ASIAN JOURNAL OF FORESTRY
Volume 7, Number 2, December 2023
Pages: 75-81
E-ISSN: 2580-2844
DOI: 10.13057/asianjfor/r070201

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

GABRIELLA RIA KIRANA[1], ANDRIO A. WIBOWO[1,♥], ERWIN NURDIN[1], WISNU WARDHANA[1], ADI BASUKRIADI[1]

Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Pondok Cina, Beji, Depok, West Java, 16424, Indonesia. Tel.: +62-21-7863436, ♥email: awbio2021d@gmail.com

Manuscript received: 1 February 2023. Revision accepted: 5 April 2023.

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.

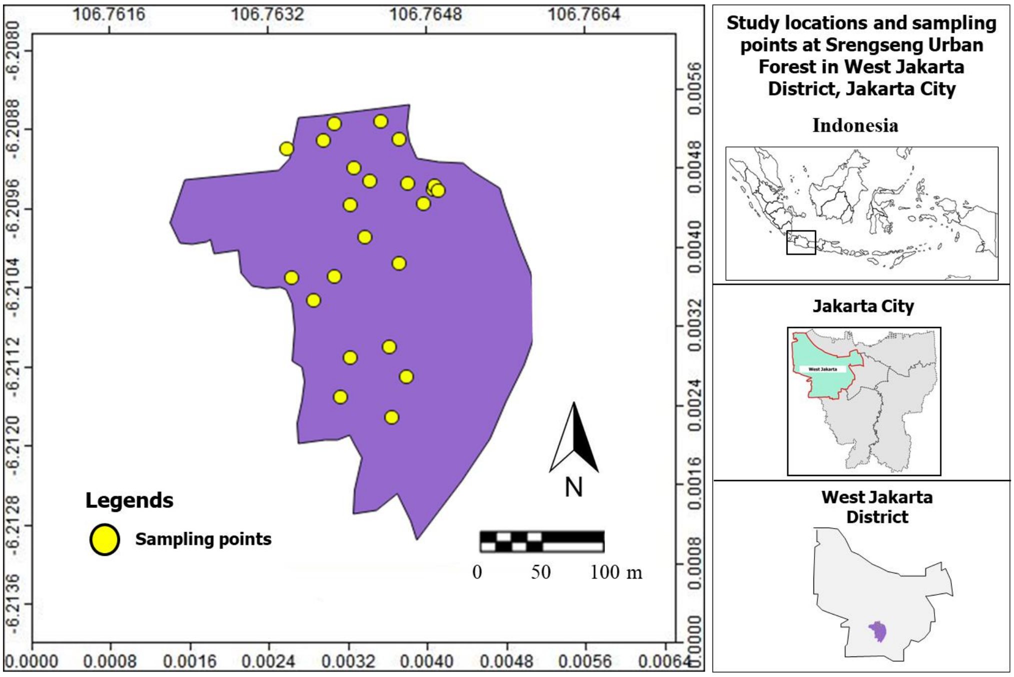

Figure 1. Map of study area and sampling points at Srengseng Urban Forest in West Jakarta City, Jakarta Province, Indonesia

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:

$$\mathbf{H' = \sum (p_i) (\log_2 p_i)}$$

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

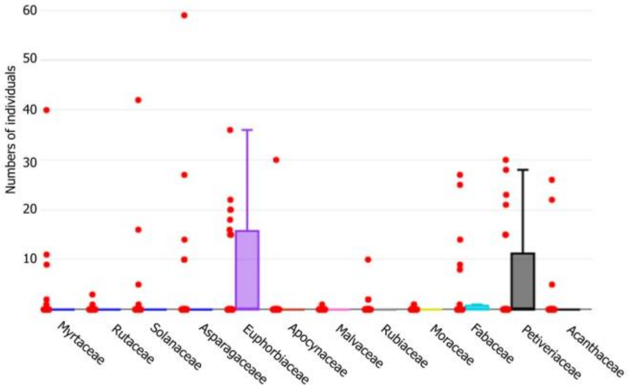

Figure 2. Boxplots of numbers of individuals based on understory shrub families in Srengseng Urban Forest, West Jakarta City, Jakarta Province. Red dots are the data points

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,

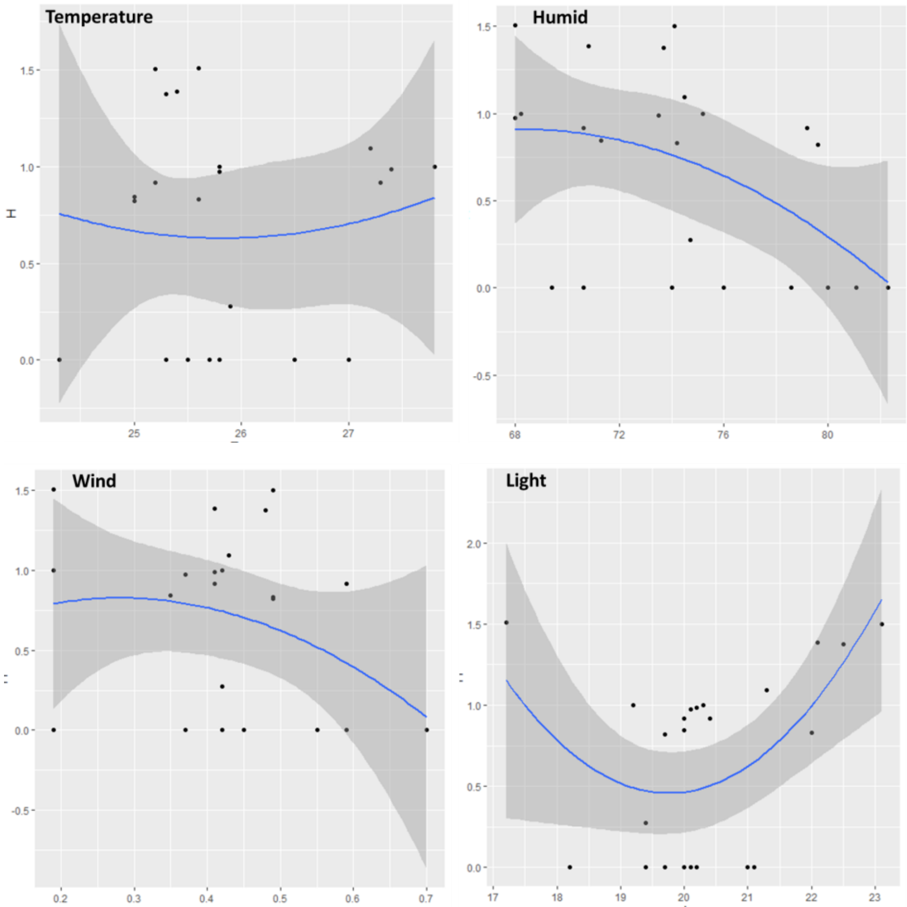

Figure 3. Correlations between Shannon-Wiener index (H') of understory shrub diversity (Y axis) and air temperature, humidity, wind, and light intensity (X axis). Note: Shaded grey shows 95% CI

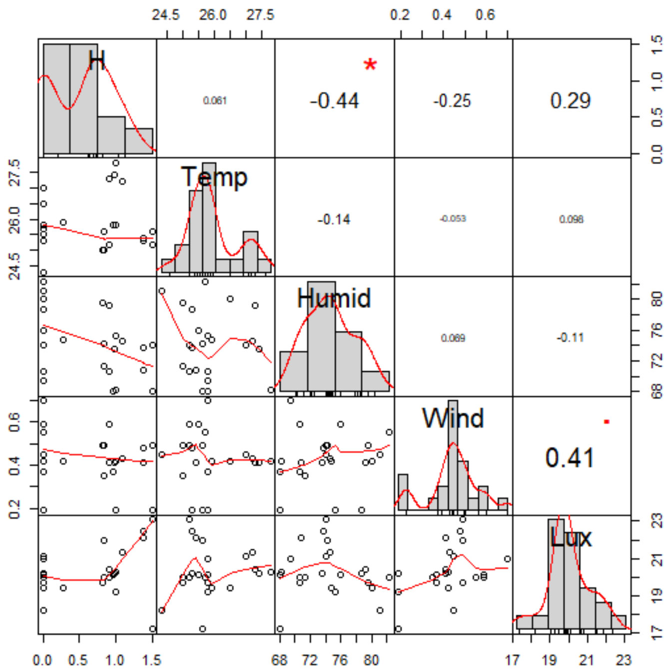

Figure 4. Pearson correlation values (R^2) between Shannon-Wiener diversity index (H') of understory shrub and air temperature (Temp), humidity (Humid), wind (Wind), and light intensity (Lux) variables

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.

ACKNOWLEDGEMENTS

We are grateful to the students that have assisted the data collection and discussion.

REFERENCES

Bang C, Sabo J, Faeth S. 2010. Reduced wind speed improves plant growth in a desert city. PloS ONE 5: e11061. DOI: 10.1371/journal.pone.0011061.

Barajas P,Weigelt P, Borregaard M, Keppel G, Kreft H. 2020. Environmental heterogeneity dynamics drive plant diversity on oceanic islands. J Biogeogr 47: 1-13. DOI: 10.1111/jbi.13925.

Bhat S, Bhandary MJ, Rajanna L. 2014. Plant diversity in the homegardens of Karwar, Karnataka, India. Biodiversitas 15: 229-235. DOI: 10.13057/biodiv/d150216.

Birch E, Wachter S. 2011. World Urbanization: The critical Issue of the Twenty-First Century. Global Urbanization. University of Pennsylvania Press, Pennsylvania. DOI: 10.9783/9780812204476.3.

Chia SY, Lim MW. 2022. A critical review on the influence of humidity for plant growth forecasting. IOP Conf Ser: Mater Sci Eng 1257: 012001. DOI: 10.1088/1757-899X/1257/1/012001.

Chowdhury M, Shafik K, Islam Md, Mohammod A, Md Nasim R, Lee W, Chung S. 2021. Effects of temperature, relative humidity, and carbon dioxide concentration on growth and glucosinolate content of kale grown in a plant factory. Foods 10 (7): 1524. DOI: 10.3390/foods10071524.

Clemants SE, Moore G. 2003. Patterns of species diversity in eight Northeastern United States Cities. Urban Habitats 1 (1): 4-16.

Dormann CF, Bagnara M, Boch S. 2020. Plant species richness increases with light availability, but not variability, in temperate forests understorey. BMC Ecol 20: 43. DOI: 10.1186/s12898-020-00311-9.

Downey P, Richardson D. 2016. Alien plant invasions and native plant extinctions: A six-threshold framework. AoB Plants 8: 1-21. DOI: 10.1093/aobpla/plw047.

English J, Barry KE, Wood EM, Wright AJ. 2022. The effect of urban environments on the diversity of plants in unmanaged grasslands in

Los Angeles, United States. Front Ecol Evol 10: 921472. DOI: 10.3389/fevo.2022.921472.

Flores P, Fernandez A, Orozco K, Endino R, Picardal J, Garces JJ. 2020. Ornamental plant diversity richness and composition in urban parks studies in Metro Cebu Philippines. Environ Exp Biol 18: 183-192. DOI: 10.22364/eeb.18.19.

Foxcroft L, Pyšek P, Richardson D, Genovesi P, McFadyen S. 2017. Plant invasion science in protected areas: Progress and priorities. Biol Invas 19: 1353-1378. DOI: 10.1007/s10530-016-1367-z.

Fu LT. 2021. Effect of the local wind reduction zone on seed dispersal from a single shrub element on sparsely vegetated land. AoB Plants 13 (4): 1-39, DOI: 10.1093/aobpla/plab025.

Gubanova T, Paliy A. 2022. The effect of negative air temperatures and humidity on the photosynthetic apparatus functioning in some species of Oleaceae family. Biol Web Conf 47: 11002. DOI: 10.1051/bioconf/20224711002.

Guiașu R, Tindale C. 2018. Logical fallacies and invasion biology. Biol Phil 33: 1-24. DOI: 10.1007/s10539-018-9644-0.

Hidayah AR, Roziaty E. 2022. Keragaman tanaman perdu yang tumbuh di sepanjang jalur pendakian Cemoro Sewu, Magetan. Seminar Nasional Pendidikan Biologi dan Saintek. [Indonesian]

Hou X, Liu S, Cheng F, Su X, Dong S, Zhao S, Liu, G. 2019. Variability of environmental factors and the effects on vegetation diversity with different restoration years in a large open-pit phosphorite mine. Ecol Eng 127: 245-253. DOI: 10.1016/j.ecoleng.2018.12.006.

Jeschke J, Bacher S, Blackburn T, Dick J, Essl F, Evans T, Gaertner M, Hulme P, Kühn, I, Mrugała A, Pergl J, Pyšek P, Rabitsch W, Ricciardi A, Richardson D, Sendek A, Vilà M, Winter M, Kumschick S. 2014. Defining the impact of nonnative species. Conserv Biol 28: 1188-1194. DOI: 10.1111/cobi.12299.

Khan MN, Ali S, Razak SA, Zaman A, Iqbal M, Shah SN. 2021. Assessment of floristic diversity in the mountain ecosystem of Marghazar Valley, Hindukush Range, Swat, Pakistan. Biodiversitas 23: 1000-1013. DOI: 10.1007/s10539-018-9644-0.

Matius P, Tjwa SJM., Raharja M, Sapruddin, Noor S, Ruslim Y. 2018. Plant diversity in traditional fruit gardens (munaans) of Benuaq and Tunjung Dayaks tribes of West Kutai, East Kalimantan, Indonesia. Biodiversitas 19: 1280-1288. DOI: 10.13057/biodiv/d190414.

Monteiro AT, Alves P, Carvalho-Santos C, Lucas R, Cunha M, da Costa EM, Fava F. 2022. Monitoring plant diversity to support agri-environmental schemes: Evaluating statistical models informed by satellite and local factors in Southern European Mountain Pastoral Systems. Diversity 14 (1): 8. DOI: 10.3390/d14010008.

Muhlisin IJ, Gunawan B, Cahyandito MF. 2021. Vegetation diversity and structure of urban parks in Cilegon City, Indonesia, and local residents' perception of its function. Biodiversitas 22: 2589-2603. DOI: 10.13057/biodiv/d220706.

Parain E, Rohr R, Gray S, Bersier L. 2018. Increased Temperature disrupts the biodiversity-ecosystem functioning relationship. Am Natur 193 (2). 000-000. DOI: 10.1086/701432.

Pourbabaei H, Haghgooy T. 2012. Plant species diversity in the ecological species groups in the Kandelat Forest Park, Guilan, North of Iran. Biodiversitas 13: 7-12. DOI: 10.13057/biodiv/d130102.

Pyšek P, Jarošík V, Hulme PE, Pergl J, Hejda M, Schaffner U, Vilà M. 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: The interaction of impact measures, invading species' traits and environment. Glob Change Biol 18: 1725-1737. DOI: 10.1111/j.1365-2486.2011.02636.x.

Sari LAD, Susanto D, Mukhlison, Nugroho P. 2022. The tree diversity of Srengseng Urban Forest in DKI Jakarta. Jurnal Penelitian Kehutanan Wallacea 11 (1): 13-20. DOI: 10.18330/jwallacea.2022.vol11iss1pp13-20. [Indonesian]

Sihaloho SH, Pariyanto. 2022. Keanekaragaman tumbuhan perdu di Taman Hutan Raya Rajolelo Kabupaten Bengkulu Tengah. Kependidikan 1 (30): 31-37. DOI: 10.36085/jrips.v1i2.3602. [Indonesian]

Siregar M, Purnomo DW, Siregar HM, Witono JR. 2020. Vegetation and ecoregion analysis at Sipirok Botanic Gardens, South Tapanuli, North Sumatra, Indonesia. Biodiversitas 21: 2526-2535. DOI: 10.13057/biodiv/d210626.

Theodorou P, Herbst SC, Kahnt B. 2020. Urban fragmentation leads to lower floral diversity, with knock-on impacts on bee biodiversity. Sci Rep 10: 21756. DOI: 10.1038/s41598-020-78736-x.

Tobin P. 2018. Managing invasive species. F1000 Res 7: 1686. DOI: 10.12688/f1000research.15414.1.

Wan J, Wang C, Yu F. 2017. Wind effects on habitat distributions of wind-dispersed invasive plants across different biomes on a global scale: Assessment using six species. Ecol Inform 42: 38-45. DOI: 10.1016/j.ecoinf.2017.09.002.