EurAsian Journal of BioSciences
Eurasia J Biosci 14, 4543-4550 (2020)

# Ecological indices on Lichen biodiversity in three main different areas (the cities, countrysides and the forests) of Jogjakarta and Surakarta, Central Java, Indonesia

**Efri Roziaty [1,2*], Sutarno [3], Suntoro Suntoro [4], Sugiyarto [3]**

[1] Doctoral Program in Environmental Science, Graduate School, Universitas Sebelas Maret, INDONESIA
[2] Department of Biology Education, Faculty of Teacher Training and Education, Universitas Muhammadiyah Surakarta, Central Java, INDONESIA
[3] Department of Biology, Faculty of Mathematics and Science Universitas Sebelas Maret, INDONESIA
[4] Department of Soil Science, Faculty of Agriculture Universitas Sebelas Maret, INDONESIA
*Corresponding author: er375@ums.ac.id

## Abstract

Lichen or commonly termed as is a symbiotic association organism between algae and fungus in nature. It is a non vascular plants. Algae comes from the Cyanobacteria while the fungus derived from Ascomycetes. Fungus needs carbon as food sources and the algae provides from photosynthetic process. Lichen is distributed in terrestrial from tropical to polar habitats. Lichen varies in terms of body size and length. Many investigation had been done to test the lichen as bio indicators. This research aimed to determine the diversity and abundance of lichen Surakarta and Jogjakarta, two middle cities in central Java, Indonesia. The research conducted in September 2018 to May 2019. It was using exploration method, by purposive sampling technique to determine the research sites and sampling locations. A total of 303 lichen individuals were taken from as many as 180 different types of host trees was carried out in three different regions. The research location as parameters was using three different location of lichen habitat, they were in the city, countryside and forest in Surakarta and Jogjakarta, Central Java, Indonesia. The city was assumed had high air pollution than countryside, while the forest was the lowest air pollution. As many as 28 species of lichen were obtained from the three locations. Parmeliaceae dominated the lichen population. The highest Shannon Winner diversity index of lichen that used was 0.09 in Surakarta than Jogjakarta was 2.7. The highest abundance value of lichen species was 0.73 in Jogjakarta, while Surakarta was 0.68. The abundance values of lichen was representation of lichen Parmeliaceae in Jogjakarta was more abundance than Surakarta.

**Keywords:** lichen, Parmeliace, biodiversity, bioindicator, abundance

Roziaty E, Sutarno, Suntoro S, Sugiyarto (2020) Ecological indices on Lichen biodiversity in three main different areas (the cities, countrysides and the forests) of Jogjakarta and Surakarta, Central Java, Indonesia. Eurasia J Biosci 14: 4543-4550.



## INTRODUCTION

Lichen is commonly known as symbiotic organism between algae and fungus (NashIII, 2008); (Markert, Breure, & Zechmeister, 2003). It is a mutualistic organism between alga usually Cyanobacteria and fungus usually Ascomycetes attached very tightly to the rude surfaces of substrate like rocks, concrete, soil and trees (Lisowska, 2011). Lichen as symbiotic group of low plants is known as symbiont. The algae is called photobiont (McMurray & Roberts, 2013) that is capable of carrying out the process of photosynthesis. The fungus is called mycobiont (Gibson, et al., 2013) which is the part that protects and shapes the body of lichen. Photobiont and mycobiont reproductive dispersal patterns were investigated in Europe about 85 lichen thalli (Steinová, Škaloud, Yahr, Bestová, & Muggia, 2019).

The lichen body is still simple. It is called thallus. The thallus are very strongly influenced by the symbiont. Based on the thallus morphology, lichen is classified into three groups namely crustose (moss-like), foliose (leafy-like) and fruticose (shrubby-like) (Gupta, et al., 2016 ). Lichen crustose spreads in terrestrial habitats from the tropics to the poles.

Lichen is very dependent on environmental conditions in terms of nutritional fulfillment (Markert, Breure, & Zechmeister, 2003) because the body structure is still very simple. Thallus gets water from droplets of dew while the source of carbohydrates comes from photosynthesis process. The temperature

Received: December 2019
Accepted: March 2020
Printed: October 2020

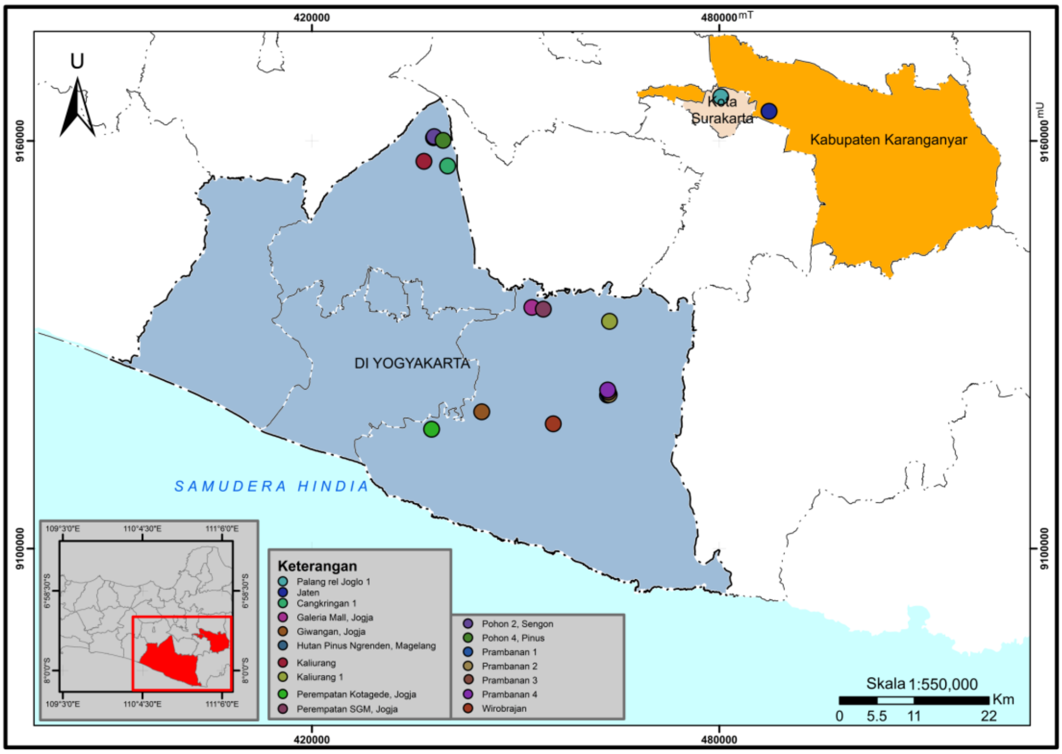


**Fig. 1.** Research sites was divided into three main environmental conditions namely the cities, country sides and the forest in Surakarta and Jogjakarta, Central Java, Indonesia

and humidity of the environment affect lichen growth greatly (McMullin, et al., 2016). From research that was conducted in the area around Niagara, Hamilton and Owen Sound, Ontario, Canada, there was a pattern of growth distribution in the lichen community in urban area (high pollution) and sub urban (middle pollution) influenced by micro climatic conditions or humidity (Affum, Oduro-Afriyie, Nartey, Adomako, & Nyarko, 2008).

Since long time ago, research on lichen as a bio indicator was developed in America and Europe. It was found that United States of America Government developed a national bio monitoring using lichen for the large scale monitoring program. Their investigated used lichen *Physchia* from low forest landscapes In Midwest USA (Wolf, Jovan, & Amacher, 2017).

In industrial areas showed that $NO_2$ and dust affected the growth of lichen species of *Lecanora conizoides* in the south of Poland. At the same area, the researcher studied recolonization of lichens in urban area found the decreased of lichen quality exposed by the pollutants (Bozkur, 2017). Other studies showed that nitrogen compounds found in the atmosphere with those in Thallus lichen were identical (Cowden, DeBues, & Dean, 2018). Other compounds that played a role in ambient air pollution were $SO_2$. The result was the high $SO_2$ content in the air affected the biodiversity of lichen. It even influenced the decreased of the lichen growth (Monge-Nájera, González, Rossi, & Méndez, 2002); (Wolseley, 1999).

The purpose of this study is to determine the diversity and abundance of lichen Surakarta and Jogjakarta, two middle cities in central Java, Indonesia, in the cities (it was assumed polluted), country side (it was assumed middle polluted) and forests as natural habitats (it was assumed not polluted).

## METHOD

### Sampling sites

The study was conducted in two region namely Surakarta and Jogjakarta, in Central Java, Indonesia in September 2018 – May 2019. Sampling was carried out into three different area in Surakarta and Jogjakarta (**Fig. 1**). The replication twice in each location, so totally there are six sampling sites in this research. The parameters were divided into three environmental conditions, the cities (assumed polluted), country side (middle polluted), and forests as natural habitats (non polluted). The repetition factor in each environmental condition was called a station. Then each station was repeated twice. At each station, there were 10 plots were made. Each plot consist of 3 trees plastered with lichen.

### Materials

A thermo higro meter was used to measure temperature and humidity. Counter was used to calculate lichen thallus. Small plot 10 x 10 cm x 5 using

**Table 1.** Number of lichen species found in various environmental conditions (the cities, countryside and the forests) in the Yogjakarta and Surakarta, Central Java, Indonesia

| No | Lichen species | Jogjakarta | | | Surakarta | | |
|---|---|---|---|---|---|---|---|
| | | City | Countryside | Forest | City | Countryside | Forest |
| 1 | *Dirinaria aplanata* (Fee) D.D. Awasthi. | 31 | 0 | 0 | 0 | 110** | 0 |
| 2 | *Dirinaria aegiliata* (Afz) B. Moore | 6 | 0 | 0 | | 17 | 0 |
| 3 | *Dirinaria picta* (Sw) Clem & Schear | 0 | 133 | 0 | 228** | 45 | 0 |
| 4 | *Lepraria incana* (L.) Ach. | 81 | | 0 | 0 | | 0 |
| 5 | *Lepraria sp* Ach. | 0 | 212* | 0 | 158 | 63 | 30 |
| 6 | *Graphis scripta* (L.) Ach. | 14 | 0 | 56 | 0 | 0 | 72 |
| 7 | *Graphis fucta* Adans. | 24 | 0 | 0 | 0 | 0 | 0 |
| 8 | *Graphis desquamescens* (Fee) Zahlbr. | 0 | 0 | 43 | 0 | 0 | 0 |
| 9 | *Graphis* Dumort. | 0 | 117 | 27 | 15 | 67 | 0 |
| 10 | *Lecidella eaelochroma* | 5 | 11 | 0 | 10 | 77 | 69 |
| 11 | *Parmelia barreneo* Ach. | 133* | 0 | 0 | 0 | 0 | 0 |
| 12 | *Parmelia sp.* Ach. | 23 | 78 | 206 | 22 | 34 | 51 |
| 13 | *Bacidia viridivarinosa* | 10 | 0 | 61 | 115 | 24 | 0 |
| 14 | *Pyxine soredinata* (Ach.) Mont. | 0 | 76 | 0 | 0 | 37 | 0 |
| 15 | *Cryptothecia striata* G. Thor. | 0 | 97 | 57 | 0 | 87 | 115 |
| 16 | *Caloplaca sp.* Th. Fr. | 0 | 0 | 35 | 0 | 0 | 0 |
| 17 | *Pyrenula punctella* Ach. | 0 | 37 | 0 | 0 | 0 | 0 |
| 18 | *Canoparmelia amabilis* Heiman & Elix. | 0 | 34 | 45 | 0 | 51 | 0 |
| 19 | *Flavoparmelia caperata* (L.) Hale | 0 | 0 | 125 | 0 | 0 | 0 |
| 20 | *Flavoparmelia baltimorensis* (Gyelnik & Foriss) Hale. | 0 | 0 | 0 | 0 | 48 | 0 |
| 21 | *Parmotrema perlatum* (Hudson) M. Choisy. | 0 | 0 | 219* | 0 | 0 | 127** |
| 22 | *Phyllopsora confusa* Swinscow & Krog. | 0 | 0 | 12 | 0 | 0 | 0 |
| 23 | *Candelaria concolor* (Dicks.) Stein | 0 | 0 | 56 | 0 | 0 | 45 |
| 24 | *Arthonia complanata* Fee. | 0 | 0 | 0 | 0 | 20 | 0 |
| 25 | *Arthonia conferta* (Fee.) Nyl. | 0 | 0 | 0 | 0 | 13 | 0 |
| 26 | *Lecanora sp.* Ach. | 0 | 0 | 0 | 0 | 0 | 9 |
| 27 | *Usnea hirta* (L.) F.H. Wigg. | 0 | 0 | 0 | 0 | 0 | 127** |
| 28 | *Phlyctis argena* (Ach.) Flot. | 0 | 0 | 0 | 0 | 20 | 88 |
| | Sum | 327 | 795 | 942 | 548 | 713 | 733 |

Notice:
* a sum of highest value of individual lichen in Jogjakarta
** a sum of highest value of individual lichen in Surakarta

mica plastic was made and was placed around tree trunks (Lovadi, Cairns, & Congdon, 2012). Knife or cutter was to scrape lichen from tree trunk. Ziploc plastic and various size labels was used for carrying lichen samples. A short roll meter was to measure the diameter of a tree trunk. Sprayer, if necessary, was to observe the thallus morphology directly in the tree. Roll meter was to measure the distance among trees. Roll meter also was used to measure tree diameter. On an android phone GPS essentials software was installed. GPS essentials software, altimeter was to measure altitude from sea level. Digital camera was used for documentation and stationaries.

## METHODS

This study used exploration method with the purposive sampling technique through an advanced survey of existing lichen. In the cities, the lichen taken was that grew on trees in along the road side and also the country side and forest. Trees taken were trees with approximately the same age determined by the diameter more than 20 cm (about 20 - 50 cm). Determination of research locations was based on pollution levels in each areas.

Lichen samples were based on tree host species with microhabitat lichen abiotic factors. Taking samples was about 1.5 m above ground level. This level was assumed to be affected by ambient air such as Nitrogen and Sulfur oxide compounds pollutants and lead (Goward, 1999); (McCune, Goward, & Meidinger, 1994).

The primary data were lichen the species and also the sum of individuals, temperature and humidity of environment. Supporting data were $SO_2$, $NO_2$ and lead (Pb) from Environmental Departement of Republic Indonesia. The identification carried out in the laboratory was to observed morphology such as the surface of the thallus. The observation used a stereo microscope with Optilab. Identification using a stereo microscope and optilab to help clarify the object and then determine with the book as follows: (Schneider, 1904); (Broad, 1989); (Elvebakk, Bjerke, & Stovern, 2014); (Hadiyati, Setyawati, & Mukarlina, 2013). The data described the form of structure and community lichen (the abundance).

Statistical analysis used PAST v (*PAlaeontological STatistics*) software to measure biodiversity and indexation of lichen species diversity in ecology.

## RESULT AND DISCUSSION

### Lichen Diversity According to Thallus Morphology

Lichen observed that grew in three types of environment, namely town, countryside and forest. The number of species found were 28 attached to 180 different of trees. The most common species was found namely *Parmelia* sp. as many as 303 individuals, dominated by *Lepraria* sp. as many as 451 species (**Table 1**).

a

b

**Fig. 2.** Lichen types: a). *Parmelia* sp. (Parmeliaceae) which dominates the city area in Jogja; b). *Lepraria* sp. (Leprariaceae) which dominates the countryside of Jogja

**Fig. 3.** Lichen type *Parmotrema perlatum* is a member of the Parmeliaceae family

a

**Fig. 4.** Lichen found in Surakarta, Central Java, Indonesia in the city, country side and forest areas, a) *Dirinaria picta*; b) and c) *Usnea* sp.

Lichen which dominated in the Jogjakarta was *Parmelia barreneo* (Ach) with 133 individuals, the countryside of Jogjakarta dominates was *Lepraria* sp. Ach. with 212 individuals and the dominant forest area was *Parmotrema perlatum* (Hudson) M. Choisy. with 219 individuals. While in the Surakarta, lichen in the town was dominated by *Dirinaria picta* as many as 228 individuals, *Dirinaria aplanata* (Fee) D.D. Awasthi. as many as 110 individuals in countryside, and in the forests there were *Parmotrema perlatum* (Hudson) M. Choisy. and *Usnea hirta* (L.) F.H. Wigg. total 127 individuals.

*Parmelia barreneo* (Ach) was a member of the Parmeliaceae family that was categorized in the foliose, with a Thallus that resembles a leafy like blade (**Fig. 2a**). Parmeliaceae which had the largest members and dominated. The distribution in the world was the largest. In cities with high levels of pollution due to human activities that use motorized vehicles each only causes a few organisms that are tolerant with high polluted conditions. The genus Parmelia was one lichen that has a high tolerance range to urban pollutants that generally come from burning fossil fuels, so that in general the Parmeliaceae lichen is commonly found epiphytes on roadside shade trees (Hoda & Vijayaraghavan, 2015).

Besides Parmeliaceae, *Lepraria* sp. also dominated the crustose attached to the phorophyte (epiphytic host) (**Fig. 2b**). *Lepraria* sp. had high tolerance range in the world specifically in the tropics, but in subtropical regions such as in South America the distribution of *Lepraria* was intolerant to environmental conditions (Araujo, et al., 2015).

Lichen *Parmotrema perlatum* (Hudson) M. Choisy. was a member of the Parmeliaceae family which has a wide distribution, this species had antimicrobial function, especially bacterial and fungal pathogens. The secondary metabolite produced by the Thallus *Parmotrema perlatum* (Hudson) M. Choisy. is Hexan which has the ability to inhibit the growth of microbes that cause infections in humans (Pescott, et al., 2015).

In Surakarta, it was dominated by the lichen type *Dirinaria picta* (Sw) Clem & Schear, on the edge of the city of Surakarta it is dominated by *Dirinaria applanata* (Fee) D.D. Awasthi. while in the forest many *Parmotrema perlatum* (Hudson) M. Choisy. and Usnea are encountered (**Fig. 4**). Lichen Usnea was a lichen

b

c

**Fig. 4 (continued).** Lichen found in Surakarta, Central Java, Indonesia in the city, country side and forest areas, a) *Dirinaria picta*; b) and c) *Usnea* sp.

corticolous lichen, which was a lichen that attaches (epiphytes) to other organisms, generally trees. It belongs to the lichen fruticose group, which was lichen with shrub morphology. Ecologically, *Usnea* was a niche for other organisms to live and survive.

Lichen Usnea was a lichen that produces usneic acid which has the potential to contain anti-inflammatory, analgesic, pain relief, anti-oxidant, anti-microbial, anti-protozoal, anti-viral, larvacidal and UV protection (Lendemer, 2011). This type of lichen was spread quite a lot in the tropical Asia region.

*Usnea*'s existence was one of them is a bioindicator of a healthy vegetation environment, air quality was still very good (Firdaous, et al., 2017) because Usnea lives in the highlands starting around 1.300 m above sea level.

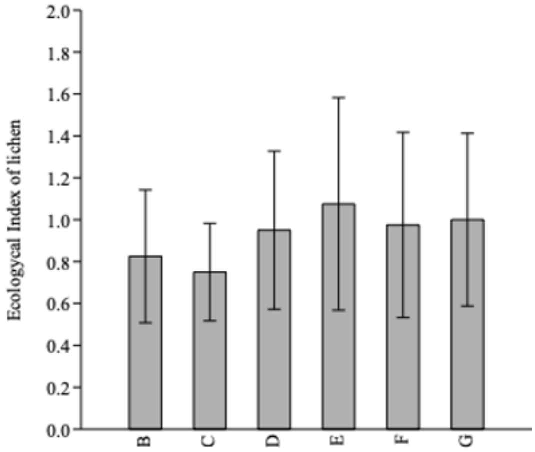


**Fig. 5.** Ecological indexation plots in six research locations in the Jogjakarta and Surakarta, Central Java, Indonesia (B = City Jogjakarta; C = Cities Surakarta; D = countryside Jogjakarta; E = Countryside Surakarta; F = Forest Jogjakarta; G = Forest Surakarta)

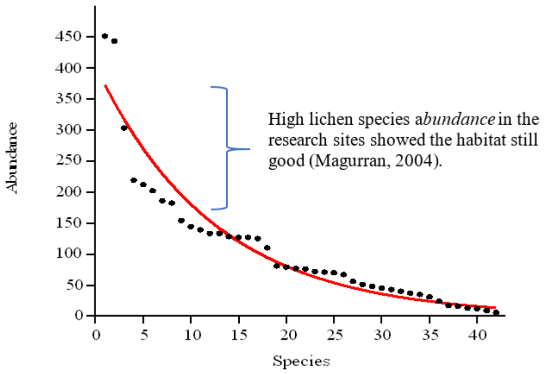


**Fig. 6.** The abundance of species (species richness) lichen in the six research sites in the city, countryside and forest areas in Jogjakarta and Surakarta as a whole in geometrics

## Ecological Indices

The Simpson Ecological Index showed that lichen (**Table 2**) in Surakarta was dominance (**Fig. 5**). The diameter of trees in roadside in Surakarta, were typical very thick bark and cracked. They were also large and old, so the host trees had large canopies. The canopy caused cool temperatures because high humidity during the day. It was a preferred habitat for lichen. The growth of lichen was influenced by temperature and humidity as well as the shade of phorophytes (trees) as lichen host.

The Shannon Diversity Index illustrated the highest species richness was lichen in Jogjakarta (**Table 2**) which was 2.783 compared to lichen in the Surakarta which was 2.616. The Jogjakarta had a high type of wealth/abundance compared to Surakarta. This was caused in Jogjakarta generally found with a smaller colonies of lichen spread on phorophytes (host trees).

The Jogjakarta had a higher type of wealth/abundance compared than Surakarta. It becaused in Jogjakarta generally found with a smaller colonies of lichen spread on phorophytes (**Fig. 6**).

**Table 2.** Overall lichen indexation values in the Jogjakarta and Surakarta Areas (the cities, country side and forests in Jogjakarta and Surakarta, Central Java, Indonesia)

| 0 | Jogjakarta | Surakarta | Boot p(eq) | Perm p(eq) |
|---|---|---|---|---|
| Taxa S | 22 | 20 | 0.002 | 0.001 |
| Individuals | 2060 | 2534 | 0 | 0 |
| Dominance | 0.07499 | 0.09545 | 0.001 | 0.001 |
| Shannon H | 2.783 | 2.616 | 0.001 | 0.001 |
| Evenness e^H/S | 0.7348 | 0.6839 | 0.003 | 0.005 |
| Simpson indx | 0.925 | 0.9045 | 0.001 | 0.001 |

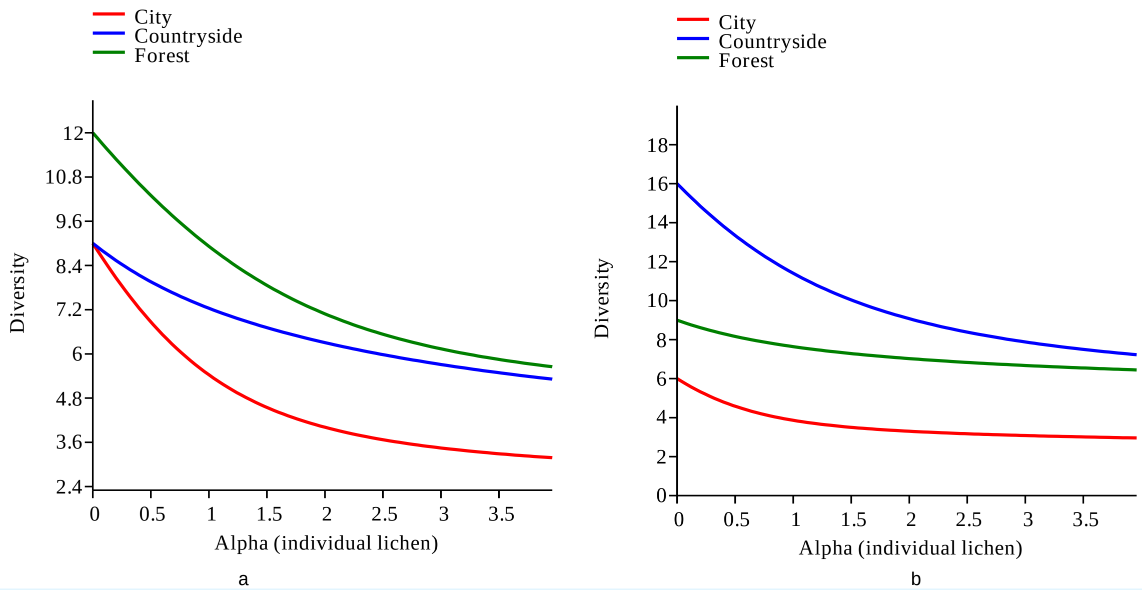


**Fig. 7.** Diversity of lichen species in the countryside of Jogjakarta and Surakarta as a whole in three different parameters namely a) cities, countryside and forests of Jogja; and b) the cities, countryside and the forest Surakarta, Central Java, Indonesia

Trees found in cities generally have a smaller diameter but the distribution of lichen grew more. It was calculated in the data causing a high lichen community which influenced the high Shanon Diversity Index in Jogjakarta (**Table 2**).

Comparison of the abundance of lichen species between Jogjakarta Surakarta in three parameters were the cities, country side and forests (**Fig. 7**). The range of individuals in both locations (Jogjakarta and Surakarta) was still quite high (Magurran, 2004), it was still within normal habitat limits. It described that the lichen community in both regions was still good.

## CONCLUSION

The result of the study obtained 28 species of lichen in the cities, countrysides and forests in Yogyakarta and Surakarta, Central Java, Indonesia. The dominant lichen was Parmeliaceae. There were differences in lichen species that were common town, countryside and forest even though they were still in one family. The highest dominance of lichen in Surakarta was 0.09. It was higher than Jogjakarta (0.07). The highest Shannon Diversity Index of Jogjakarta was 2.7 higher than Surakarta was 2.6. The highest abundance of lichen species Jogjakarta was 0.73 and Surakarta was 0.68. The Simpson Index in Jogjakarta was higher than the one in Surakarta (0.925 and 0.9).

## REFERENCES

Affum, H. A., Oduro-Afriyie, K., Nartey, V. K., Adomako, D., & Nyarko, B. J. (2008). Biomonitoring of airborne heavy metals along a major road in Accra, Ghana. Environment Monitoring Assessment, Vol 137: p 15–24.

Amstrong, R., & Bradwell, T. (2010). Growth of crustose lichens : A review. Journal compilation Swedish Society for Anthropology and Geography-Geogr. Ann.,, Vol 92 A (1): 3–17.

Araujo, A., Melo, M. d., Rabelo, T., Nunes, P., Santos, S., Serafini, M.,... Gelain, D. (2015). Review of the Biological Properties and Toxicity of Usnic Acid. Natural Product Research, p 1-17.

Bozkur, Z. (2017). Determination of Airborne Trace Elements in an Urban Area Using Lichens as Biomonitor. Environment Monitoring Assessment, Vol 189 (573) : p 1-12.

Broad, K. (1989). Lichens in Southeren Woodlands. Holdborn, London: HMSO Publications Centre.

Conti, M., & Cecchetti, G. (2001). Biological monitoring : lichena as bioindicators of air pollution assessment - a review. Environmental Pollution, 114 : 471-492.

Cowden, P., DeBues, M., & Dean, C. (2018). The Influence of Vehicular Air Pollution on Lichen Abundance in Two Central Ontario Forests. JUST, Vol IV No 1, p 1-6.

Ellis, C. J., & Coppins, B. J. (2010). Integrating multiple landscape-scale drivers in the lichen epiphyte response: climatic setting, pollution regime and woodland spatial-temporal structure. Diversity and Distributions, (Diversity Distrib.), Vol 16, pp 43–52.

Elvebakk, A., Bjerke, J., & Stovern, L. (2014). Parmelioid Lichens (Parmeliaceae) in Southernmost South America. Phytotaxa, Vol 173 (1): p 1–30.

Firdaous, S. S., Khan, S., Dar, M. E., Shaheen, H., Habib, T., & Ullah, T. S. (2017). Diversity and Distribution of Lichens in Different Ecological Zones of Western Himalayas Pakistan. Bangladesh J. Bot., Vol 46 (2): p 805-811.

Flakus, A., & Kukwa, M. (2007). New Species and Records of Lepraria (Stereocaulaceae, Lichenized Ascomycota) from South America. The Lichenologist, Vol 39 (5): p 463–474.

Friendl, T., & Budel, B. (2008). Photobionts. In T. H. Nash, Lichen Biology (pp. 8-26). Cambridge, UK: Cambridge University Press.

Gibson, M. D., Heal, M. R., Li, Z., Kuchta, j., King, G. H., Hayes, A., & Lambert, S. (2013). The Spatial and Seasonal Variation of Nitrogen Dioxide and Sulfur Dioxide in Cape Breton Highlands National Park, Canada, and the association with lichen abundance. Athmospheric Environment, Vol 64 : p 3030-311.

Goward, T. (1999). The Lichen of British Columbia Ilustrated Keys Part 2 - Fruticose Lichens. British Columbia, Vancouver Canada: Ministry of Forest and Research Program of British Columbia.

Gupta, N., Gupta, V., Dwivedi, S. K., & Upreti, D. K. (2015). Comparative bioaccumulation potential of Pyxine cocoes and Bacidia submediallis in and around Faizabad city, Uttar Pradesh, India. G- Journal of Environmental Science and Technology, Vol 2(6): (2015) : pp 86 - 92.

Gupta, S., Khare, R., Bajpai, O., Rai, H., Upreti, D. K., Gupta, R. K., & Sharma, P. K. (2016). Lichen as Biodindicator for Monitoring Environmental Status In Western Himalaya India. International Journal of Environment, Volume-5, No 2, p 1-16.

Hadiyati, M., Setyawati, T. R., & Mukarlina. (2013). Kandungan Sulfur dan Klorofil Thallus Lichen Parmelia sp. dan Graphis sp. pada Pohon Peneduh Jalan di Kecamatan Pontianak Utara. Protobiont, Vol. 2 (1): p 12 – 17.

Hoda, S., & Vijayaraghavan, P. (2015). Evaluation of Antimicrobial Prospective of Parmotrema perlatum Hexane Extract. IJPRAS-International Journal of Pharmacheutical Research and Allied Sciences, Volume 4, Issue 2 : p 47-53.

Honegger, R. (2008). Mycobionts. In T. H. Nash, Lichen Biology (pp. 27-28). New York: Cambridge University Press.

Kondratiuk, A. S., Savchuk, O. M., & Hur, J. S. (2015). optimization of Protein Extraction for Lichen Thalli. Mycobiology, Vol 43 (2) : pp 157-162.

Lendemer, J. C. (2011). A Standardized Morphological Terminology and Descriptive Scheme for Lepraria (Stereocaulaceae). The Lichenologist, Vol 43 (5): p 379–399.

Lhare, R., Rai, H., Upreti, D., & Gupta, R. K. (2013). Lichen as indicators of habitat heterogenity in high altitude montaine pass (Sela pass) in Eastern Himalaya. UGC Sponsored National Conference on Resource Management and Its Sustainable Use (pp. 17-21). Uttarakhan, India : PT. Lalit Mohan Sharma Government Post Graduate College.

Lisowska, M. (2011). Lichen Recolonisation in an Urban-Industrial Area of Southern Poland as a Result of Air Quality Improvement. Environment Monitoring Assessment, Vol 179: p 177–190.

Lovadi, I., Cairns, A., & Congdon, R. (2012). A Comparison of Three Protocols for Sampling Epiphytic Bryophytes in Tropical Montane Rainforest. Tropical Bryology, Vol 34: p 93-98.

Magurran, A. E. (2004). Mesuring Biological Diversity. Oxford, UK: Blackwell Publishing Company.

Markert, B. A., Breure, A. M., & Zechmeister, H. G. (2003). Defininitions, Strategies and Principles for Bioindication/Biomonitoring of the Environment. In B. Markert, A. Breure, & H. Zechmeister, Bioindicators and biomonitors (pp. p 1-20). Serbia: Elsevier Science Ltd.

McCune, B., Goward, T., & Meidinger, D. (1994). The Lichen of British Columbia - Part I - Folious and Squamulose Species. British Columbia, Vancouver, Canada: Ministry of Forests Research Program British Columbia.

McMullin, R. T., Bennett, L. L., Bjorgan, O. J., Bourque, D. A., Burke, C. J., & Clarke, M. A. (2016). Relationships Between Air Pollution, Population Density, and Lichen Biodiversity in the Niagara Escarpment World Biosphere Reserve. The Lichenologist, Vol 48 (5): p 593–605.

McMurray, J. A., & Roberts, D. W. (2013). Using Epiphytic Lichens to Monitor Nitrogen Deposition Near Natural Gas Drilling Operations in the Wind River Range, WY, USA. Water Air Soil Pollution, Vol 224 (1487) : p 1-14.

Monge-Nájera, J., González, M. I., Rossi, M. R., & Méndez, V. H. (2002). A new method to assess air pollution using lichen as bioindicators. Rev. Biol. Trop., 50(1): 321-325.

NashIII, T. H. (2008). Lichen Sensitivity to Air Pollution. In T. H. Nash, Lichen Biology (pp. p 299-301). New York: Cambridge University Press.

Peksa, O., & Skaloud, P. (2011). Do photobionts influence the ecology of lichens? A case study of environmental preferences in symbiotic green alga Asterochloris (Trebouxiophyceae). Molecular Ecology, Vol 20, 3936–3948.

Pescott, O., Simkin, J. M., August, T. A., Randle, Z., Dore, A. J., & Botham, M. (2015). Air Pollution and Its Effects on Lichens, Bryophytes, and Lichen-Feeding Lepidoptera: Review and Evidence from Biological Records. The Linnean Society of London, Biological Journal of the Linnean Society, p 1-26.

Schedegger, C., Groner, U., Keller, C., & S.Stofer. (2002). Biodiversity Assessment Tools - Lichens. In C. S. P.L Nimis, Monitoring with Lichens - Monitoring Lichens (pp. 359-365). Birmensdorf, Switzerland : Kluwer Academic Publishers.

Schneider, A. (1904). A Guide to The Study of Lichens. Boston: Knight and Millet.

Steinová, J., Škaloud, P., Yahr, R., Bestová, H., & Muggia, L. (2019). Reproductive and Dispersal Strategies Shape the Diversity of Mycobiont - Photobiont Association in Cladonia Lichens. Molecular Phylogenetics and Evolution, Vol 134 : p 226 - 237.

Wolf, S. W., Jovan, S., & Amacher, M. C. (2017). Lichen Elemental Content Bioindicators for Air Quality in Upper Midwest USA : A Model for Large Scale Monitoring. Ecological Indicators, Vol 78 : p 253 - 263.

Wolseley, P. (1999). Appendix III: Lichen sampling Protocols. London, UK: Department of Botany, The Natural History Museum, London.