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A portrait of the ecological clusters in the urban fringe area of Surakarta, Indonesia

CYNTHIA PERMATA SARI[1], SIGIT HERU MURTI BUDI SANTOSA[1,2,♥], DJOKO MARSONO[1,3]

[1]Doctoral Program in Environmental Science, Graduate School, Universitas Gadjah Mada. Jl. Teknika Utara, Sleman 55281, Yogyakarta, Indonesia
[2]Department of Geographic Information Science, Faculty of Geography, Universitas Gadjah Mada. Jl. Sekip Utara, Bulaksumur, Sleman 55281, Yogyakarta, Indonesia. Tel.: +62-274-544975, Fax.: +62-274-564239, ♥email: sigit.heru.m@ugm.ac.id, cynthiapermata87@mail.ugm.ac.id
[3]Department of Forest Resource Conservation, Faculty of Forestry, Universitas Gadjah Mada. Jl. Agro No. 1, Bulaksumur, Sleman 55281, Yogyakarta, Indonesia

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Abstract. *Sari CP, Santosa SHMB, Marsono D. 2022. A portrait of the ecological clusters in the urban fringe area of Surakarta, Indonesia. Biodiversitas 23: 670-679.* The population growth in Surakarta has led to agglomeration. To fulfill human needs, Surakarta has seen some major land-use changes across decades. The availability of natural resources and ecosystem services is very important for the sustainability of life. Biodiversity index-based area management is one of the best ways. Cluster methods will facilitate the planning, implementation and subsequent management of an area. This study divides the urban fringe of Surakarta into 48 ecological units. The biotic analysis of biodiversity index calculations is used to assess all ecological units. The value of the biodiversity indices is the basis for forming clusters. From the statistical analysis, 5 clusters were formed based on the level of similarity. The majority of the clusters were located in Karanganyar District. Cluster 3 was the cluster with the most members and the most value of the index of biodiversity. Cluster 2 had only 2 clusters. The range of biodiversity index in each cluster was not much different. The richness of the species in each cluster was in the medium-high range (tree level 0.945-4.500, saplings 0.908-4.889 and seedlings 0.638-4.440). The diversity of the species was at a moderate level with the tree level diversity index value of 2.044-2.290, saplings 1.610-2.294, seedlings 1.557-2.291 and was at a moderate level with the tree level index evenness value of 0.735-1.421, saplings 0.641-1.412, seedlings 0.730-1.645. In each cluster, the condition of the biodiversity was quite good and able to support the function and services of the ecosystem of urban areas and urban fringes. There was no dominance of plants, and the types were still diverse for the ecosystem stability. The development of Surakarta was faster in the south and the north. Biodiversity in eastern Surakarta was found to be more effective in supporting the ecosystem services of Surakarta City.

Keywords: Biodiversity index, cluster analysis, ecological unit, urban fringe

INTRODUCTION

Urban areas are growing rapidly in line with population growth. Surakarta is one of the main cities close to the center of the surrounding areas. For this reason, the further expansion of the Surakarta City area cannot be avoided (Putri et al. 2016). The land-use changes are necessary to meet the needs of new settlements, which in turn affect environmental conditions (Guo et al. 2021; Yang et al. 2020). The changes in the ecosystem function and the decrease in the available amount of natural resources are some of the problems that must be faced. For this reason, the development of good area management based on ecology is needed. Since the start of the Millennium Ecosystem Assessment (MEA 2005), several studies on ecosystem services (ES) have increasingly received increasing attention to be studied (Ndong et al. 2020). The assessment and correlation of ecosystem services provide key information in the framework of policymakers, and decisions in environmental management efforts can be measured by the assessment and correlation of ecosystem services (Han et al. 2017) and in this regard, better land management and planning can be made (Castro et al. 2014).

Land-use changes are the consequence of the fulfillment of human life needs (Wilkinson et al. 2018). Human intervention, particularly in vulnerable urban setting, leads to a decrease in the quality of the environment (Fayiah et al. 2019). Infrastructure development activities are known to reduce the area of open land. This has an impact on reducing habitats for plants and animals. As a result, biodiversity conditions are experiencing a decrease in quality and quantity as stated in the Convention on Biological Diversity. The availability of environmental services shall decrease with the decrease of urban biodiversity.

Global biodiversity is lost as a result of changes in land cover from anthropogenic activities. The local species richness and the availability of biodiversity functions are both significantly reduced by the transfer of urban open spaces. The increased intensity of land use has no subsequent impact on biomass, species evenness and distribution. Changes in land cover due to agricultural expansion and extension are currently the main drivers of global biodiversity loss (Phalan et al. 2013). It is important to understand how these changing landscapes are impacting urban biodiversity and there is a need to prepare their protection mechanism.

Recent innovations such as the Millennium Ecosystem Assessment (MEA 2005) emphasize the linkage between ecological systems and human well-being. Increased negative human intervention in the environment leads to a decrease in the quality of the environment. Developmental activities are known to will reduce the area of open land and this, in turn, leads to the reduction of habitats for plants and animals. Biodiversity has been facing steady pressure in qualitative and quantitative terms and reduction in urban biodiversity is bound to impact environmental services. Urban biodiversity problems are one of the challenges for the City of Surakarta. Therefore, basic data can be used as a reference for policy-making and biodiversity management.

Ecological unit classification is one of the ways that aid in managing an area well (Castellar et al. 2021). Ecosystem classification is a tool that facilitates the formulation of environmental management policies. These management policies are planned and ordered according to the problems faced in each classification unit, which thus will be easier to map and solve. The environment is complex and dynamic, and there are interactions between its components. One of these important components for life sustainability in urban areas is biotic factors. Urban ecosystem services depend on vegetation. The hierarchical analysis and classification of the major ecological factors in the context of biodiversity are possible. This will fill the gap and provide a comprehensive basis for conservation analysts (Schick et al. 2019).

Biodiversity indices are commonly used for calculating the quality value of a unit or habitat (Perrin and Waldren 2020). They include richness, diversity, and evenness indices and provide a glimpse of the status of biodiversity components. The analysis of these indices is useful for knowing the relationship between biodiversity, ecosystem functions, ecosystem services, and supporting conservation efforts in a region. Sutomo et al. (2018) also mentioned that the abundance of tree species could also be used as an environmental indicator. The abundance of species in a region will help determine environmental improvement measures. The knowledge of the species that can survive and dwell in the physical condition of the environment will determine the level of stability. The knowledge of the diversity index is crucial in maintaining the ecosystem health of urban areas and their surroundings. A well-conserved regional/local biodiversity provides better ecosystem services. Ecosystem services, among others, include providing food availability, air quality, water, and climate and cultural arrangements reflecting the close relationship between people and nature (Chan et al. 2016). One method of multivariable statistical analysis is cluster analysis (Liu et al. 2021), which is based on reducing dimensions of a dataset and helps determine what factors are underlying and representative among the original variables (Subramaniyan et al. 2020). The basic method of cluster analysis is classifying objects into groups that show the fundamental relationships of one object with another. Objects with similarities are grouped in the same cluster, and different objects are grouped in different clusters. There are several ways of forming clusters. One of them is hierarchical grouping. The results of the cluster hierarchy analysis are described as a dendrogram. This analysis is used to map ecological communities with relatively discrete ecological boundaries.

MATERIALS AND METHODS

Study area

This research was done in the urban fringe area of Surakarta (Boyolali, Karanganyar and Sukoharjo; Figure 1), Central Java, Indonesia. The development of the Surakarta Region is increasing towards the south, i.e. towards the Sukoharjo District. Most of the land is subject to land-use changes into settlements and trade blocks. The construction of toll roads that cross the Boyolali District has resulted in the development of the northern part of Surakarta. Open land is more common in the eastern part of Surakarta, which borders Karanganyar District. Most of the ecological units are located in the eastern urban fringe areas of Surakarta. Biodiversity studies in the urban fringe of Surakarta divide the area into 48 ecological units, most of which are located in the eastern urban fringe areas. Most of the ecological units are widely spread over Gondangrejo Subdistrict, Karanganyar. This area still has less land conversion.

In the study region, air temperature ranges from 29-31°C with an average humidity of 70%. The most common types of vegetation are shade plants and have high economic value. Soil type is dominated by regosol, alluvial and latosol soil. The topography of this area is flat, wave and sloping. The part of Sukoharjo District (Grogol Sub-district) and western Karanganyar District (Colomadu Sub-district) are areas that experience a faster agglomeration process. The condition of open space has decreased due to land conversion. Economic and sociocultural aspects influence vegetation type on this location.

Procedures

Classifying the urban fringe areas of Surakarta

Based on the interpretation of Sentinel 2A imagery, the urban fringe areas of Surakarta were divided into 48 ecological units. The NDVI value is an index obtained from analysis of satellite images with the formula:

$$\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$$

Where:
NDVI : Vegetation index
NIR : reflection in the near-infrared spectrum
Red : reflection in the red range of the spectrum

The NDVI value has a range between -1 to 1. This makes it easier to determine areas with high vegetation density (Sari et al. 2019). The ecological have functioned as garden, moor and open land.

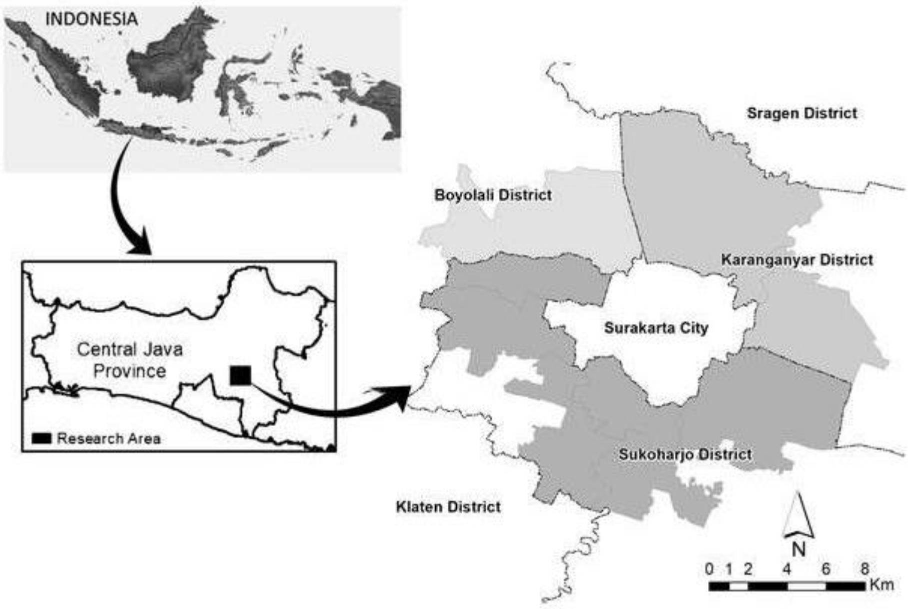

Figure 1. Location of the urban fringe areas of Surakarta, Central Java, Indonesia

Analysis of biotic factors and biodiversity index

The biotic factors in this study were analyzed using the biodiversity indices. The richness, diversity, and evenness indices were calculated from 48 ecological units in the urban fringe areas of Surakarta. The samples were taken from 10 plots in each ecological unit, giving a total of 480 sampling plots. The studied indices incorporated richness, diversity, and evenness indices measured within all plots.

Species richness was taken as the number of species in a given area. Menhinick's index (R) was simply the number of species (n) divided by the square root of the total number of individuals (N).

$$R = \frac{S}{\sqrt{N}}$$

Where:
R : richness index
N : number of all individual vegetations
S : number of species/species of vegetation

The Shannon diversity index (H') is another index that is commonly used to characterize species diversity in a community. Shannon's index accounts for both the abundance and evenness of the species present. In the Shannon index, p is the proportion (n/N) of individuals of one particular species recorded (n) divided by the total number of individuals recorded (N), 'ln' is the natural log, 'Σ' is the sum of the calculations, and 's' is the number of species.

$$H' = \sum_{i=1}^{s} \left[\frac{n}{N} ln\right.$$

Where:
n : individuals of one particular species recorded
N : total number of individuals recorded
H' : Shannon index

Species evenness refers to how close in number each species in an environment is present. Species evenness is a metric to describe the relative abundance of the different species in an area.

$$E = \frac{H'}{S}$$

Where:
E : evenness index
H' : Shannon index
S : total number of all species

Three species diversity indices Margalef, Shannon-Wiener index, and Pielou's evenness measure, were used to explore the relative abundance of species dominance (Chinchilla et al. 2021). Two indices were only used based on the total number of species, thus avoiding biases caused by the presence of more dominant species in diversity outcomes (Magurran 1988). The rangeability of functionally similar species can increase functional diversity. A species under certain landscape conditions may establish a balance where previously under-represented functions or diminish it where these communities replace or dominate one with greater functional diversity (Redhead et al. 2020). The functional evenness of species provides a measure of the distributional evenness of the functional traits of a species. It is possible that functional diversity will respond differently to species richness and a comparison of three indices shall provide a better understanding of biodiversity status, especially when multi-stage vegetational diversity is studied (Morris et al. 2014).

Cluster analysis

Cluster analysis classifies the ecological units based on the level of similarity. The SPSS statistic software was used for the analysis. The initial stage of the cluster analysis is to determine the distance between each ecological unit. The distance calculation formula uses the calculation of "Euclidean Distance" (Pielou 1984). The relationship between biodiversity and ecosystem functions can be estimated by focusing on biodiversity functions rather than taxonomic diversity (Gagic et al. 2015). An in-depth assessment of the natural function of biodiversity for humans will improve the understanding of biodiversity's spatial and temporal distribution, which will facilitate conservation efforts (Devictor et al. 2010).

$$d\,(j,k) = \sqrt{\sum_{i=1}^{s}(Xij - Xi}$$

Where:
d : distance coefficient
X_{ij} : variable to i on ecological unit to j
X_{ik} : variable to i on ecological unit to k

RESULTS AND DISCUSSION

Biodiversity Index

Biodiversity is one of the prime factors in the sustainability of urban life. Humans and biodiversity have an intricate relationship in the ecosystem (Hugé et al. 2020). The availability of environmental services and the bioresource-based economy rely on biodiversity and local ecosystem resources (IPBES 2021). Therefore, threats to biodiversity are an urgent issue to be addressed (Costanza et al. 2017). The calculation of biodiversity in a functional context is of particular interest in ecological studies. The assessment of biodiversity functions can be used to understand and predict changes in vegetation. Vegetation is a major component in supporting the biodiversity of urban landscapes and it is important for developing countries to sustainably manage and conserve biodiversity. The value of the biodiversity index may be calculated from each stage of vegetational growth and after that, the complexity and stability of an ecosystem may be understood. However, the indicators for measuring and calculating biodiversity status, mostly in many urban landscapes are insufficient due to a lack of supportive policies. In this study, the calculation of the biodiversity index in the urban fringe of Surakarta area was done at the stages of vegetational growth viz. trees, saplings and seedlings. The following table depicts the biodiversity indices for the urban fringe area of Surakarta.

The ecological units were spread in Colomadu, Gondangrejo, and Jaten Sub-districts (Karanganyar District), Mojolaban and Kartasura Sub-districts (Sukoharjo District), and Ngemplak Sub-district (Boyolali District) (Figure 2). The calculations of the biodiversity indices in 48 ecological units result in the values displayed in Table 1. The biodiversity index values include richness, diversity, and evenness at three growth rates: tree, saplings, and seedling levels. In general, the environmental conditions of biodiversity in urban fringe areas based on the three index values were still in a stable condition. This condition cannot be separated from other environmental factors especially physical factors. The results show that the biodiversity index urban fringe area of Surakarta varies across three vegetational stages.

The trees of the urban fringe area of Surakarta had a species richness of 0.95-4.5 (with a mean of 2.66±1.07) and an evenness of 0.74-1.42, which indicated that there was a diversity of species composition without dominance in each ecological unit (Table 1; Figure 3). Every tree has its own niche potential and has an important role in maintaining environmental conditions and the stability of an ecological community. The diversity index value ranged from 2.04-2.29, indicating the presence of moderate biodiversity. The diversity types in these ecological units vary, and the community's stability was good enough to deal with the local dynamics of environmental changes. A total of 93 species were noted from the entire ecological unit. The three common species are the canopy and fruit tree *Mangifera indica* and the timber trees such as *Tectona grandis*, and *Senna siamea*. The most common species found in all ecological units was *T. grandis* (Teak), which may be because the teak trees support ecological functions and provide high economic value as a traded commodity. Though this tree's growth takes a long time, This tree has an exuding substance, tectoquinon, that is not favored by wood-destroying pests.

The richness value for saplings ranged from 0.98-4.89 (with a mean of 2.41±1.07) and the evenness of 0.64-1.41 (Table 1; Figure 4). The saplings were noted for 85 species spread throughout the ecological units. The diversity index value ranged from 1.61-2.29, indicating the presence of moderate biodiversity. Among the saplings, the most common were *T. grandis*, *Leucaena leucocephala* and *Gigantochloa apus*. Among the saplings, also Teak plants were the most common.

The richness value for seedlings ranged from 0.63 to 4.44 (with a mean of 1.99±0.78) and the evenness of 0.73-1.65 (Table 1; Figure 5). The saplings were noted for 85 species spread throughout the ecological units. The diversity index value ranged from 1.56-2.29, indicating the presence of moderate biodiversity. However, the diversity was on the lower side than the other two vegetational growth forms. The evenness of seedlings was the highest, so it can be assumed that there is almost no dominance among seedlings.

Table 1. Biodiversity index of the urban fringe area of Surakarta, Central Java, Indonesia

Biodiversity index	Trees	Saplings	Seedlings
Richness	0.945-4.500	0.908-4.889	0.638-4.440
Diversity	2.044-2.290	1.610-2.294	1.557-2.291
Evenness	0.735-1.421	0.641-1.412	0.730-1.645

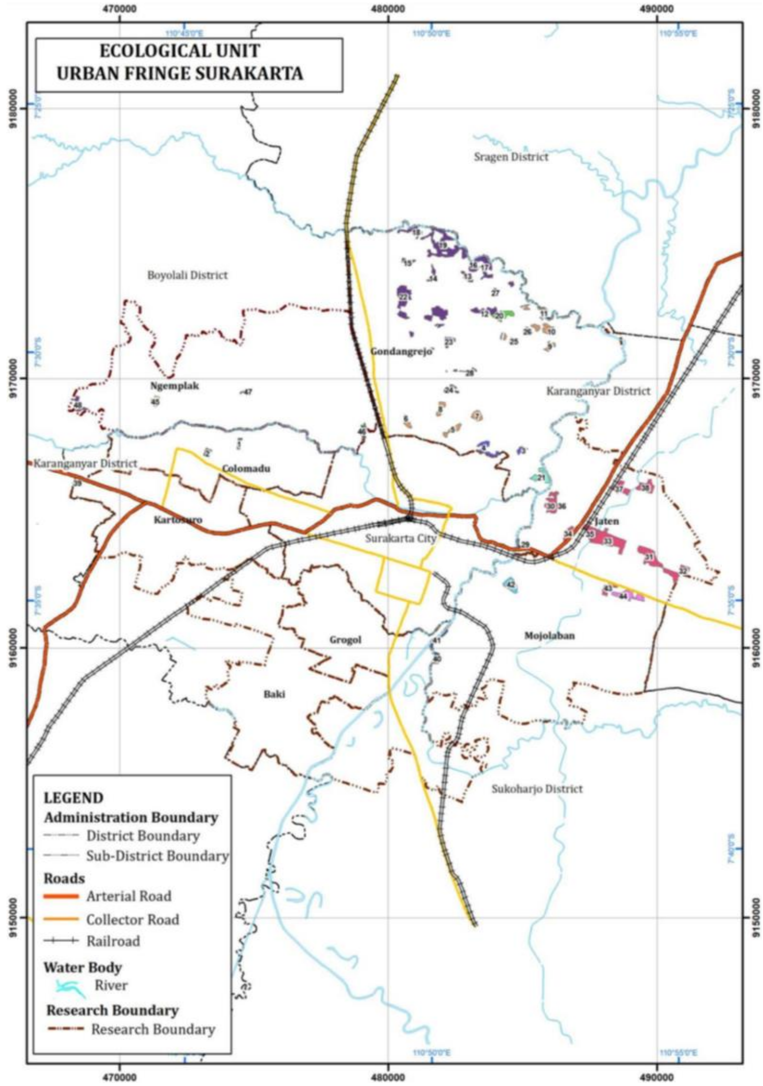

Figure 2. Map showing ecological cluster in the urban fringe area of Surakarta, Central Java, Indonesia

Land use in most ecological units in the form of gardens and moors was managed and owned by the local community. However, there were some lands and gardens that had no owners. Locals used the land to plant economically productive trees. In Jaten Sub-district, much ecological units were around residential areas and river borders.

Cluster analysis

The purpose of hierarchical clustering was to capture the underlying data structure and generate a set of nested clusters which are then described as a hierarchical tree. One of the main advantages of hierarchical clustering is that it can capture more complex cluster structures. In this study, the cluster analysis was based on the biodiversity indices of 48 ecological units in the urban fringe areas of Surakarta. This analysis divided all the ecological units into five major clusters, most of which were represented from the eastern urban fringe area located in Karanganyar District (Figures 6, 7, and 8). Cluster 3 had the highest ecological units. All the members of the cluster were widely found in Karanganyar District.

Cluster 1 had 15 ecological units, with10 ecological units located in the Karanganyar District and the other five ecological units located in the Districts of Sukoharjo and Boyolali. Cluster 2 had at least 2 members, and both were from the Karanganyar District area. While the total of 11 ecological units in cluster 3 was scattered in Karanganyar District. The other 2 ecological units in this cluster were located in the Districts of Sukoharjo and Boyolali. Besides, 9 ecological units were the members of cluster 4, and are located in the Karanganyar and Sukoharjo Districts. Cluster 5 consists of 11 ecological units, most spread over the District of Karanganyar and one cluster in Boyolali District.

From the results of the cluster analysis, most of the ecological units were found to be present in Karanganyar District. As Karanganyar Region has high biodiversity index value, it can be the main buffer of environmental services in Surakarta. Therefore, the management of biodiversity in the area needs to get more attention.

Management policy may be based on the clustering of the urban fringe biodiversity index of Surakarta City. In this way, the steps in the conservation and safeguarding of biodiversity will be more efficient.

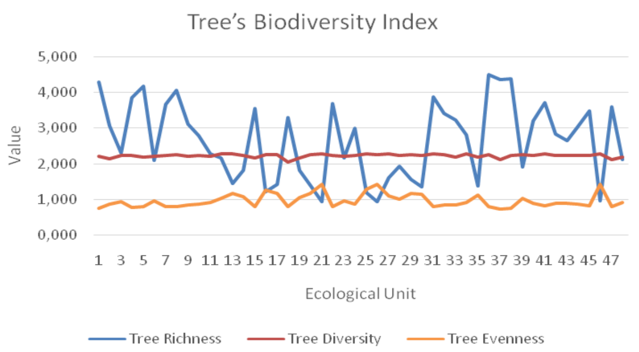

Figure 3. Tree Biodiversity Index of the urban fringe area of Surakarta, Central Java, Indonesia

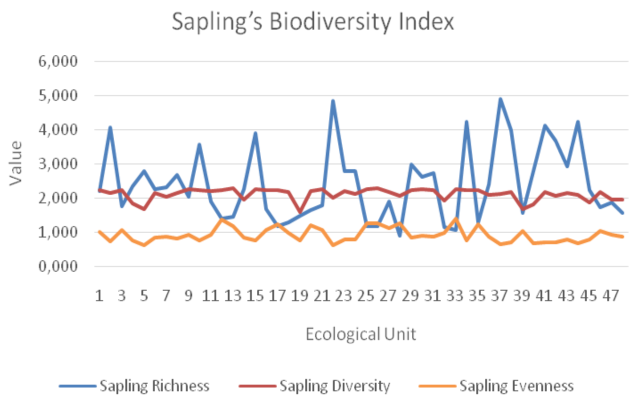

Figure 4. Sapling's Biodiversity Indices of the urban fringe area of Surakarta, Central Java, Indonesia

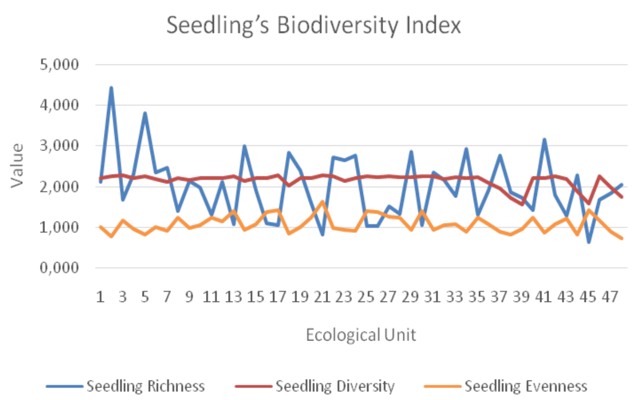

Figure 5. Seedlings' Biodiversity Index of the urban fringe area of Surakarta, Central Java, Indonesia

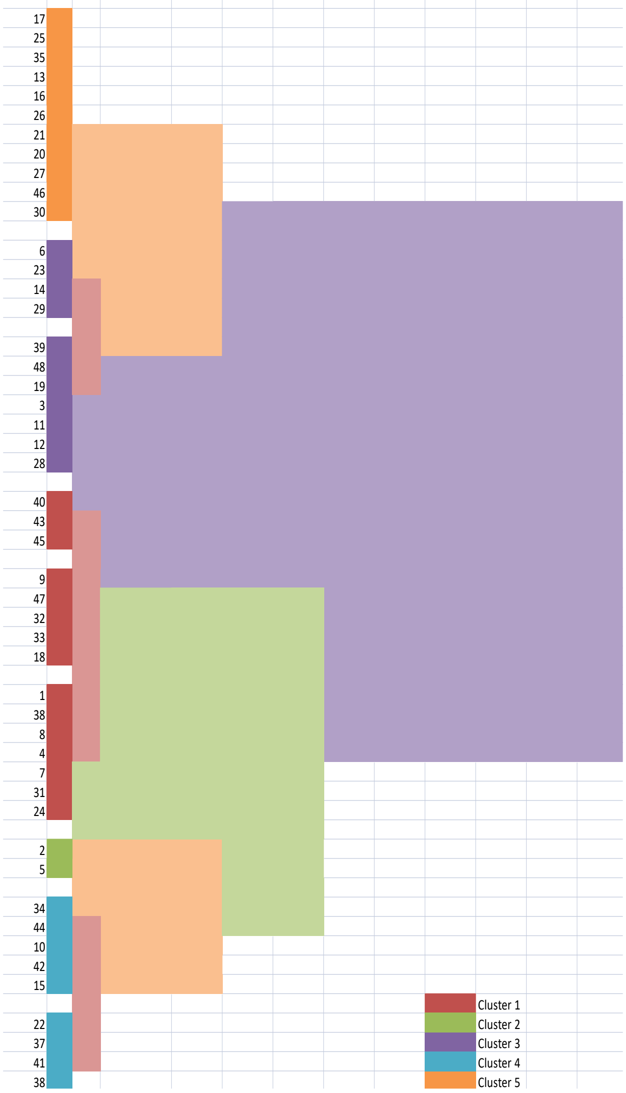

Figure 6. Dendrogram of the ecological unit biodiversity index in the urban fringe area of Surakarta, Central Java, Indonesia

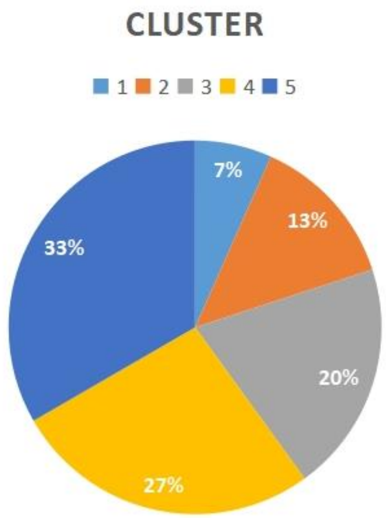

Figure 7. Percentage of **c**luster biodiversity index of the urban fringe area of Surakarta, Central Java, Indonesia

Discussion

The urban fringe area of Surakarta plays an important role in supporting the balance of Surakarta City's ecosystem. The biodiversity in the urban fringe area of Surakarta supports the sustainability of urban life. Ecosystem classification is one way to facilitate the planning and management of an area. The 48 ecological units based on the value of the biodiversity index in the urban fringe area of Surakarta resulted in 5 clusters based on the diversity index of the individual cluster. The ecological units were located in the Districts of Karanganyar, Sukoharjo, and Boyolali. The majority of them were scattered across the Karanganyar District. Species richness in ecosystem functions generally indicates that with a greater richness of plant species, it tends to have improved primary productivity, nutrient absorption and greater stability against disturbances. Further, the species with the highest representation at any vegetational stage shall dominate the community, but highly diverse communities with high evenness tend to be more stable.

Taken together, the location and biological quality of green urban spaces are important factors having positive relation to human convenience (Carrus et al. 2015). In this study area NDVI ranged from 0-099 (Figure 9). Low NDVI value means that the environment is crowded with built-up land, and a high NDVI value means more green areas. The rate of land conversion on the urban fringe area of Surakarta from 2015 to 2020 was about 0.9%, which is still quite low as there are still open green spaces, which is good for biodiversity and its ecosystem service to support urban life.

Cluster 3 had the most members of ecological units. Cluster 2 had the lowest members, and both of them were from the same district. Cluster 1 and 3 showed a high biodiversity index. Cluster 1 and 3 were more diverse and richer in vegetation. Clusters 1 and 3 were more diverse and optimally helpful for maintaining the urban environment. The study suggested that out of the three districts, Karanganyar had a better biodiversity potential, and also the land-use change in this district was still lower than the other two studied districts.

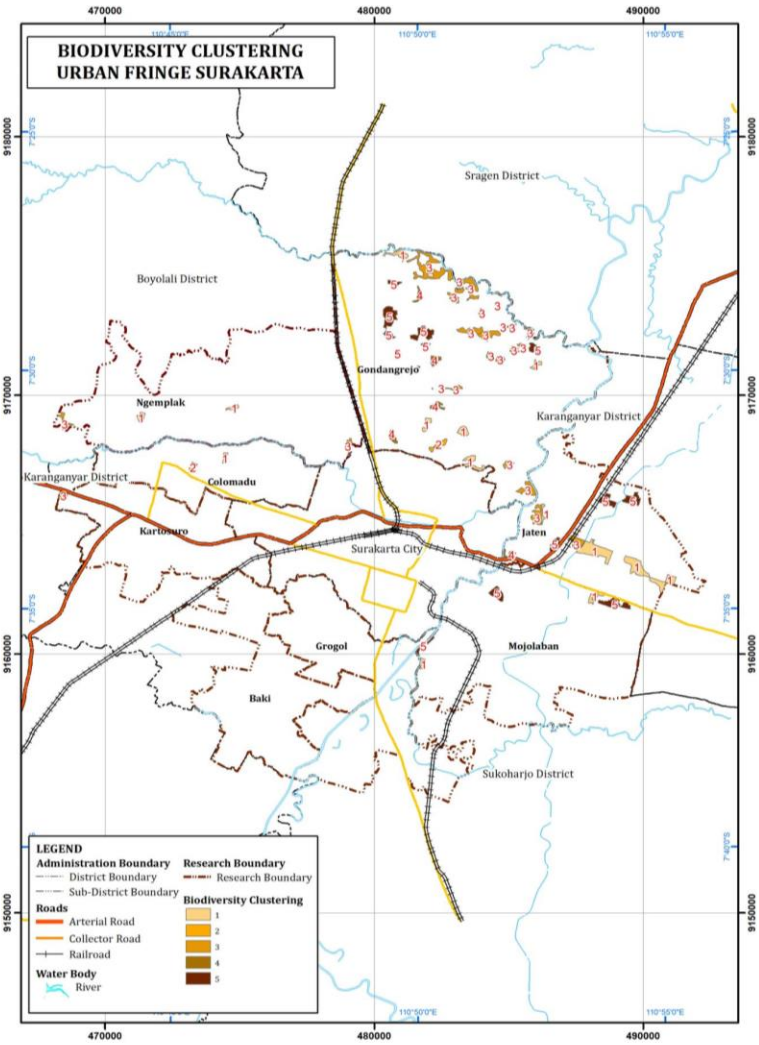

Figure 8. Cluster biodiversity index of the urban fringe area of Surakarta, Central Java, Indonesia

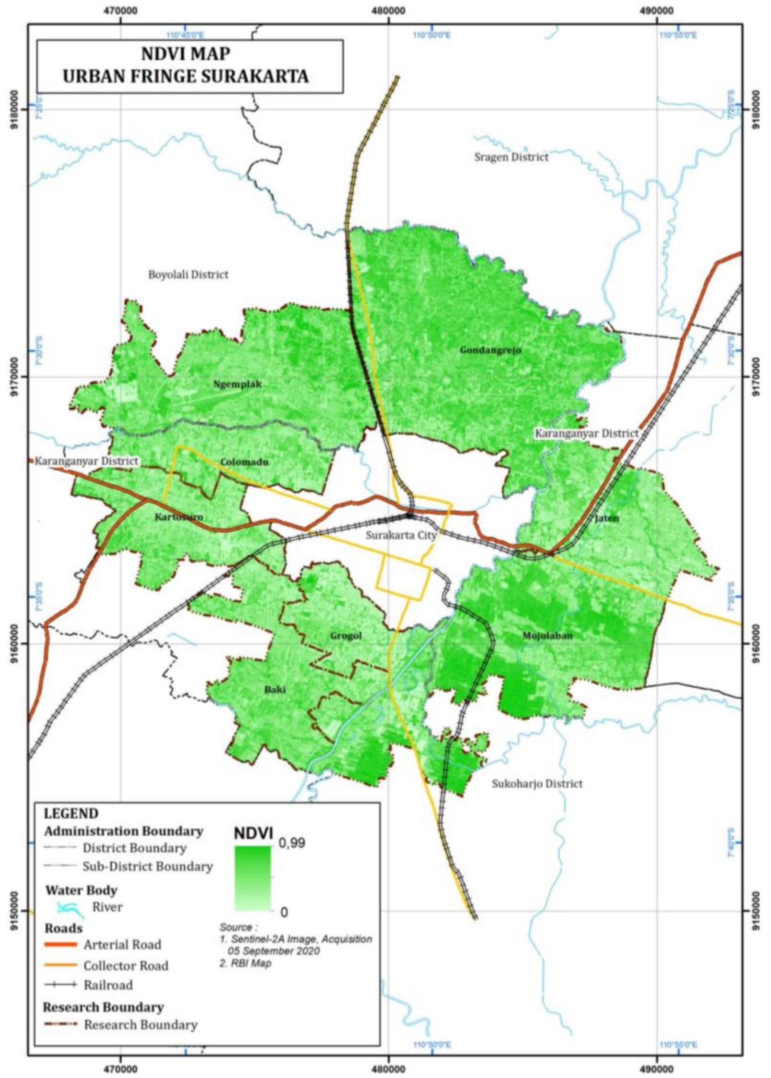

Figure 9. NDVI map of urban fringe area Surakarta, Central Java, Indonesia in 2020

From the important value index, vegetation on an urban fringe area is dominated by economically important vegetation. *Tectona grandis* had the highest important value index and were almost widespread. *Mangifera indica* was in second place, and people planted it because of its multifunctional benefits. From an economic aspect, it can be a source of food and trade. Besides that, it can be aesthetic and shade plant on a home yard or even vacant land. *Senna siamea*, *Leucaena leucocephala* and *Swietenia macrophylla* were shade vegetation having the highest important value index after *T. grandis* and *M. indica*.

This study showed the economic plant such as *T. grandis* to be widely spread among 3 districts. Food source plant-like *M. indica* was the dominant plant in this research area. People of 3 urban fringe area districts (Sukoharjo, Karanganyar and Boyolali) were still rustic. Some of this area is located in a transitional area from rural to urban. Sukoharjo district more rapidly on development land-use changes as a trade area. Biodiversity functions as life support for the urban area optimally found in Karangayar District. There is still less land conversion there. It is very important to improve and manage the biodiversity of the urban area as the main factor for urban life sustainability. The selection of plant species to support ecological functions needs to be added. The economic, ecological and sociocultural functions of urban biodiversity need to be understood better. The classification methods of the urban ecosystem as a unit of ecology are easier to be studied. It can be the basis of decision-making. Characteristics of every ecological unit can give a better understanding for implementation. Further, during urban plantation activities, emphasis should be given to the recreation the landscape's natural (restorative) structure (Hoyle et al. 2017).

Urban biodiversity has a high value in resilience to climate change, heat island effects, air pollution (Capotorti et al. 2019). Still, it is influenced by driving factors like urbanization, environmental policies and economic growth, which have an important role in managing urban green space (Xu et al. 2019). Synthesis of some varying factors showed that the dynamic relationship between the development stages of the urban agglomeration's regional system might conform to the Environmental Kuznets Curve (Feng et al. 2021). Maintaining urban biodiversity is a part of sustainable urban ecosystem functions. Economic and sociocultural aspect is the crucial factor that can lead to perspective on biodiversity issue. The structural and functional system of urban vegetation are important factors to the sustainable life of the urban environment, however, due to intangibility ecological functions of urban vegetation are less realized by people, and this needs to be changed through adequate sensitization and awareness.

In conclusion, it can be said that a well-conserved regional/local biodiversity provides better environmental services. In fast-changing urban landscapes, vegetation and biodiversity-rich urban fringe areas can be seen as hope for supporting environmental services to adjacent urban areas. The management and conservation of urban/sub-urban biodiversity require an efficient and precise strategy. The ecosystem classification method with cluster analysis is one of the efforts that can be done to facilitate and maximize management. The result of the present study may be utilized to maintain the status of biodiversity of the identified from 48 biodiversity-rich clusters in urban fringe areas of Surakarta.

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REFERENCES

Castellar JAC, Popartan LA, Pueyo-Ros J, Atanasova N, Langergraber G, Säumel I, et al. 2021. Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services. Sci Total Environ 779: 146237. DOI: 10.1016/j.scitotenv.2021.146237.

Castro AJ, Verburg PH, Martín-López B, Garcia-Llorente M, Cabello J, Vaughn CC, López E. 2014. Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. Landsc Urban Plan 132: 102-110. DOI: 10.1016/j.landurbplan.2014.08.009.

Chan KMA, Balvanera P, Benessaiah K, Chapman M, Díaz S, Gómez-Baggethune E, et al. 2016. Why protect nature? Rethinking values and the environment. Proc Nat Acad Sci USA 113: 1462-1465. DOI: 10.1073/pnas.1525002113.

Chinchilla J, Carbonnel A, Galleguillos M. 2021. Effect of urban tree diversity and condition on surface temperature at the city block scale. Urban For Urban Green 60: 127069. DOI: 10.1016/j.ufug.2021.127069.

Costanza R, de Groot R, Braat L, Kubiszewski I, Fioramonti L, Sutton P, et al. 2017. Twenty years of ecosystem services: how far have we come and how far do we still need to go? Ecosyst Serv 28: 1-16. DOI: 10.1016/j.ecoser.2017.09.008.

Carrus G, Scopelliti M, Lafortezza R, Colangelo G, Ferrini F, Salbitano F, Agrimi M, Portoghesi L, Semenzato P, Sanesi G. 2015. Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. Landsc Urban Plan 134: 221-228. DOI: 10.1016/j.landurbplan.2014.10.022.

Devictor V, Mouillot D, Meynard C, Jiguet F, Thuiller W, Mouquet N. 2010. Spatial mismatch and congruence between taxonomic, phylogenetic and functional diversity: the need for integrative conservation strategies in a changing world. Ecol Lett 13: 1030-1040. DOI: 10.1111/j.1461-0248.2010.01493.x.

Fayiah M, Dong S, Li Y, Xu Y, Gao X, Li S, Shen H, Xiao J, Yang Y, Wessell K. 2019. The relationships between plant diversity, plant cover, plant biomass and soil fertility vary with grassland type on Qinghai-Tibetan Plateau. Agric Ecosyst Environ 286: 106659. DOI: 10.1016/j.agee.2019.106659.

Feng R, Wang F, Wang K, Wang H, Li L. 2021. Urban ecological land and natural-anthropogenic environment interactively drive surface urban heat island: An urban agglomeration-level study in China. Environ Int 157: 106857. DOI: 10.1016/j.envint.2021.106857.

Gagic V, Bartomeus I, Jonsson T, Taylor A, Winqvist C, Fischer C, et al. 2015. Functional identity and diversity of animals predict ecosystem functioning better than species-based indices. Proc R Soc B: Biol Sci 282: 20142620. DOI: 10.1098/rspb.2014.2620.

Capotorti G, Alós Ortí MM, Copiz R, Fusaro L, Mollo B, Salvatori E, Zavattero L. 2019. Biodiversity and ecosystem services in urban green infrastructure planning: A case study from the metropolitan area of Rome (Italy). Urban For Urban Green 37: 87-96. DOI: 10.1016/j.ufug.2017.12.014.

Guo Z, Wang X, Fan D. 2021. Ecosystem functioning and stability are mainly driven by stand structural attributes and biodiversity, respectively, in a tropical forest in Southwestern China. For Ecol Manag 481: 118696. DOI: 10.1016/j.foreco.2020.118696.

Han Z, Song W, Deng X, Xu X. 2017. Trade-offs and synergies in ecosystem service within the three-rivers headwater region, China. Water 9: 588. DOI: 10.3390/w9080588.

Hoyle H, Hitchmough J, Jorgensen A. 2017. All about the 'wow factor'? The relationships between aesthetics, restorative effect and perceived biodiversity in designed urban planting. Landsc Urban Plan 164: 109-123. DOI: 10.1016/j.landurbplan.2017.03.011.

Hugé J, Rochette AJ, de Béthune S, Paitan CCP, Vanderhaegen K, Vandervelden T, Passel SV, Vanhove MPM, Verbist B, Verheyen D, Waas D, Janssens I, de Bisthoven LJ. 2020. Ecosystem services assessment tools for African Biosphere Reserves: A review and user-informed classification. Ecosyst Serv 42: 101079. DOI: 10.1016/j.ecoser.2020.101079.

IPBES 2021. Intergovernmental Science-Policy Platform on Biodiversity & Ecosystem Services. Bonn, Germany.

Liu N, Xu Z, Zeng XJ, Ren P. 2021. An agglomerative hierarchical clustering algorithm for linear ordinal rankings. Inf Sci 557: 170-193. DOI: 10.1016/j.ins.2020.12.056.

Magurran AE. 1988. Ecological Diversity and Its Measurements. Springer, Dordrecht. DOI: 10.1007/978-94-015-7358-0.

MEA 2005. Ecosystems and Human Well-being: General Synthesis, MEA, Washington, DC.

Morris EK, Caruso T, Buscot F, Fischer M, Hancock C, Maier TS, et al. 2014. Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. Ecol Evol 4: 3514-3524. DOI: 10.1002/ece3.1155.

Ndong GO, Therond O, Cousin I. 2020. Analysis of relationships between ecosystem services: A generic classification and review of the literature. Ecosyst Serv 43: 101120. DOI: 10.1016/j.ecoser.2020.101120.

Pielou EC. 1984. The Interpretation of Ecological Data: A Primer on Classification and Ordination. J. Wiley and Sons, New York.

Putri MA, Rahayu MJ, Putri RA. 2016. Bentuk Kenampakan Fisik (Morfologi) Kawasan Permukiman Di Wilayah Pinggiran Selatan Kota Surakarta. J Pengembangan Kota 4 (2): 120-128. DOI: 10.14710/jpk.4.2.120-128. [Indonesian]

Redhead JW, Powney GD, Woodcock BA, Pywell RF. 2020. Effects of future agricultural change scenarios on beneficial insects. J Environ Manag 265: 110550. DOI: 10.1016/j.jenvman.2020.110550.

Sari CP, Wiryanto, Setyono, P. 2019. Aplikasi Penginderaan Jauh Untuk Mengkaji Tutupan Vegetasi Kawasan Urban Kota Surakarta 2017 Menggunakan Citra Satelit Sentinel 2A. J Pengelolaan Sumberdaya Alam dan Lingkungan 9 (1): 152-158. DOI: 10.29244/jpsl.9.1.152-158. [Indonesian]

Schick A, Porembski S, Hobson PR, Ibisch PL. 2019. Classification of key ecological attributes and stresses of biodiversity for ecosystem-based conservation assessments and management. Ecol Complex 38: 98-111. DOI: 10.1016/j.ecocom.2019.04.001.

Subramaniyan M, Skoogh A, Muhammad AS, Bokrantz J, Johansson B, Roser C. 2020. A generic hierarchical clustering approach for detecting bottlenecks in manufacturing. J Manuf Syst 55: 143-158. DOI: 10.1016/j.jmsy.2020.02.011.

Sutomo, Darma IDP, Priyadi A, Iryadi R. 2018. Short Communication: Trees species diversity and indicator species in Bedugul forest ecosystem, Bali, Indonesia. Biodiversitas 19 (6): 2213-2218. DOI: 10.13057/biodiv/d190629.

Perrin PM, Waldren S. 2020. Vegetation richness and rarity in habitats of European conservation value in Ireland. Ecol Indic 117: 106387. DOI: 10.1016/j.ecolind.2020.106387

Phalan B, Bertzky M, Butchart SHM, Donald PF, Scharlemann JPW, Stattersfield AJ, et al. 2013. Crop expansion and conservation

priorities in Tropical Countries. PLoS ONE 8 (1): e51759. DOI: 10.1371/journal.pone.0051759.
Wilkinson CL, Yeo DCJ, Hui TH, Fikri AH, Ewers RM. 2018. Land-use change is associated with a significant loss of freshwater fish species and functional richness in Sabah, Malaysia. Biol Conserv 222: 164-171. DOI: 10.1016/j.biocon.2018.04.004.
Xu Z, Zhang Z, Li C. 2019. Exploring urban green spaces in China: Spatial patterns, driving factors and policy implications. Land Use Policy 89: 104249. DOI: 10.1016/j.landusepol.2019.104249.
Yang Q, Liu G. Giannetti BF, Agostinho F, Almeida CMVB, Casazza M. 2020. Emergy-based ecosystem services valuation and classification management applied to China's grasslands. Ecosyst Serv 42: 101073. DOI: 10.1016/j.ecoser.2020.101073.