Most of this region is extremely sloped in the northern part of Chure/Siwalik. The vegetation in the study area includes *Shorea robusta, Terminalia chebula, Adina cordifolia, Acacia catechu, Terminalia bellirica, Bombax ceiba, D. sissoo, Schima wallichii, Castanopsis indica, Pinus roxburghii, Alnus nepalensis, Rhododendron arboreum, Lyonia ovalifolia, Myrica esculenta*, etc. (Lamichhane and Karna 2009). The study area has tropical and subtropical climate with an annual minimum temperature of 16.8°C, and annual maximum temperature of 28.1°C and annual rainfall is about 1349.2 mm (DoHM 2017).

The plantation sites examined in this study were situated only at an elevation range of 180-390 m asl (Figure 1). These sites were selected based on accessibility and the availability of data. While the selected sites may not represent the entire plantation area of the study region, they do provide valuable insights into the factors affecting seedling survival in the low to mid-elevation range. Details of plantation sites are presented in Table 1.

Data collection

From the District Forest Office's records, it was possible to identify the plantations that were carried out in 9 community forests and 1 bare land of national forest site in 2020 (Table 1). Pits of standard size of 30x30x30 cm were prepared in April/May of 2020, and plantation was completed in June/July of that year. The District Forest Office, Udayapur (Triveni) provided one-year old seedlings that were planted. About 1600 seedlings were planted per hectare with spacing of 2.5m x 2.5m according to Division Forest Officials.

The assessment of the survival of the planted seedlings was addressed with concern of community forest members. In January/February 2021, a total seedling count was performed with the help of the community forest user groups. For this research work, the community forestry inventory guideline 2061 (DoF 2016) was followed. To evaluate the regeneration status, systematic random sampling with a 0.1% sample size was used because the site exclusively consisted of planted seedlings. The sample plot and map were created using Arc Map 10.8. The sample plots were located by Garmin GPSMAP 60CSx with accuracy of 3 meters. In each plantation site, minimum of five square sample plots of 5m x 5m were established, and an inventory was completed.

To gather information on possible reason behind mortality and stunted growth of seedlings, we conducted discussions with officials and interactions with local users and *heralu* (plantation site guards). We also spoke with officials responsible for plantation management to gain insights into their experiences and observations on seedling mortality. Additionally, we held discussions with local users who had practical knowledge of the area to gain further insights on the potential causes of mortality. We selected these causes based on their frequency of occurrence and potential impact on seedling survival for data analysis.

Some additional causes of mortality identified in the field observations were not represented in figures in the result section as they were not mentioned by the majority of respondents in the survey. However, we included the additional causes identified through field observations in the Result and Discussion sections to provide a more comprehensive understanding of the factors affecting seedling survival in the study area.

Data analysis

The data were pooled and analyzed with Ms-Excel 2013 Version 15.0. The total seedlings planted was estimated by multiplying the total plantation area of CFs with 1600 seedlings. Survival percentage was calculated by simple formulae, calculating the total plant survived in the 5x5m area and calculating the total number of plants planted in the same area (Khanal et al. 2021). Similarly, total survived seedlings in each plantation site was calculated by multiplying survival rate with total planted seedlings in each plantation site.

Survival rate (%) = (total plants survived in the sampled plots/total plants planted in the sampled plots) x 100%.

Total survived seedlings in each plantation site = survival rate × total planted seedlings in each plantation site

RESULTS AND DISCUSSION

Site-wise survival rate of plantation

According to DFO officials, a total of 253,664 seedlings were planted in 10 CFs of the study area. Among the total planted seedlings, only 36.02% (n = 91,375) were found to survived in the area during our study. It should be noted that this survival rate is based on the sample that we studied, not the entire population of planted seedlings. The highest number of seedlings were planted in Solubhir CF (n = 94,880). However, Paluwatar CF has highest survival rate (87.73%), while Sunkoshi CF has lowest survival rate (10.76%) (Table 2).

Species-wise survival rate of plantation

A total of 18 species of plants were used for plantation in 10 different locations. Among which, *Senegalia catechu* was planted in the highest number (n = 46,200), followed by *E. camaldulensis* (n = 34,100), and so on, while *Ficus semicordata* was planted in lowest quantity (n = 600). The survival rate was highest for *Syzygium cumini* (80%) and lowest for *Cassia siamea* (5.55%) (Table 3). The highest number of species were planted in Solubhir CF (n = 13).

Causes of stunted growth of planted seedlings

We noted that the carelessness during handling, transportation, and after plantation were the major causes of stunted growth of seedlings (response by 21% of the respondent). While, 18% of respondents had no idea about the causes (Figure 3). In the field, authors also observed that carelessness during species selection, lack of care of planted seedlings, no weeding, drought, and soil composition as the causes for stunted growth.

Causes of seedlings mortality

The result showed that majority of the respondent (38%) mentioned soil composition and quality as the main cause of seedlings mortality in the site, followed by drought (27%), plant diseases (12%), and so on (Figure 2). Moreover, in the field we observed the inappropriate pit size and wrong species selection, which might be the possible causes of mortality.

Discussion

The purpose of this study was to assess the survival rate and causes of mortality of seedlings planted in different sites and species in Udayapur District, Nepal. A total of 253,664 seedlings were planted, and the survival and mortality rate was evaluated after a certain period of time. The results of this study indicate that the overall survival rate of seedlings planted in the study area was only 36.02% (n = 91,375) which was quite lower than the findings of Paudel and Acharya (2018) and Khanal et al. (2021).

Table 2. Site-wise survival rate of the seedlings planted in ten sites in Udayapur District, Nepal

Name of plantation site	Total planted seedlings	Survival rate (%)	Total survived seedlings
Kalikhadi CF	6400	52.78	3378
Lekhani Bare Land	48,000	25.52	12,250
Kalikhola CF	4800	75.02	3601
Paluwatar CF	24,000	87.73	21,056
Baliya Tawakhola CF	8000	74.15	5932
Sisaghari CF	16,000	27.08	4332
Solubhir CF	94,880	32.80	31,119
Solubhir Bhangbhari CF	22,784	25.30	5766
Sunkoshi CF	22,400	10.76	2410
Tapli CF	6400	23.93	1531
Total	253,664	36.02	91,375

Table 3. Species-wise survival rate of the planted seedling across ten sites in Udayapur District, Nepal

Species name	Planted	Survived	Survival rate (%)	Mortality rate (%)
Artocarpus heterophyllus	2000	222	11.10	88.90
Cassia siamea	2000	111	5.55	94.45
Dalbergia sissoo	23,200	12,044	51.91	48.09
Delonix regia	500	200	40.00	60.00
Eucalyptus camaldulensis	34,100	9918	29.08	70.92
Ficus semicordata	600	456	76.00	24.00
Gmelina arborea	16,300	4290	26.32	73.68
Leucaena leucocephala	11,000	4207	38.24	61.76
Morus alba	7000	484	6.91	93.09
Phyllanthus emblica	16,200	3882	22.60	77.40
Pinus roxburghii	26,200	13,831	52.79	47.21
Psidium guajava	12,200	1904	15.60	84.40
Rhododendron arboreum	7000	4599	65.70	34.30
Senegalia catechu	46,200	20,958	41.03	58.97
Swietenia macrophylla	19,164	7314	38.16	61.84
Syzygium cumini	1000	800	80.00	20.00
Tectona grandis	22,000	3133	14.24	85.76
Tsuga dumosa	7000	3022	43.17	56.83
Total	253,664	91,375	36.02	63.98

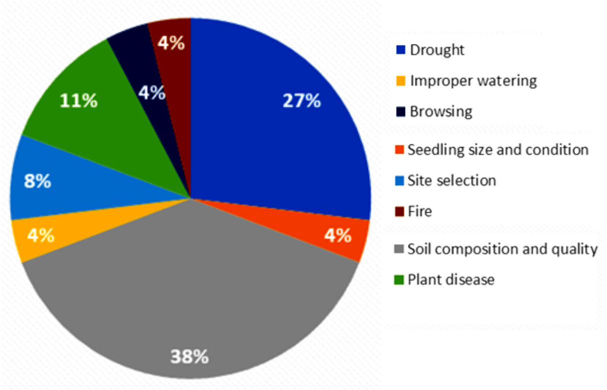

Figure 2. Causes of mortality of the planted seedling across ten sites in Udayapur District, Nepal

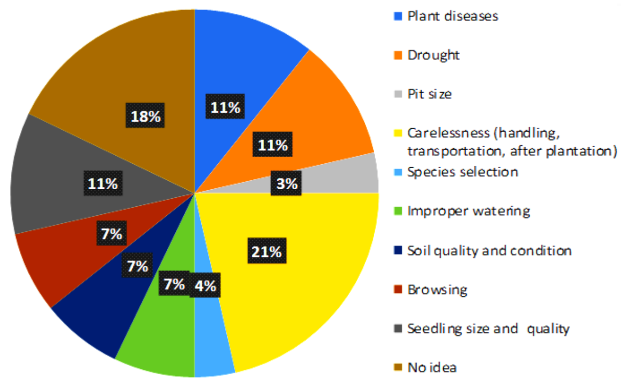

Figure 3. Causes of stunted growth of the planted seedling across ten sites in Udayapur District, Nepal

The differences in study locations and tree species planted may have contributed to the variation in survival rates. The study by Paudel and Acharya (2018) was conducted in Parbat District and assessed survival rate of 11 tree species which were different than species planted in our study area. Similarly, study by Khanal et al. (2021) was conducted in Tanahun district and focused on *Cinnamomum* plantation. Analyzing the survival rates of each plantation site in our study, it was found that some sites have survival rates above the desired ratio of 80%, while others fall below it. For instance, Paluwatar CF had a survival rate of 87.73%, indicating that replacement planting may not be necessary in that area. However, Sunkoshi CF had a survival rate of only 10.76%, indicating a need for replacement planting in that site. Thus, proper land use involving the replacement of dead or unviable seedlings with new healthy seedlings is necessary to improve the stock and maintain healthy plantations (World Vision 2020).

Site-specific conditions play a significant role in seedling survival rates (Duan and Abduwali 2021). In our study, site-wise survival rate varied significantly, with Paluwatar CF having the highest survival rate of 87.73% and Sunkoshi CF having the lowest survival rate of 10.76%. Inappropriate species selection according to site conditions and lack of care of planted seedlings may have influenced the survival rates of these plantation sites. Similarly, a study by Abrha et al. (2020) reported average seedling survival rate of 50% due to poor management of seedlings after planting. In addition, previous studies (Wang et al. 2017; Kambo and Danby 2018; Duan and Abduwali 2021) had reported that local site conditions can have a significant impact on seedling survival. Therefore, we emphasize the importance of considering factors such as soil quality and composition, water availability, temperature, topography, and exposure to wind when planning future plantation works to improve the survival rates of seedlings.

Species-wise survival rate also varied, with *S. cumini* having the highest survival rate of 80% and *C. siamea* having the lowest survival rate of 5.55%. While different species have different growth requirements that can impact survival rates (Duan and Abduwali 2021), it is also possible that seedlings of these species were planted in sites with inappropriate soil conditions or other unsuitable environmental factors. The selection of appropriate tree species that can tolerate or thrive under the prevailing climatic conditions is critical for plantation success (Rudolf et al., 2020; Masaba and Etemesi 2021). For example, some species may require specific temperatures, precipitation levels, or soil pH levels to grow and survive (Parlucha et al. 2017). Therefore, it is important to carefully consider the species-specific requirements when choosing species for planting, as it can significantly affect seedling survival and growth.

The surveyed respondents identified soil composition and quality (38%), drought (27%), and plant diseases (12%) as the major causes of seedling mortality. In a study by Eshetie et al. (2020), 78.49 % of respondents found that planting seedling in infertile soil as abiotic factor affecting seedling survival. Similarly, research studies such as Chen et al. (2010) and Record et al. (2016) have shown that soil nutrients are a crucial factor in tree seedling survival. Specifically, soil properties such as total phosphorus and total nitrogen concentrations have been found to positively affect seedling survival rates (Wang et al., 2012). In addition to these nutrients, other soil properties such as soil organic carbon and soil moisture have also been identified as important factors for seedling survival, as indicated by studies such as Pu et al. (2017). Therefore, soil quality can impact the availability of essential nutrients and water for seedlings, which can have a direct impact on their survival and growth rates. Seedling growth can also be negatively affected by drought stress, which can cause a decrease in shoot length, leaf size, leaf area, and dry leaf weight (Pettigrew 2004). Furthermore, increased plant water stress has been associated with a decline in photosynthesis and chlorophyll contents (Chastain et al. 2016). In addition, drought stress can indirectly lead to seedling mortality by exacerbating other stresses such as salinity, pathogen attack, and heat (Ahluwalia et al. 2021). Similarly, several plant pathogens, including fungi, bacteria, and viruses, can infect seedlings and cause various symptoms, such as wilting, discoloration, and necrosis (Nazarov et al. 2020).

These symptoms can weaken or kill the seedlings, depending on the severity of the infection and the plant's resistance to the pathogen. Additionally, it can also exacerbate the effects of other stresses, such as drought or nutrient deficiencies, and further contribute to seedling mortality (Seleiman et al. 2021). Field observations by authors further indicated that pit size and wrong species selection according to site condition were also possible causes. This suggest that multiple factors can contribute to seedling mortality in the study area. While the respondents' perception may not entirely match the field observation, both perspectives provide valuable insights into the factors that contribute to seedling mortality. Our finding however was contrasted with findings of Paudel and Acharya (2018) where small size and unhealthy seedlings and careless in transportation and handling of seedlings caused 52% mortality. This could be due to differences in the seedling quality, growing conditions, or other factors specific to their study area (Masaba and Etemesi 2021).

In our study, high percentage of respondents (21%) identified carelessness during handling, transportation, and after plantation as the cause of stunted growth of seedlings. This might be due to physical damage to seedlings such as broken stems, damaged roots, or bent leaves caused by carelessness. These physical injuries can impede the seedling's ability to absorb water and nutrients from the soil, leading to stunted growth (Kennelly et al. 2012). In addition, mishandling during transportation and planting can result in improper planting depth or inadequate soil contact, both of which can limit root growth and cause stunted growth (Elefritz et al. 1998). Furthermore, improper handling of seedlings can expose them to stressors like extreme temperatures or sunlight by damaging their leaves, stems, or roots, which can also impact their growth and survival (Van Der Zanden 2008). This highlights the need for increased attention to these stages of the plantation process. It also emphasizes the importance of providing adequate training and education to those involved in plantation activities, so that seedlings can be handled and planted correctly. The field observations further indicate that other factors such as species selection, drought, soil composition, and no weeding can also play a role in stunted growth of planted seedling.

In conclusion, this study aimed to assess the survival rate and causes of mortality of seedlings in a different plantation sites of study area. The results showed that the site-wise survival rate varied significantly, with Paluwatar CF (87.73%) having the highest survival rate and Sunkoshi CF (10.76%) having the lowest. The species-wise survival rate also varied, with *S. cumini* (80%) having the highest survival rate and *C. siamea* (5.5%) having the lowest. The study also identified soil composition and quality as the main cause of seedlings mortality and carelessness during handling, transportation, and after plantation as the major cause of stunted growth. These results highlight the importance of considering local site conditions and carefully selecting species when planning future plantation works, as well as ensuring proper care of seedlings after planting to promote growth and survival. In light of these findings, it is recommended to implement best practices for seedling handling, transportation, and after plantation care to improve the survival rate and growth of seedlings in future plantation efforts. Our study provides valuable insights into the factors affecting seedling survival in low to mid-elevation plantation sites in the study region. However, it is important to note that the findings of this study may not be applicable to the entire plantation area of the study region due to the limited elevation range of the examined sites. Further research is needed to investigate the factors affecting seedling survival in higher elevation plantation sites. Similarly, further research on various biotic and abiotic factors that influences survival and mortality rate of seedlings in plantation sites is recommended to better understand the complex interactions between different factors and to develop effective strategies for improving seedling survival and growth.

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Diversity of arbuscular mycorrhizal fungi in the rhizosphere of *Angelica glauca* and *Valeriana jatamansi* in NW Himalaya, India

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Abstract. *Tapwal A, Kumar A, Sharma S. 2023. Diversity of arbuscular mycorrhizal fungi in the rhizosphere of* Angelica glauca *and* Valeriana jatamansi *in NW Himalaya, India. Asian J For 7: 89-98.* The diverse mycorrhizal association helps to conserve plant biodiversity, ecosystem function, and the accumulation of pharmaceutically important compounds in medicinal plants. Climate change may have an impact on plant diversity as well as on associated microbiota. The mycorrhizal association and diversity of Arbuscular Mycorrhizal Fungi (AMF) in the rhizosphere of two important medicinal plants of the North-Western (NW) Himalayas were explored during different seasons in two distant locations. The endomycorrhizal association in *Angelica glauca* Edgew. and *Valeriana jatamansi* Jones was confirmed by morpho-anatomical characterization of the roots. Microsclerotia, vesicles, and intracellular hyphal coils were found in the roots of both medicinal plant species. The research revealed 24 AMF representing eight genera in the rhizosphere of *A. glauca* and 19 AMF representing seven genera in the rhizosphere of *V. jatamansi*. The AMF colonization varied between 55.63-86.34% in the roots of *A. glauca* and 55.23-78.74% in *V. jatamansi*. The Spore Density (SD) in the rhizosphere soil of selected medicinal plants was highest during the winter season. The rhizosphere soil of *A. glauca* exhibited a rich diversity of AM fungi during the rainy season. On the other hand, in various seasons and locations, the maximum diversity of AM fungi was observed during the summer season in *V. jatamansi*. The genera–*Glomus* and *Acaulospora* had the highest species in both study sites.

Keywords: AMF, *Angelica glauca*, mycorrhiza, Northwest Himalaya, *Valeriana jatamansi*

INTRODUCTION

India is endowed with a rich wealth of medicinal plants. Although various medicinal plants are found throughout the country, Indian Himalayan Region is highly significant concerning varietal richness. *Angelica glauca* Edgew and *Valeriana jatamansi* Jones (Indian valerian) are two valuable medicinal plants in the family Apiaceae and Caprifoliaceae, respectively. These families were native to the North-Western (NW) Himalayas and are in high demand in the local market and the herbal and pharmaceutical sectors. *A. glauca* is found in the Himalayan northern temperate to alpine zones in the altitudinal range of 2,000-4,000 masl (Butola and Badola 2004). *V. jatamansi* is found in the North-Western Himalayan region at elevations of 3,000 masl but also reported between 1,500-1,800 meters above sea level (masl) from Khasi and Jaintia Hills (Bhardwaj et al. 2021).

Angelic acid, valeric acid, and Angeline resin are bitter furocoumarins found in the roots of *A. glauca* (Blake 2004; Butola and Vashistha 2013). They treat dyspepsia, infantile atrophy, gastric disorders, dysentery, constipation, menorrhagia, rinderpest, etc. (Joshi 2016). The essential oil of *A. glauca* has antibacterial, antifungal, and radical scavenging activity (Irshad et al. 2011). The *V. jatamansi* also contains valepotriates, non-glycosidic iridoid esters, monoterpenoids (Baby et al. 2005), and acetoxy isovaleric acids, which improve the therapeutic potential of the plant (Kaur et al. 1999). This medicinal herb is also known to have antihypertensive, anticancer, antidyspeptic, analgesic, antidepressant, cytotoxic, antimicrobial, antifungal, antibacterial, anticonvulsive, antispasmodic, laxative, carminative, anti-insomniac, and other pharmacological properties (Yang et al. 2005; Dinda et al. 2009; Dhiman et al. 2020).

The over-extraction of these plants from wild habitats to meet the increasing demand of the pharmaceutical industry is causing a threat to their genetic diversity. Although to meet the ever-increasing industrial need, numerous medicinal plants, including *A. glauca* and *V. jatamansi*, are currently in cultivation. However, the cultivated medicinal plants produce lower-quality secondary metabolites than their in-situ wild equivalents. Therefore, incorporating mycorrhizal fungi during medicinal plant cultivation may enhance their vegetative growth, tolerance to harsh environmental conditions, and secondary metabolite accumulation (Vierheilig et al. 2000; Karagiannidis et al. 2011).

Around 80% of plant species on the earth are known to be associated with arbuscular mycorrhizal fungi (AMF) (Remy et al. 1994; Wang and Qui 2006; Kivlin et al. 2015). Soluble or volatile exudates containing secondary metabolites like flavonoids and phenolics attract the AMF to young roots (Giovannetti and Sbrana 1998). Therefore, before the cultivation of medicinal plants through the artificial inoculation of AMF, assessing the dominant mycorrhizal mycobiota in the selected medicinal plant's rhizosphere region is preferable. Many researchers have observed the diversity of AMF in the rhizospheres of medicinal and aromatic plants (Koul et al. 2012; Zeng et al. 2013; Song et al. 2019; Kumar and Tapwal 2022). The AMF association has been reported with most medicinal and aromatic plants, and it was observed that host and climatic conditions greatly influenced their diversity. For example, in different locations of Uttarakhand, Gaur and Kaushik (2011) found 16 AMFs associated with *Catharanthus roseus* (L.) G.Don, *Ocimum sanctum* L., and *Asparagus racemosus* Willd.. Ghosh and Verma (2015) evaluated the AMF diversity in the rhizosphere of 54 medicinal plants growing in Purulia's Gar-Panchakot hills, finding greater diversity in the rainy season than in the summer and winter. Verma et al. (2019) studied AMF diversity in the rhizosphere soil of seven ethnomedicinal plants from the Western Himalayas and recorded the association of 23 AMFs.

Bueno de Mesquita et al. (2018) analyzed 177 plant species, including *Angelica grayi* (J.M.Coult. & Rose) J.M.Coult. & Rose, and observed that AMF, Dark Septate Endophytes (DSE), or both colonized 86% of the plants. The most prevalent AMF genera were *Acaulospora* and *Entrophospora*, but *Archaeospora*, *Claroideoglomus*, and *Glomus* were also recorded. Although the AMF relationship has been thoroughly researched with numerous medicinal and aromatic plants, little material is accessible concerning *A. glauca* Edgew. and *V. jatamansi* Jones. In the current study, we identified 24 and 19 AMF from the rhizosphere of *A. glauca* and *V. jatamansi*, respectively. In addition, the diversity indices of AMF in rhizosphere soil and root colonization were also investigated.

MATERIALS AND METHODS

Sample collection

Rhizosphere soil and roots of *A. glauca* and *V. jatamansi* were collected from two sites viz.: Site-I: Dhrudi (31°14′49.55″ N and 077°28′50.64″ E, 2547 masl) in Shimla district, and Site-II: Chhikkadhar (32°12′02.13″ N and 077°15′24.44″ E, 2964 masl) in Kullu District of Himachal Pradesh, India (Figure 1). The samples were collected during the rainy, winter and summer, seasons from the rhizosphere of five plants and prepared one composite sample. Three composite samples were collected from each site in each season. The soil pH and EC ranged from 6.4-6.9 and 168.2-188.6 (dS/m), respectively.

Arbuscular mycorrhizal spore isolation and identification

Wet sieving and decanting were followed to extract AM spores (Gerdemann and Nicolson 1963). First, 20 g soil was air-dried, suspended in 1000 mL water, agitated for 10 minutes, and undisturbed for 1 hour to allow heavier particles to settle down. Next, the soil suspension was decanted through a succession of sieves with pore sizes of 700 µm, 250 µm, 75 µm, and 40 µm in descending order of pore size. The material retained on the second, third, and fourth sieves was collected in Petri dishes and examined using a stereomicroscope (Nikon SMZ 1500). Finally, the AMF was identified by recording morphological features under the Nikon E-400 microscope.

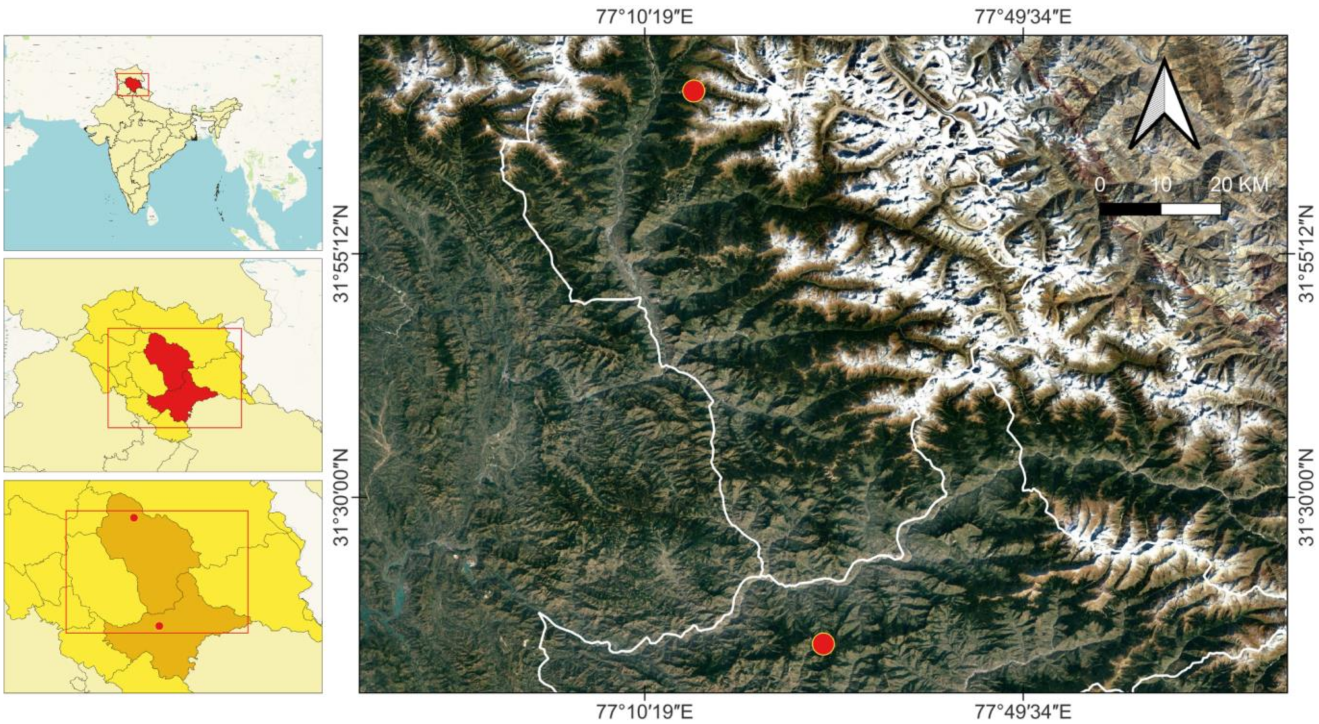

Figure 1. Map of study area in Shimla (31°14′49.55″N, 077°28′50.64″ E) and Kullu (32°12′02.13″N, 077°15′24.44″E) District, Himachal Pradesh, India

Percentage root colonization

Root samples were washed with tap water, sliced into 1 cm lengths, clarified in 10% KOH for 1 hour at 90°C, acidified with 1% HCl, and stained with trypan blue. The grid line intersects method assessed root colonization (Phillips and Hayman 1970; Giovannetti and Mosse 1980). The formula determined the colonization of the roots:

$$\% \textbf{ root colonization} = \frac{\text{Total no. of colonized root segments}}{\text{Total no. of root segments investigated}} x\ 100$$

Diversity indices: The following formulas were used to determine diversity indices:

$$\textbf{Relative Abundance} = \frac{\text{Numbers of spores of a species}}{\text{Total number of spores}} x\ 100$$

$$\textbf{Isolation Frequency} = \frac{\text{Number of soil samples where species occurred}}{\text{Total number of soil samples}} x\ 100$$

Shannon-Wiener Index of Diversity (Shannon 1948) $= -\sum \text{Pi} \ln \text{Pi}$

Where, Pi = ni/N, where ni is the spore number of a species, and N is the total number of identified spore samples).

Simpson's Index of Dominance (Simpson 1949) = 1-(∑n(n-1)/N(n-1)

Evenness (Pielou 1966)= $\frac{H'}{H'\text{max}}$

H'max is the maximal H' and is calculated by the following formula:

H' = ln S,

Where, S is the total number of identified species per sampling site

$$\textbf{Sorenson's coefficient (Sørensen 1948)} = \frac{2j}{(a+b)}$$

Where, a or b is the total number of species per sampling site, and j is the number of species common to both sites.

The Pearson correlation coefficient was computed using Microsoft Excel, and the relationship between spore density and root colonization, relative abundance, and isolation frequency was determined.

RESULTS AND DISCUSSION

The endomycorrhizal association in *A. glauca* and *V. jatamansi* was confirmed by morpho-anatomical characterization of the roots. Microsclerotia, vesicles, and intracellular hyphal coils were all found in the roots of both species; however, arbuscular were only found in *A. glauca* (Figures 1 and 2). Vesicles are terminal swellings of hyphae that form inter-and intracellularly, with sizes ranging from 5 to 10µm. In the roots of *A. glauca*, AMF colonization ranged from 55.63 to 86.34%, while in the roots of *V. jatamansi*, AMF colonization ranged from 55.23 to 78.74%. In the terse, maximum root colonization was recorded in the rainy season and minimum in the winter at both study sites of these medicinal plants. In addition, dark septate hyphae were seen in the cells of both plants. They formed the microsclerotia or moniliform cells, which were light to dark brown in color, thick-walled, and ranging in diameter from 1-2 µm.

The presence of 24 AMF representing eight genera was identified in the rhizosphere soil of *A. glauca*. *Glomus* had the most species (6), followed by *Acaulospora* and *Funneliformis* (Table 1; Figure 4). Data from this study revealed that Site-I had 7 AMF and Site-II had 6 AMF genera. *Gigaspora* and *Halonatospora* were only found at site I, while *Entrophospora* was only in site II. In all seasons, four AMFs were found: *Funneliformis constrictus*, *F. mosseae*, *Glomus aggregatum*, and *Rhizophagus clarus*. *V. jatamansi*'s rhizosphere soil comprised 19 AMF from seven genera. With nine species, *Acaulospora* was the most common genus, followed by *Glomus* and *Funneliformis* (Table 2, Figure 4). The site-by-site assessment, Sorenson's Index indicated that in rainy (23%), winter (50%), and in summer season 47% of AMF were shared by both sites of *A. glauca*. In the case of V. jatamansi, both sites shared 57% of AM fungi in the rainy season, 14% in winter, and 58% in summer. *Claroideoglomus* and *Rhizophagus* were only found at site I, while *Oehlia* and *Scutellospora* were only at site II. The remaining genera were found at both sites. In all seasons, four AMFs were found: *Acaulospora foveata*, *Acaulospora laevis*, *F. constrictus*, and *Glomus rubiforme*.

The ecological measures like relative abundance and isolation frequency of AMF in the rhizosphere of *A. glauca* and *V. jatamansi* were also studied. The data analysis showed that in *A. glauca*, the *Glomus macrocarpum* species had the highest relative abundance (29.41%) at site I, where the RA (%) ranged from 2-29.41%. At site II, the relative abundance was between 1.92-26.27%, with the highest percentage (29.41%) recorded for *F. constrictus*. On the other hand, the relative abundance of AMF in the rhizosphere of *V. jatamansi* varied between 4.16-25.94% at site I, with the highest RA (25.94%) recorded for *F. mosseae*. At site II, the relative abundance ranged from 1.88 to 22.99%, with the highest value (22.99%) also recorded for *F. mosseae*. Both study sites of medicinal plants showed isolation frequencies ranging from 25 to 100%. At site I of *A. glauca*, the AMF, including *F. constrictus*, *G. ambisporum*, and *G. macrocarpum*, had the highest isolation frequency (100% IF), while at site II, it were *C. etunicatum*, *F. constrictus*, *F. mosseae*, *G. aggregatum*, *G. ambisporum*, and *G. rubiforme*. Additionally, at site I of *V. jatamansi*, the highest IF (100%) was recorded for *F. mosseae*, *F. constrictus*, *G. aggregatum*, and *R. intraradices*. In contrast, at site II, the highest IF (100%) was recorded for *F. contrictus*, *F. mosseae*, and *R. rubiforme* (Tables 1 and 2).

The spore density (SD) in the rhizosphere soil of selected medicinal plants was highest during the winter, i.e., 2.14 and 3.25 in *A. glauca* and 2.64 and 1.65 in *V. jatamansi* at Site-I and Site-II, respectively. At the same time, the minimal SD in *A. glauca* rhizosphere soil was measured during the rainy season at Sites I (1.03) and II (0.5). In comparison, a minimum (1.09) SD was reported at

Site-I in the summer and rainy season (0.96) at site II of *V. jatamansi* (Figure 5).

In both sites, the Shannon-Wiener index of AMF diversity in the rhizosphere soil of *A. glauca* was highest during the summer season (1.81) and lowest in the rainy season (1.71) at Site-I, while it was maximum in the rainy season (1.97) and lowest in winter (1.55) at Site-II. On the other hand, the Shannon-Wiener index of AMF diversity in the rhizosphere soil of *V. jatamansi* was recorded as highest (2.02) during summer and minimum (1.57) in rainy season at Site-I, whereas higher (1.96) in rainy and lower (1.65) in summer season at Site-II (Figure 6).

In the rhizosphere of *A. glauca*, there was maximum (0.82) dominance of species (*G. ambisporum*) in the winter and minimum (0.76) in the rainy season at Site-I. In comparison, high dominance (0.85) of species (*F. constrictus*) was recorded in the rainy season and lowest in winter at site II. The higher dominance (0.85) of species was recorded in the summer season (*F. constrictus*) and lowest in the rainy season at Site-I of *V. jatamansi*, while higher dominance (0.87) of species (*Funneliformis mosseae*) recorded in rainy and low (0.80) in winter season at Site-II (Figure 7).

At both sites, AMF evenness in the rhizosphere soil of *A. glauca* was highest (0.91 and 0.96) in the winter season and lowest 0.75 and 0.79 at Site-I and II, respectively, in the summer season. In the case of *V. jatamansi*, it was highest in the winter (0.94) and lowest in the summer (0.84) at Site-I, whereas it was maximum in rainy (0.94) and minimum in the winter (0.83) season at Site-II (Figure 8).

Table 3 and Figure 9 show the results of an analysis of the data for correlations between root colonization, relative abundance, and diversity indices of selected plants. Data analysis of *A. glauca* root colonization demonstrated a substantial negative correlation with Spore Density (SD) and Isolation Frequency (IF) at both sites. The relative abundance was also found to have a positive correlation with the IF and SD while a negative correlation with the diversity index (H'). In the case of *V. jatamansi*, root colonization is negatively correlated to spore density at both sites. The correlation of relative abundance with SD is positive and negative with H' at both study sites. But the correlation between all the variables is statistically non-significant ($\alpha = 0.05$).

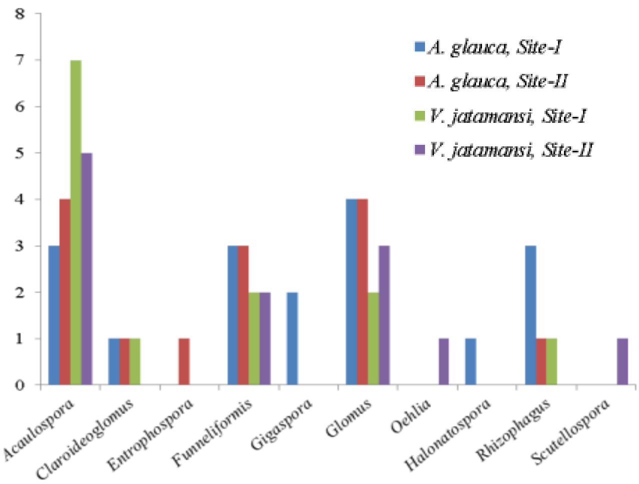

Figure 4. Species representation of AMF

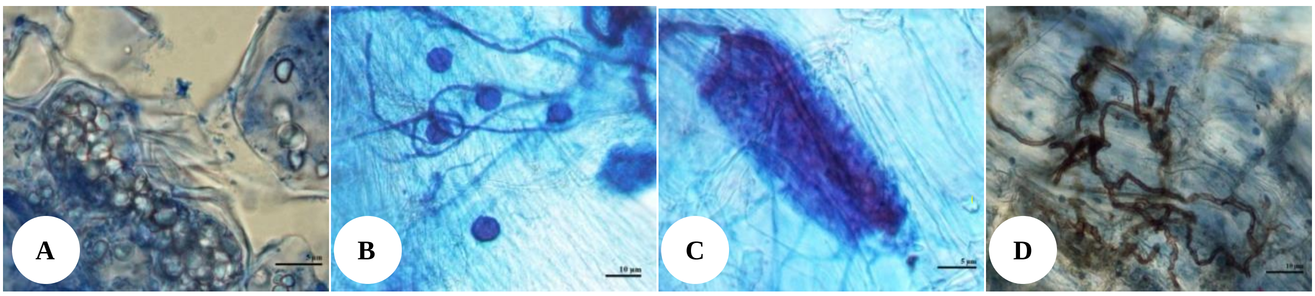

Figure 2. Mycorrhizal association and dark septate hyphae in the roots of *A. glauca*. A. Clusters of microscleridia in the cortical cells, B. Vesicles with extraradical hyphae, C. Arbuscules, D. Dark septate hyphae; scale bar: a, d – 50µm, b, c – 10µm

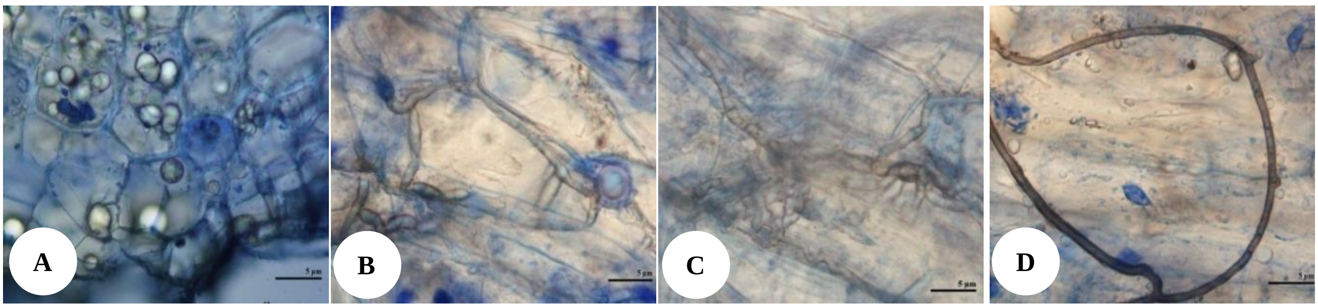

Figure 3. Mycorrhizal association and dark septate hyphae in the roots of *V. jatamansi*. A. Clusters of microsclerotia in the cortical cells, B. H-shaped hyphae, C. Intracellular hyphal coils, D. Dark septate hyphae; scale bar: –10µm

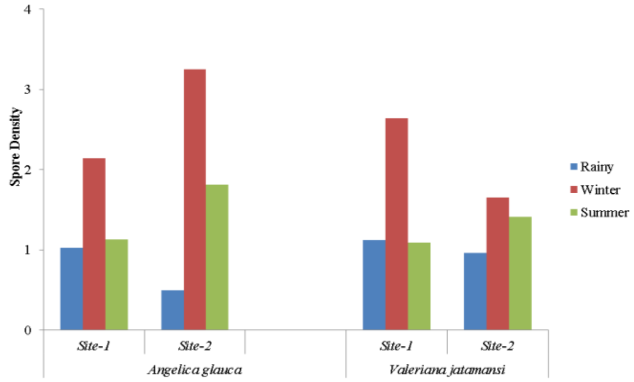

Figure 5. Spore density of AMF

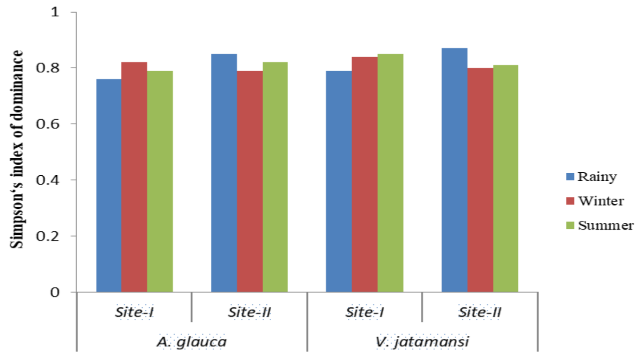

Figure 7. Simpson's Index dominance of AMF

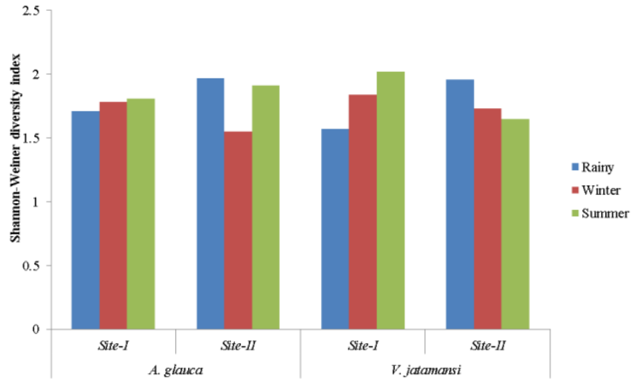

Figure 6. Shannon-Weiner Diversity Index of AMF

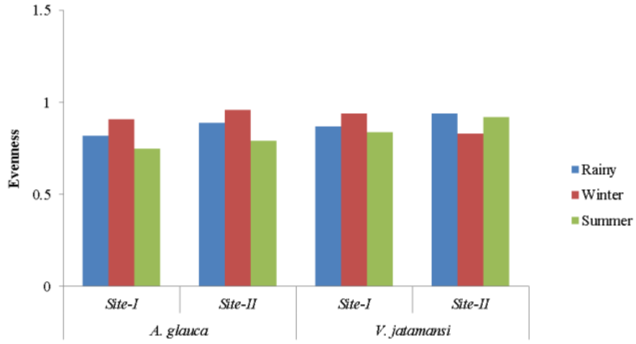

Figure 8. Evenness index of AMF

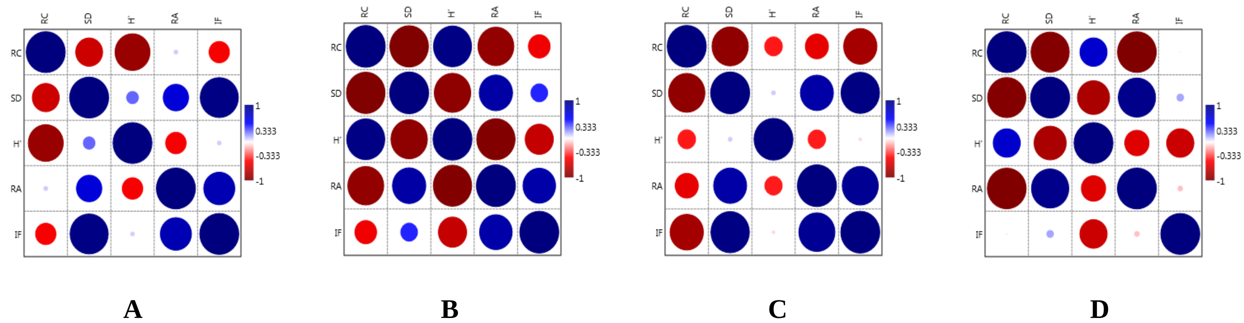

Figure 9. Pearson correlation between different variables (A. Site-I and B. Site-II of *A. glauca*; C. Site-I and D. Site-II of *V. jatamansi*). Note: RC: Root Colonization; SD: Spore Density; H': Shannon-Weiner Diversity Index; RA: Relative Abundance; IF: Isolation Frequency

Table 1. Occurrence, relative abundance, and isolation frequency of AMF in the rhizosphere of *A. glauca*

Name of AMF	Site	Seasonal presence of AMF			RA (%)	IF (%)
		Rainy	Winter	Summer		
Acaulospora alpina Oehl, Sýkorová & Sieverd.	I	–	–	–	--	--
	II	–	–	+	1.92	25
Acaulospora foveata Trappe & Janos	I	–	+	+	6.5	62.5
	II	+	–	–	3.84	50
Acaulospora lacunosa J.B. Morton	I	–	+	+	3.5	37.5
	II	+	–	+	3.84	50
Acaulospora laevis Gerd. & Trappe	I	–	–	–	--	--
	II	+	–	+	3.84	50
Acaulospora pustulata Palenz., Oehl, Azcón-Aguilar & G. A. Silva	I	–	–	+	2.0	25
	II	–	–	–	--	--
Claroideoglomus claroideum (N.C. Schenck & G.S. Sm.) C. Walker &A. Schüßler	I	+	–	–	9.09	50
	II	–	–	–	--	--
Claroideoglomus etunicatum (W.N. Becker & Gerd.) C. Walker & A. Schüßler	I	–	–	–	--	--
	II	–	–	+	9.61	100
Funneliformis caledonius (T.H. Nicolson & Gerd.) C. Walker & A. Schuessler	I	–	–	+	2.0	25
	II	–	–	–	--	--
Funneliformis constrictus (Trappe) C. Walker & A. Schüßler	I	–	+	+	24.0	100
	II	+	+	+	26.27	100
Entrophospora sp.	I	–	–	–	--	--
	II	–	–	+	1.92	25
Funneliformis geosporum (T.H. Nicolson & Gerd.) C. Walker & A. Schluessler	I	–	–	–	--	--
	II	+	–	+	5.76	62.5
Funneliformis mosseae (T.H. Nicolson & Gerd.) C. Walker & A. Schuessler	I	+	+	+	23.37	91.66
	II	+	+	+	21.15	100
Gigaspora albida N.C. Schenck & G.S. Sm.	I	+	–	–	6.06	50
	II	–	–	–	--	--
Gigaspora decipiens I.R. Hall & L.K. Abbott	I	+	–	–	6.06	25
	II	–	–	–	--	--
Glomus aggregatum N.C. Schenck & G.S. Sm.	I	+	+	+	7.13	58.33
	II	+	–	–	7.69	100
Glomus ambisporum G.S. Sm. & N.C. Schenck	I	–	+	+	33.0	100
	II	+	–	+	18.26	100
Glomus glomerulatum Sieverd.	I	–	–	–	--	--
	II	–	+	+	8.88	75
Glomus macrocarpum Tul. & C. Tul.	I	+	–	–	29.41	100
	II	–	–	–	--	--
Glomus microcarpum Tul. & C. Tul.	I	+	–	–	6.06	25
	II	–	–	–	--	--
Glomus rubiforme (Gerd. & Trappe) R.T. Almeida & N.C. Schenck	I	–	–	–	--	--
	II	–	+	–	24.61	100
Halonatospora pansihalos (S.M. Berch & Koske) Błaszkowski, Niezgoda, B.T. Goto & Kozłowska	I	+	–	–	6.06	25
	II	–	–	–	--	--
Rhizophagus clarus (T.H. Nicolson & N.C. Schenck) C. Walker & A. Schuessler	I	–	+	+	7.0	50
	II	+	+	+	8.96	75
Rhizophagus irregularis (Błaszk., Wubet, Renker & Buscot) C. Walker & A. Schüßler	I	–	–	+	2.0	25
	II	–	–	–	--	--
Rhizophagus fasciculatus (Taxt.) C. Walker & A. Schüßler	I	–	–	+	6.0	50
	II	–	–	–	--	--

Note: Site-I: Dhrudi, Site-II: Chhikkadhar, RA: Relative Abundance, IF: Isolation Frequency, +: Present, –: Absent, --: Not applicable

Table 2. Occurrence, relative abundance, and isolation frequency of AMF in the rhizosphere of *V. Jatamansi*

Name of AMF	Site	Seasonal presence of AMF			RA	IF
		Rainy	Winter	Summer	(%)	(%)
Acaulospora alpina Oehl, Sýkorová & Sieverd.	I	–	–	+	4.16	50
	II	–	–	–	--	--
Acaulospora excavate Ingleby & C. Walker	I	–	–	–	--	--
	II	–	+	–	1.88	25
Acaulospora foveata Trappe & Janos	I	–	+	+	4.41	62.5
	II	+	+	+	9.84	6.66
Acaulospora lacunosa J.B. Morton	I	–	+	+	6.16	75
	II	+	–	+	7.63	50
Acaulospora laevis Gerd. & Trappe	I	+	+	+	7.25	75
	II	+	–	+	7.77	50
Acaulospora mellea Spain & NC. Schenck	I	–	–	+	2.08	25
	II	–	–	–	--	--
Acaulospora rehmii Sieverd. & S. Toro	I	–	–	+	2.08	25
	II	–	–	–	--	--
Acaulospora rugosa J.B. Morton	I	+	–	–	11.11	50
	II	–	–	–	--	--
Acaulospora spinosa C. Walker & Trappe	I	–	–	–	--	--
	II	–	+	–	3.77	50
Claroideoglomus etunicatum (W.N. Becker & Gerd.) C. Walker & A. Schüßler	I	–	–	+	4.16	50
	II	–	–	–	--	--
Funneliformis constrictus (Trappe) C. Walker & A. Schüßler	I	+	+	+	25.68	100
	II	+	–	+	19.82	100
Funneliformis mosseae (T.H. Nicolson & Gerd.) C. Walker & A. Schüßler	I	+	+	–	25.94	100
	II	+	–	+	25.99	100
Glomus aggregatum N.C. Schenck & G.S. Sm.	I	+	–	+	16.54	100
	II	–	–	–	--	--
Glomus macrocarpum Tul. & C. Tul.	I	–	–	–	--	--
	II	+	+	–	11.71	75
Glomus rubiforme (Gerd. & Trappe) R.T. Almeida & N.C. Schenck	I	+	+	+	14.24	75
	II	+	–	+	19.96	100
Glomus versiforme (P. Karst.) S.M. Berch	I	–	–	–	--	--
	II	+	+	–	17.77	87.5
Oehlia diaphana (J.B. Morton & C. Walker) Błaszk., Kozłowska, Niezgoda, B.T. Goto & Dalpé	I	–	–	–	--	--
	II	–	+	–	3.77	25
Rhizophagus intraradices (N.C. Schenck & GS Sm.) C. Walker & A. Schüßler	I	–	+	+	14.35	100
	II	–	–	–	--	--
Scutellospora sp.	I	–	–	–	--	--
	II	–	+	–	5.66	75

Note: Site-I: Dhrudi, Site-II: Chhikkadhar, RA: Relative Abundance, IF: Isolation Frequency, +: Present, –: Absent, --: Not Applicable

Table 3. Pearson correlation of root colonization and relative abundance with diversity indices

	SD		H'		IF	
	Site-I	Site-II	Site-I	Site-II	Site-I	Site-II
Angelica glauca						
Root colonization	-0.69	-0.98	-0.89	0.97	-0.52	-0.55
Relative Abundance	0.65	0.85	-0.52	-0.98	0.79	0.83
Valeriana jatamansi						
Root colonization	-0.93	-0.98	-0.45	0.69	-0.85	0.025
Relative Abundance	0.84	0.95	-0.44	-0.62	0.92	-0.12

Note: at $\alpha = 0.05$

Discussion

The diversity and population of AMF in the rhizosphere of medicinal plants play a vital role in their growth and accumulation of secondary compounds of therapeutic and pharmacological value. *A. glauca* and *V. jatamansi*, two important medicinal plants of temperate Himalaya, were investigated for the mycorrhizal association in roots and diversity of AMF in the rhizosphere soil. The distribution of AMF has not exhibited a consistent trend in the selected sites, but the genus *Glomus* and *Acaulospora* had the highest number of species in both study sites. The *Glomus* species are most widely distributed and considered a cosmopolitan presence in many ecosystems (Sýkorová et al. 2007). Their wide adaptability of sporulation patterns in varied environmental conditions adds to their wide distribution in different geographical regions (Stutz et al. 2000). They dominate habitats in various climatic conditions, from tropical to cold temperate regions (Suresh and Nelson 2015). Previously, the genus *Glomus* was reported to be dominant with numerous medicinal plants (Selvaraj et al. 2001). *Acaulospora* species are regarded as facultative symbionts with a wide host range. They are also suited to various soil conditions and can be found in various nutrient-rich soils (Shepherd et al. 1996, Straker et al. 2010). The comparatively low abundance of *Acaulospora*, which is more frequent in acidic soils, could potentially be due to high soil pH (Wang et al. 2019). The study also identified AMF genera with low species abundance. That suggests these species are likely to be weak competitors in colonizing the roots of selected medicinal plants, resulting in a lower frequency of occurrence. Major genera's occurrence may be attributed to their high competitive interaction and adaptability, allowing them to develop better than other AMFs (Singh et al. 2010).

The diversity (Shannon-Weiner Diversity Index) of AMF in the rhizosphere soil of *A. glauca* and *V. jatamansi* was highest during the summer and lowest in the rainy season at Site-I. In comparison, rich diversity was recorded in the rainy season at Site-II. Both environmental factors and host plant species influence the diversity of soil fungal communities. The higher AMF diversity in the summer could be related to the harsh environmental conditions experienced by the host plant, which encourages the development of chlamydospores by AMF. Low moisture in the rhizosphere soil creates drought-like conditions, potentially affecting the composition and dominance of AMF populations. In addition, seasonal variations in AMF diversity were observed in selected medicinal plants and study sites. Seasonal variation has a substantial impact on the occurrence of AMF (Mallesha and Bagyaraj 1991). The host and seasons are major factors determining the spore density and species richness of AMF in natural settings (Su et al. 2011). AMF species' abundance is known to be affected by disturbance, sporulation efficiency, and dormancy (Walker et al. 1982; Zhao 1999).

Simpson's Index, relative abundance value, and percent isolation frequency were also used to describe the community structure of AM fungi associated with medicinal plants during different seasons, providing additional ecological diversity measures. These measures explain a more comprehensive understanding of the AM fungi community and their dynamics throughout the year. The data analysis revealed the maximum abundance and dominance of AM fungal genera (*Glomus* and *Funneliformis*) belonging to the order Glomarales in the rhizosphere soil of both medicinal plants (*A. glauca* and *V. jatamansi*). The predominance of Glomerales is due to their efficient sporulation and infective efficacy (Redecker et al. 2013), or it might also be due to the phenology of the host plants (Liu and Wang 2003; Bauer et al. 2020). It has been reported that low pH (5.5-6.5) favors the production of more spores by *Glomus* species (Wang et al. 1993). Moreover, several studies worldwide reported Glomerales members' predominance in medicinal plants' rhizosphere (Thapa et al. 2015; Wang and Jiang 2015; Verma et al. 2019; Kumar and Tapwal 2022). The species were found more evenly distributed in the winter season at both the sites of *A. glauca*. Whereas, in the case of *V. jatamansi*, the AMF was more equally spread in winter and summer at sites-I and II, respectively. As discussed earlier that several factors can influence the distribution and composition of arbuscular mycorrhizal (AM) fungi, including soil type, texture, temperature, moisture, host plant, disturbance, as well as nutrient availability (Hawkes et al. 2011; Martinez-Garcia et al. 2015; Bauer et al. 2020).

At both sites of selected plants, maximum spore density and low root colonization were observed during the winter season. Due to good vegetative growth in favorable environmental conditions, less spore density was reported on average throughout the rainy season. Root colonization is poor during cool and dry conditions, while sporulation is high (Moreira et al. 2006). Sporulation occurs during the dry season due to root senescence by the possibility of considerable root turnover, particularly in annuals or competitions (Sitienei et al. 2015). Spores germinate quickly during the wet season or disintegrate due to high moisture and may be destroyed by microbes, reducing their number (Guadarrama and Avarez-Sánchez 1999; Cuenca and Lovera 2010; Sitienei et al. 2015). The host species also influence AMF spores' density (Varela-Cervero et al. 2016); rather than the AMF species, the host plant species and environmental conditions control the spore abundance of AMF (Koske and Halvorson 1981). AMF spore output is known to vary considerably among ecosystems. It is regulated by various parameters, including habitat, host, fungus, and spore density, which tends to rise during root inactivity or senescence (Muthukumar et al. 2003). The uneven spatial distribution of AMF spores and the complex structure of the underground root component could be key variables impacting AMF spore density (Zhao et al. 2001). Earlier research has shown that environmental conditions and vegetation play a significant role in the makeup of AMF communities (Brundrett 1991). The density of propagules varies from plant to plant and site to site (Allen and Allen 1980).

Root colonization was highest during the rainy season and lowest during the winter at all *V. jatamansi* and *A. glauca* sampling sites. There may be a strong link between soil moisture and AMF root colonization. Zangaro et al.

(2013) also recorded higher mycorrhizal colonization in fine roots during spring and summer than in the fall and winter. Kumar et al. (2013) recorded similar results in the rainy season. Some researchers believe seasonal precipitation positively impacts root growth, leading to AMF spore germination and colonization (Oliveira 2001; He et al. 2002). The data analysis revealed that at sites I and II, there was a negative correlation between root colonization percentage and density in the selected medicinal plants (Figure 9). This could indicate that when the number of spores increases, root colonization decreases and vice versa. Radhika and Rodrigues (2010) and Urcoviche et al. (2014) have also recorded a negative correlation between AMF root colonization and spore density in medicinal plants.

In conclusion, the study was primarily focused on the seasonal diversity of AMF in the rhizosphere *A. glauca* and *V. jatamansi* and their root colonization by AMF. Furthermore, 24 (twenty-four) and 19 (nineteen) AMF were identified from the rhizosphere soil of *A. glauca* and *V. jatamansi*, respectively. *Glomus* and *Acaulospora* were the dominant AMF genera in both study sites. The degree of colonization of roots and spore density in rhizosphere soil varied in both study sites and during sampling seasons.

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The macrofungal diversity and its potential from the karst forest of Kalipoh Village, Kebumen District, Indonesia

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Abstract. *Armadhan WS, Sari SP, Aji MYMB, Permatasari DP, Amalia BW, Berlin GE, Aszar AS, Indrawan M, Pradhan P, Setyawan AD. 2023. The macrofungal diversity and its potential from the karst forest of Kalipoh Village, Kebumen District, Indonesia. Intl J Trop Drylands 7: 99-106.* Indonesia is one of the world's most biodiverse countries, with fungi being one of its most diverse groups of organisms. Many fungi species have been identified and have potential benefits for both living things and the environment. Kalipoh Village Forest, located in the karst area of Ayah Sub-district, Kebumen District, Central Java, Indonesia, offers suitable environmental conditions that provide habitat for various species of fungi. The objective of this study was to determine the diversity and potential use of macrofungi in Kalipoh Village Forest. Data collection was carried out using the survey method, where every encountered fungus was observed and its cap, gills, stalk, color, odor, substrate, and growth habits were recorded. Macrofungal diversity was calculated using the Shannon-Wiener Diversity Index, Simpson’s Diversity Index, Richness Index, and Evenness Index Formula. The exploration results obtained 34 species of macrofungi from 22 genera and 18 families, with most of the species found on weathered logs and leaf litter. Two genera, namely *Marasmius* and *Marasmiellus*, were quite common. Based on the index value calculation, the diversity of macrofungi in this area was in the medium category (H'=2.695). It had a high index of richness (R=5.252) and evenness (E=0.764). The high evenness of the species indicates lower dominance, which can also be observed from the results of the high Simpson’s Diversity Index value (0.910). A total of 24 species of macrofungi were known to have the potential as food and medicine.

Keywords: Evenness, Kalipoh Village forest, mushrooms, richness, survey

INTRODUCTION

Indonesia has the highest biodiversity in the world, following Brazil. This fact has significant implications for global climate, as well as human health and welfare (Rintelen et al. 2017). One of the many biodiverse groups found in Indonesia is fungi. Fungi are eukaryotic microorganisms that lack chlorophyll and rely on spores for their transmission. These spores may take the form of single cells (unicellular) that then grow into filamentous or branched structures. Fungi are heterotrophic organisms, among which macrofungi or mushrooms produce large basidiomas (fruiting bodies) that make them easy to locate without specialized tools (Dutta et al. 2011a,b,c; Pradhan et al. 2011; Putra and Astuti 2021). However, some fungi produce small fruiting bodies, known as microscopic fungi, that require special tools for detection of their physical form (Ramadianty et al. 2022). The heterotrophic nature of fungi causes these organisms to be highly dependent on the surrounding environmental conditions. Environmental factors such as temperature, pH, humidity, and light intensity greatly affect the growth of fungi. Fungal habitat is usually moist, such as litter or dead logs, where they can grow either in groups or individually. Fungi are classified into five major groups: Ascomycota, Basidiomycota, Chytridiomycota, Glomeromycota, and Zygomycota (Hibbett et al. 2007).

The global number of fungi has been estimated to be around 1.5 million, of which approximately 300 species are known to have the potential to cause disease in humans (Putra and Hermawan 2021). Fungi are important indicators of environmental health in ecosystems, and they also have potential medicinal, food, and other uses that have yet to be fully explored (Paloi et al. 2016; Mayasari et al. 2018). In forest ecosystems, fungi play an important role in the decomposing organic matter alongside with bacteria and protozoa, thus accelerating the recycling of materials (Situmorang et al. 2019). However, several species of fungi are also pathogenic to humans and attack various organ systems, especially the skin and respiratory system, causing various signs and symptoms of disease (Faturrachman and Mulyana 2019).

Karst is a unique landscape formed by the dissolution of easily soluble rocks such as limestone, resulting in distinctive hole-shaped landforms due to weathering of rock by water (Pertiwi et al. 2020). The karst terrain is characterized by numerous passages and caves that can be found at the bottom of the land due to carbonate dissolving process (Kalhor et al. 2019). The soil in karst areas is typically infertile and barren due to the rock's secondary porosity characteristics and easy solubility (Wisnuaji and Pamungkas 2022). Rainwater flows into the rock, not being accommodated for long periods, and is channeled directly into the aisle before flowing out into springs. This feature makes it challenging to find water on the karst's surface area, but high-quality water resources are available at the bottom of the surface due to runoff water being stored beneath the surface of the karst land.

Indonesia has quite extensive karst land, estimated at approximately 15.4 million hectares (Has and Sulistiawaty 2018). One such karst area is located in Kebumen District, Central Java, which is locally known as the South Gombong Karst Area (KKGS). This area encompasses an area of approximately 8 km (north to south) with a width of 3 km, spanning three sub-districts in Kebumen District, including Ayah, Buayan, and Rowokele. The South Gombong Karst Area is characterized by numerous caves and karst forests, including one in Kalipoh Village.

The objective of this study is to determine the diversity of macrofungi and their potential use in the karst forest of Kalipoh Village, Ayah, Kebumen, Indonesia. The choice of the karst forest area in Kalipoh Village was based on its dense cover canopy and diverse vegetation. Besides, the region is dominated by teak trees, which promote the growth of various fungal species due to the teak leaf litter serving as organic material for fungal growth (A'yun et al. 2022).

MATERIALS AND METHODS

Study area

Data collection was carried out in November 2022, in the karst forest of Kalipoh Village, Ayah Sub-district, Kebumen District, Central Java Province, Indonesia (Figure 1). Kalipoh Village is a natural habitat forkarst forests that host a various biodiversity components. This karst forest is a part of the South Gombong Karst Area (KKGS) and is situated at an altitude of 101.3 m asl, not far from the coast. The location of this karst forest is quite distant from residential areas, which allows the forest environment to remain undisturbed and retain its natural beauty. Despite being a karst area, this forest has various types of vegetation, with teak trees dominating the region (Suhendar et al. 2018).

Procedures

Research methods

The research was conducted using the survey method by exploring all accessible forest areas (Lingga et al. 2019). Thismethod is considered more effective for observing and collecting data that are not evenly distributed in large forest areas (Arif and Al-Banna 2020). The exploration was conducted based on the direction of cruising, which is adjusted to the direction of the route (Pardosi et al. 2019).

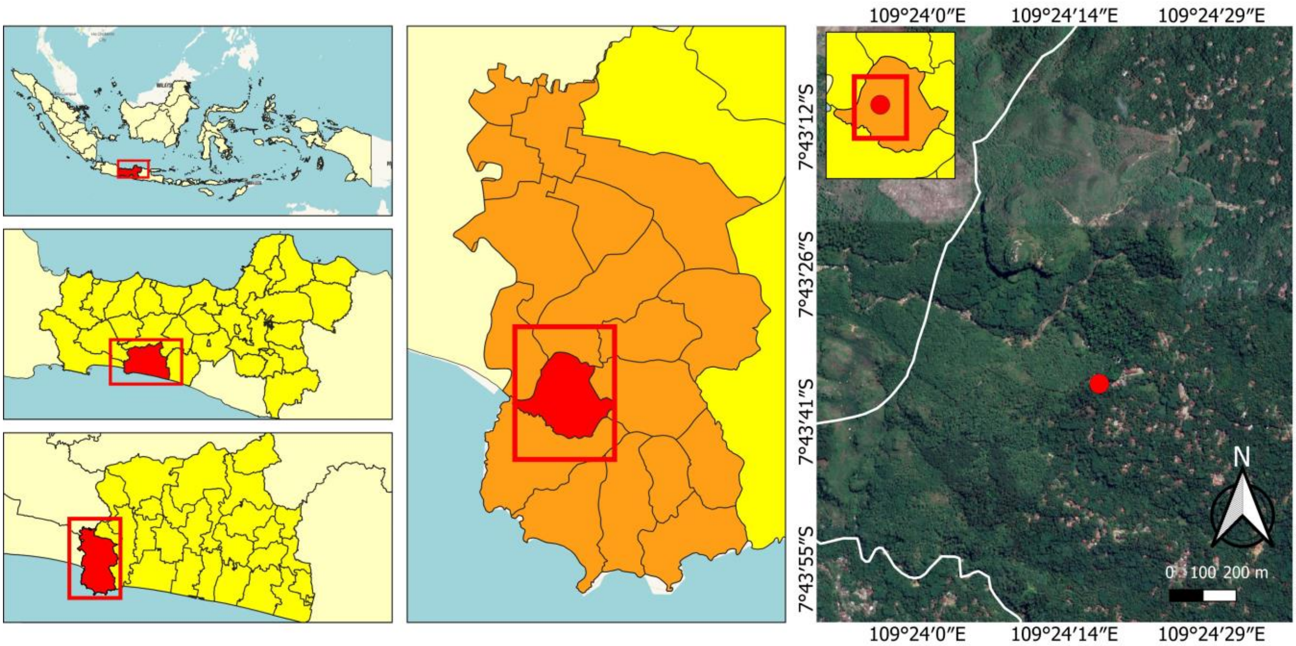

Figure 1. Map of data collection locations in Kalipoh Village Forest, Ayah, Kebumen, Central Java, Indonesia

Data collections

The macrofungi studied were observed for the cap (pileus), gills (lamellae), stalk (stipe), substrate, growth habit, and other information such as the color and smell of the fungi (Aqilah et al. 2020). The characteristics of the specimens were recorded and documented after observation. If the condition of the specimen was in good condition, spore prints were made to determine the color of the spore print. The abiotic factors, including temperature, pH, humidity, light intensity, and wind speed were measured, as they affect the development and growth of fungi (Nasution et al. 2018; Wati et al. 2019).

Identification

Macrofungal specimens were characterized according to standard procedures outlined by Largent et al. (1977). Their identification were carried out based on literature studies using books, monographs, journals, and websites. Suryani and Cahyanto (2022) was followed for identification of fungal species, and the names of fungal species were validated based on references to www.indexfungorum.org (Redhead and Norvell 2012).

Data analysis

According to Rozak et al. (2020), the diversity of fungi can be assessed using two indices: the Shannon-Wiener Diversity Index (1963) and Simpson's Diversity Index (1949). The Shannon-Wiener index (H') can be calculated using the formula $H' = -\sum(ni/N) \ln (ni/N)$, where ni is the number of individuals of the ith species, N is the total number of individuals, and ln is the natural logarithm. The value of H' ranges from 1.5 to 3.5 and rarely exceeds 4, with a higher value indicating a higher diversity. Simpson's Diversity Index (D) can be calculated using the formula $D= 1-\sum(ni/N)^2$, where ni is the number of individuals of the ith species, N is the total number of individuals, and $\sum$ is the sum. The value of D ranges from 0 to 1, with a value of 0 indicating a homogeneous community and a value of 1 indicating high diversity. The richness of fungal species can be calculated using the formula $R= (S-1)/\ln N$, where S is the total number of species and ln is the natural logarithm. The value of R ranges from 2.5 to 4. The evenness of fungal species can be calculated using the formula $E= \sum(H'/\ln S)$, where $\sum$ is the sum, H' is the Shannon-Wiener index, and S is the total number of species. Evenness index values range from 0 to 1.

RESULTS AND DISCUSSION

Macrofungi found in the karst forest of Kalipoh Village, Kebumen

The exploration of macrofungi in Kalipoh Village Forest yielded 34 species from 22 genera and 18 families, with the majority of specimens belonging to Basidiomycota. Two species were identified from the Ascomycota, namely *Exidia* sp. and *Xylaria* sp. Among the families, the Marasmiaceae, Omphalotaceae, and Polyporaceae exhibited the highest species diversity, with six, seven, and four species, respectively (Figure 2).

Based on the data presented in Table 1, the most commonly found macrofungi belong to the genera *Marasmius* and *Marasmiellus* (Marasmioid fungi). These fungi are typically found in the leaf litter on the forest floor and have good adaptability to changing environmental conditions (Kuo 2013). Figure 3 indicates that the majority of the fungi were found on substrate such as rotten wood, dead tree trunks, and litter. This may be due to the fact that logging activities had left many logs in the forest, and the teak leaf litter was observed to be in the stage of decomposition.

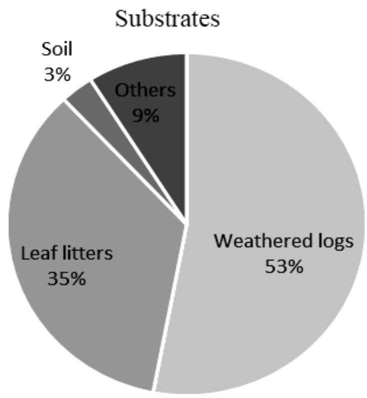

Figure 3. Variation of macrofungal substrates found in Kalipoh Village Forest, Ayah, Kebumen, Central Java, Indonesia

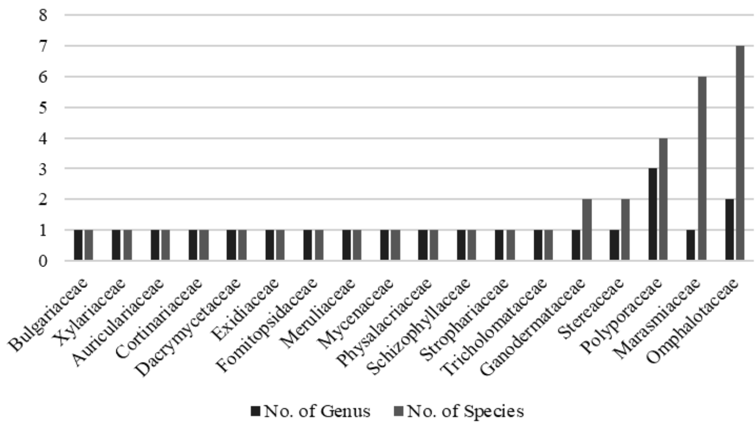

Figure 2. The composition of the genus and species of macrofungi obtained from each family

Table 1. Macrofungi found in the karst forest of Kalipoh Village, Ayah, Kebumen, Indonesia

Phylum	Family	Species	Substrates
Ascomycota	Bulgariaceae	*Bulgaria* sp.	Weathered logs
Ascomycota	Xylariaceae	*Xylaria* sp.	Weathered logs
Basidiomycota	Auriculariaceae	*Auricularia polytricha* (Mont.) Sacc.	Weathered logs
Basidiomycota	Cortinariaceae	*Cortinarius* sp.	Weathered logs
Basidiomycota	Dacrymycetaceae	*Dacryopinax spathularia* (Schwein.) Alvarenga	Weathered logs
Basidiomycota	Exidiaceae	*Exidia* sp.	Weathered logs
Basidiomycota	Fomitopsidaceae	*Fomitopsis* sp.	Weathered logs
Basidiomycota	Ganodermataceae	*Ganoderma lucidum* (Curtis) P. Karst.	Weathered logs
Basidiomycota	Ganodermataceae	*Ganoderma* sp.	Weathered logs
Basidiomycota	Marasmiaceae	*Marasmius delectans* Morgan	Weathered logs
Basidiomycota	Marasmiaceae	*Marasmius elegans* (Cleland) Grgur.	Dry grass
Basidiomycota	Marasmiaceae	*Marasmius haematocephalus* (Mont.) Fr.	Leaf litters
Basidiomycota	Marasmiaceae	*Marasmius siccus* (Schwein.) Fr.	Leaf litter, dry grass
Basidiomycota	Marasmiaceae	*Marasmius* sp. 1	Leaf litters
Basidiomycota	Marasmiaceae	*Marasmius* sp. 2	Soil
Basidiomycota	Meruliaceae	*Ceriporiopsis* sp.	Weathered logs
Basidiomycota	Mycenaceae	*Mycena chlorophos* (Berk. & M.A. Curtis) Sacc.	Weathered logs
Basidiomycota	Omphalotaceae	*Gymnopus dryophilus* (Bull.) Murrill	Weathered logs
Basidiomycota	Omphalotaceae	*Gymnopus* sp.	Weathered logs
Basidiomycota	Omphalotaceae	*Marasmiellus candidus* (Fr.) Singer	Weathered logs
Basidiomycota	Omphalotaceae	*Marasmiellus ramealis* (Bull.) Singer	Dry grass
Basidiomycota	Omphalotaceae	*Marasmiellus reniformis* Retn.	Leaf litters
Basidiomycota	Omphalotaceae	*Marasmiellus* sp. 1	Weathered logs
Basidiomycota	Omphalotaceae	*Marasmiellus* sp. 2	Leaf litters
Basidiomycota	Physalacriaceae	*Rhizomarasmius setosus* (Sowerby) Antonin & A. Urb	Leaf litters
Basidiomycota	Polyporaceae	*Polyporus arcularius* (Batch) Fr.	Weathered logs
Basidiomycota	Polyporaceae	*Pycnoporus* sp.	Weathered logs
Basidiomycota	Polyporaceae	*Trametes* sp. 1	Weathered logs
Basidiomycota	Polyporaceae	*Trametes* sp. 2	Weathered logs
Basidiomycota	Schizophyllaceae	*Schizophyllum commune* Fr.	Weathered logs
Basidiomycota	Stereaceae	*Stereum ostrea* (Blume & T. Nees) Fr.	Live plant stems
Basidiomycota	Stereaceae	*Stereum* sp.	Weathered logs
Basidiomycota	Strophariaceae	*Pholiota* sp.	Weathered logs
Basidiomycota	Tricholomataceae	*Collybia* sp.	Weathered logs

Table 2. Results of measurements of abiotic factors in Kalipoh Village Forest, Ayah, Kebumen, Indonesia

Parameter	Average
Soil temperature (˚C)	35,67
Soil pH	7.0
Soil moisture (RH)	5,67
Air temperature (˚C)	29,4
Humidity (%)	85.5
Light intensity (lux)	664x10A 20000
Wind speed (m/s)	0.4
Altitude (masl)	100.33

Table 3. The results of the calculation of the Shannon-Wiener Diversity Index, Simpson's Diversity Index, Richness Index, and evenness index

Calculated index	Index value	Category
Shannon-Wiener Diversity Index (H')	2,695	Moderate
Simpson's Diversity Index (D)	0.910	High
Richness Index (R)	5,252	High
Evenness index (E)	0.764	High

Macrofungal diversity in Kalipoh Village Forest, Ayah, Kebumen

The Kalipoh Village Forest is a biodiverse location for fungi, supported by abiotic factors that facilitate fungal growth in the forest environment (Table 2). The soil pH in the forest is around 7, which falls within the optimum pH range (4.5 to 8) for fungal growth (Noerhandayani et al. 2022). The high humidity in the air and soil, with an average of 85.5% and 5.67, respectively, further promotes fungal growth in the karst forest of Kalipoh Village. High light intensity inhibits fungal growth, while low light intensity encourages fungal growth (Noverita et al. 2019). The light intensity in the forest area is 664x10 lux, which is not too high due to the dense vegetation cover from teak and other plants. The litter from the existing vegetation serves as a substrate for fungal growth, contributing to the high fungal species diversity found in the area (Figure 4).

The Shannon-Wiener Diversity Index indicates that the Kalipoh Village forest has a moderate level of species diversity (H'=2.695), which can be attributed to the presence of a high number of fungal species in the area. Additionally, the forest has a high species richness (R=5.252) and good evenness (E=0.764). The Simpson's Diversity Index also suggests a high level of diversity

(D=0.910), which can be attributed to a balanced distribution of individuals among different species in the area (Table 3). These results are supported by the favorable biotic and abiotic conditions in the forest that facilitate fungal growth. According to Rahmawati et al. (2018), the biotic and abiotic factors significantly influence the growth and survival of fungi. Niem and Baldovino (2015) reported the presence of fungi from the phyla Ascomycota and Basidiomycota in the CURCC karst area, which is consistent with the phyla found in the karst forest of Kalipoh Village. However, the species diversity in the two locations differs due to differences in the biotic and abiotic factors that affect fungal growth.

Potential use of macrofungi found in Kalipoh Village Forest, Ayah, Kebumen

The study of fungi in Kalipoh Village forest identified a total of 34 species, of which 23 have been analyzed for their potential applications, including use as food, medicine, for ecological and environmental purposes, and toxicity. However, 11 species have yet to be assessed for their potential uses (Table 4).

Potential as a food

Fungi are a biological resourcewith potential as food due to their high protein and nutritional content, as well as the presence of compounds such as polysaccharides (glycans), triterpenoids, nucleotides, mannitol, and alkaloids (Bahar et al. 2022). Certain fungal species found in Kalipoh karst forests, including *A. polytricha*, *M. ramealis*, *Marasmiellus* sp., and *S. commune*, have potential as food sources (De Kesel et al. 2008; Noverita et al. 2016; Noverita et al. 2019; Nurlita et al. 2021). Among these, *A. polytricha*, commonly known as black ear fungus and belonging to the Heterobasidiomycetes class, is often used in Chinese cuisine. Its distinctive ear-like shape and dark brown color make it a popular ingredient in food preparations. Cultivation of this fungus can be carried out for use as a food source or as a mixture of food ingredients.

Table 4. Potential use of macrofungi found in Kalipoh Village forest, Ayah, Kebumen, Indonesia

Species	Food	Medicine	Poisonous	Unknown	References
Exidia sp.				✓	-
Xylaria sp.		✓			Fauzi et al. 2018
Auricularia polytricha	✓				De Kesel et al. 2008
Bulgaria sp.				✓	-
Cortinarius sp.		✓			Putra 2020
Dacryopinax spathularia	✓				Bitzer et al. 2017
Fomitopsis sp.		✓			Muszyńska et al. 2020
Marasmius delectans		✓			Fauzi et al. 2018
Marasmius elegans				✓	-
Marasmius haematocephalus				✓	-
Marasmius siccus				✓	-
Marasmius sp. 1				✓	-
Marasmius sp. 2				✓	-
Ceriporiopsis sp.	✓				
Mycenae chlorophos		✓			Fauzi et al. 2018
Collybia sp.	✓				Mahardhika et al. 2021
Gymnopus dryophilus			✓		Suryani and Cahyanto 2022
Gymnopus sp.			✓		Suharjo 2007
Marasmiellus candidus				✓	-
Marasmiellus ramealis	✓				Noverita et al. 2016
Marasmiellus reniformis				✓	-
Marasmiellus sp. 1	✓				Noverita et al. 2019
Marasmiellus sp. 2	✓				Noverita et al. 2019
Rhizomarasmius setosus				✓	-
Ganoderma lucidum		✓			Sudarwati and Fernanda 2021
Ganoderma sp.		✓			Noverita et al. 2016
Polyporus arcularius		✓			Fauzi et al. 2018
Pycnoporus sp.				✓	-
Trametes sp. 1		✓			Fauzi et al. 2018
Trametes sp. 2		✓			Fauzi et al. 2018
Schizophyllum commune	✓				Nurlita et al. 2021
Stereum ostrea		✓			Akata 2020
Stereum sp.				✓	-
Pholiota sp.				✓	-

Figure 4. Kalipoh Village Karst Forest, Ayah, Kebumen, Central Java, Indonesia

Potential as a medicine

Macrofungi are valuable sources of pharmacologically active ingredients, and their use as medicine provides a wide range of benefits, such as antibacterial and antioxidant properties. Several species of fungi have potential as medicine, including *Cortinarius* sp., *D. spathularia*, *Fomitopsis* sp., *G. lucidum*, *Ganoderma* sp., *M. candidus*, *M. delectans*, *M. chlorophos*, *P. arcularius*, *S. ostrea*, *Trametes* sp., and *Xylaria* sp. While some of these fungi are known to contain specific drugs, others have yet to be fully characterized. For instance, *Cortinarius* sp. has exhibited antibacterial and anticancer properties; *D. spathularia* contains bioactive compounds with potential antibacterial properties; *G. lucidum* contains polysaccharides and proteins and is used as an antimicrobial; *Ganoderma* sp. contains Ganoderic acid, which can neutralize and reduce compounds that cause various diseases; *M. delectans* has demonstrated both antibacterial and antioxidant effects; *M. chlorophos* is an antimicrobial agent; *P. arcularius* exhibits antibacterial and antifungal activity; *Trametes* sp. has antioxidant properties, and *Xylaria* sp. is an antibacterial agent (Fauzi et al. 2018; Kumar et al. 2019; Putra 2020; Qi et al. 2021; Sudarwati and Fernanda 2021).

Poisonous fungi

This study has identified *G. dryophilus*, a poisonous and inedible fungus due to its tough texture that makes it unsuitable for human consumption and harmful to health (Suryani and Cahyanto 2022). Additionally, the fungus has the ability to accumulate Cadmium (Cd) compounds from the soil, which, if ingested, can lead to adverse health effects in humans, such as chronic kidney failure and increased risk of cancer (Yamaç et al. 2007; Wulandari et al. 2021).

Potential for ecology or environment

From an ecological perspective, macrofungi play a crucial role in maintaining ecosystems by improving soil fertility and overall environmental conditions. Certain fungal species, such as *Ceriporiopsis* sp., *Collybia* sp., and *Pholiota* sp., have demonstrated significant potential for improving ecological and environmental health. For instance, *Ceriporiopsis* sp. produces enzymes like lignin peroxidase, manganese peroxidase, and laccase, which have been utilized in waste treatment and bioethanol production (Sari et al. 2016). *Collybia* sp. is known for its ability to decompose litter effectively (Putra et al. 2018). Similarly, *Pholiota* sp. has been found to contain enzymes capable of decolorizing the color components in textile industry waste (Hadi et al. 2020), thereby reducing environmental pollution.

Fungi with undiscovered potential

In this study, there were several species of macrofungi, including *Bulgaria* sp., *Exidia* sp., *M. reniformis*, *M. elegans*, *M. haematocephallus*, *M. siccus*, *Marasmius* sp., *Pycnoporus* sp., *R. setosus*, and *Stereum* sp., whose potential is not known yet, hence further research is needed to determine the potential of these species.

This study concludes that the Kalipoh Village forest in Ayah, Kebumen provides good biotic and abiotic conditions for macrofungal growth. Based on the diversity index values, the area has moderate diversity, good richness, and evenness. Macrofungi in this area commonly inhabit dead tree trunks and litter. Of the 34 species identified, 24 have known potential while the remaining 10 species require further study. Some species were known to have potential benefits such as food, medicine, poisonous, and environmental stability, while other were known to be toxic to living things. Consequently, caution is advised when dealing with unknown macrofungi.

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Comparison of plant diversity between managed and unmanaged forests in Haftkhal, Mazandaran Province, North of Iran

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Abstract. *Kiasari MSh, Sagheb-Talebi Kh, Rahmani R, Ghelichnia H. 2023. Comparison of plant diversity between managed and unmanaged forests in Haftkhal, Mazandaran Province, North of Iran. Asian J For 7: 107-114.* The relationship of plant diversity with silvicultural practices has not been fully understood for the oriental beech forests (*Fagus orientalis* Lipsky), which is a widespread forest tree in the Hyrcanian Region, Iran. The implementation of appropriate forestry practices in the oriental beech forests is therefore crucial in terms of sustainable forest management. Hence, assessing the impacts of silvicultural practices on plant diversity is essential with the regard to sustainable forest management. This study aimed to compare plant species diversity between two managed and unmanaged forest stands in Mazandaran Province, Iran. Forest inventory in an area of 131 ha was performed using in a systematic random sampling with a 150 × 200 m grid size. In addition, the area of sampling was 100 m^2 (10 × 10 m). Twenty and thirty sampling plots were established in managed (compartment No. 8) and unmanaged (compartment No. 36) forests, respectively. Shannon-Wiener and Simpson Indices were used to calculate plant species diversity, while Margalef and Sheldon indices were used to determine species richness and evenness, respectively. The results revealed that 50 and 56 plant species were found in managed and unmanaged forests, respectively. Rosaceae, Asteraceae, and Fabaceae were the main families in these studied areas. This study showed that the diversity and richness of plants in the managed forest slightly increased compared to the unmanaged forest. On the other hand, the evenness of plants in the managed forest slightly decreased compared to the unmanaged forest. Changes in plant diversity indices between managed and unmanaged forests were not statistically significant. This research showed that forest management of oriental beech forests using the single-tree selection cutting has not reduced or weakened the diversity of plant species in the managed forest compared to the unmanaged forest.

Keywords: Biodiversity indices, evenness, Hyrcanian forests, richness, single-tree selection cutting

INTRODUCTION

A decrease in the diversity of plant species reduces forest ecosystem services. Therefore, plant species diversity is one of the most important variables in evaluating the management of forest areas (Baran et al. 2018; Miller et al. 2019). The amount of plant species diversity in the forest is influenced by the location of the forest areas in terms of elevation, aspect, slope, rainfall, average temperature and fertility (Mahmodi et al. 2019; Muys et al. 2022; Tynsong et al. 2022), the type of vegetation (Lelli et al. 2019), the evolutionary stages of natural stands (Mohammadnezhad-Kiasari et al. 2018), the type of management (Kazemi et al. 2015; Wulandari et al. 2018), the history of forest exploitation (Nasiri et al. 2022) and the influence of canopy gaps size (Hamrang et al. 2014). Numerous studies have shown that the protection of forest areas increases the biodiversity of plant species compared to abandoned forests (Miller et al. 2019; Muys et al. 2022; Opuni-Frimpong et al. 2021; Rezaipoor et al. 2022). Furthermore, according to some studies, the partial and scattered exploitation of forest areas has caused an increase in plant species diversity compared to unmanaged forests (Hosseinpour et al. 2019; Amini et al. 2021). The implementation of forestry plans in managed forests affects the plant species diversity due to the protection of forest areas (Miller et al. 2019; Rezaipoor et al. 2022), forestation activities (Pourbabaei et al. 2012), the implementation of silvicultural practices, the stand structure changes (Sefidi et al. 2022), the creation of man-made canopy gaps (Amini et al. 2021; Mirzazadeh et al. 2022), road construction and the removal of wood from the forest (Mohammadnezhad-Kiasari et al. 2020).

Hyrcanian forests in Iran are approximately 800 km long and 110 km wide with a total area of 1.85 million ha, or equivalent to 15% of the total Iranian forests and 1.1% of the country area (Sagheb-Talebi 2017). These forests in northern Iran have important tree and shrub elements of Euro-Siberian; among them, oriental beech (*Fagus orientalis* Lipsky) is one of the most important industrial species and widely covers from the Western to the Eastern Hyrcanian region (Espahbodi et al. 2021; Nasiri et al. 2022). Oriental beech is native to Eurasia, from Eastern Europe to Western Asia, and the implementation of appropriate management in beech forests is highly important due to economic and ecological values (Sagheb-Talebi et al. 2014; Francesco et al. 2023).

Over the past two decades, many areas of productive forests in the north of Iran have been managed using the uneven-aged mixed forest method with the single-tree selection cutting (Alipour and Mohammadnezhad-Kiasari 2017). Initially, many areas of oriental beech forests in the north of Iran have been managed using the even-aged forest method with the shelterwood cutting system. The results of numerous researches on the effect of shelterwood cutting system on stand structure and regeneration abundance have confirmed that instead of shelterwood cutting system, other silvicultural practices such as the single-tree selection cutting should be applied for the mountainous beech stands of Hyrcanian forests. The selection silvicultural system is a system of tree harvesting in which one (tree-selection) or a few (group-selection) numbers of trees are being cut at each intervention (Pourmajidian et al. 2010; Sagheb-Talebi et al. 2014; Habashi and Waez-Mousavi 2018; Nasiri et al. 2022). In the context of this study, forest management is referred to the single-tree selection cutting.

There have been previous studies that used the diversity of plant species to evaluate forestry plans with the single-tree selection cutting in the lower and middle altitude areas in the north of the country (e.g., Pourbabaei et al. 2012; Hosseinpour et al. 2019; Amini et al. 2021). Nonetheless, no similar study has been conducted in Hyrcanian forests at high elevation. Therefore, this study is the first to evaluate forestry plans with the single-tree selection cutting in the high altitude areas of Mazandaran Province. This study was conducted to analyze the diversity of woody species (trees and shrubs), herbaceous species, and natural regeneration, as well as all plant species between the managed and unmanaged (control) forests. In this research it is assumed that the management of forest using the single-tree selection cutting did not have a significant negative effect on the diversity of plant species. The results of this study can be potentially useful for all foresters and ecologists working in other Fagus-dominated forests worldwide, particularly those dominated by *Fagus sylvatica* L. in Europe, which seem to be highly similar to the oriental beech forests in the north of Iran.

MATERIALS AND METHODS

Study area

This study was performed in the northern forests of Iran known as the Hyrcanian forests (Neka City, Mazandaran Province, Iran) (Figure 1). The management of forests in the north of the country takes place in the form of a ten-year forestry plan and is regulated at the extent of 1000 to 2000 ha. The annual implementation of the forestry plan is also carried out at smaller extent of 50 to 70 ha, which is called compartment. Each compartment is a management unit. We used compartment No. 8 to represent managed forest using the single-tree selection cutting and had been applied two stages of harvest, i.e., 2688 m^3 of wood were harvested for the first stage (2004) and 1266 m^3 for the second stage (2014). The unmanaged forest was represented by compartment No. 36, which was a protected forest and never been harvested. To be comparable, these managed and unmanaged forests had similar edaphic conditions and the least economic and social problems or issues such as the presence of mines and landfill sites (Forest and Rangelands Organization of Iran 2011).

The total studied forest had an extent of 131 ha, and it was located between 53° 31′ 55″ to 53° 33′ 18″ E and 36° 20′ 41″ to 36° 21′ 37″ N. Elevation ranges between 1480 and 1610 m asl. The bedrock is limestone, dolomitic limestone, and marl limestone, and the pH is approximately 7.7-8.2. The texture of the soil is silt loam at the medium level and clay at the bottom depth. The soil depth is about 80 to 85 cm, and the root penetration depth is 65 to 70 cm. Furthermore, the mean annual precipitation is 618.8 mm, and the mean annual temperature is 14.7°C. The climate is moderate semi-humid according to the Emberger climate classification (Forest and Rangelands Organization of Iran 2011).

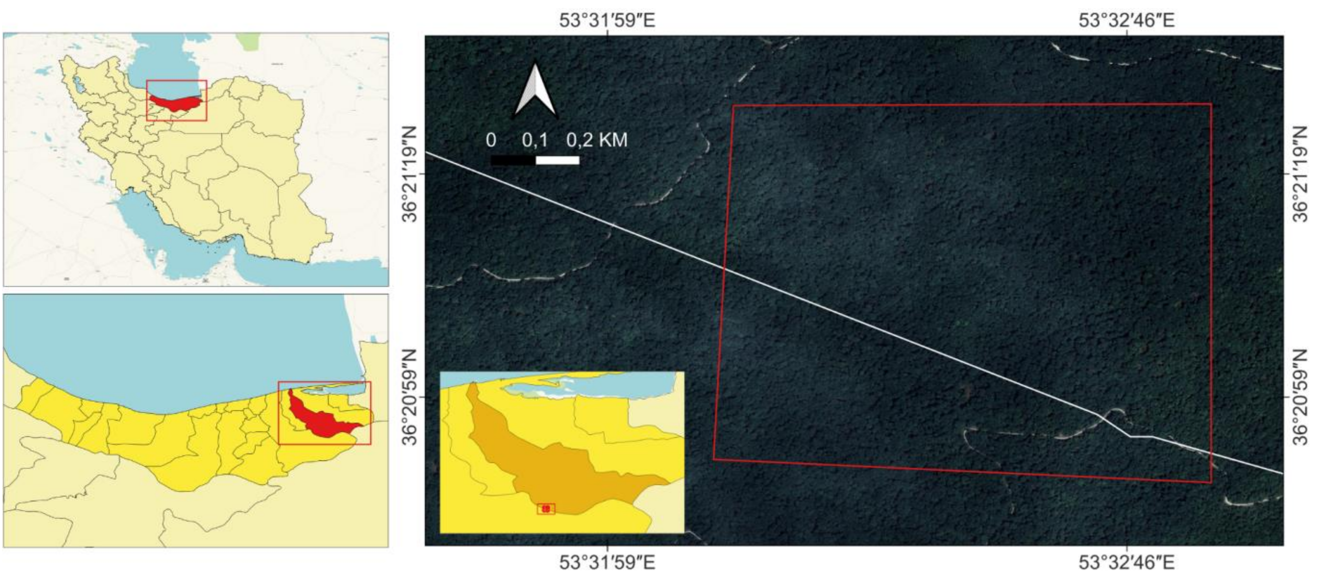

Figure 1. Location of study areas in the Neka forests, Mazandaran Province, Iran

After field inspection and based on the forestry plan information, two adjacent compartments were selected that were similar in terms of soil type, plant community, and site quality. The forests of the studied areas included broad-leaved trees of different ages, and in terms of composition, they included pure beech with a mixture of other hardwood species. The average number of trees per ha were 322.22 and 297.65 trees, the average basal areas per ha were 26.25 m^2 and 22.37 m^2, the average diameter of trees were 34.69 cm and 32.19 cm and the average height of trees were 24.89 m and 24.58 m in unmanaged and managed forests respectively. Also, the average rates for total regeneration abundance were accounted for 109.52 and 129 tree per 100 m^2 in unmanaged and managed forests, respectively. Significant differences were not observed for these quantitative parameters between the unmanaged and managed forests (Mohammadnezhad-Kiasari et al. 2020).

Field sampling

The sampling of canopy coverage used systematic random method with the sampling network size was 150 × 200 m. The starting point was randomly selected, and the sampling network was systematically located on the map (Figure 1). The forest inventory was conducted on 131 hectares, which included 20 and 30 sample plots in the managed and unmanaged forests, respectively (Mohammadnezhad-Kiasari et al. 2020; Mirzazadeh et al. 2022). The inventory operations of this research was done in the middle of the summer. The average canopy cover is the most appropriate variable in the summer season to determine the diversity of plant species (Mohammadnezhad-Kiasari et al. 2018). The area of square plots was obtained by the minimal area method (Pourrahmati et al. 2018; Mahmodi et al. 2019). In the center of each plot, the canopy coverage of all plant species was estimated using the Van der Maarel criterion in 100 m^2 (10 × 10 m). The collected plant samples were identified using Colored Flora of Iran (Ghahreman 1990-1999). In this research, apart from calculating the species diversity of plants, the diversity of the variables of herbaceous species, natural regeneration, and woody species (trees and shrubs) were measured as well. In addition, given that the minimum area was different in each of the vegetation layers, the highest minimum area obtained for the variable of all plant species (100 m^2) was used for the other variables (Pourbabaei et al. 2012).

Data analysis

In this research, Shannon-Wiener (H'), Simpson (1-D), Margalef richness (R) and Sheldon evenness (E) indices were used to investigate the diversity of plant species and in different life forms (Mohammadnezhad-Kiasari et al. 2018). The Shannon-Wiener Index (H') was used due to its greater sensitivity to the abundance of rare species. Also, the Simpson diversity Index (1-D) was used due to its sensitivity to species that are present in greater abundance (Pourbabaei et al. 2012; Mirzazadeh et al. 2022). The formulas are given in Table 1.

Table 1. Biodiversity indices and their equations

Index	Equation
Shannon-Wiener (H´)	$H' = -\sum_{i=1}^{s} p_i \ln p_i$
Simpson (1-D)	$D = \sum_{i=1}^{s} \left[\frac{n_i(n_i-1)}{N(N-1)} \right]$
Margalef (R)	$R = \frac{S-1}{LnN}$
Sheldon (E)	$E = \frac{e^{H'}}{S}$

Note: H'= Shannon-Wiener, Pi = the relative frequency of the ith species, D= dominance index, N= total number of all individuals, ni= the number of individuals of the ith species, R= Margalef, E= Sheldon, S= the total number of species, e= 2.71828

After grouping and rearranging the data, the normality of the data was evaluated with the Kolmogorov-Smirnov test, and the homogeneity of variances was evaluated with the Levene test. The indices of diversity, richness, and evenness in different life forms were calculated using PAST software (Hosseinpour et al. 2019; Amini et al. 2021). Then, the average of each of these data was compared between the managed and unmanaged forests using independent samples *t* test using SPSS version 18 (SPSS Inc., Chicago, Ill, USA).

RESULTS AND DISCUSSION

In the unmanaged forest, 56 plant species belonging to 30 families and 51 genera were recorded. The most species-rich families were Rosaceae, Asteraceae, and Fabaceae, with 6, 4, and 3 genera and 6, 4, and 4 species, respectively. In this forest, 8 tree species, 3 shrub species, and 45 herbaceous species were identified. On the other hand, in the managed forest, 50 plant species belonging to 31 families and 49 genera were recorded. The most species-rich families were Rosaceae, Asteraceae, and Fabaceae, with 5, 4, and 3 genera and 5, 4, and 2 species, respectively. In this forest, 6 tree species, 3 shrub species, and 41 herbaceous species were identified. Also, the life forms in these forests include cryptophytes at 36.06%, hemicryptophytes at 34.43%, phanerophytes at 26.23%, and chamaephytes at 3.28%, respectively (Tables 2 and 3).

The means of different biodiversity indices for herbaceous species (Table 2) in managed and unmanaged forests are presented in Table 4. This research showed that based on the single-tree selection cutting, there were no significant differences in the managed and unmanaged compartments in terms of herbaceous species. However, the mean of diversity (Shannon-Wiener and Simpson indices), richness (Margalef index), and evenness (Sheldon index) of herbaceous plants in the managed forest had a slight increase compared to the unmanaged forest (Table 4).

Table 2. The recorded herbaceous species and the average percentage of their presence in the unmanaged and managed forests

Scientific name	Family name	Life form	The presence of each species	
			Unmanaged forest	Managed forest
Sanicula europaea L.	Apiaceae	He	23.53	14.81
Dryopteris filix-mas (L.) schott	Aspidiaceae	Cry	22.22	11.76
Polystichum aculeatum (L.) Roth.	Aspidiaceae	Cry	7.41	0
Asplenium adiantum-nigrum L.	Aspleniaceae	Cry	3.70	5.88
Phyllitis scolopendrium (L.) Newm.	Aspleniaceae	Cry	7.41	5.88
Athyrium filix-femina (L.) Roth.	Athyriaceae	Cry	25.93	17.65
Erigeron acer L.	Asteraceae	He	3.70	17.65
Lapsana communis L.	Asteraceae	He	7.41	7.41
Sonchus oleraceus L.	Asteraceae	Cry	7.41	7.41
Tussilago farfara L.	Asteraceae	Cry	44.44	41.18
Sambucus ebulus L.	Caprifoliaceae	He	3.70	11.76
Stellaria media (L.) Cyr.	Caryophyllaceae	Cry	37.04	58.82
Calystegia sepium (L.) R. Br.	Convolvulaceae	He	0	5.88
Convolvulus arvensis L.	Convolvulaceae	He	0	5.88
Sedum stoloniferum S. G. Gmel.	Crassulaceae	He	7.41	5.88
Carex sylvatica L.	Cyperaceae	Cry	70.37	58.82
Tamus communis L.	Dioscoraceae	Cry	11.11	11.76
.*Euphorbia amygdaloides* L	Euphorbiaceae	He	3.70	0
Mercurialis perennis L.	Euphorbiaceae	Cry	3.70	0
Lathyrus laxiflorus (Desf.) O. Kuntze	Fabaceae	Cry	7.41	52.94
Lathyrus vernus (L.) Bemh.	Fabaceae	He	7.41	17.65
Polygonum hydropiper L.	Fabaceae	Cry	3.70	0
Rumex acetosa L.	Fabaceae	He	3.70	11.76
Hypericum androsaemum L.	Hypericaceae	Ch	29.63	35.29
Calamintha aquatic L.	Lamiaceae	He	7.40	5.88
Calamintha officinalis Moench	Lamiaceae	Cry	29.63	41.18
Lamium album L.	Lamiaceae	He	59.26	47.06
Circaea lutetiana L.	Onagraceae	Cry	11.11	0
Cephalanthera caucasica Kranzl	Orchidaceae	Cry	5	17.65
Epipactis persica (Soo) Nannfeldt	Orchidaceae	Cry	33.33	23.53
Chelidonium majus L.	Papaveraceae	He	66.67	47.06
Bromus adjaricus Sommier & Levier	Poaceae	Cry	29.63	52.94
Poa nemoralis L.	Poaceae	Cry	22.22	17.65
Geranium robertianum L.	Poaceae	Cry	25.93	0
Cyclamen coum Miller	Primulaceae	Cry	37.04	5.88
Primula heterochroma vulgaris L.	Primulaceae	He	25.93	47.06
Fragaria vesca L.	Rosaceae	He	29.63	29.41
Geum kokanicum Regel & Schmalh	Rosaceae	He	3.70	0
Asperula odorata L.	Rubiaceae	He	100	51.85
Galium verum L.	Rubiaceae	He	3.70	0
Galium rotundifolium L.	Rubiaceae	He	7.41	11.76
Solanum kieseritzkii C. A. Mey	Solanaceae	Ch	29.63	0
Solanum nigrum L.	Solanaceae	Cry	7.41	5.88
Urtica dioica L. *var. dioica*	Urticaceae	He	0	5.88
Viola odorata L.	Violaceae	He	59.26	64.71

Table 3. The recorded woody species and the average percentage of their presence in the unmanaged and managed forests

Scientific name	Family name	Life form	The presence of each species	
			Unmanaged forest	Managed forest
Ilex aquifolium L.	Aquifoliaceae	Ph	44.44	11.76
Danae racemosa (L.) Moench	Asparagaceae	Ph	11.11	17.65
Ruscus hyrcanus Woron.	Asparagaceae	Ph	18.52	17.65
Hedera pastuchovii L.	Araliaceae	Ph	0	5.88
Alnus subcordata C. A. Mey.	Betulaceae	Ph	14.81	11.76
Carpinus betulus L.	Betulaceae	Ph	92.59	100
Fagus orientalis Lipsky	Fagaceae	Ph	100	100
Quercus castaneifolia C. A. Mey.	Fagaceae	Ph	29.63	47.06
Acer cappadocicum Gled.	Sapindaceae	Ph	7.41	0
Acer velutinum Boiss.	Sapindaceae	Ph	85.18	82.35
Crataegus melonocarpa M.B.	Rosaceae	Ph	48.15	58.82
Mespilus germanica L.	Rosaceae	Ph	14.81	23.53
Prunus spinosa L.	Rosaceae	Ph	25.93	41.18
Rubus hyrcanus Juz.	Rosaceae	Ph	18.52	17.65
Tilia platyphylloss Scop. subsp. caucasica	Tiliaceae	Ph	22.22	11.76
Ulmus glabra Hudson	Ulmaceae	Ph	3.70	0

The means of different biodiversity indices for the variables of natural regeneration and woody plants (Table 3) in managed (using the single-tree selection cutting) and unmanaged forests are presented in Table 5, while those for all plant species can be seen in Figure 2. There was no significant difference between the managed and unmanaged compartments with regard to these variables. The mean of the diversity (Shannon-Wiener and Simpson Indices) and richness (Margalef Index) of natural regeneration, woody species, and all plant species in the managed forest represented a slight increase in comparison to the unmanaged forest. On the other hand, the mean of the evenness (Sheldon Index) of these variables in the managed forest had a slight decrease compared to the unmanaged forest (Table 5, Figure 2).

Table 4. Mean, standard deviation and *t* test of the mean biodiversity indices in herbaceous species layer

Vegetation layer	Biodiversity indices	Mean in managed forest	Mean in unmanaged forest	T	P-Value
Herbaceous species	H´	2.348±0.304	2.214±0.763	0.686	0.497
	1-D	0.896±0.032	0.828±0.245	1.132	0.264
	R	2.614±0.700	2.606±1.198	0.027	0.979
	E	0.962±0.024	0.960±0.027	0.182	0.857

Note: H′= Shannon-Wiener diversity, 1-D= Simpson diversity, R= Margalef richness, E= Sheldon evenness

Table 5. Mean, standard deviation and *t* test of the mean biodiversity indices in different vegetation layers

Vegetation layers	Biodiversity indices	Mean in managed forest	Mean in unmanaged forest	T	P-Value
Natural regeneration	H´	1.432±0.230	1.359±0.344	0.779	0.441
	1-D	0.742±0.063	0.713±0.111	0.958	0.344
	R	1.094±0.255	1.020±0.326	0.839	0.432
	E	0.947±0.050	0.951±0.037	0.263	0.795
Woody species (tree and shrub)	H´	1.379±0.233	1.313±0.310	0.801	0.428
	1-D	0.711±0.067	0.689±0.102	0.875	0.387
	R	1.196±0.294	1.092±0.343	1.061	0.295
	E	0.866±0.049	0.889±0.039	1.615	0.117

Note: H′= Shannon-Wiener diversity, 1-D= Simpson diversity, R= Margalef richness, E= Sheldon evenness

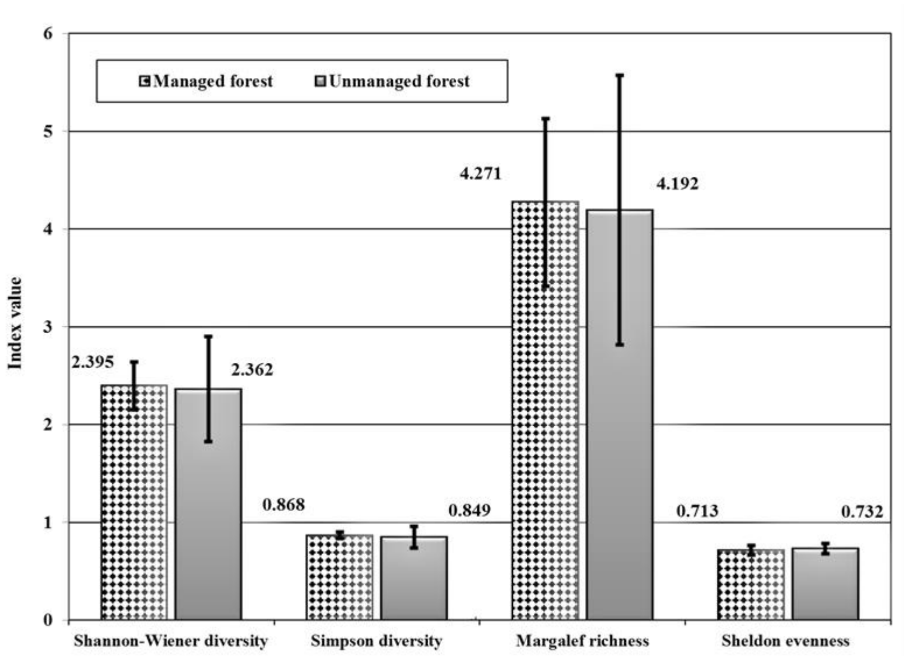

Figure 2. Mean of diversity indices and their standard deviation for plant species

Discussion

The Fagus (beech) genus is one of the most abundant and economically important hardwood genera in the northern hemisphere temperate forests. Beech forests play a primary role in the context of climate change mitigation and biodiversity conservation. They are also the primary sources of timber and firewood (Latterini et al. 2023). So far, 20 beech species have been identified, while all these species are distributed in the northern hemisphere, and only the oriental beech (*F. orientalis*) occurs in Iran. The oriental beech belt is connected to the European forests and plant composition in this study is highly similar to Balkan's beech forests. The natural range of the oriental beech tree's extends from southeastern Bulgaria's Strandja mountain, through northwest Turkey, and east to the Caucasus Mountains in Georgia and Russia, to the Alborz Mountains in Iran (Sagheb-Talebi et al. 2014).

Biodiversity loss is a major threat to ecological, social, and economic stability. Different forest management practices have various different impacts on biodiversity. In managed forests, biodiversity is often extremely lower than in natural forests, mainly due to the decrease of diversity in relationship with tree species, the heterogeneity of tree age, and special habitat niches, such as deadwood or tree microhabitats. Forest management traditionally focused on wood production but has now evolved to include multiple ecosystem services. With this new approach, forest management is a key driving factor to restore, maintain, and promote biodiversity in forests (Muys et al. 2022). On the other hand, protected areas are vital for conserving biodiversity and minimizing biodiversity loss. Protected forests have become a vital component of the biodiversity conservation strategy due to the increasing extinction and vulnerability of different species (Opuni-Frimpong et al. 2021). The current study sought to evaluate forest management using the single-tree selection cutting regime by comparing the diversity of plant species with unmanaged forests.

The use of plant species diversity measures has become one of the most important variables in evaluating the sustainability of forest operations (Kazemi et al. 2015; Hosseinpour et al. 2019; Rezaipoor et al. 2022). Diversity is affected by richness and evenness. Therefore, apart from determining the average species diversity of plants, the average amount of richness and evenness variables is calculated. In this study, the indices of richness, evenness, and diversity in various variables did not show a significant difference between the managed and unmanaged forests. These results are mostly related to the choice of the single-tree selection cutting in forest management and its correct implementation (Eshaghi et al. 2009; Tavonkar et al. 2011; Kazemi et al. 2015; Hosseinpour et al. 2019). The effects of forest management regime were investigated by the single-tree selection cutting on tree diversity indices in the Watson Forest (Eastern Mazandaran Province), representing that after the 10-year period of the implementation of the forest management, the species diversity indices increased by 30% of the area. Approximately 60% of the area remained unchanged, while about 11% of the area had reduced species diversity (Hosseinpour et al. 2019). In another study, after the implementation of the forest management regime using the single-tree selection cutting, the variations of woody species diversity were evaluated in the Beech-Hornbeam and Hornbeam stands of the Janbe-Sara District located in the west of Guilan Province. In this research, shrub and tree species sampling was applied in the first and last year of the 10-year period. The results revealed that species richness with Simpson and Shannon-Wiener diversity indices in Hornbeam and Beech-Hornbeam stands somewhat increased with no significant differences (Eshaghi et al. 2009). Moreover, the impact of the implementation of the single-tree selection cutting on the diversity of tree species in the forests of Nave-Asalem, Guilan Province, demonstrated that the index of species diversity in all stages of seedlings, young stems, and trees at the end of the 10-year period had a slight increase compared to the beginning of the period, but these increases were not statistically significant (Tavonkar et al. 2011). The study of the effect of forest management on plant diversity in two unmanaged (protected) and managed compartments in the lower altitude area of a forestry plan in Khalil-Mahalleh, Mazandaran Province indicated that the indices of the diversity and richness of woody species and herbaceous species were more in the managed compartment than in the unmanaged compartment (Kazemi et al. 2015).

In the single-tree selection cutting, exploitation is carried out in all storeys and scattered in all parts of the forest. Also, creating and maintaining uneven-aged mixed forests is one of the important goals of this system (Marvie-Mohajer 2018). The effects of low-intensity exploitation management are similar to the natural changes (Baran et al. 2018). In this regard, other research results in Haftkhal forest areas showed that quantitative and qualitative parameters of trees in managed and unmanaged forests did not differ significantly (Mohammadnezhad-Kiasari et al. 2020). On the contrary, another study investigated two managed compartment and unmanaged (protected) compartment forest stands in the Larvechal, Golband forestry plan in the west of Mazandaran Province were investigated. The results of plant species diversity in the managed and unmanaged forests showed that the richness and evenness of average tree species were 2.43 and 3.37, as well as 0.78 and 0.71, respectively. According to the Shannon-Wiener diversity index, the average tree species was 0.57 and 0.79, while based on the Simpson diversity index, it was 0.34 and 0.43. In addition, the average of all diversity indices of herbaceous species was higher in the unmanaged forest than in the managed forest. It should be explained that there were statistically significant differences between managed and unmanaged forests regarding diversity indices values. Based on the finding, their destruction of forest stands caused by cutting trees and livestock grazing in managed forests led to a sharp decrease in the diversity indices of plants compared to the unmanaged compartment (Kazemnezhad et al. 2011). In another study, the effect of protection on plant species diversity was examined Dr. Dorostkar Forest Reserve and Gisum Forest Park in the Talash region, Guilan Province.

The results of this research revealed that the average amount of richness, evenness, and diversity indices of tree species and herbaceous species was higher in the protected forest (Dr. Dorostkar Forest Reserve) than in the unprotected forest (Gisum Forest Park). Plant species in the park were heavily influenced by recreational activities and livestock grazing (Rezaipoor et al. 2022). Overall, it is obvious that for the management of forest areas, apart from the correct implementation of the forestry plan, it is necessary to take care of the non-entry of domestic animals and avoid economic and destructive human activities in the forest areas (Kazemnezhad et al. 2011; Rezaipoor et al. 2021).

Another noteworthy point is the biodiversity parameters of Shannon-Wiener and Simpson Indices with the Margalef richness of various vegetation layers had a slight increase in the managed forest than in the unmanaged forest. In the natural state, the presence of dead trees on the forest surface provides more space, light, and moisture for herbaceous plants, natural regeneration, and the growth of young trees (Eshaghi et al. 2009; Sagheb-Talebi 2017). The implementation of the Haftkhal management plan with the single-tree selection cutting during two stages (2005 and 2015) caused the creation of small and medium gaps scattered in the level of the managed forest (Mohammadnezhad-Kiasari et al. 2020). The effects of implementing two stages of tree harvesting in Haftkhal forests in terms of the values of Margalef richness, Sheldon evenness, Simpson diversity, and Shannon-Wiener diversity for herbaceous species in the managed forest were slightly increased compared to the unmanaged forests. However, it should be noted that if the area of gaps increases in the single-tree selection cutting, the frequency and percentage of invasive species coverage will increase as well (Hamrang et al. 2014). In this regard, the results of a study showed that medium-sized man-made gaps (150-300 m^2) had the highest value of richness, diversity, and regeneration density compared to the categories of small (20-150 m^2), and large (more than 300 m^2) man-made gaps (Amini et al. 2021). In general, similar to several other studies in the lower and middle altitude forests in the north of the country (Eshaghi et al. 2009; Tavonkar et al. 2011; Hosseinpour et al. 2019), the present research showed that the forest management with the single-tree selection cutting did not have a negative effect on the plant species diversity in the high altitude forest of Mazandaran Province.

Based on the results of this research, it is recommended the forest management regime for production forests should be implemented with the single-tree selection cutting. Of course, in these production forests, it is necessary to take care of the non-entry of domestic animals and avoid economic and destructive human activities. Creating and maintaining uneven-aged mixed forests are among the important goals of this system. To achieve this goal, exploitation should be performed with low intensity in all layers and scattered in all parts of the forest. Additionally, the small and medium gaps should be dispersed in all levels of the managed forest. In these circumstances, the forest management has no negative effect on the plant species diversity.

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Woody plant diversity and aboveground carbon stock of *Dipterocarpus chartaceus* dominant forests in Binh Chau-Phuoc Buu Nature Reserve, South Vietnam

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Abstract. *Hop NV, Quy NV, Lam NV, Trong PT, Thinh PC. 2023. Woody plant diversity and aboveground carbon stock of* Dipterocarpus chartaceus *dominant forests in Binh Chau-Phuoc Buu Nature Reserve, South Vietnam. Asian J For: 115-125.* The dominant forest of *Dipterocarpus chartaceus* Symington in Binh Chau-Phuoc Buu Nature Reserve, South Vietnam, has an important ecological role and high conservation value relevant to climate change by storing large amounts of CO_2 from the atmosphere. This study assesses the diversity of woody plants and estimates biomass and carbon stocks in different forest states. The study used a typical sample plot setting method was used. Trees with a Diameter at Breast Height (DBH) > 6 cm were measured, and species were identified in 9 sample plots of 50m x 20m in the very poor, poor, and medium forests. A total of 640 tree individuals belonging to 45 species, 34 genera, and 25 families were recorded. The most species-rich family was represented by Dipterocarpaceae (7 species). A total of 15 threatened species (33.33%) belonging to 11 genera from 8 families were listed in the Vietnam Red Data Book (2007) and IUCN Red List (2022). The Margalef (d), Shannon-Wiener (H'), Simpson (Cd), and Sorensen Index (SI) were analyzed for tree species. The study illustrated that medium forests had the highest diversity, followed by poor forests, and the lowest belonged to very poor forests. The ability to accumulate biomass and aboveground carbon stocks varied widely from 48.15 t/ha-196.15 t/ha and 24.07 Ct/ha-98.42 Ct/ha. The medium forest had the highest total carbon stock, followed by the very poor forest and the lowest poor forest. The study provides an essential database for strategies and plans for conserving plant biodiversity and improving the power of CO_2 accumulation to adapt to climate change.

Keywords: AGB, biomass, carbon assimilation, DBH, Dipterocarp forest, plant diversity, Vietnam

INTRODUCTION

Plant diversity, in general, and woody plant diversity, in particular, have significant roles and values for the existence and development of humanity because they are considered important resources and carbon sinks. It reduces greenhouse gas concentrations by absorbing vast amounts of carbon from the atmosphere. Meanwhile, human activities such as land-use conversion, illegal farming, and logging have reduced the area of forests worldwide; there have been increased emissions of CO_2 and greenhouse gases and which are directly affecting the global climate (Hop et al. 2021a).

Biodiversity has socio-economic and cultural value and provides many other important benefits such as climate regulation, waste decomposition, reduction of negative impacts of natural disasters, and especially the potential for carbon storage. Previous studies have shown that the key biodiversity areas and biodiversity corridors with developed forest vegetation, such as the Northeast, Northwest, Central Coast, and Central Highlands, are where total biomass carbon storage is highest (Ministry of Natural Resources and Environment 2013; Hop et al. 2021b). Plant diversity and carbon stocks have been hot topics of interest since the last century. This is a big issue that has been and is being given focus by many countries worldwide. However, this topic has not yet received due attention, commensurate with the potential of plant biodiversity in Vietnam (Hop et al. 2021b), one of the global biodiversity centers.

Biodiversity and carbon stocks play an important role in the context of increasingly complex climate change (Hop et al. 2020). In Asia, some typical studies on this topic have been carried out. This issue was only implemented in Vietnam on evergreen broad-leaved objects, deciduous forests from the North to South Central (Hop et al. 2021b), and Highlands (Hop et al. 2021b). At the same time, most other studies on plant diversity and carbon stocks have been conducted independently. Simultaneous biodiversity and carbon stock studies have been conducted on some vegetation types. However, these are still very limited and inadequate to the potential of forest ecosystem diversity, vegetation types, and land use types in Vietnam (Hop et al. 2021b).

Moreover, studying biodiversity and carbon stocks has practical and important implications for the REDD+ program. However, reality has shown that improving carbon stock capacity and promoting biodiversity can hardly be done simultaneously due to limitations in human resources, finances, management capacities, etc. (Mandal et al. 2013; Hop et al. 2021b). Therefore, studies about quantifying forest carbon stock and plant diversity have been conducted worldwide. However, many forest ecosystems and vegetation types have remained unexplored (Japitana et al. 2020), especially the *Dipterocarpus chartaceus* Symington dominant forest in Binh Chau-Phuoc Buu Nature Reserve, South Vietnam.

Binh Chau-Phuoc Buu Nature Reserve (NR) was established in 1996 in southern Vietnam's Dipterocarp forest ecological region, one of the biodiversity conservation areas highly prioritized by WWF (Baltzerm et al. 2001; Bang et al. 2013). The primary vegetation type is a tropical moist, semi-evergreen closed forest (Baltzerm et al. 2001; Bang et al. 2013). including sub-types: Semi-evergreen closed forest on sandy soil, Semi-evergreen closed forest on basalt, Dipterocarp forest on sandy soil, and grassland (Baltzerm et al. 2001; Bang et al. 2013). A new species for science and a new record for Vietnam flora were found, such as *Stereospermum binhchauensis* (Son 2015), *Kaempferia champasakensis* (Van et al. 2018), etc. A total of 732 plant species were recorded (Minh 2019), of which 121 species, 113 genera 63 families were identified as having medicinal value (Hop and Huong 2017), and many endangered, precious, and rare species, such as *Dalbergia bariensis*, *Afzelia xylocarpa*, *D. chartaceus*, etc. (Minh 2019). The *D. chartaceus* and other plants form the dominant forest of *D. chartaceus*. It is considered an endemic plant species of the Nature Reserve. Moreover, up till now, no quantitative studies of plant diversity and carbon have been conducted in the *D. chartaceus* forest of Binh Chau-Phuoc Buu Nature Reserve. This study aims to (i) quantitatively evaluate some plant diversity indexes and (ii) identify the potential of the *D. chartaceus* forest in Binh Chau - Phuoc Buu as a valuable carbon pool.

MATERIALS AND METHODS

Study area

The study was carried out from July to December 2021 in Binh Chau - Phuoc Buu Nature Reserve, Ba Ria - Vung Tau Province, Vietnam (10°28’65" to 10°38’04" North Latitude and 107°24’77" to 107°33’52" East Longitude) (Figure 1). The total natural area was 10,400.9 ha of flat terrain and low slope. The flat area occupies the most significant area, about 9,000 ha. The hilly area had an area of about 600ha; the coastal sandy area covers about 500 hectares, and the lake area has about 200 hectares. The Nature Reserve was located in the tropical rainy season. The average annual rainfall was 1,396 mm; from May to October, the rainy season was concentrated in July, August, and September. The dry season was from November to April next year. The average annual temperature was 25.3°C, and the average annual air humidity was 85.2%. The dominant forest of *D. chartaceus* was distributed on typical coastal sandy soil near the wetlands and swamps. Besides, the slope was less than 5°, an altitude of 20 m-35 m above sea level, often affected by a forest fire. This type of forest forms patches of land surrounding wetlands or forms small patches (Hop and Huong 2017).

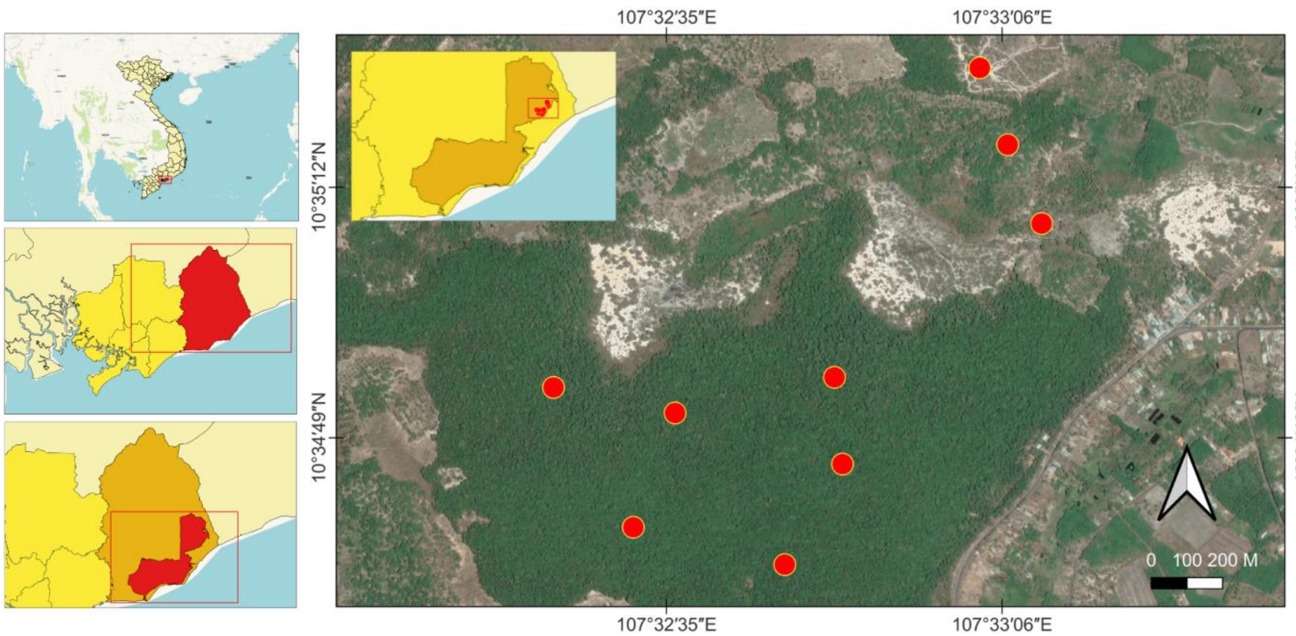

Figure 1. Map of the study area and sample plots of investigation in Binh Chau - Phuoc Buu Nature Reserve, Xuyen Moc District, Ba Ria - Vung Tau Province, Vietnam

Field survey

Based on the preliminary survey results and the current forest status map in 2020, the location of the samples was set up using typical samples representing three forest states (very poor, poor, and medium forests). Then based on the terrain, sample plots were arranged in the field and adapted to the investigation site. Nine sample plots of 50m x 20m were divided equally among very poor, poor, and medium forests. The location of the sampling plots was recorded using the Global Positioning System (GPS 64s) device. The tree individuals with more than 6 centimeters DBH were considered for measuring the total height (Hvn) and DBH (Figure 1).

Data analysis

Determination of the forest status

The forest status name (forest type) was identified and described according to Circular 33/2018/TT of the Ministry of Agriculture and Rural Development, Vietnam (Ministry of Agriculture and Rural Development. 2018), which includes (i) Very poor forest: from 10 to 50 m^3/ha, (ii) Poor Forest: from 50 to 100 m^3/ha, (iii) Medium forest: from 100 to 200 m^3/ha.

Plant species identification

The collecting and processing of plant samples were carried out, according to Thin (1997). Comparative morphological and expert methods were used to treat and identify plant specimens, and voucher specimens were deposited in the Vietnam National University of Forestry - Dong Nai Campus. We used the technical documents of (Ho 1999-2003) and (Hop 2002) were consulted to determine species names that did not have specimens for comparison. The accepted scientific name of the plants was checked with Plants of the World Online (2022) and World flora online (2022). The plant species list was arranged according to Brummitt (1992).

Determination of threatened species

Threatened species were identified according to the Vietnam Red Data Book (Ministry of Science and Technology 2007) and the IUCN Red List (2021) (updated September 2022).

Some plant diversity indices

Margalef Index (d): The Margalef Index was calculated using the formula:

$$d = \frac{s-1}{\log N}$$

Where:

d: Margalef diversity index

S: A total of species in the sample

N: A total of the individual in the sample.

Shannon – Wiener Diversity Index (H'): Shannon – Wiener Index (H') assessed species diversity in each sample plot. The species diversity outcomes were interpreted using the description by Fernando (1998): Low (H' = 1-2.49), Moderate (H' = 2.50-2.90), and High (H' = 2.91-4.0).

$$H' = -\sum_{i=l}^{s} Pi * \ln(Pi)$$

Where:
H': Shannon – Wiener Index
Pi: Ni/N
Pi: A proportion of individuals in the population
S: The number of species
Ni: The number of individuals of species i
N: A total number of individuals of all species
Ln: Log base

The concentration of dominance (Cd): The concentration of Dominance (Cd) was determined by the formula of Simpson (1949).

$$Cd = \sum_{i=l}^{s} (Pi)^2$$

Where:
Cd: Concentration of Dominance Index or the Simpson Index.
Pi: Ni/N
Ni: Number of individuals of species i
N: Total number of individuals of all species.

Sorensen's index: The Index of similarity (SI) was determined by the formula: SI = 2C/(A + B), where: C = the number of species in sample A and sample B; A = the number of species in sample A; B = several species in sample B.

Estimation of biomass and carbon stock

The Aboveground Biomass (AGB) of each tree was calculated for each plot using Eq. (1) for the dry forest, where rainfall was below 1500 mm/year (Brown et al. 1989). This equation was selected as it was appropriate to estimate a wide range of parameters ranging from DBH to AGB with the lowest prediction error value. Moreover, this equation was developed for semi-deciduous or deciduous forest types and DBH from 5 cm-40 cm. Besides, this equation was developed in areas having similar environmental conditions (climate and soils) in the study area.

AGB (kg/tree) = exp (- 1.996 + 2.320 * ln (DBH (cm)), DBH = 5cm - 40cm, R^2 = 0.89 (1)

For the biomass density, the total biomass per plot was multiplied by 10,000 m^2 divided by the plot size in square meters, which was 50 m x 20 m (0.1 ha). On the other hand, tree carbon stock was computed by multiplying the tree biomass with the IPCC default carbon fraction value of 50% (0.50) (Houghton et al. 1997).

C(AGB) (kg/tree) = AGB (kg/tree) * 0.50 (2)

Where:
AGB: Estimation of the Aboveground Biomass
C(AGB): Aboveground carbon stocks
DBH: Diameter (cm) at Breast Height (1.3 m).

Tree data were converted into tree biomass per unit area (ha^{-1}).

RESULTS AND DISCUSSION

Species diversity and conservation status

Species component

A total of 640 tree individuals belonging to 45 species and 34 genera, and 25 families were identified (Table 3). The most species-rich family was characterized by Dipterocarpaceae, with seven species (15.56%), followed by Anacardiaceae, with four species (8.89%); Ebenaceae and Clusiaceae, three species each (6.67%); Sapotaceae, Myristicaceae, Hypericaceae, and Annonaceae two species each (4.44%); while single species represented by 16 families each were *Syzygium* represented the most species-rich genus with four species (6.67%), followed by *Diospyros* and *Shorea* with three species each (5.50%); *Madhuca, Knema, Cratoxylum,* and *Garcinia* with two species each (3.33%); while rest 27 genera had single species. Among 45 species, *D. chartaceus* had the highest number of trees, with 244 trees (38.13%), followed by *S. roxburghii* with 75 trees (11.72%), *A. costata* with 48 trees (7.50%), while the remaining species represented 0.16%-4.06%.

Regarding species richness, there were 149 tree individuals, 17 species, and 17 genera belonging to 12 families in the very poor forest; while the poor forest had 215 trees, 25 species, and 21 genera belonging to 18 families; and the medium forest had 276 trees, 31 species, 27 genera belonging to 19 families respectively.

In terms of tree abundance, the very poor forest: *D. chartaceus* had the highest number of trees (86 trees), followed by *G. usitata* (15 trees), *A. costata* (12 trees), and the remaining species had 1-7 trees; in a poor forest: *D. chartaceus* had the highest number of trees (83 trees), followed by *S. roxburghii* (42 trees), *A. costata* (19 trees), *X. vielana* (13 trees), and the remaining species had 1-8 trees; while in the medium forest, *D. chartaceus* had the highest number of trees (75 trees), followed by *S. roxburghii* (33 trees), *A. costata* (17 trees), *X. noronhianum* (14 trees), *H. odorata* (13 trees), and the remaining species (101 trees) (Table 3).

The analysis showed that medium forest was rich in species composition and abundance in trees, followed by poor forest, and the lowest is very poor forest. In addition, the number of species and individual trees belonging to Dipterocarpaceae is the highest and plays an essential ecological role in the three forest states.

Species diversity

The Shannon – Wiener Index (H') ranges from low to moderate. The medium forest was the highest (H': 2.79), with 276 trees of 31 species. The poor forest (H': 2.19) had 215 trees belonging to 25 species. At the same time, the very poor forest had the value of lowest (H': 1.66), with 149 trees belonging to 17 species (Table 1).

For the Margalef Index (d), the value was highest for the medium forest (d: 12.29), followed by the poor forest (d: 10.29), while the value was lowest for the very poor forest (d: 7.36) (Table 1).

For the Simpson Index (Cd), the value was highest for the medium forest (Cd: 0.11), followed by the poor forest (Cd: 0.20) and the very poor forest (Cd: 0.36).

For the Index of Similarity (SI), the species composition in the poor and medium forests had the highest similarity (SI: 0.50), followed by the very poor and poor forests (SI: 0.48), the lowest was the very poor and medium forests (SI: 0.46) (Table 2).

Conservation status

There were 15 threatened species (33.33%) belonging to 11 genera of 8 families. Nine species were least concern (LC), four species were Vulnerable (VU), and two species were Endangered (EN) as per IUCN (2022) (Table 2). The *A. costata* was listed in Vietnam Red Data Book (2007) as Endangered. For the very poor forest, six species were listed in IUCN (2022) (three species at the LC level, two species at the EN level, and one species at the VU level), and one species was listed at the EN level in Vietnam Red Data Book (2007). For the poor forest, eight species were listed in IUCN (2022) (five species at LC, two species at EN, and one species at the VU), and one species was listed as EN in Vietnam Red Data Book (2007); While in the medium forest, 11 species were listed in IUCN (2022) (five species at LC, two species at EN, four species at the VU) and one species was listed as EN in Vietnam Red Data Book (2007).

In addition to the conservation value, species of high ecological and economic importance were confirmed as *A. costata, H. odorata, S. roxburghii, S. siamensis, S. guiso, T. calamansanai, V. pinnata, D. chartaceus*, etc. (Table 4). These species have experienced a decrease in both population and range due to a significant reduction in forest area and quality in recent years. Deforestation, forest fires, and illegal encroachment have become complex, posing a threat to the natural habitat of wild plants (Minh 2019).

Table 1. Species richness, abundance, and some diversity indices

Forest status	Species richness	Abund.	Margalef (d)	Shannon-Wiener (H')	Simpson (Cd)
Very poor	17	149	7.36	1.66	0.36
Poor	25	215	10.29	2.19	0.2
Medium	31	276	12.29	2.79	0.11

Table 2. Index of Similarity (SI) between forest states

Forest status	Very poor	Poor	Medium
Very poor	1.00	0.48	0.46
Poor		1.00	0.50
Medium			1.00

Table 3. The species composition of woody plants in Binh Chau-Phuoc Buu Nature Reserve, South Vietnam

Scientific name	Vietnamese name	Family name	No. of trees	No. of species	No. of genera	Forest status		
						Very poor	Poor	Medium
Bouea oppositifolia (Roxb.) Meisn.	Thanh trà	Anacardiaceae	1	4	1			x
Gluta usitata (Wall.) Ding Hou	Sơn đào	Anacardiaceae	26		1	x	x	x
Semecarpus cochinchinensis Engl.	Sưng nam bộ	Anacardiaceae	8		1	x		x
Spondias pinnata (L. f.) Kurz	Cóc rừng	Anacardiaceae	5		1	x		
Sphaerocoryne affinis (Teijsm. and Binn.) Ridl.	Cơm nguội	Annonaceae	6	2	1			x
Xylopia vielana Pierre	Dền đỏ	Annonaceae	17		1		x	x
Peltophorum dasyrrhachis (Miq.) Kurz	Lim vàng	Caesalpiniaceae	3	1	1		x	
Capparis micrantha A.Rich.	Cáp gai	Capparaceae	1	1	1		x	
Parinari ananmensis Hance	Cám	Chrysebalanceae	5	1	1		x	x
Calophyllum calaba L.	Còng tía	Clusiaceae	2	3	1		x	
Garcinia celebica L.	Rỏi mật	Clusiaceae	10		2			x
Garcinia vilersiana Pierre	Vàng nhựa	Clusiaceae	6			x		x
Terminalia calamansanai (Blanco) Rolfe	Chiêu liêu nước	Combretaceae	1	1	1		x	
Dillenia ovata Wall.	Sổ trai	Dilleniaceae	8	1	1	x	x	x
Anisoptera costata Korth.	Vên vên	Dipterocarpaceae	48	7	1	x	x	x
Dipterocarpus chartaceus Symington	Dầu cát	Dipterocarpaceae	244		1	x	x	x
Hopea odorata Roxb.	Sao đen	Dipterocarpaceae	16			x		x
Shorea guiso (Blanco) Blume	Chò chai	Dipterocarpaceae	8		3			x
Shorea roxburghii G.Don	Sến mủ	Dipterocarpaceae	75				x	x
Shorea siamensis Miq.	Cẩm liên	Dipterocarpaceae	7			x	x	
Vatica odorata (Griff.) Symington	Làu táu	Dipterocarpaceae	11		1		x	x
Diospyros malabarica (Desr.) Kostel.	Cườm thị	Ebenaceae	22	3	3	x	x	x
Diospyros maritima Blume	Cẩm thị	Ebenaceae	8				x	
Diospyros venosa Wall. ex A.DC.	Săng đen	Ebenaceae	1					x
Aporosa tetrapleura Hance	Thầu tấu	Euphorbiaceae	9	1	1		x	x
Millettia diptera Gagnep.	Mát hai cánh	Fabaceae	1	1	1			x
Lithocarpus dinhensis (Hickel and A.Camus) A.Camus	Dẻ núi dinh	Fagaceae	2	1	1		x	
Cratoxylum cochinchinense (Lour.) Blume	Thành ngạnh nam	Hypericaceae	2	2	2		x	
Cratoxylum formosum (Jacq.) Benth. and Hook.f. ex Dyer	Thành ngạnh đẹp	Hypericaceae	7			x	x	x
Irvingia malayana Oliv. ex A.W.Benn.	Kơ nia	Irvingiaceae	4	1	1	x		x
Barringtonia pauciflora King	Chiếc tam lang	Lecythidaceae	2	1	1		x	
Memecylon ligustrinum Blume	Sầm lá lớn	Melastomataceae	8	1	1	x	x	x
Knema globularia (Lam.) Warb.	Máu chó lá nhỏ	Myristicaceae	11	2	2			x
Knema pierrei Warb.	Máu chó Pierrei	Myristicaceae	1					x
Syzygium borneense (Miq.) Miq.	Trâm sẻ	Myrtaceae	4	4	4			x
Syzygium cumini (L.) Skeels	Trâm mốc	Myrtaceae	8				x	x
Syzygium pachysarcum (Gagnep.) Merr. and L.M.Perry	Trâm nhuộm	Myrtaceae	4				x	
Syzygium lanceolatum Wight and Arn.	Trâm trắng	Myrtaceae	1			x		
Ochna integerrima (Lour.) Merr.	Mai	Ochnaceae	1	1	1			x
Carallia brachiata Merr.	Săng mã nguyên	Rhizophoraceae	5	1	1			x
Gardenia philastrei Pierre ex Pit.	Dành dành láng	Rubiaceae	4	1	1	x	x	
Xerospermum noronhianum (Blume) Blume	Trường	Sapindaceae	17	1	1	x	x	x
Madhuca elliptica (Pierre ex Dubard) H.J.Lam	Viết	Sapotaceae	4	2	2			x
Madhuca floribunda (Pierre ex Dubard) H.J.Lam	Sến nhiều hoa	Sapotaceae	2			x		
Vitex pinnata L.	Bình linh lông	Verbenaceae	4	1	1			x

Table 4. Conservation status of woody plants

Scientific name	Vietnamese name	The entire study area		Forest status					
				Very poor		Poor		Medium	
		IUCN (2021)	Vietnam Red Data Book (2007)	IUCN (2021)	Vietnam Red Data Book (2007)	IUCN (2021)	Vietnam Red Data Book (2007)	IUCN 2020	Vietnam Red Data Book (2007)
Anisoptera costata Korth.	Vên vên	EN	EN	EN	EN	EN	EN	EN	EN
Cratoxylum cochinchinense (Lour.) Blume	Thành ngạnh nam	LC				LC			
Cratoxylum formosum (Jacq.) Benth. et Hook.f. ex Dyer	Thành ngạnh đẹp	LC		LC		LC		LC	
Diospyros maritima Blume	Cẩm thị	LC				LC			
Dipterocarpus chartaceus Symington	Dầu cát	EN		EN		EN		EN	
Hopea odorata Roxb.	Sao đen	VU		VU				VU	
Irvingia malayana Oliv. ex A.W.Benn.	Kơ nia	LC		LC				LC	
Knema globularia (Lam.) Warb.	Máu chó lá nhỏ	LC						LC	
Knema pierrei Warb.	Máu chó Pierrei	VU						VU	
Shorea guiso (Blanco) Blume	Chai	VU						VU	
Shorea roxburghii G.Don	Sến mủ	VU				VU		VU	
Shorea siamensis Miq.	Cẩm liên	LC		LC		LC			
Syzygium cumini (L.) Skeels	Trâm mốc	LC				LC		LC	
Terminalia calamansanai (Blanco) Rolfe	Chiêu liêu nước	LC							
Vitex pinnata L.	Bình linh lông	LC						LC	

Note: EN: Endangered, VU: Vulnerable, LC: Least Concern

Mean DBH

Among the three forest states, the medium forest was the highest range of mean DBH with 510.83 cm, followed by the poor forest (365.99 cm) and the very poor forest (203.01 cm) (Table 5).

Generally, species with a large diameter, including woody trees with minor ecological roles and economic value, are found in low numbers (usually 1-3 trees) in extremely poor forests, with exceptions such as *D. chartaceus*. Examples of such species and their respective diameters are *M. confusum* (29.3 cm), *G. usitata* (15.31 cm), *X. noronhianum* (14.01 cm), and *D. malabarica* (15.15 cm). In the poor forest, species like *S. cumini* (21.18 cm), *C. micrantha* (3.89 cm), and *D. malabarica* (19.94 cm) can be found. In the medium forest, the prominent species include *S. cinereum* (39.17 cm), *M. elliptica* (24.47cm), and *G. usitata* (25.04 cm). Species with significant ecological, conservation, and economic value, often characterized by numerous trees and varying diameter sizes, are primarily found in poor and medium forests. These species are mainly from the Dipterocarpaceae family. Examples include *A. costata* (11.82-15.79 cm), *S. roxburghii* (18.53 cm), *H. odorata* (9.72 cm), and *D. chartaceus* (15.75 cm). However, in the very poor forest, larger specimens of *A. costata* (39.3 cm), *D. chartaceus* (20.38 cm), *H. odorata* (43.51 cm), and *S. roxburghii* (21.45 cm) can be found.

Total aboveground biomass and carbon stock

In the very poor forest, the estimated biomass and carbon stock range from 53.34 t/ha to 84.03 t/ha and 26.67 t/ha to 42.02 t/ha, respectively, representing 6.15% to 9.68% of the total. The highest values were recorded in Plot 2, with 84.03 t/ha for biomass and 42.02 t/ha for carbon stock, accounting for 9.68% of the total. For *D. chartaceus*, the biomass and carbon stock ranged from 14.41 t/ha to 35.23 t/ha and 7.21 t/ha to 17.62 t/ha, respectively. The highest values were observed in Plot 1, with 35.23 t/ha for biomass and 14.62 t/ha for carbon stock. The percentage of biomass and carbon stock attributed to *D. chartaceus* compared to the entire area exhibited significant variability, ranging from 1.66% to 4.06%, with the highest value recorded in plot 1 (4.06%). Other species, such as *A. costata, S. roxburghii, P. ananmensis, D. malabarica*, and *S. siamensis,* also displayed relatively high biomass and carbon stock values.

For the poor forest, the estimated biomass and carbon stocks vary from 48.15 t/ha-73.84 t/ha and 24.07 t/ha-36.92 t/ha, respectively, representing 5.55%-8.51% of the total. The highest values were observed in Plot 4, with 73.84 t/ha for biomass and 36.92 t/ha for carbon stock, accounting for 8.51% of the total. As for *D. chartaceus*, the biomass and carbon stocks ranged from 42.65 t/ha-55.62 t/ha and 21.33 t/ha-27.81 t/ha, respectively. The highest value was recorded in Plot 4, with 55.62 t/ha for biomass and 27.81 t/ha for carbon stock, representing 6.41% of the total. Comparatively, the contribution of *D. chartaceus* to the entire area in terms of biomass and carbon stock was relatively low, accounting for a substantial percentage (4.92%-6.41%), with the highest value observed in plot 4 (6.41%). The main species contributing to biomass and carbon stocks include *S. cochinchinensis, G. usitata, A. costata*, and *D. malabarica*.

In the medium forest, the estimated biomass and carbon stocks range from 44.04 t/ha to 196.83 t/ha and 72.02 t/ha to 98.42 t/ha, respectively, representing 16.60% to 22.68% of the total. The highest values were recorded in Plot 3, with 196.83 t/ha for biomass and 98.42 t/ha for carbon stock, accounting for 22.68% of the total. For *D. chartaceus*, the biomass and carbon stocks ranged from 23.60 t/ha to 46.45 t/ha and 11.80 t/ha to 23.22 t/ha, respectively. The highest values were observed in plot 9, with 46.45 t/ha for biomass and 23.22 t/ha for carbon stock. The biomass and carbon stocks of *D. chartaceus* compared to the entire area represent a relatively low percentage (2.72% to 5.35%), with the highest value found in plot 9 (5.35%). Other species such as *A. costata, S. roxburghii, H. odorata, G. usitata, D. malabarica, S. cinereum*, and *I. malayana* also contribute significantly to biomass and carbon stocks in this forest type.

The biomass and carbon stock was the highest in the medium forest (56.27%), followed by the poor forest (22.74%), and lowest in the very poor forest (21.00%) (Figure 2). Meanwhile, biomass and carbon stocks of *D. chartaceus* were highest in the poor forest (16.80%), followed by the medium forest (12.19%), and lowest in the very poor forest (8.12%) (Figure 3).

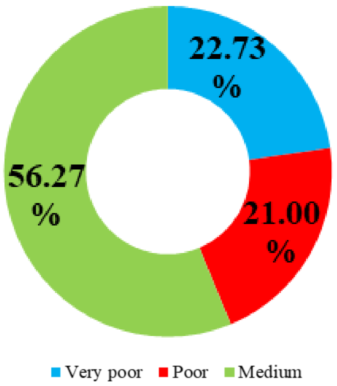

Figure 2. The percentage of biomass and carbon stocks by forest status

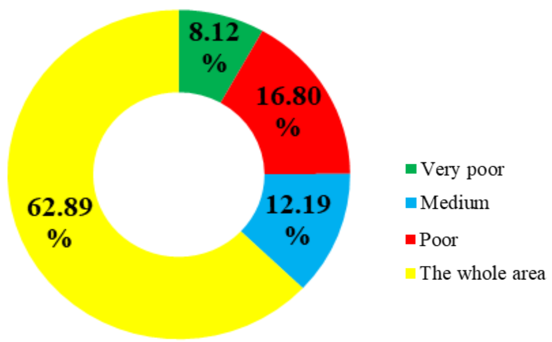

Figure 3. The percentage biomass and carbon stock of *D. chartaceus* and the whole area

Table 5. Abundance and mean diameter of trees by forest status

Status	Botanical name	Vietnamese name	No. of trees	Mean DBH (cm)
Very poor	*Gluta usitata* (Wall.) Ding Hou.	Sơn huyết	15	15.31
	Semecarpus cochinchinensis Engl.	Sưng nam bộ	7	12.18
	Spondias pinnata (L. f.) Kurz	Cóc rừng	5	8.81
	Garcinia vilersiana Pierre	Vàng nhựa	1	6.37
	Dillenia ovata Wall.	Sô trai	2	7.17
	Anisoptera costata Korth.	Vên vên	12	11.82
	Dipterocarpus chartaceus Symington	Dầu cát	86	21.74
	Hopea odorata Roxb.	Sao đen	3	9.72
	Shorea siamensis Miq.	Cẩm liên	1	7.64
	Diospyros malabarica (Desr.) Kostel.	Cườm thị	7	15.15
	Cratoxylum formosum (Jacq.) Benth. and Hook.f. ex Dyer	Thành ngạnh đẹp	1	12.42
	Irvingia malayana Oliv. ex A.W.Benn.	Kơ nia	1	7.32
	Memecylon confusum Blume	Sâm lá lớn	1	29.3
	Syzygium lanceolatum Wight and Arn.	Trâm trăng	1	7.64
	Gardenia philastrei Pierre ex Pit.	Dành dành láng	2	8.44
	Xerospermum noronhianum Blume	Trường	2	14.01
	Madhuca floribunda H.J.Lam	Sến nhiều hoa	2	7.96
	Total		17	203.01
Poor	*Anisoptera costata* Korth.	Vên vên	19	15.79
	Aporosa tetrapleura Hance	Thẩu tấu	1	14.97
	Barringtonia pauciflora King	Chiếc tam lang	2	11.62
	Calophyllum calaba L.	Còng tía	2	7.48
	Capparis micrantha A.Rich.	Cáp gai	1	23.89
	Cratoxylum cochinchinense (Lour.) Blume	Thành ngạnh nam	1	9.55
	Cratoxylum formosum (Jacq.) Benth. and Hook.f. ex Dyer	Thành ngạnh đẹp	1	8.28
	Dillenia ovata Wall.	Sô trai	4	13.06
	Diospyros malabarica (Desr.) Kostel.	Cườm thị	5	19.94
	Diospyros maritima Blume	Câm thị	8	12.02
	Dipterocarpus chartaceus Symington	Dầu cát	83	15.75
	Gardenia philastrei Pierre ex Pit.	Dành dành láng	2	11.62
	Gluta usitata (Wall.) Ding Hou.	Sơn đào	4	14.81
	Lithocarpus dinhensis (Hickel and A.Camus) A.Camus	Dẻ núi dinh	2	16.72
	Memecylon confusum Blume	Sâm lá lớn	2	11.15
	Parinari anamensis Hance	Cám	4	22.53
	Peltophorum dasyrhachis (Miq.) Kurz	Lim vàng	3	8.07
	Shorea roxburghii G.Don	Sến mủ	42	18.53
	Shorea siamensis Miq.	Cẩm liên	6	18.52
	Syzygium cumini (L.) Skeels	Trâm mốc	2	21.18
	Syzygium pachysarcum (Gagnep.) Merr. and L.M.Perry	Trâm nhuộm	4	12.42
	Terminalia calamansanai (Blanco) Rolfe	Chiêu liêu nước	1	21.34
	Vatica odorata (Griff.) Symington	Làu táu	2	17.68
	Xerospermum noronhianum Blume	Trường	1	9.24
	Xylopia vielana Pierre	Dền đỏ	13	9.84
	Total		25	365.99
Medium	*Anisoptera costata* Korth.	Vên vên	17	39.13
	Aporosa tetrapleura Hance	Thẩu tấu	8	13.83
	Bouea oppositifolia (Roxb.) Adelb.	Thanh trà	1	10.51
	Carallia brachiata Merr.	Săng mã nguyên	5	15.71
	Cratoxylum formosum (Jacq.) Benth. and Hook.f. ex Dyer	Thành ngạnh đẹp	6	8.23
	Dillenia ovata Wall.	Sô trai	2	11.78
	Diospyros malabarica (Desr.) Kostel.	Cườm thị	10	14
	Diospyros venosa Wall.	Săng đen	1	7.32
	Dipterocarpus chartaceus Symington	Dầu cát	75	20.38
	Garcinia celebica L.	Rỏi mật	10	13.38
	Garcinia vilersiana Pierre	Vàng nhựa	5	14.55
	Gluta usitata (Wall.) Ding Hou.	Sơn đào	7	25.04
	Hopea odorata Roxb.	Sao đen	13	43.51
	Irvingia malayana Oliv. ex A.W.Benn.	Kơ nia	3	18.16
	Knema globularia (Lam.) Warb.	Máu chó lá nhỏ	11	10.64
	Knema pierrei Warb.	Máu chó pierrei	1	8.92
	Madhuca elliptica H.J.Lam	Viết	4	24.47
	Memecylon confusum Blume	Sâm lá lớn	5	11.62
	Millettia diptera Gagnep.	Mát hai cánh	1	9.24
	Ochna integerrima (Lour.) Merr.	Mai rừng	1	11.15
	Parinari anamensis Hance	Cám	1	15.92
	Semecarpus cochinchinensis Engl.	Sưng nam bộ	1	13.69
	Shorea guiso Blume	Chò chai	8	10.15
	Shorea roxburghii G.Don	Sến mủ	33	21.45
	Sphaerocoryne affinis Ridl.	Cơm nguội	6	11.94
	Syzygium borneense Miq.	Trâm sẻ	4	39.17
	Syzygium cumini (L.) Skeels	Trâm mốc	6	15.54
	Vatica odorata (Griff.) Symington	Làu táu	9	9.48
	Vitex pinnata L.	Bình linh lông	4	10.77
	Xerospermum noronhianum Blume	Trường	14	19.21
	Xylopia vielana Pierre	Dền đỏ	4	11.94
	Total		31	510.83

Table 6. Total biomass, carbon stocks, and the whole area

Plot	Very poor forest Biomass density (t/ha)	Very poor forest Carbon Stock (t/ha)	%	Plot	Poor forest Biomass density (t/ha)	Poor forest Carbon Stock (t/ha)	%	Plot	Medium forest Biomass density (t/ha)	Medium forest Carbon Stock (t/ha)	%
1	53.34a	26.67a	6.15	4	73.84a	36.92a	8.51	8	147.38a	73.69a	16.98
	35.23b	17.62b	4.06		55.62b	27.81b	6.41		23.60b	11.80b	2.72
2	84.03a	42.02a	9.68	5	60.21a	30.11a	6.94	9	144.04a	72.02a	16.60
	14.41b	7.21b	1.66		47.53b	23.76b	5.48		46.45b	23.22b	5.35
7	59.92a	29.96a	6.90	6	48.15a	24.07a	5.55	3	196.83a	98.42a	22.68
	20.83b	10.42b	2.40		42.65b	21.33b	4.92		35.70b	17.85b	4.11
Total	197.29a	98.64a	22.74		182.20a	91.10a	21.00		488.25a	244.13a	56.27
	70.48b	35.24b	8.12		145.80b	72.90b	16.80		105.75b	52.87b	12.19
Average	65.76a	32.88a	7.58		60.73a	30.37a	7.00		162.75a	81.38a	18.76
	23.49b	11.75b	2.71		48.60b	24.30b	5.60		35.25b	17.62b	4.06

Note: a: Biomass and carbon stocks of plot/forest status, b: Biomass and carbon stock of *D. chartaceus*

Discussion

Diversity of woody plants

The results of the present study indicate a low to moderate diversity, as reflected by H' values ranging from 1.66 to 2.79. This can be attributed to the dominance of *D. chartaceus, A. costata,* and *S. roxburghii* in the forest. The species composition structure within the studied tree species communities is relatively simple, with species richness (S) ranging from 17 to 31 species. In a dominant forest of *S. roxburghii* in Dong Nai province, Vietnam, a higher species richness (S=61-64 species) and diversity ranging from medium to high (H'=2.87-3.05) were recorded in comparison to the present study (Hop et al. 2020). A report focusing on dominant communities of *D. dyeri, D. alatus, H. odorata, S. roxburghii, and A. costata* showed higher species richness and Shannon-Wiener index values than the present study. The recorded species richness for these communities was 53, 62, 60, 42, and 57 species, respectively, with corresponding H' values of = 2.95, 3.23, 2.78, 2.52, and 2.87, respectively (Hop et al. 2021b).

The species richness in the present study was lower than in some studies reported from Asia. A report in the deciduous forest of Odisha, India discovered 70 species belonging to 63 genera and 35 families (Pattnayak et al. 2021); in the Western Ghats, India also showed similar results with 76 recorded tree species (Kothandaraman and Sundarapandia 2017). Studies in Myanmar's mixed deciduous and dipterocarp forests have determined that the number of species varies from 25 to 57 (Myo et al. 2016). Reporting on tropical deciduous forests of the Eastern Ghats, Odisha also discovered 57 species of trees (Sahu et al. 2012); in Western India, where 93 plant species belonging to 85 genera of 24 families were recorded (Kumar et al. 2010); In the Northeastern Ghats, India recorded 135 species of 105 genera, belonging to 45 plant families (Naidu et al. 2018). The diversity and composition of tree species can change due to the variation in latitude, longitude, and altitudinal factors (Thakur and Khare 2006). Tree species diversity varies considerably from site to site due to changes in habitat and biogeographic disturbances (Majumdar et al. 2014).

Several studies in Asia showed that the diversity index (H') in Odisha, India was lower than in the present study (H' = 0-2.31) (Pattnayak et al. 2021); in the West, India (H') ranged from 0.67 to 0.79 (Kumar et al. 2010). The study carried out in the Eastern Ghats, India, also gave similar results to this study (H'= 1.85-2.05) (Panda et al. 2013). However, some other studies recorded a higher diversity, such as in the Northeastern Ghats, India, the index (H') ranged from 3.59 to 4.05 (Naidu et al. 2018); in the dipterocarp and mixed deciduous forest in Myanmar, diversity varied from low to high (H' = 2.39-3.68). The study in Chhatisgarh, India, showed that the index (H') varied widely from 0.19 to 3.35 (Lal et al. 2015). When studying mixed dipterocarp forests in Malaysia, recorded (H') from 3.1 to 4.3 (Ganivet et al. 2020). This comparison shows that the present study plots have been disturbed to varying degrees by anthropogenic and ecological factors. Differences in diversity in different ecological regions due to the influence of different disturbance levels, latitudes, environments, soils, and climates. Areas with high biodiversity often occur in stable environmental conditions with low disturbance.

Carbon stock of woody plants

This study is lower than the *S. roxburghii* dominant forest, which obtained average biomass and carbon stock from 106.20t/ha-282.63 t/ha and 53.07 tC/ha -141.32 tC/ha (Hop et al. 2020). The report was conducted by Hop et al. (2021a) in some communities dominant of Dipterocarpaceae, where it gained average carbon stock from 108.89 tC/ha-174.61 tC/ha in different forest statuses. However, the study of Hai and Trieu (2015) in the deciduous forest is similar to this study, which recorded average carbon stock ranging from 27.84 tC/ha-90.58 tC/ha in different forests. Some studies in Asia showed that carbon stocks ranged from 59.18t/ha to 60.62t/ha in Nepal's dominant forest *S. robusta*, lower than this study (Rawal and Subedi 2022). At the same time, the carbon stock of *S. robusta* ranged from 29.94 t/ha to 38.95 t/ha, which is higher than this study's (Rawal and Subedi 2022). A study in Central Nepal showed that carbon stocks ranged from 70 t/ha to 183 t/ha, lower than the present study (Magar and

Shrestha 2015). However, another study in western Nepal recorded a variable carbon stock of 148.5-202.3 t/ha, higher than the present study (Bhatta and Devkota 2020).

Plant communities can serve as a source and retain large amounts of carbon over a long period since trees assimilate carbon through photosynthesis, of which woody plants are vital and play a major role in carbon sequestration. Therefore, maintaining species richness and individual tree abundance plays a decisive role in the potential for carbon storage. In addition, enhancing the growth in DBH of individual trees is also a key factor contributing to promoting the forest's ability to assimilate carbon. Human activities at low, medium, and high levels affect species diversity and carbon stocks in forest areas, which are positively and significantly correlated (Kpontsu 2011). The degree of anthropogenic disturbance has a significant impact and is positively correlated with woody plant diversity and carbon stocks in the forests of southern Ethiopia (Yohannes et al. 2015). However, some other studies have found that the degree of disturbance by human activities complicates the correlation between carbon and plant diversity (Hop et al. 2021b). Some diversity indices showed a significant correlation, while others did not (Hop et al. 2021b). This study found a statistically significant but weakly negative correlation between the (J') index and the carbon stock ($r = -0.388$, p-value < 0.001). At the same time, there was no statistically significant correlation (p-value > 0.05) between species richness, abundance, (H'), (Cd), and (d) index with the carbon stock. The above statement is supported by Zhang et al. (2011). This finding reported a negative relationship between woody plant diversity and carbon stock and suggested that carbon stocks are determined not only by the number of species but are more likely to be determined by DBH and the density characteristics of the present species. The reciprocal relationship between woody plant species diversity and carbon stock reflects that carbon stock management and biodiversity conservation can be done simultaneously (Assaye and Asrat 2016). Therefore, minimizing disturbance can be a dual solution for maintaining woody plant diversity and carbon stocks (Hop et al. 2021b). The study highlights the significant role of the dominant forest, particularly the species *D. chartaceus*, in the accumulation of biomass and carbon stocks. This underscores its importance in environmental protection and climate regulation. The findings indicate that *D. chartaceus* serves as a potential carbon pool, suggesting its potential contribution to addressing climate change issues in the study area. The study emphasizes the ecological significance of this species and its capacity to mitigate the effects of climate change.

In conclusion, the dominant forest of *D. chartaceus* exhibits high species richness and abundant tree individuals, highlighting its conservation value and crucial ecological role. This study emphasizes the significant role of this forest type in mitigating climate change in the study area, primarily through its aboveground biomass and carbon stocks, with *D. chartaceus* playing a significant role in carbon accumulation. Additionally, this forest type harbours numerous species of ecological and conservation importance. As a result, it is crucial to prioritize and effectively manage this forest type, particularly in terms of preventing detrimental human activities. Further research should focus on developing policies and programs for conserving this area in the future. Furthermore, future studies should consider other carbon pools, such as soil, roots, stems, branches, and foliage, to understand this ecosystem's carbon dynamics comprehensively.

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Effect of forest fire on soil properties and natural regeneration in Chirpine (*Pinus roxburghii*) forests of Himachal Pradesh, India

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Abstract. *Sharma Y, Gupta T, Gupta RK, Sharma PP. 2023. Effect of forest fire on soil properties and natural regeneration in Chirpine (*Pinus roxburghii*) forests of Himachal Pradesh, India. Asian J For 7: 126-133.* Forest fires have a significant impact on the physical environment, such as land cover, land use, forest ecosystems, and biodiversity. The present study was carried out to quantify the effect of forest fire on soil properties and natural regeneration of Chirpine (*Pinus roxburghii* Sargent) forests in Himachal Pradesh, India. Data collection was conducted at six different sites in three forest divisions, namely Solan Forest Division, Hamirpur Forest Division and Dehra Forest Division during the year 2020. Burnt and unburnt forests were selected at each site and were compared with each other to study the effect of fire. The results reported that electrical conductivity, pH, available nitrogen, available phosphorus, available potassium were higher in burnt forests when compared to unburnt forests of the studied sites whereas organic carbon (%) was lower in burnt forests as compared to unburnt forests. Seedling density of trees was found higher in burnt forests whereas sapling density was found higher in unburnt forests. This indicates that fire is good for regeneration but frequent fires can be detrimental for the survival of seedlings. Frequent forest fires need to be prevented and that can be done mainly by social awareness and developing strategies for use of pine needles in farming practices and commercial use in paper, pulp and wood industries.

Keywords: Burnt, forest fire, *Pinus roxburghii*, soil, unburnt

INTRODUCTION

India is one of the world's biodiversity hotspots, both in terms of fauna and flora. Forests are regarded as one of the most important terrestrial ecosystems, providing habitat for biodiversity as well as variety of goods and services to rural communities. These vital resources are constantly degraded and exploited as a result of anthropogenic activities and changes in climatic conditions (Tata et al. 2018; Pokhriyal et al. 2020). The Indian Himalayan Region (IHR) has a rich and diverse forested area, and thus forests are now regarded as a major repository of nature that must be conserved and managed for posterity, rather than being regarded solely as an important source of revenue (Negi et al. 2012).

Himachal Pradesh, located in the heart of the Himalayas, has abundant forest resources and ecologically significant geographical areas. These forests are vulnerable to forest fires for a variety of biotic and geographical reasons. The severity of the problem can be gauged by the 1995 forest fires in the state, which resulted in a 1750 million dollar loss (FSI 2009). The Himalayas are home to the Indian Pines, which constitute an economically important community of species, provide valuable natural resources and make a major contribution to the country's local and industrial economy. Lower Himalaya, which is located between latitudes 26°N to 36°N and longitudes 71°E to 93°E (Ghildiyal et al. 2009), is home of chirpine (*Pinus roxburghii* Sargent). In Himachal Pradesh, 10.40% of forest cover is under forest type 9/C1a (Lower or Siwalik Chirpine Forest) and 3.76% of forest cover is under 9/C1b (Upper or Himalayan Chirpine Forest) (FSI 2019). Coniferous forests are important because they cover a large part of the earth's surface, representing the largest land habitat for plant and animal species. It occurs chiefly in Arunachal Pradesh, Himachal Pradesh, Uttarakhand and Punjab. In Himachal Pradesh, it is found in Kangra, Shimla, Solan, Sirmaur, Mandi, Chamba, Bilaspur, Kullu and Hamirpur (FSI 2019).

Forest fire and climate change reinforce each other and fires these days are more intense and last longer than they used to be earlier (Flannigan et al. 2000; Gavin et al. 2007). Wildfires are mainly due to human activities intentional or unintentional. The needle litter of chirpine is very combustible, making it prone to forest fires. The locals set fire to the pine forests every year to eliminate the needle litter, as the needles make it difficult for humans and animals to navigate through the forests. When there is a dearth of fodder, fire is set to encourage fresh grass growth before the monsoon rains. Accidents from road surfacing activity, cigarette butts thrown into the forest, and villagers traveling through the forest paths at night carrying lighted torchwood all contribute to forest fires and these fires then lead to a decrease in flora and fauna of forest ecosystem (Chandran et al. 2011).

Pine forests are most susceptible to frequent occurrence of fires every year. The pre to post fire consequences include decrease in frequency and density of understorey vegetation and most of the species decline immediately after fire particularly at higher altitudes (Kumar et al. 2013). There are instances of decrease in the number of seedlings and saplings in the areas with frequent instances of forest fires. Surface fires and ground fires affect the ground vegetation like grasses and also natural regeneration of various trees, herbs and shrubs (Joshi et al. 2013). The chances of soil erosion increase in burnt areas and it also alters the soil parameters and chemical properties. Forest fires affect the survival of plant growth promoting microbes and hence indirectly affects the plant growth (Mittal et al. 2019). So, keeping in view the precarious effects of wildfire on ecosystem as well as the local environment, this study aimed to assess the effect of forest fire on soil properties and natural regeneration of forest ecosystem. The findings will aid environmentalists and ecologists to work in other areas of the same region.

MATERIALS AND METHODS

Study area and period

The present investigation was carried out at six locations in Solan, Hamirpur and Kangra Districts of India (21°N 78°E / 21°N 78°E), Himachal Pradesh (Figure 1 and 2; Table 1): i.e., Solan Forest Division (Table 2), Hamirpur Forest Division (Table 3) and Dehra Forest Division (Table 4) in the year 2020. Studies were conducted in the natural fire affected area and nearby unburnt area at each site. The distance between burnt and unburnt areas was approximately 300m at each site. The administrative and geographical information of the study sites is detailed in Table 1. The geomorphological variables, accessibility, socio-economic condition and fire history of the study sites are presented in Tables 2, 3 and 4.

Data collection procedure

At each location, three soil samples from 0-15cm deep layers were drawn randomly from burnt areas and three from unburnt areas in the month of July during 2020 for soil analysis. Soil samples were air dried, grinded and passed through 2mm sieve and subjected to physico-chemical analysis.

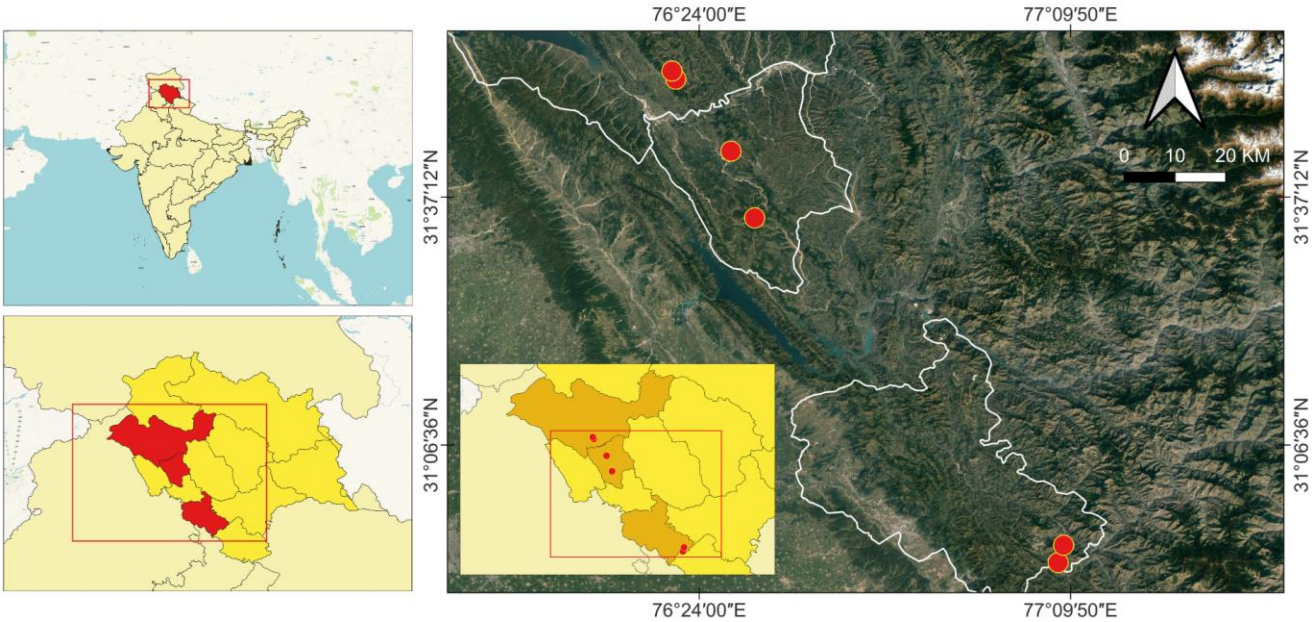

Figure 1. Map of study area in Himachal Pradesh, India

Table 1. Details of study sites in Himachal Pradesh, India

	Solan Forest Division		Hamirpur Forest Division		Dehra Forest Division	
	Oachhghat	**Jaunaji**	**Salauni**	**Jhaniari**	**Tehri 1**	**Tehri 1**
District	Solan	Solan	Hamirpur	Hamirpur	Kangra	Kangra
Range	Solan	Solan	Dehri	Hamirpur	Jwalamukhi	Jwalamukhi
Division	Solan	Solan	Hamirpur	Hamirpur	Dehra	Dehra
Altitude	1325 m	1379 m	1050 m	849 m	955 m	939 m
Latitude (^{0}N)	30.8682	30.9038	31.5773	31.7145	31.8627	31.8794
Longitude (^{0}E)	77.1384	77.1496	76.5138	76.4652	76.3516	76.3437

Regeneration potential of woody species through seeds in respect of density of seedlings of trees and shrubs and density of saplings of trees were observed in burnt and unburnt forests of all the selected sites. Natural regeneration potential was observed randomly in 20 quadrates of 5 x 5 m^2 for trees and shrubs under both the conditions, i.e., burnt and unburnt in all the selected sites. Regeneration potential of woody species through seeds in respect of density of seedlings of trees and shrubs and density of saplings of trees were observed in burnt and unburnt forests of all the selected sites (Kumar and Thakur 2008).

Data analysis

Soil physico-chemical analysis was done by using various methods (Table 5). Analysis of variance of the data collected was done through Completely Randomized Design (CRD factorial) as described by Panse and Sukatme (1967). Factors being analyzed were factor A (sites), factor B (conditions: burnt and unburnt) and interaction between sites and conditions. OP Stat was used for the analysis of data.

Table 2. Details of study areas of Solan Forest Division

Name	Oachhghat	Jaunaji
Geomorphology		
Slope	Moderate	Moderate
Rock type	Ferromagnesian, carbonaceous shales and dolomitic limestones	Ferromagnesian, carbonaceous shales and dolomitic limestones
Erosion	Moderate	Moderate
Soil structure	Sub-angular to blocky	Sub-angular to blocky
Approached by	Road	Road
Nearest town	Solan	Solan
Biotic interferences		
Dependence on forests for		
Fuelwood collection	Yes	Yes
Medicines	Yes	Yes
Grass cutting	Yes	Yes
Grazing	Yes	Yes
Other	Yes	Yes
Developmental activities	Construction	Construction
Fire history		
Causes	Unextinguished bidis, cigarette butts, matchsticks etc., by forest laborers, graziers or by roadside charcoal panniers	Unextinguished bidis, cigarette butts, matchsticks etc., by forest laborers, graziers or by roadside charcoal panniers
Interval (in fire affected areas)	2015, 2017, 2018, 2019	2016, 2017, 2019

Table 3. Details of study areas of Hamirpur Forest Division

Name	Salauni	Jhaniari
Geomorphology		
Slope	Moderate	Moderate
Rock type	Ferromagnesian, carbonaceous shales and dolomitic limestones	Ferromagnesian, carbonaceous shales and dolomitic limestones
Erosion	Moderate	Moderate
Soil structure	Sub-angular to blocky	Sub-angular to blocky
Approached by	Road	Road
Nearest town	Hamirpur	Hamirpur
Biotic interferences		
Dependence on forests for		
Fuelwood collection	Yes	Yes
Medicines	Yes	Yes
Grass cutting	Yes	Yes
Grazing	Yes	Yes
Other	Yes	Yes
Developmental activities	-	-
Fire history		
Causes	Unextinguished bidis, cigarette butts, matchsticks etc., by forest laborers, graziers or by roadside charcoal panniers	Unextinguished bidis, cigarette butts, matchsticks etc., by forest laborers, graziers or by roadside charcoal panniers
Interval (in fire affected areas)	2012, 2013, 2019	2013, 2019

Table 4. Details of study areas of Dehra Forest Division

Name	Tehri 1	Tehri 2
Geomorphology		
Slope	Moderate	Moderate
Rock type	Ferromagnesian, carbonaceous shales and dolomitic limestones	Ferromagnesian, carbonaceous shales and dolomitic limestones
Erosion	Moderate	Moderate
Soil structure	Sub-angular to blocky	Sub-angular to blocky
Approached by	Road	Road
Nearest town	Jwalamukhi	Jwalamukhi
Biotic interferences		
Dependence on forests for		
Fuelwood collection	Yes	Yes
Medicines	Yes	Yes
Grass cutting	Yes	Yes
Grazing	Yes	Yes
Other	Yes	Yes
Developmental activities	-	-
Fire history		
Causes	Unextinguished bidis, cigarette butts, matchsticks etc., by forest laborers, graziers or by roadside charcoal panniers	Unextinguished bidis, cigarette butts, matchsticks etc., by forest laborers, graziers or by roadside charcoal panniers
Interval (in fire affected areas)	2014, 2015, 2019	2014,2015,2019

Table 5. Methods for physico-chemical properties of soil

Physico-chemical property	Method employed
Soil pH	1:2 Soil:Water suspension, measured with digital pH meter (Jackson 1973)
Electrical Conductivity (dS/m)	1:2 Soil:Water suspension, measured with digital EC meter (Jackson 1973)
Organic Carbon (kg/ha)	Walkley and Black wet digestion method (Walkley and Black 1934)
Available Nitrogen (kg/ha)	Alkaline $KMnO_4$ method (Subbiah and Asiza 1956)
Available Phosphorus (kg/ha)	Olsen method (Olsen et al. 1954)
Available Potassium (kg/ha)	Ammonium acetate method (Merwin and Peech 1951)

RESULTS AND DISCUSSION

In general, the result of our study indicated that physico-chemical properties of soil are altered due to fire and the changes may be conducive or detrimental to growth and development of plants.

Chemical properties of soil in burnt and unburnt areas

Table 6 depicts that the value of pH was higher in burnt forests (6.99) in all the sites compared to unburnt forests (6.49). This may be due to the increase of soluble cations in the ash. Similar result was reported by Rojas et al. (2016) and Tufekcioglu et al. (2010) in which soil pH is significantly higher in burned sites than in unburned sites. Soil pH usually changes due to fire and the extent of change depends upon the frequency and type of fire. Destruction of some organic acids and liberation of some bases may be the reason for this change.

The data is significant for electrical conductivity. The value of electrical conductivity in soil is higher in burnt forests (0.46 dS/m) as compared to unburnt forests (0.41 dS/m). The higher value of EC after fire is reported by Nigussie and Kissi (2011) and Rojas et al. (2016). There is also significant interaction between the factors of site and fire on electrical conductivity.

The data of organic carbon is statistically significant for burnt and unburnt conditions. Data regarding soil organic carbon (%) indicated that the value of organic carbon in soil decreased due to fire as it was found lower in burnt forests (0.60) as compared to unburnt forests (0.75) of all the sites. It may be because severe burns can result in complete destruction of organic matter and can even cause changes in physical, chemical and biological properties of the upper layer of soil. The results are almost similar to Kumar (2004) and Beyer et al. (2011). Decreased amount of soil organic matter after fire is also reported by Robyn et al. (2015) which persisted for about 25 months.

Soil nutrient status of burnt and unburnt areas

Table 7 shows that, the value of available nitrogen (kg/ha) was higher in burnt forests (394.01 kg/ha) as compared to unburnt forests (390.12 kg/ha) of all sites. The results are in line with Kumar (2004), Ekinci (2006) and da Silva and Batalha (2008). Nonetheless, the result for available nitrogen contradicted with the result of Robyn et al. (2015) who reported decreased amount of available nitrogen after fire and this decrease persisted for about 25 months.

Table 6. Chemical properties of soil in burnt and unburnt areas

Site	Soil pH			Organic carbon (%)			Electrical conductivity		
	B	UB	Mean	B	UB	Mean	B	UB	Mean
Solan Forest Division									
Oachhghat	6.43	5.68	6.06	0.84	0.98	0.91	0.4	0.32	0.36
Jaunaji	6.25	5.52	5.89	0.83	0.94	0.89	0.37	0.31	0.34
Hamirpur Forest Division									
Salauni	7.52	7.03	7.28	0.99	1	1	0.48	0.47	0.48
Jhaniari	7.94	7.6	7.77	0.66	0.71	0.68	0.57	0.5	0.54
Dehra Forest Division									
Tehri 1	6.66	6.46	6.56	0.12	0.43	0.28	0.45	0.42	0.44
Tehri 2	6.79	6.65	6.72	0.14	0.47	0.31	0.46	0.43	0.45
Mean value of burnt and unburnt conditions of all the selected sites									
Mean	6.99	6.49		0.60	0.75		0.46	0.41	
		pH			Organic carbon (%)			Electrical conductivity	
		CD (0.05)			CD (0.05)			CD (0.05)	
Site (S)		0.09			0.07			0.02	
Condition (C)		0.05			0.04			0.01	
Interaction SxC		0.12			0.10			0.03	

Note: B: Burnt, UB: Unburnt, CD: Critical difference

Table 7. Soil nutrient status of burnt and unburnt areas

	Available Nitrogen (kg/ha)			Available Phosphorous (kg/ha)			Available Potassium (kg/ha)		
	B	UB	Mean	B	UB	Mean	B	UB	Mean
Solan Forest Division									
Oachhghat	431.32	427.00	429.16	33.10	27.92	30.51	279.36	276.73	278.05
Jaunaji	400.73	392.53	396.63	31.87	27.77	29.82	240.63	237.86	239.25
Hamirpur Forest Division									
Salauni	380.20	374.93	377.57	31.27	29.82	30.55	251.20	248.33	249.77
Jhaniari	379.50	377.23	378.37	31.09	29.53	30.31	255.13	252.77	253.95
Dehra Forest Division									
Tehri 1	386.50	385.53	386.02	33.86	31.53	32.70	259.00	256.27	257.63
Tehri 2	385.80	383.46	384.63	32.97	31.17	32.07	260.43	258.13	259.28
Mean of burnt and unburnt conditions of all the selected sites									
Mean	394.01	390.12		32.36	29.62		257.63	255.02	
	Available Nitrogen (kg/ha)			Available Phosphorous (kg/ha)			Available Potassium (kg/ha)		
	CD (0.05)			CD (0.05)			CD (0.05)		
Site	2.15			1.05			1.43		
Condition	1.24			0.61			0.83		
Interaction SxC	3.04			1.48			NS		

Note: B: Burnt, UB: Unburnt, CD: Critical difference

The available phosphorus was higher in burnt sites that means it increased due to fire. This may be due to less organic matter in burnt areas. The mean value of available phosphorus in burnt areas was 32.36 kg/ha and in unburnt site was 29.62 kg/ha. The increases available phosphorus after fire has been reported by Kumar (2004) and Rojas et al. (2016). The value of available potassium (kg/ha) increased in burnt forest. This may be due to the addition of ash to the soil. The reason behind this may be the addition of plant ash due to fire that contains a large amount of potassium. Mittal et al. (2019) documented the increase of available potassium in burnt forests.

Regeneration potential of tree species in burnt and unburnt areas

Table 8 depicts that the density of seedlings was higher in burnt forests as compared to unburnt forests. Our finding is in accordance with the study by Konsam et al. (2017). Suitable conditions for regeneration and growth of seedlings of woody species in Chirpine forest is facilitated by fire and forest fire may also result in clearance of site which enhance natural regeneration.

In Solan Forest Division, the highest density of seedlings of *P. roxburghii* was observed in burnt forest of Oachhghat (1.15) followed by burnt) forest of Jaunaji (0.95, unburnt forest of Oachhghat (0.85), while the lowest was recorded in unburnt forest of Jaunaji (0.65). The highest density of seedlings of all the trees was observed in burnt forest of Oachhghat (1.65) and the lowest was in unburnt forest of Jaunaji (0.95).

In Hamirpur Forest Division, the highest density of seedlings of *P. roxburghii* was observed in burnt forest of Jhaniari (1.25) followed by unburnt forest of Jhaniari (1.15), burnt forest of Salauni (1.05) and the lowest was recorded in unburnt forest of Salauni (0.95). The highest density of seedlings of all the trees was in burnt forest of Jhaniari (2.95) and the lowest was in unburnt forest of Salauni (0.95).

In Dehra Forest Division, the highest density of seedlings of *P. roxburghii* was observed in burnt forest of Tehri 2 (1.45) followed by burnt and unburnt forests of Tehri 1 and Tehri 2 (1.35), while the lowest was recorded in unburnt forest of Tehri 1(1.30). The highest density of seedlings of all the trees was in burnt forest of Tehri 2 (1.7) and the lowest was in unburnt forest of Tehri 1 (1.35).

If compared across the sites, in unburnt conditions, the highest density of saplings of trees was recorded in Jhaniari with 3.30 followed by Oachhghat with 2.30, Tehri 1 with 1.60, Tehri 2 with 1.50, Salauni with 1.25 and the lowest density of saplings was 1.20 in Jaunaji and Jhaniari. The lower number of saplings in burnt forests were documented by Joshi et al. (2013).

Our findings suggest that the density of seedlings of trees was recorded to be higher in burnt conditions of all the studied sites whereas density of saplings of trees was recorded to be higher in unburnt conditions. These results are inline to the study by Kumar (2004). The higher density of seedlings in burnt conditions shows that natural regeneration is enhanced due to fire. On the other hand, Verma et al. (2017) reported decreased number of saplings after fire but increased after five years, indicating that frequent fires can be detrimental for saplings. Verma and Jayakumar (2015) suggested that one or two fires every 15 years can be beneficial to tree species regeneration. After one or two fires every 15 years with equal time intervals, plants have enough time and more available soil nutrients for regeneration.

Regeneration potential of shrubs in burnt and unburnt areas

Table 9 depicts that in Solan Forest Division the highest density of seedlings of shrubs within the sampling area of 25 m^2 was found in unburnt forest of Jaunaji (4.00), followed by burnt forest of Oachhghat (3.80), unburnt forest of Oachhghat (3.15) and the lowest was in burnt forest of Jaunaji (3.00).

In Hamirpur Forest Division, the highest density of seedlings of shrubs was found in burnt forest of Jhaniari (3.60) followed by burnt forest of Salauni (3.15), unburnt forest of Jhaniari (2.90) and the lowest was in unburnt forest of Salauni (2.50). In Dehra Forest Division, the highest density of shrubs was found in burnt forest of Tehri 1 (3.75) followed by burntforest of Tehri 2 (3.65) and the lowest was recorded in unburnt forests of Tehri 1 and Tehri 2 (1.95). Higher density of seedlings in burnt conditions shows that natural regeneration is enhanced due to fire. The higher density of seedlings in burnt forests as compared to unburnt forests is also reported by Kumar (2004); Konsam et al. (2017) and Verma et al. (2017).

Table 8. Regeneration potential of tree species (as total number of seedlings or saplings per 25 m^2) in burnt and unburnt areas

Name of tree species	Oachhghat		Jaunaji		Salauni		Jhaniari		Tehri 1		Tehri 2	
	B	UB	B	UB	B	UB	B	UB	B	UB	B	UB
Density of seedlings												
Pinus roxburghii	1.15	0.85	0.95	0.65	1.05	0.95	1.25	1.15	1.35	1.3	1.45	1.35
Quercus leucotrichophora	-	0.40	0.45	0.30	-	-	-	-	-	-	-	-
Pyrus pashia	0.50	0.30	-	-	-	-	-	-	-	-	-	-
Cassia fistula	-	-	-	-	-	-	0.20	0.10	-	-	-	-
Bombax ceiba	-	-	-	-	-	-	0.40	-	-	-	-	-
Shorea robusta	-	-	-	-	-	-	0.70	-	-	-	-	-
Acacia catechu	-	-	-	-	-	-	0.40	-	-	-	-	-
Ficus roxburghii	-	-	-	-	-	-	-	-	0.05	0.05	-	-
Toona ciliate	-	-	-	-	-	-	-	-	-	-	-	0.15
Grewia optiva	-	-	-	-	-	-	-	-	-	-	0.25	-
Total	1.65	1.55	1.40	0.95	1.05	0.95	2.95	1.25	1.40	1.35	1.70	1.50
Density of saplings												
Pinus roxburghii	0.95	1.05	0.65	0.75	1.00	1.25	1.20	1.00	0.90	1.35	1.20	1.30
Quercus leucotrichophora	-	0.50	0.40	0.45	-	-	-	-	-	-	-	-
Pyrus pashia	0.60	0.75	-	-	-	-	-	-	-	-	-	-
Cassia fistula	-	-	-	-	-	-	-	0.40	-	-	-	-
Bombax ceiba	-	-	-	-	-	-	-	0.50	-	-	-	-
Shorea robusta	-	-	-	-	-	-	-	0.80	-	-	-	-
Acacia catechu	-	-	-	-	-	-	-	0.60	-	-	-	-
Ficus roxburghii	-	-	-	-	-	-	-	-	0.20	0.25	-	-
Toona ciliata	-	-	-	-	-	-	-	-	-	-	-	0.20
Grewia optiva	-	-	-	-	-	-	-	-	-	-	0.30	-
Total	1.55	2.30	1.05	1.20	1.00	1.25	1.20	3.30	1.10	1.60	1.50	1.50

Note: B: Burnt, UB: Unburnt

Table 9. Regeneration potential of shrubs (as total number of seedlings per 25 m^2) in burnt and unburnt areas

Name of shrubs species	Oachhghat		Jaunaji		Salauni		Jhaniari		Tehri 1		Tehri 2	
	B	UB	B	UB	B	UB	B	UB	B	UB	B	UB
Berberis lyceum	0.75	0.60		-	-	-	-	-	-	-	-	-
Buddleia asiatica	-	-	0.50	-	-	-	-	-	-	-	-	-
Carissa carandus	0.65	0.75	0.50	-	0.80	0.50	0.95	0.80	0.70	0.65	0.95	0.65
Lantana camara	0.50	0.40	0.80	0.85	0.75	0.60	0.70	0.55	0.55	0.35	0.35	0.30
Murraya koenjii	0.95	-	-	-	1.05	0.95	0.65	0.50	0.85	0.45	0.85	0.55
Abrus precatorius	-	0.35	-	-	-	-	-	-	-	-	-	-
Rosa moschata	0.20	0.25	-	0.75	-	-	-	-	-	-	-	-
Rubus ellipticus	0.30	0.30	-	0.80	-	-	-	-	0.65	0.50	0.75	0.45
Urtica dioica	-	0.50	-	-	-	-	-	-	-	-	-	-
Woodfordia fruticosa	0.45	-	0.35	-	0.55	0.45	0.75	0.65	0.40	-	0.30	-
Spirea canescens	-	-	0.30	-	-	-	-	-	-	-	-	-
Myrsine Africana	-	-	0.55	0.65	-	-	0.55	0.40	-	-	-	-
Zanthoxylum alatum	-	-	-	0.35	-	-	-	-	-	-	-	-
Lespedeza gerardiana	-	-	-	0.60	-	-	-	-	-	-	-	-
Datura stramonium	-	-	-	-	-	-	-	-	0.60	-	0.45	-
Total	3.80	3.15	3.00	4.00	3.15	2.50	3.60	2.90	3.75	1.95	3.65	1.95

Note: B: Burnt, UB: Unburnt

In conclusion, our study shows that the physico-chemical properties of soil were altered due to fire. Electrical conductivity, pH, available nitrogen, available phosphorus, available potassium were higher in burnt forests when compared to unburnt forests of the studied sites whereas organic carbon (%) was lower in burnt forests as compared to unburnt forests. The density of seedlings of trees was higher in burnt forests as compared to unburnt forests whereas density of saplings of trees was recorded more in unburnt forests as compared to burnt forests. This indicates that fire is good for regeneration but frequent fires can be detrimental for the survival of those seedlings. Frequent forest fires need to be prevented and that can be done mainly by social awareness and developing strategies for use of pine needles in farming practices and commercial use in paper, pulp and wood industries.

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Structure and composition of tree and shrub species and their invasiveness in conservation areas of West Timor, Indonesia

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Abstract. *Lumban-Gaol M, Mudita IW. 2023. Structure and composition of tree and shrub species and their invasiveness in conservation areas of West Timor, Indonesia. Asian J For 7: 134-146.* This study aimed to investigate the composition of vegetation of tree and shrub species and their invasiveness in West Timor conservation forests, Indonesia. Three conservation zones were purposefully chosen to showcase Timor Island's conservation forest. Baumata Nature Recreation Park (Baumata NRP), Camplong Nature Recreation Park (Campong NRP), and Herman Yohannes Grand Forest Park (Herman Yohannes GFP) are three such parks. The point-centered quarter approach was used to collect data. The Important Value Index (IVI) was established for each existing species. Each plant was classed as either invasive or non-invasive. Approximately 59 tree and shrub species were found in these three conservation zones. Based on IVI, the forest was dominated by *Cassia siamea* Lam. (23.53%), *Tectona grandis* L.f. (21.97%), *Schleichera oleosa* (Lour.) Oken (19.61%), and *Syzygium aqueum* (Burm.fil.) Alston (14.95%). More than 40% of the species present were potentially invasive. Based on the IVI, the potentially invasive species were dominated by *C. siamea* (23.53%), *Tamarindus indica* L. (11.69%), *Gmelina arborea* Roxb. ex Sm. (10.73%), *Swietenia macrophylla* G.King (10.30%), *Ficus benjamina* L. (7.45%), *Antidesma bunius* (L.) Spreng. (7.40%), and *Albizia* Durazz. (7.31%). The presence of invasive trees and shrubs in the conservation area of West Timor was relatively high. Therefore, it requires management actions to prevent further spread and dominance.

Keywords: Conservation, forest, Importance Value Index (IVI), invasive species, shrub, tree

INTRODUCTION

Timor Island is in the southern part of the Indonesian archipelago, divided between the independent state of Timor Leste and the territory of West Timor, part of the Indonesian Province of East Nusa Tenggara. With an area of about 30,777 km², Timor Island is the second-largest oceanic island in the archipelago and the largest island in the Lesser Sundas (Trainor 2010). The island was formed as a result of uplift caused by the movement of the Australo-Papuan plate to the north and the subsequent collision with the oriental plate about 4 million years ago, resulting in the hilly and mountainous topography, with the highest peak reaching 2500 m above sea level (Jouannic et al. 1988; van Marle 1991; Vita-Finzi and Hidayat 1991; Nguyen et al. 2013). Steep slopes (slope >40%) account for 44% of the total area (Monk et al. 1997). The island is part of the Wallacean biogeographic region where different Asian and Australian assemblages of plants, birds, mammals, reptiles, and insects mix (Braby and Pierce 2007). The climate in Timor Island is characterized by a short rainy and long dry season. The rainy season is mainly from December to March, and the dry season is from June to September yearly (Monk et al. 1997). The land cover of the West is dominated by savanna, seasonal lowland forest, and secondary vegetation, especially in the lowlands. The majority of the original forest has been removed, and the remaining primary and secondary forests are also under threat, leaving only a few scattered pockets of remnant woodland. These pockets of remaining forest vegetation are now threatened by loss due to forest clearing practices for shifting cultivation, timber exploitation, overgrazing, burning, and weed invasion, all of which affect species diversity (Cowie 2006).

One of the problems faced in forest management in East Nusa Tenggara is the high level of forest degradation. Many forest areas have been cleared and deforested, and as a result, the diversity of plant species has undergone many changes in structure and composition. This forest clearing will provide an entry site for invasive alien plants and threaten the existence of native plants. Invasion of alien species in forest areas, especially in conservation forests, has been reported by Siregar and Tjitrosoedirdjo (1999). The quality of the forest and the diversity of flora and fauna found in conservation forests can be threatened if such an invasion is not managed. Research on invasive species in Indonesia has become one of the popular topics related to species diversity, ecology, control, and utilization aspects (Tjitrosoedirdjo 2005; Setyawati et al. 2015; Sunaryo and Girmansyah 2015; Sutomo et al. 2016; Padmanaba et al. 2017; Utami et al. 2017; Tampubolon et al. 2018; Mukaromah and Imron 2020; Sayfulloh et al. 2020). Various plant life forms can be invasive, ranging from trees, shrubs, lianas, vines, grasses, herbs, and other types of succulents, including plants that have tubers and rhizomes, to aquatic plants (Sindel 2000). Many woody plants have recently been recognized as a new invasive species (Holm et al. 1977). In the last few centuries, humans have introduced many types of woody plants for various purposes, and many of these woody tree and shrub species have been naturalized from their natural habitats and become invasive (Binggeli et al. 1998; Richardson and Rejmánek 2004; Williams and Cameron 2006; Richardson 2011). In Indonesia, most alien plant species were introduced for cultivation, as experimental, and through a Botanic Garden collection (Tjitrosoedirdjo 2005). The alien species might also be introduced through plant propagules infecting imported agricultural products. Research on invasive plants by Lestari (2021) at the Bogor Botanic Gardens, Indonesia, found 69 species of invasive plants from 44 families. Of 69 species present, the most invasive species were shrubs (20 species), or around 28.99%, followed by trees (17 species), or around 24.64%. Reichard and Campbell (1996) noted that 85% of the 235 woody invasive plants in the United States were initially introduced as ornamentals and 14% as crops. Such woody plants are now considered invasive alien species in many locations, and they have caused significant damage in others. Among 235 woody plants, 21 species are on the list of the '100 worst invaders' in the World' (Boudjelas et al. 2000), seven species are on the list of Europe's '100 worst invaders species, and 20% of the most intensively studied invasive species are woody plant species (Pyšek et al. 2008). Invasion of woody plants has known to be able to inhibit and suppress the regeneration of native species, leading to overtaking the native species (Webster et al. 2006). Many traits of trees and shrubs allow them to be invasive, including fast growth, shade tolerance, drought, and resistance to fire. Invasive exotic trees and shrubs can outcompete native species for growing space (Webster et al. 2006). Invasive trees and shrubs are aggressive invaders of disturbed areas, and because they are fast-growing, some are well-adapted to relatively undisturbed forests. Consequently, if left unchecked, invasive trees and shrubs can potentially replace commercially and ecologically important native species (Webster et al. 2006).

The most crucial problem faced in forest conservation actions in West Timor is the need for more information regarding invasive plant species composition. In order to evaluate forest sustainability, determine conservation priorities, direct ecosystem management, and prioritize restoration activities, an understanding of invasive plant species, particularly woody trees and shrubs, is required. Therefore, this study was conducted to determine the structure and composition of tree and shrub species and their invasiveness in the conservation area of West Timor with a focus on measuring species density, dominance, and frequency needed to calculate the Importance Value Index (IVI), as a measure of the composition and structure of the forest.

MATERIALS AND METHODS

Study area

This study was carried out in Kupang District (Indonesia), a district located in the southwest part of Timor Island with a land area of about 7,178.26 km^2 and geographically located between 9º19'-10º57' South Latitude and 121º30'-124º11' East Longitude. The forest area in Kupang is 288,397 ha, consisting of 109,463.41 ha of Protected Forest and 831.92 ha of Conservation Forest (BPS Provinsi Nusa Tenggara Timur 2022). The research was conducted in its three conservation forests: Baumata Nature Recreation Park (Baumata NRP), Camplong Nature Recreation Park (Camplong NRP), and Herman Yohannes Grand Forest Park (Herman Yohannes GFP) (Figure 1).

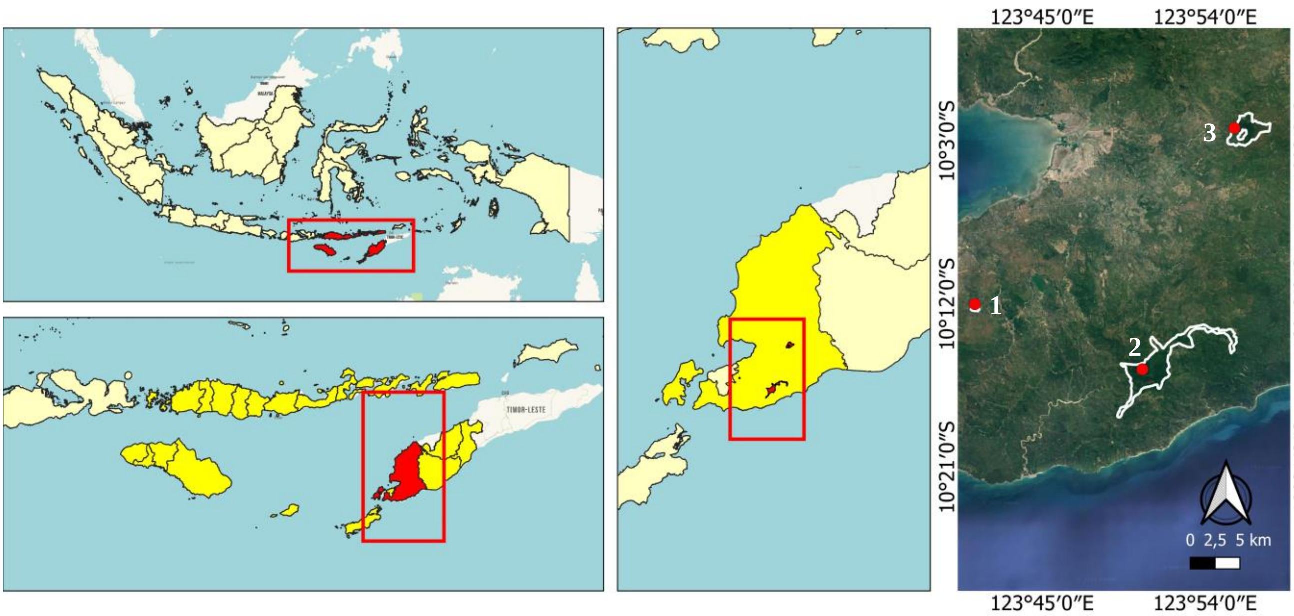


Figure 1. Map of the study area in (1) Camplong NRP, (2) Herman Yohannes GFP, and (3) Baumata NRP of East Nusa Tenggara, Indonesia

Baumata NRP has an area of 36.21 ha. The Baumata Forest area was located at 211-263 masl with a wavy and hilly topography with calcareous or karst soil conditions. Baumata NRP has vegetation that is representative of the type of medium land forest ecosystem (BBKSDA NTT 2022). This area has a wealth of natural resources, including the potential for natural tourism and environmental services, the potential for fauna, and the diversity of vegetation types. The Camplong NRP is located at 245-480 masl with sloping, wavy, hilly, or mountainous topography and calcareous or karst soil conditions. Camplong NRP has vegetation that is representative of the type of medium and forest ecosystem. The habitat type of Camplong NRP was classified as a semi-deciduous forest type because climatic conditions and local altitude strongly influenced the vegetation condition in this area. The above conditions show that the vegetation that could live in this area was generally dominated by vegetation that sheds its leaves in the long dry season. With an area of 1,900 ha, Herman Yohannes GFP was the only GFP located in West Timor. The GFP suffered severe damage from illegal logging, illegal grazing, wildlife hunting, encroachment, and other environmentally unsound activities.

Data collection and analysis

Three conservation areas were chosen purposively to represent conservation areas in Timor Island: one Grand Forest Park and two Nature Recreation Parks [(*Taman Wisata Alam* Baumata (Baumata NRP), *Taman Wisata Alam* Camplong (Camplong NRP), and *Taman Hutan Raya* Prof. Ir. Herman Yohanes (Herman Yohanes GFP)]. The selection of this Nature Recreation Park was carried out because, apart from being used for recreational purposes, the Nature Recreation Park is expected to be able to maintain the local biodiversity of plant species present in West Timor. The method used to collect data was the point-centered quarter method (Mueller-Dombois and Ellenberg 2003). In each selected conservation area, four 100 m long transects were placed in the direction of the compass. The first transect was placed randomly, and the second and third transects were placed at a distance of 100 m parallel to the first transect. Sample points were then determined in 10 m intervals across the 100 m transect (10 points in total per transect). To construct four quarters, a 1 m timber meter was placed perpendicular to the line transect at each sample point. In each quarter, the nearest tree or shrub (≥1 m height) was identified, and the distance from the sample point was measured (Figure 2). All plants belonging to the group of trees and shrubs present were recorded and identified. Trees were defined as perennial woody plants with a distinct main trunk. Woody plants without these criteria and with many small stems were classified as shrubs. The measurement did not include woody grasses, woody parasitic plants, woody cacti, herbaceous, seedlings, and all other plant statures. Basal area was obtained by measuring the diameter of the stem at a height of 0.5 m.

Plant density was calculated from the average distance, while the diameter or dominance and frequency were calculated from the presence of plants at each sample point. Every plant present was recorded, labeled, and sampled. The plant samples were dried and then identified in the laboratory of the Department of Biology, Faculty of Science and Engineering, Universitas Nusa Cendana, Indonesia. The identified name of each tree and shrub species was then subject to a scientific name search at the GBIF (https://www.gbif.org/) and WFO (http://www.worldfloraonline.org/) sites to ensure it was a current name. For each species present, the number of individuals (density), dominance, frequency, and Importance Value Index (IVI) were calculated (Mueller-Dombois and Ellenberg 2003). Species Density (DE) was estimated as the proportion of places where the species was found multiplied by the estimated density of all species. The Relative Density (RDE) of each species was calculated as the percentage of the total number of observations of that species. Each species' Dominance (DO) was expressed in stem diameter per hectare. The Relative Dominance (RDO) for a species was defined as the trunk diameter for that species divided by the total trunk diameter × 100. A Species' Frequency (FE) was the percentage of sample points at which a species was present. Relative frequency (RFE) was calculated by dividing the species frequency of each species by the total frequency of all species multiplied by 100. The IVI for trees and shrub species was defined as the sum of relative density, relative dominance, and relative frequency (IVI = RDE + RDO + RFE), while grass, herbaceous, seedling, and all other plant statures were not included in the measurement. Each type of plant present was checked for its invasiveness at the site of the CABI Invasive Species Compendium (https://www.cabi.org/ISC) and the site of IUCN Global Invasive Species (http://www.iucngisd.org/gisd/) and later was crosschecked with the list of invasive species for Indonesia as provided by the the Minister of Forestry Regulation (*Permenhut*) Number 94 of 2016 concerning Invasive Species and the list of invasive species provided in the guide book to invasive species in Indonesia (Setyawati et al. 2015).

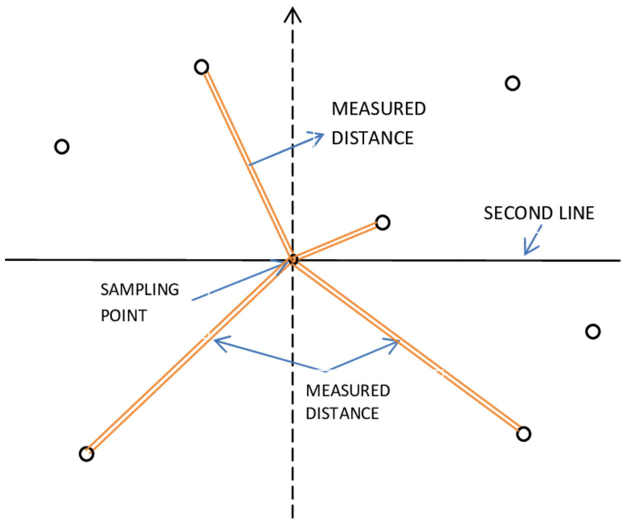


Figure 2. Graphic representation of points center quarter method (Okereke et al. 2016)

RESULTS AND DISCUSSION

Structure and composition of vegetation

In Camplong NRP, 22 species of trees and shrubs were found with a population density of 654 plants/ha. Based on density, the forest was dominated by *Syzygium aqueum* (Burm.fil.) Alston (18.74%), *Elaeocarpus petiolatus* (Jack) Wall. ex Kurz (15.66%), *Cananga odorata* (Lam.) Hook.f. & Thomson (12.63%), and *Senna siamea* (Lam.) H.S.Irwin & Barneby (11.36%). Based on dominance, the area was dominated by *Wrightia calycina* A.DC. (27.21%), *C. odorata* (13.72%), *Schleichera oleosa* (Lour.) Oken (9.90%), *Tetrameles nudiflora* R.Br. (8.10%), and *S. siamea* (7.71%). Based on frequency, the area was dominated by *S. agueum* (21.02%), *C. odorata* (13.81%), *S. siamea* (13.71%), and *Ziziphus timoriensis* DC. (12.20%). Based on IVI, the area was dominated by *S. agueum* (45.77%), *C. odorata* (40.16%), *W. calycina* (37.12%), *S. siamea* (32.79%), *Z. timoriensis* (26.34%), and *E. petiolatus* (22.28%) (Figure 3.A). Of the 22 species present, 16 (72.73%) were trees, and six (27.27%) were shrubs. The tree has a density of 80.89%, dominance of 82.93%, frequency of 78.81%, and IVI of 244.41 (81.47%). Therefore, the forest area was dominated by tree species. The shrub has a density of 19.10%, a dominance of 15.27%, a frequency of 21.19%, and an IVI of 55.58 (18.33%). The shrub species was *Broussonetia papyrifera* (L.) Vent., *Jatropha gossypiifolia* L., *Z. timoriensis*, *Ziziphus oenopolia* (L.) Mill., *Annona squamosa* L., and *Gliricidia sepium* (Jacq.) Kunth, while all other species were in the tree category.

In Herman Yohannes GFP, 24 trees and shrubs were present, with a 742 plants/ha density. Based on the density, the plants were dominated by *Neolitsea cassiifolia* (Blume) Merr. (10.00%), *Maesa junghuhniana* Scheff. (10.00%), *Aglaia teysmanniana* (Miq.) Miq. (8.30%), *Antidesma bunius* (L.) Spreng. (7.50%), and *Albizia* spp. (7.50%). Based on dominance, the forest area was dominated by *N. cassiifolia* (20.74%), *M. junghuhniana* (13.07%), *Ficus benjamina* L. (8.04%), *Miliusa horsfieldii* (Benn.) Pierre (7.47%), and *A. bunius* (7.20). Based on the frequency, the forest was dominated by *N. cassiifolia* (10.00%), *M. junghuhniana* (10.00%), *A. teysmanniana* (8.33%), *A. bunius* (7.50%), and *Albizia* Durazz. (7.50%). Based on IVI, the stand was dominated by *N. cassiifolia* (40.70%), *M. junghuhniana* (33.07%), *A. bunius* (22.20%), *Albizia* (21.92%), and *A. teysmanniana* (19.86%) (Figure 3.B). Of the 24 species present, about 18 (75.00%) species belong to the tree category and six (25.00%) species to the shrub category. The tree category has a density of 87.42%, dominance of 96.71%, frequency of 87.45%, and an IVI of 90.52%. The shrub category has a density of 12.48%, a dominance of 3.27%, a frequency of 12.48%, and an IVI of 9.41%. The shrubs were *A. squamosa*, *Maesa latifolia* (Blume) DC., *Harrisonia perforata* (Blanco) Merr., *Sambucus javanica* Reinw. ex Blume, *Daphniphyllum glaucescens* Blume, and *Coffea* sp., while all other species belong to the tree category.

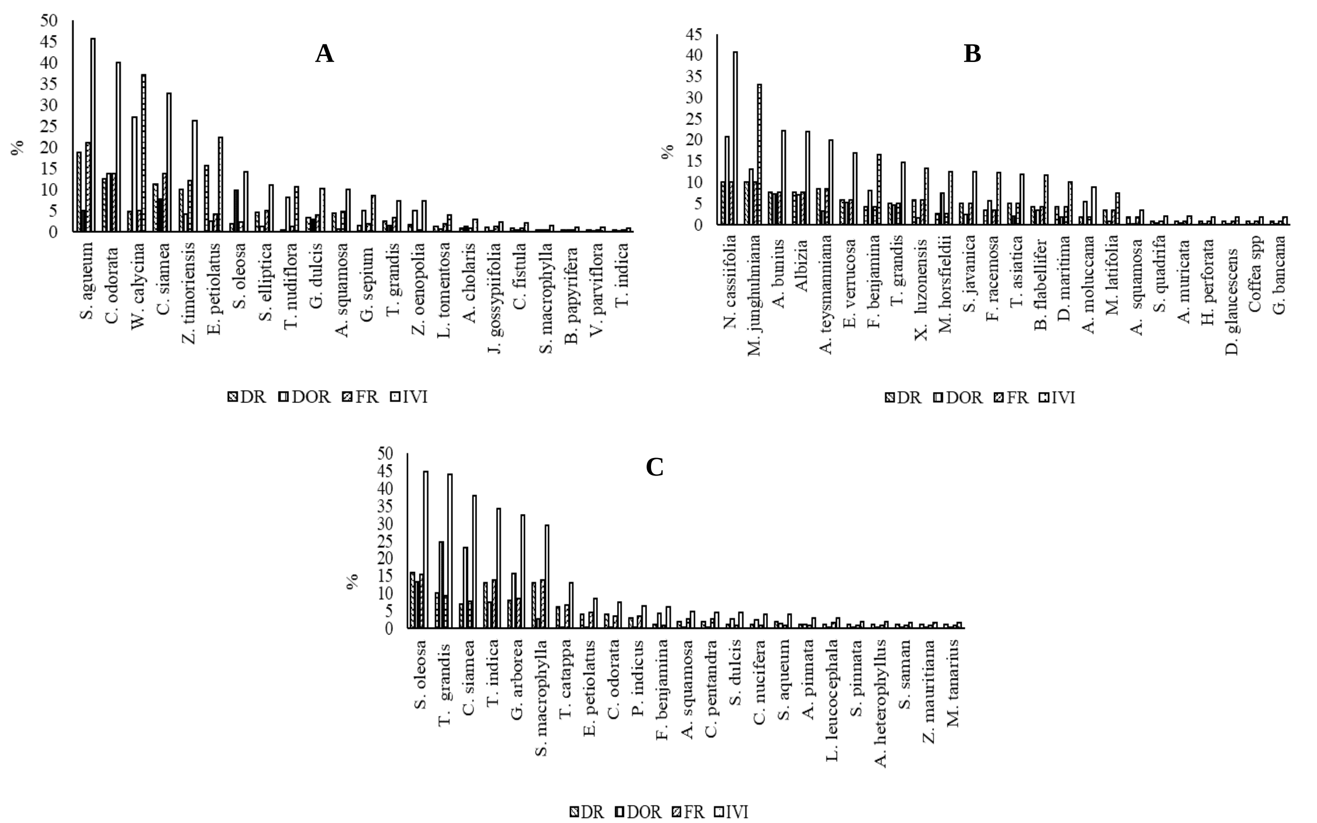


Figure 3. Plant composition on A. Camplong, B. Yohannes, C. Baumata Forest (DR: Relative Density, DOR: Relative Dominance, FR: Relative Frequency, IVI: Importance Value Index)

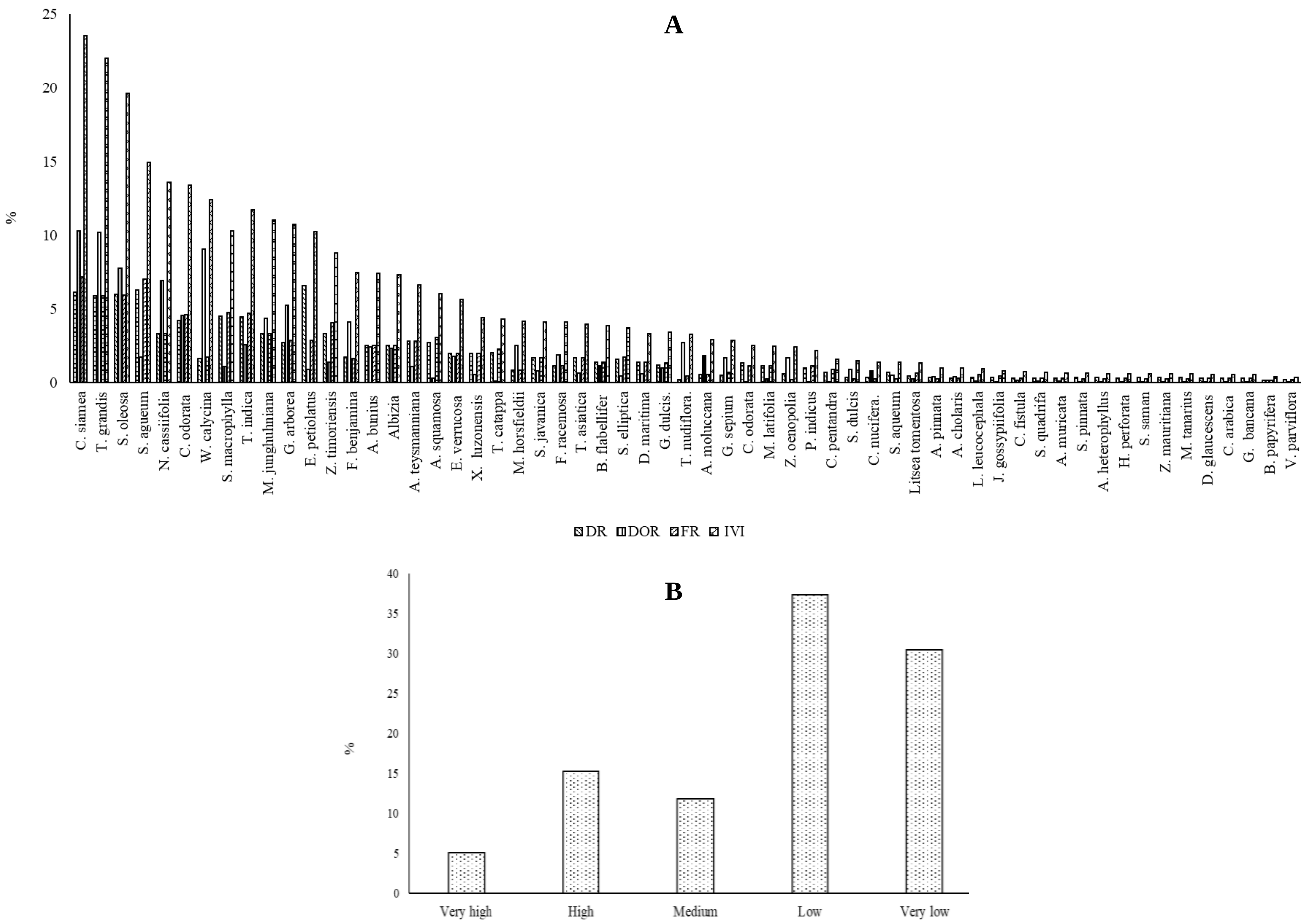


Figure 4. A. Composition and B. Categories of Importance Value Index (IVI) of plants in conservation areas of West Timor (DR: Relative Density, DOR: Relative Dominance, FR: Relative Frequency, IVI: Importance Value Index)

In Baumata NRP, 23 species of trees and shrubs were found, with a density of 408 plants/ha. Based on density, this area was dominated by *S. oleosa* (16.00%), followed by *Swietenia macrophylla* G.King (13.00%), *Tamarindus indica* L. (13.00%), and *Tectona grandis* L.f. (10.00%). Based on dominance, the plants were dominated by *T. grandis* (24.60%), *S. siamea* (23.10%), *Gmelina arborea* Roxb. ex Sm. (15.70%), and *S. oleosa* (13.30%). Based on frequency, the plants were dominated by *S. oleosa* (15.40%), followed by *S. macrophylla* (13.70%), *T. indica* (13.70%), and *T. grandis* (9.30%). Based on IVI, the plants were dominated by *S. oleosa* (44.70%), *T. grandis* (43.90%), *S. siamea* (37.80%), *T. indica* (34.20%), *G. arborea* (32.20%), and *S. macrophylla* (29.40%). Those six plants have a total IVI of 222.20 (74.07%) (Figure 3.C). Of the 23 species present, as many as 20 (86.96%) species belong to the tree stature category and three (13.04%) to the shrub category. Trees have a density of 93%, dominance of 99.90%, frequency of 93.30%, and IVI of 95.40%, while shrubs have a density of 7.00%, dominance of 0.10%, frequency of 6.70%, and IVI of 4.60%. Plants belonging to the shrub category were *Chromolaena odorata* (L.) R. King & H.Rob., *A. squamosa*, and *Ziziphus mauritiana* Lam., while all other plant species were of the tree category.

The plant population density was lower in Baumata NRP (4.08 plants/ha) than in Camplong NRP (6.54 plants/ha) and Herman Yohannes GFP (7.42 plants/ha). The dominance of the tree population in the Baumata NRP was higher (86.96% with an IVI of 95.40%) than in Herman Yohannes GFP (75.00% with an IVI of 90.52%) and Camplong NRP (72.73% with an IVI of 81.47%). The low plant population density in the Baumata NRP compared to the other two conservation areas can be due to the more disturbances of the former conservation area than in the other two conservation areas or can be due to the higher dominance of tree species in the former conservation area so that there was less opportunity for bush species to be present. However, further research was needed to confirm this. Of the three conservation areas, 59 trees and shrubs had a 601.33 plants/ha density. In general, the number of tree and shrub species found in the three conservation areas was relatively lower compared to that commonly found in rainforest communities where woody plant diversity can reach 150 tree species/ha (Kessler et al. 2005) and in the Amazon forest even reaches 283 tree species/ha (Gentry 1988). The relatively lower number of species found in West Timor can also be affected by forest health, where most of the forests are currently heavily disturbed, and forest areas are limited to small remnant vegetation (Lesmana et al. 2000). In addition, the dryland ecosystems in West Timor were generally relatively less stable than ecosystems in humid areas in the tropics which may also affect the number of species present (Monk et al. 1997). Kessler et al. (2005) stated that the number of native tree species was higher in natural forests than in unnatural forests, and the number of tree species gradually decreased with increasing intensity of forest disturbance.

The low number of species found in the forests of West Timor compared to those found in most areas of the rainforest may also be influenced by the geographical position of Timor Island in central Malesia, the transition zone called (Wallacea) located between the Sunda Shelf and the Sahul Shelf (van Welzen et al. 2005; Cowie 2006). Being located in the transition zone between these areas, Timor Island's flora lacks the diversity of much of the flora of the primary rainforest (van Steenis 1979; Cowie 2006). The geological history, climate, patterns of plant distribution, soil conditions, and topography can also influence the flora of Timor (van Steenis 1979; Cowie 2006). As the island of Timor is closer to Australia than West Malesia, the Timorese flora appears to have been more influenced by the Australian than the Malesian flora. During the ice ages, the northwest coast of Australia was some 100-200 km from Timor (Barlow 1981; Cowie 2006). This proximity also appears to facilitate the exchange of plant species between the two regions (van Steenis 1979; Cowie 2006). Timor also has a generally drier monsoon climate than the climate surrounding New Guinea and West Malesia, which may also limit the diversity of flora on the island of Timor. Timor is a relatively new island in terms of its geology, having been lifted from the seabed by the Australian tectonic plate drifting northward over the last 10 million years, and the time for the species to evolve thus was shorter than in many other parts of Malesia (Barlow 1981; van Welzen et al. 2005), and this may also affect the species diversity present in West Timor.

Of the 59 species present in the conservation areas of West Timor, based on the density, the forest area was dominated by *E. petiolatus* (6.55%), *S. aqueum* 6.25%), *S. siamea* (6.12%), *S. oleosa* (5.96%), and *T. grandis* (5.88 %). Based on the dominance, the forest was dominated by *Cassia siamea* Lam. (10.27%), *T. grandis* (10.21%), *W. calycina* (9.07%), and *S. oleosa* (7.73%). Based on the frequency, the area was dominated by *C. siamea* (7.14%), *S. agueum* (7.01%), *S. oleosa* (5.92%), and *T. grandis* (5.89%). Based on the IVI, the area was dominated by *C. siamea* (23.53%), *T. grandis* (21.97%), *S. oleosa* (19.61%), and *S. agueum* (14.95%). These four species had a total IVI of 80.06 (26.69%) or dominated almost 30.00% of the conservation areas (Figure 4.A). Species with high IVI indicate that they were more adaptive and able to adapt to changing environmental conditions better than other species in a forest community (Soerianegara and Indrawan 1998). They were able to make better use of available resources than other species and have a greater chance of sustaining their growth and reproduction. Species with high IVI could adapt to the environment by using what energy sources are available in the community, indicating that these species have an essential role in ecosystem sustainability (Soerianegara and Indrawan 1998).

Based on IVI, *S. siamea* was the most dominant plant in the conservation areas of West Timor. The *S. siamea* is an evergreen tropical plant that grows fast in various climatic conditions but prefers monsoon climates. This tree was often planted as roadside shade, as shade in tea, coffee, or cocoa plantations, as an ornamental tree, and as a pioneering tree in rehabilitating mining areas. In West Timor, this tree was introduced as part of the reforestation programs following the introduction of *T. grandis* to the island as part of the plantation forest program several decades ago. The presence of these two tree species in the conservation areas of West Timor was initially the result of planting and later the result of natural regeneration. *S. oleosa* was mainly found in Indonesia in areas with an extended and robust dry season, starting from the eastern hemisphere of Java, Bali, Nusa Tenggara, Sulawesi, and Maluku, growing either wild or planted (van Steenis 1979). This tree is also found outside West Timor in Sumba, Rote Ndao, Kalabahi, Alor, and others (van Steenis 1979). The wood of this plant was widely used as firewood for preparing a pork-based local delicacy called *Sei*. On the other hand, *S. aqueum* is a fruit-producing tree that is generally eaten fresh or used for preparing fruit salad.

The IVI of the above tree and shrub species was grouped based on their IVI into categories of very high (IVI>15), high (10<IVI<15), medium (5<IVI<10), low (1<IVI<5), and very low (IVI<1). Of the 59 trees and shrubs present, three (5.08%) species belonged to the category of very high importance; nine (15.25%) to the category of high; seven (11.86%) to the category of medium; 22 (37.29%) to the category of low, and 18 (30.51%) to the category of meager (Figure 4.B). Species of very high importance (NP>15) were *S. siamea*, *T. grandis*, and *S. oleosa*. The general pattern of forest community composition is that only a few species are categorized as abundant, and many others are categorized as locally rare. Most species (67.80%) in Timor Island forest communities belong to low and very low-importance categories. Many species in this category indicate that most species present are rare in this forest area. The large number of rare species encountered in this study confirms the general assumption that most species in the ecological communities are rare, not ordinary (Magurran 2003; Françoso et al. 2016). The scarcity of species can be due to various reasons, namely strong density-dependency in the forest, the existence of a resource gradient that causes species to occupy different positions resulting in variations in the distribution of abundance, the low ability of species to spread, the presence of natural or human-induced disturbances, and the process of competition taking place in the forest (Schwarz et al. 2003). The IVI is commonly used in ecological studies to indicate the ecological importance of a species in an ecosystem and to determine the conservation priority of species where species with low IVI values require a high conservation priority compared to those species with high IVI (Zegeye et al. 2006). Based on their low IVI values, *Arenga pinnata* (Wurmb) Merr., *Alstonia scholaris* (L.) R.Br., *Leucaena leucocephala*

(Lam.) de Wit, *J. gossypiifolia*, *Cassia fistula* L., *Sterculia quadrifida* R.Br., *Annona muricata* L., *Spondias pinnata* (L.fil.) Kurz, *Artocarpus heterophyllus* Lam., *H. perforata*, *Samanea saman* (Jacq.) Merr., *Z. mauritiana, Macaranga tanarius* (L.) Müll.Arg., *D. glaucescens, Coffea* spp, *Garcinia bancana* (Miq.) Miq., *Vitex parviflora* A.Juss., and *B. papyrifera* can be of high conservation priority in conservation areas.

Understanding tree species' composition and structure is a crucial instrument in assessing the sustainability of forest management, species conservation, and ecosystem management (Madoffe et al. 2006; Addo-Fordjour et al. 2009). Rapid human population growth has been shown to negatively impact forest size, species richness, and diversity (Kacholi 2014). If no action is taken, the remaining forest areas will continuously decrease and become more fragmented, leaving remnant forests that will lose their capacity to preserve the original biological diversity. Biodiversity conservation has become an increasingly important priority and essential issue in recent years, which, by describing the status of the structure and composition of tree and shrub species in the West Timor conservation areas, this study is expected to contribute. Using the available data, urgent intervention measures are needed to minimize further disturbances, primarily anthropogenic disturbances such as illegal logging, livestock grazing, fires, overexploitation, unsustainable agricultural practices, land conversion, and invasion by alien species as the primary driver of biodiversity loss.

Invasive trees and shrubs

In the Camplong NRP, of the 22 species of trees and shrubs present, nine species (40.91%) were potentially invasive. It is considered “potentially” invasive because a species is invasive in an area but has not been formally registered as an invasive species. Those potentially invasive species included *C. siamea*, *A. squamosa*, *G. sepium*, *J. gossypiifolia*, *C. fistula*, *B. papyrifera*, *V. parviflora*, *T. indica*, and *S. macrophylla*. Potentially invasive species had a density of 21.02%, a dominance of 14.86%, a frequency of 24.44%, and an IVI of 60.33 (20.11%). Potentially invasive species were dominated by *C. siamea* (IVI 32.79%), followed by *A. squamosa* (IVI 10.02%), *G. sepium* (IVI 8.51%), while other potentially invasive species only had relatively low importance (<3.00%) (Figure 5.A). Four of the nine potentially invasive species were shrubs (*A. squamosa*, *G. sepium*, *J. gossypiifolia*, and *B. papyrifera*), and the five remaining species were trees.

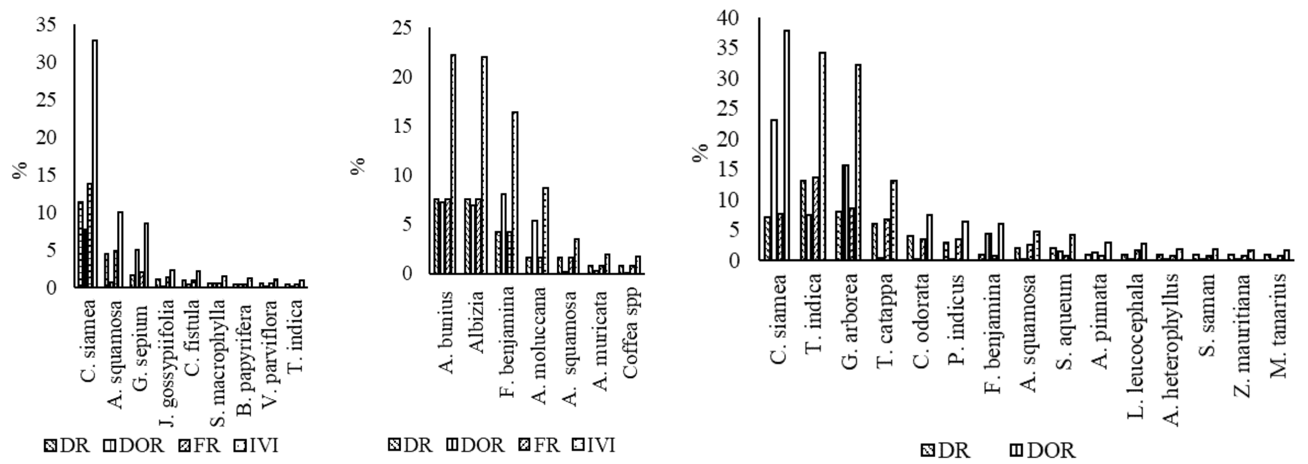
Seven of the 24 species of trees and shrubs present at Herman Yohannes GFP (29.17%) were potentially invasive. Based on density, dominance, frequency, and IVI, the potentially invasive species had a total density of 24.14%, dominance of 27.94%, frequency of 24.14%, and IVI of 25.41%. Those potentially invasive species included *A. bunius*, *Albizia*, *F. benjamina*, *Aleurites moluccanus* (L.) Willd., *A. squamosa*, *A. muricata*, and *Coffea* spp. Based on IVI, potentially invasive species were dominated by *A. bunius* (22.20%), *Albizia* (21.92%), and *F. benjamina* (16.37%), while other species had IVI<10.00% (Figure 5.B). Two of the seven potentially invasive species were shrubs (*A. squamosa* and *Coffea* spp.), and the five remaining species were trees.

In Baumata NRP, of the 23 species of trees and shrubs present, 16 (69.57%) species were potentially invasive, indicating that the number of invasive species was relatively large, at around 70.00%. Potentially invasive species included *C. siamea*, *T. indica*, *G. arborea*, *S. macrophylla*, *Terminalia catappa* L., *C. odorata*, *Pterocarpus indicus* Willd., *F. benjamina*, *A. squamosa*, *S. aqueum*, *A. pinnata*, *L. leucocephala*, *A. heterophyllus*, *S. saman*, *Z. mauritiana*, and *M. tanarius*. Potentially invasive species have a total density of 65.00%, dominance of 56.69%, frequency of 66.20%, and IVI of 62.63%. So, based on IVI, potentially invasive species have an IVI of more than 50.00%. Based on IVI, the potentially invasive species were dominated by *C. siamea* (37.80%), *T. indica* (34.20%), *G. arborea* (32.20%), and *S. macrophylla* (29.40), while other potentially invasive species had an IVI of <13%. (Figure 5.C). Of the 15 potentially invasive species present, three were shrubs (*C. odorata*, *A. squamosa*, and *Z. mauritiana*), and 13 remaining species were trees.

Based on the number of species potentially invasive, Baumata NRP has higher potentially invasive tree and shrub (69.57%), followed by Camplong NRP (40.91%) and Herman Yohannes GFP (29.17%) (Figure 6.A). Based on their IVI, potentially invasive species in Baumata NRP were significantly higher (paired T-Test) (62.63%) than in Camplong Forest (20.11%) (P <0.001), and Herman Yohannes Forest (25.41%) (P<0.001), while between Herman Yohannes and Camplong Forest were not different (P >0.001). Thus, the contribution of potentially invasive tree and shrub species to the Baumata NRP was relatively more significant than to the other two conservation areas. The high presence of potentially invasive species in the Baumata NRP indicates more significant damage to the conservation area than Camplong NRP dan Herman Yohannes GFP.

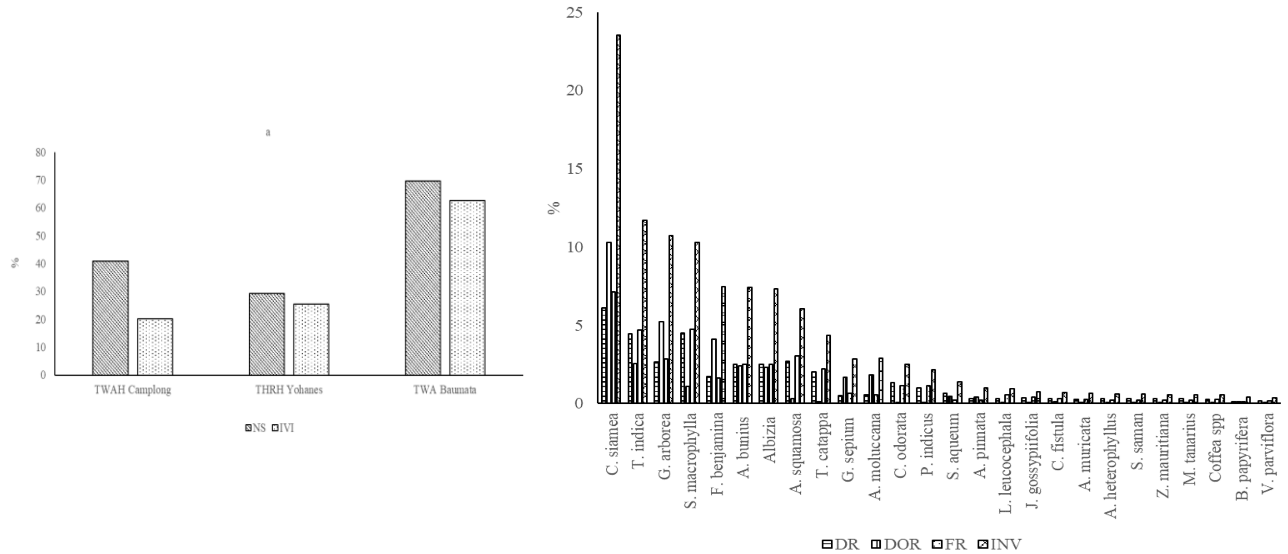
Of the 26 potentially invasive tree and shrub species present, based on density, the species were dominated by *C. siamea* (6.12%), *T. indica* (4.47%), *S. macrophylla* (4.50%), *A. squamosa* (2.70%), and *G. arborea* (2.67%). Based on the dominance, the potentially invasive species were dominated by *C. siamea* (10.27%), *G. arborea* (5.23%), *F. benjamina* (4.10%), and *T. indica* (2.53%). Based on the frequency, the potentially invasive species were dominated by *C. siamea* (7.14%), *T. indica* (4.69%), *S. macrophylla* (4.73%), *A. squamosa* (3.04%), and *G. arborea* (2.83%). Based on IVI, the potentially invasive species were dominated by *C. siamea* (23.53%), *T. indica* (11.69%), *G. arborea* (10.73%), *S. macrophylla* (10.30%), *F. benjamina* (7.45%), *A. bunius* (7.40%), and *Albizia* (7.31%) (Figure 6.B). Of the 26 potentially invasive species present, seven species (26.92%) were shrub (*J. gossypiifolia*, *A. squamosa*, *G. sepium*, *Coffea* spp, *B. papyrifera*, *C. odorata*, and *Z. mauritiana*), and 19 species (73.08%) were tree (*C. siamea*, *T. indica*, *G. arborea*, *F. benjamina*, *A. bunius*, *Albizia*, *T. catappa*, *A. moluccanus*, *P. indicus*, *S. aqueum*, *A. pinnata*, *L. leucocephala*, *C.*

fistula, *A. muricata*, *A. heterophyllus*, *S. saman*, *M. tanarius*, *S. macrophylla*, and *V. parviflora*). Invasive species can be present in various forms of habitus or form, ranging from the form of trees, shrubs, lianas, climbing or vines, grasses, herbs, and succulent plant species, including plants that have tubers, rhizomes, or aquatic plants (Sindel 2000). Each form of habitus can have a different effect on the ecosystem and its flora and fauna. Weeds in the form of shrubs can form dense and dense clumps when they successfully invade and dominate an area. This shrub will then directly prevent and inhibit the growth of seedlings of native plant species in the area.



A B C

Figure 5. Potentially invasive species in three conservation forest areas on Timor Island. A. Camplong, B. Yohannes, and C. Baumata forest (DR: Relative Density, DOR: Relative Dominance, FR: Relative Frequency, IVI: Importance Value Index)



A B

Figure 6. A. Number of species (NS) and Importance Value Index (IVI), B. Species composition of potentially invasive trees and shrubs in Timor conservation forest (DR: Relative Density, DOR: Relative Dominance, FR: Relative Frequency, IVI: Importance Value Index)

Table 1. The potential invasive species in Baumata NRP, Camplong NRP, and Herman Yohannes GFP after checking at the site of CABI Invasive Species Database and IUCN Global Invasive Species Database and crosschecking with the list of invasive species according to Permen LHK No. P.94/Menlhk/Setjen/Kum.1/12/2016 and Setyawati et al. (2015)

Species	Notes on Invasiveness on CABI Invasive Species Database	GISD	Permen LHK No. P.94 Year 2016	Setyawati et al. (2015)	Status of Introduction	Invasiveness to the Conservation areas
Albizia lebbeck and *Falcataria moluccana* (*Albizia falcataria*)	A nitrogen-fixing tree native to Southeast Asia and Papua New Guinea, listed as invasive elsewhere	-	Not listed	Not listed	Introduced	*A. lebbeck* is native, and *F. moluccana* is invasive only if mass-planted (1)
Aleurites moluccanus	A native species to Southeast Asia, listed as invasive outside Indo-Malaya region	Not Found	Not listed	Not listed	Local	Not invasive, part of native species
Annona muricata	A native species to Southeast Asia, listed as invasive in the Pacific Island	Not Found	Not listed	Not listed	Local	Not invasive, part of native species
Annona squamosa	A native species to Southeast Asia, listed as a "cultivation escape, naturalized weed" in the Global Compendium of Weeds	Found	Not listed	Not listed	Local	Not invasive, part of native species
Arenga pinnata	A native palm species of Southeast Asia. Listed as invasive to disturbed areas, forests, forest gaps/edges, riparian vegetation, and lowlands	Not Found	Not listed	Not listed	Local	Invasive only because its fruits are not utilized (2)
Artocarpus heterophyllus	Listed as invasive to roadsides, disturbed areas, urban open spaces, forest edges/gaps, and secondary forest	Not Found	Not listed	Not listed	Local	Not invasive, a cultivated species rarely escapes from cultivation
Broussonetia papyrifera	It is listed as a highly invasive species, becoming weedy and difficult to remove after its introduction.	Not Found	Not listed	Not listed	Local	Not invasive, part of native species
Cassia fistula	A native species to Southeast Asia, listed as an 'agricultural weed,' 'casual alien,' 'cultivation escape,' 'environmental weed,' 'garden thug,' 'naturalized,' and 'weed' in the Global Compendium of Weeds, listed as invasive only in Queensland, Australia.	Not Found	Not listed	Not listed	Local	Not invasive, part of native species
Chromolaena odorata	Listed as the world's worst weeds	Found	Listed	Listed	Introduced	Invasive, potentially replacing ground-cover species, high risk of fire (1)
Ficus benjamina	Listed as 'environmental weed, naturalized, weed' in the Global Compendium of Weeds, invasive in Cuba (Oviedo-Prieto et al. 2012), Pacific Island, USA, Galapagos, Australia, not in Malesia region	Not Found	Not listed	Not listed	Local	Not invasive, part of native species
Gliricidia sepium	A fast-growing tree for land rehabilitation, it is listed as invasive in Australia, Hawaii, the Philippines, Cook Islands, French Polynesia, Tonga, Singapore, Comoros, and Trinidad and Tobago.	Not Found	Not listed	Not listed	Introduced	Invasive, potentially replacing native species (2)
Jatropha gossypiifolia	It is considered invasive in Australia, Africa, Asia, and North and South America. In Australia, it is declared invasive in Queensland, the Northern Territory, and Western Australia.	Found	Not listed	Not listed	Introduced	Invasive, potentially replacing ground-cover species (3)
Gmelina arborea	Widely used in reforestation programs in tropical and subtropical regions of the world and as a source of commercial timber and cellulose, it entered wild habitats where it is now replacing native trees and becoming invasive, listed as invasive in Costa Rica, the Dominican Republic, Ghana, Australia, and the Cook Islands.	Not Found	Not listed	Not listed	Introduced	Invasive, potentially replacing native species (4)

Leucaena leucocephala	A 'miracle tree' to produce valuable animal fodder and firewood while also being fast-growing and tolerant to drought and poor soils, it is regarded as an invasive species in Asia, Australia, and Pacific islands, and elsewhere	http://www.iucngisd.org/gisd/speciesname/Leucaena+leucocephala	Listed	Listed	Introduced	Invasive, potentially replacing native species (5)
Macaranga tanarius	A fast-growing pioneer plant, it is often found growing in secondary forests, especially in cleared rainforests; the spread is favored by disturbance and so rapidly colonizes gaps or margins in well-developed rainforests (Australian Tropical Rainforest Plants 2010). It is also found in thickets, brushwood, village groves, coastal rainforest, and estuaries	Not Found	Not listed	Not listed	Local	Not invasive, help recover degraded part of the conservation areas
Pterocarpus indicus	Native to tropical and temperate Asia and parts of the Pacific region, a nitrogen-fixing species is invasive because of being introduced	Not Found	Not listed	Not listed	Local	Not invasive, part of native species
Samanea saman	A large nitrogen-fixing tree may be invasive because of prolific seeding and livestock as effective dispersers of seeds, conflicting reference sources about its invasiveness	Found	Not listed	Not listed	Local	Invasive only if it is mass-planted in the conservation area (3)
Senna siamea	A widespread forestry and ornamental tree native to Southeast Asia, listed as invasive in Australia (especially the Cape York Peninsula, Queensland), Mexico, the Caribbean (Dominican Republic and Puerto Rico), the Pacific (Fiji and French Polynesia), and Africa (CABI Invasive Species Database)	Not Found	Not listed	Not listed	Introduced	Invasive only if it is mass-planted in the conservation area (4)
Sizygium aqueum	No information	Not Found	Not listed	Not listed	Local	
Tamarindus indica	a large perennial nitrogen-fixing tree native to Southeast Asia, an invasive plant of environmental concern elsewhere because it has the potential to suppress and outcompete other plant species	Not Found	Not listed	Not listed	Local	Not invasive, part of native species
Terminalia catappa	A native species to Asia, Australia, the Pacific, Madagascar, and Seychelles, listed as invasive in the United States (Florida and Hawaii), Brazil, the Bahamas, Cuba, Dominican Republic, Trinidad and Tobago, Puerto Rico, and the Virgin Islands, where it is displacing native vegetation and altering coastal dynamics.	Found	Not listed	Not listed	Local	Not invasive, part of native species
Vitex parviflora	A tropical tree native to the Philippines and Indonesia, highly valued for its durable wood and ornamental potential, it is listed as invasive in Guam and Hawaii, USA, as a species of Least Concern in the IUCN Red List of Threatened Species.	Not Found	Not listed	Not listed	Local	Not invasive, part of native species
Ziziphus mauritiana	A fast-growing, spiny, drought-tolerant, thicket-forming shrub or tree, which can produce fruits prolifically and disperse seeds over a wide area using mammalian and avian vectors, declared a noxious weed in three Australian states and is noted as invasive in parts of southern Africa and on some Pacific and Indian Ocean islands	Found	Not listed	Not listed	Local	Invasive only if large trees are felled (5)

The summary of invasiveness, means of movement and dispersal, and risk of invasiveness available for each species were carefully reviewed to check the potential invasiveness of each species. In addition, the natural distribution of each species was also consulted, and whether the species was introduced for a particular purpose or not to West Timor was also taken into account. As a result, of the 26 initially considered invasive and 23 listed as potentially invasive, only five species were invasive, and five were invasive under certain conditions. The five species categorized as invasive were *C. odorata*, *G. sepium*, *J. gossypiifolia*, *G. arborea*, and *L. leucocephala*, all introduced species. *C. odorata* and *J. gossypiifolia* were introduced as weeds; *G. sepium* and *L. leucocephala* as fast-growing nitrogen-fixing species for land rehabilitation; and *G. arborea* as plantation forest trees for timber production. Of these five species, *C. odorata* and *L. leucocephala* were the only listed invasive species under the Permen LHK No. P.94/Menlhk/Setjen/Kum.1/12/2016.

Cananga odorata was listed as invasive because of its ability to produce many seeds that are easily dispersed with the help of the wind and animals due to the presence of palpable hairs that help them buoyant in the air and stick to animal fur. In dry areas such as West Timor, the above-ground part of the shrub dry up at the end of the dry season that was easy gets burnt, leaving the underground part remaining alive to produce new shoots at the onset of the rainy season, thereby disrupting the function of natural ecosystems (Den Breeyen et al. 2006). On the other hand, *L. leucocephala* was introduced as a fast-growing nitrogen-fixing species to produce feed and rehabilitate degraded land but was later considered a weed on arable lands. The five species categorized as invasive under certain conditions were *A. pinnata*, *F. moluccana*, *S. saman*, *S. siamea*, and *Z. mauritiana*. Of these five species, *F. moluccana*, *S. saman*, and *S. siamea* are nitrogen-fixing tree species introduced as part of land rehabilitation and could become invasive to the conservation areas only if they were intentionally planted. On the other hand, *A. pinnata* and *Z. mauritiana* were part of native vegetation; the first could become invasive if the fruits were not harvested, and the latter only if the existing trees were felled.

A study conducted in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia (Balai Taman Nasional Bantimurung Bulusaraung 2017) found 18 species of invasive plants belonging to 12 families. The number of invasive species in this National Park was relatively higher than that found in the conservation areas of West Timor. However, this study included all plant species, including herbs, shrubs, and tree species. Three species of woody plants (*C. siamea*, *C. odorata*, and *S. macrophylla*) considered invasive in this study were also found as invasive or invasive under certain conditions in the conservation areas of West Timor. Sitepu (2020) investigated invasive species in the Samboja forest in East Kalimantan, Indonesia, and found six species of invasive trees and 11 species of invasive shrubs. However, again, they included all groups of plants ranging from herbs, shrubs, and tree species. Four species considered invasive in this study (*C. odorata*, *L. leucocephala*, *S. siamea*, and *Swietenia mahagoni* (L.) Jacq.) were also found in the conservation areas of West Timor. The study by Yuliana and Lekitoo (2018) in the Gunung Meja Manokwari, West Papua Province, Indonesia, found 39 invasive plants, consisting of 6 invasive species of woody plants in the form of shrubs, while all the others were herbaceous or grasses. Yuliana and Lekitoo (2018) also investigated invasive alien plants in the Protected Forest Management Unit area of Sorong, West Papua, and found 23 invasive plant species ranging from shrubs, grasses, and lianas to trees. The tree and shrub species they considered invasive species were *C. odorata*, *Crotalaria juncea* L., *G. sepium*, *L. leucocephala*, *Lantana camara* L., *Melaleuca leucadendra* (L.) L., *Mimosa pudica* L., *Senna alata* (L.) Roxb., and *Spathodea campanulata* Beauverd, of which *C. odorata*, *G. sepium*, and *L. leucocephala* were also found as either invasive or invasive under certain conditions in the conservation areas of West Timor. Sunaryo and Girmansyah (2015) identified only three invasive species of woody plants (*Acacia mangium* Willd., tree form, *Melastoma malabathricum* L., and *Rhodomyrtus tomentosa* (Aiton) Hassk. in the form of shrubs) in Tanjung Puting National Park, Central Kalimantan, Indonesia, while the remaining invasive species were of non-grass herb species.

Ihsan et al. (2022) conducted a study in Sungai Buluh Peat Protection Forest, Jambi Province, Indonesia, and found 20 invasive species. However, only a few were woody tree and shrub species, such as *Mimosa pigra* L., *Clibadium surinamense* L., *Hyptis capitata* Jacq., *Clidemia hirta* (L.) D.Don, and *M. malabathricum*, while the remaining species were from the Asteraceae family who are generally herbaceous. Sulistiyowati et al. (2020) found 13 invasive species, of which one was a tree (*Schima wallichii* (DC.) Korth.), 3 were shrubs (*Agathis dammara* (Lamb.) Rich. & A.Rich., *Calliandra houstoniana* var. *calothyrsus* (Meisn.) Barneby, and *Brugmansia suaveolens* (Humb. & Bonpl. ex Willd.) Bercht. & J.Presl), and the remaining species were herbs and grasses. In Meru Betiri National Park, East Java, Indonesia, Susilo (2018) found six essential species that were included in the 100 most invasive plant species in the world, namely *C. odora*, *L. camara*, *Mikania micranta* Kunth, *Imperata cylindrica* (L.) Raeusch., *Sida rhombifolia* L., and *Stachtarpheta jamaicensis* (L.) Vahl, two of which, namely *C. odorata* and *L. camara* invaded the Pringtali grassland area, the feeding ground of banteng (*Bos javanicus* d'Alton). According to Sunaryo et al. (2012), currently, there are 74 foreign plant species in Gunung Gede Pangrango National Park, West Java, Indonesia, while in all regions in Indonesia, there were approximately 2000 foreign plant species (Kementerian Lingkungan Hidup dan Kehutanan 2003). Of the 74 foreign and potentially invasive species, the largest belong to the Asteraceae (22 species), then Solanaceae (7 species), Caryophyllaceae (five species), Euphorbiaceae, and Lamiaceae (four species each), while the other 20 families were of different families.

In general, the contribution of invasive tree and shrub (woody plants) species to the three conservation areas of West Timor indicated that the conservation areas have been severely degraded. The presence of invasive species further threatens the integrity and composition of native forest ecosystems. It inflicts various negative impacts on forest health, biodiversity, and ecosystem services, increases tree seedling mortality, inhibits regeneration, and reduces the growth of native plant species. Invasive species are known as species that threaten the integrity of the environment and have a significant impact on flora and fauna communities (Vilà et al. 2011). The presence of *A. moluccanus*, *Coffea* sp., and *A. heterophyllus* may indicate a high level of human intervention in the three conservation areas of West Timor. Those tree species are commonly grown on agricultural land and not commonly present in natural forests. Invasion of these woody plants poses various challenges to forest management because they inhibit and outperform desired native species regeneration to suffocate or remove native species. When such invasive tree species have become abundant, they can suppress native species' growth (Webster et al. 2006).

In conclusion, for the conservation of the West Timor conservation area, management actions are needed to prevent the further presence, spread, and dominance of invasive species; to detect early the presence of new invasive species; to determine the priority scale of which species will be eradicated and which species may occupy an area, and to eradicate invasive plant populations both physically, chemically and biologically. Restoration actions are also required to prevent further destruction of the remaining forest. Efforts to prevent the degradation, both naturally and anthropogenically caused, are also needed to minimize the opportunity for invasive species to dominate.

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