European Journal of Ecology, 10.1, 2024, pp. 84-91

DIVERSITY AND ABUNDANCE OF SOIL MACROARTHROPODS IN KENDARI GREEN OPEN SPACES, INDONESIA

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Abstract

Information on soil macroarthropods in Kendari City has not been reported so far, even though soil macroarthropods play an important role in supporting the lives of other organisms and in recent years have decreased in number globally. This study aimed to identify soil macroarthropod communities and calculate the diversity of soil macroarthropods located in green open spaces in Kendari City. The green open spaces include Baruga forest, Mayor's park, and Nanga-nanga botanical garden. The data obtained were integrated to calculate the Shannon-Wiener index and Simpson index. Individuals of each taxa were evaluated with Menhinick index and Pielou index. The similarity of soil macroarthropod groups was measured using the similarity index and the ratio of diversity index values at each location had tested by using ANOVA single factor with p value of 0.05. The soil macroarthropod communities found in green open space was 3505 individuals consisting of 4 Classes, 12 Orders, 27 Families, and 54 Genera. The number of genera in three consecutive research locations, namely Nanga-nanga botanical garden with 26 genera, Baruga forest with 25 genera and Mayor's park with 21 genera. Baruga forest had the highest diversity of soil macroarthropods compared to other locations. The highest abundance of soil macroarthropods was shown by Family Formicidae (Ants), followed by Isoptera (Termites), Aranae (Spiders), and the lowest were Dermaptera (Earwig), Scolopendromorpha (Centipedes), and Isopoda (Dead woodli).

Key Words: *Diversity; Formicidae; Green open spaces; Soil macroarthropod*

Introduction

Cities are the primary residence of more than half of the world's population today. This figure is estimate to increase by 68% on 2050 (Ring et al. 2021). Closed areas with infrastructure and high-density housing are increasing, while green open spaces are threatened (Haaland & Konijnendijk van den Bosch 2015; Yu et al. 2016). Green Open Space is an area with an elongated or grouped shape consisting of animals and plants that either grow naturally or are deliberately planted. Green open space around urban settlements is a natural space to improve the ecological environment in urban areas. Kendari City has a number of green open spaces including RTH in Baruga Sub-district, Kendari Mayor's park area and Nanga-nanga botanical garden. Green open spaces have several important roles in improving the ecological environment such as being a water catchment area (water conservation), providing oxygen needs for living things, reducing air pollution, maintaining microclimate, recreational facilities, and maintaining biodiversity (Fulong et al. 2023).

The loss of biodiversity is now globally a major environmental problem, strengthened by a large number of scientific evidences. Although there has historically been little research on invertebrates, in recent years several studies have reported data on the trending global population decrease of arthropods (Sánchez-Bayo & Wyckhuys 2019; van Klink et al. 2020), and many environmental factors are causing this trend (Wagner et al. 2021). As the most numerous and diverse group, arthropods play key roles in ecosystem functioning (pollination, pest control, nutrient cycling, soil formation) and provide important ecosystem services to humans (Brussaard et al. 2012).

One type of arthropod that plays an important role in soil is macroarthropods. The activity of soil macroarthropods in digging and mixing soil (bioturbation) shows that these organisms play an important role in soil aggregation and porosity. This in turned influences the environment such as soil aeration and moisture to support other organisms (Ruiz & Lavelle 2008; Ramirez et al. 2023). Soil macroarthropods in detritus food webs can occupy basal trophic levels as detritivores and as apex predators. A number of taxonomic groups of soil macroinvertebrates classified as detritivores include luing (Diplopoda) and termites (Isoptera), while macroinvertebrates classified as

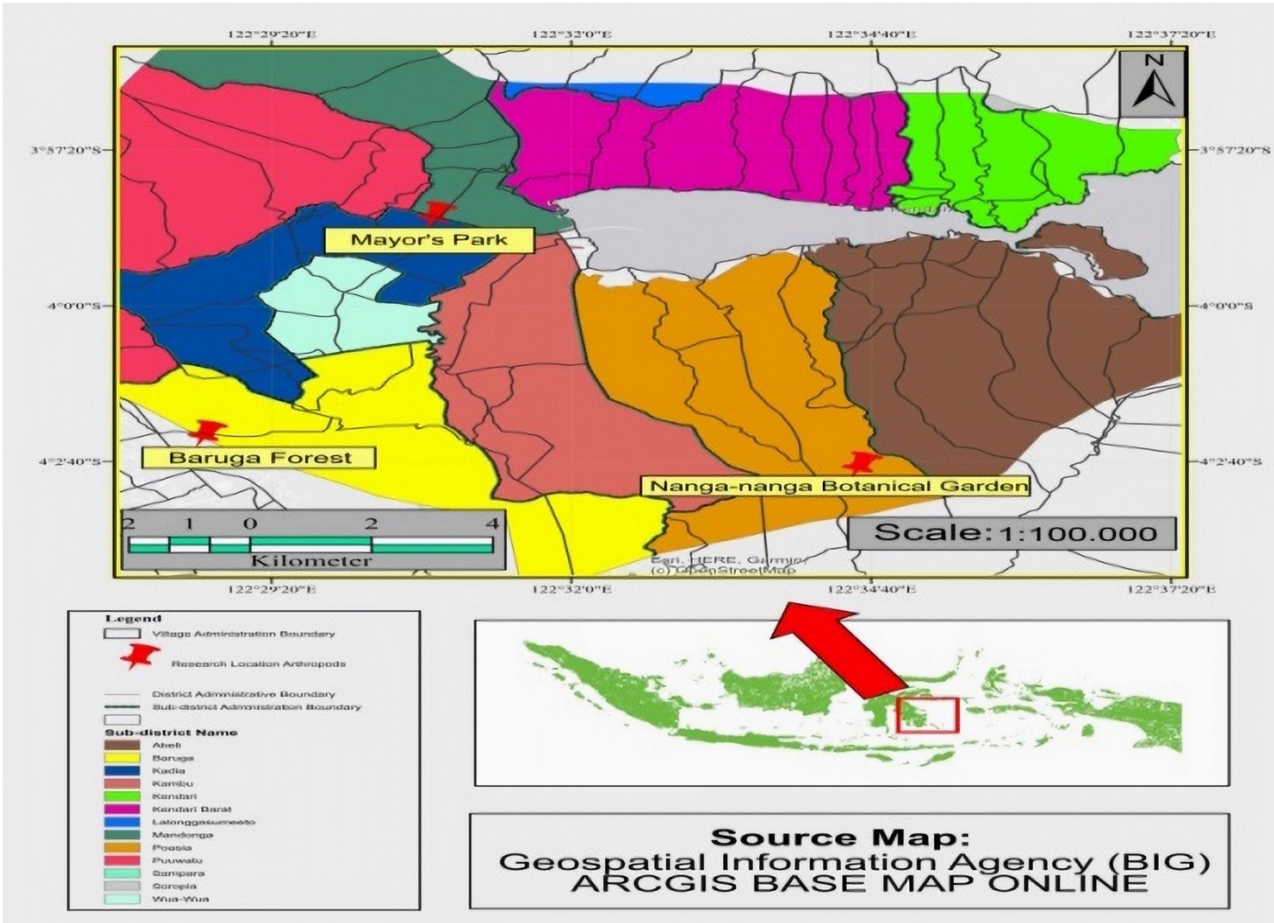

Figure 1. Map of Research Location.

predators include ants (Formicidae), beetles (Coleoptora), centipedes (Chilopoda) and spiders (Aranae) (Berg et al. 2001; Lavelle & Spain 2001).

So far, no information on soil macroarthropods in Kendari City has been reported, even though soil macroarthropods play an important role in supporting the life of other organisms and in recent years has been decreasing in population globally. Therefore, it is important to conduct this research. This study aims to identify soil macroarthropod communities and calculate the diversity of soil macroarthropods in green open spaces in Kendari City.

Material and Methods

The name Kendari refers to a local municipality and the Indonesian region of Southeast Sulawesi. By Indonesian Law No. 6 of 1995, Kendari was established as a municipality (and is currently a city) on September 27, 1995. The city has a population of 350,267 and a 271.8 km2 (26,847 Ha) land area. With a land area of 271.8 km2, or 0.70 percent of Southeast Sulawesi Province's total land area, Kendari City is a mountainous plain that is traversed by rivers that empty into Kendari Bay, which is a rich source of marine products.

The study area comprises in the green open spaces of Kendari City which includes Baruga forest, Mayor,s park, and Nanga-nanga botanical garden. The first location, Baruga forest, has a geographical location of 122,479042E; -4,036774S. The second location is the Mayor's park with a geographical location of 122,51305E; -3,97331S and the third location is the Nanga-nanga botanical garden with a geographical location of 122,57720E; -4,04780S (Figure 1).

Soil macroarthropod samples were taken 4 times with an interval of 2 weeks. In a square measuring 50 m x 50 m, 25 sampling points were set with a distance of 10 m from one point to another, for more details can be seen in Figure 2. At each sampling point, soil was taken using a sample ring with a diameter of 20 cm and a height of 15 cm. The sample ring is inserted into the ground using a hammer until it is flat with the ground surface. Then it was dug using a hoe. The soil in the sample ring was removed on the surface of the sack, then soil macroarthropods were separated from the soil using the hand sorting method (Swift, et al. 2004), termites and ants were preserved in 70% alcohol (Merck), while beetles, centipedes, and spiders were anesthetized using 70% chloroform solution (Merck) and preserved in 70% alcohol (Gullan and Cranston 2010).

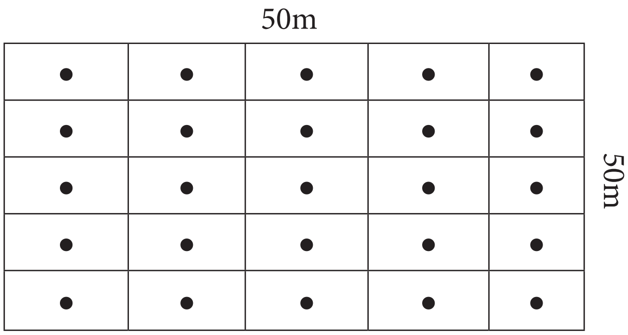

Figure 2. Illustration of quadrants and sampling points of soil macroarthropods

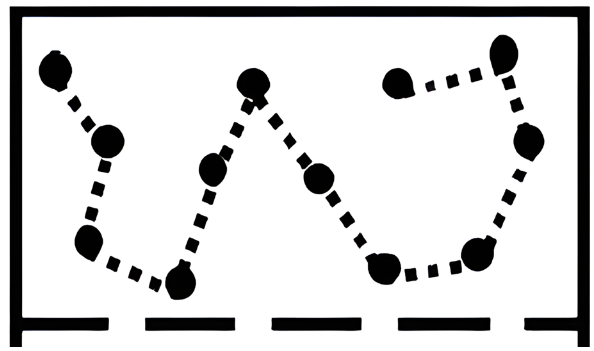

Figure 3. Illustration of soil sampling point determination. (Source: Carter & Gregorich 2008; Rab et al. 2023)

Soil samples were taken simultaneously with soil macroarthropod sampling. Soil samples were taken using the composite method like figure 3 where the determination of soil core sampling points using the zigzag sampling method (Carter & Gregorich 2008; Rab et al. 2023). The number of soil cores taken was 25 cores by thinly slicing each core 25 cm deep. The soil samples taken were composited until homogeneous and put into a container and brought to the Laboratory Biology of State Islamic Institute of Kendari to be dried for 3-4 days. Furthermore, sample preparation was carried out by pounding until smooth and put into plastic bags with a volume of 1 kg for analysis. The soil samples were each taken to the Biomolecular and Environmental Laboratory, as well as the Faculty of Mathematics and Natural Sciences, UHO, Kendari to be analyzed for N, P, K, and Soil C-Organic content.

Each soil macroarthropod taxa was identified using a stereo microscope (Leica EZ4HQ) at the Biomolecular and Environmental Laboratory, Faculty of Mathematics and Natural Sciences, UHO. The stereo microscope (Leica EZ4HQ) was also used to collect soil macroarthropod samples. The identification books used in this study were identification books by Hashimoto & Rahman (2010), Wenying (2000), Mohammed (1999), Tho (1992), Dindal (1990), Goulet & Huber (1894). After identification, sample images were matched at www.brisbaneinsect.com, www.boldsystems.org, and www.bugguide.net. In the identification process, the ant samples obtained were identified using a point mount measuring 2.5 mm x 7-10 mm and a needle (Gullan & Cranston 2010), more details presented in Figure 4.

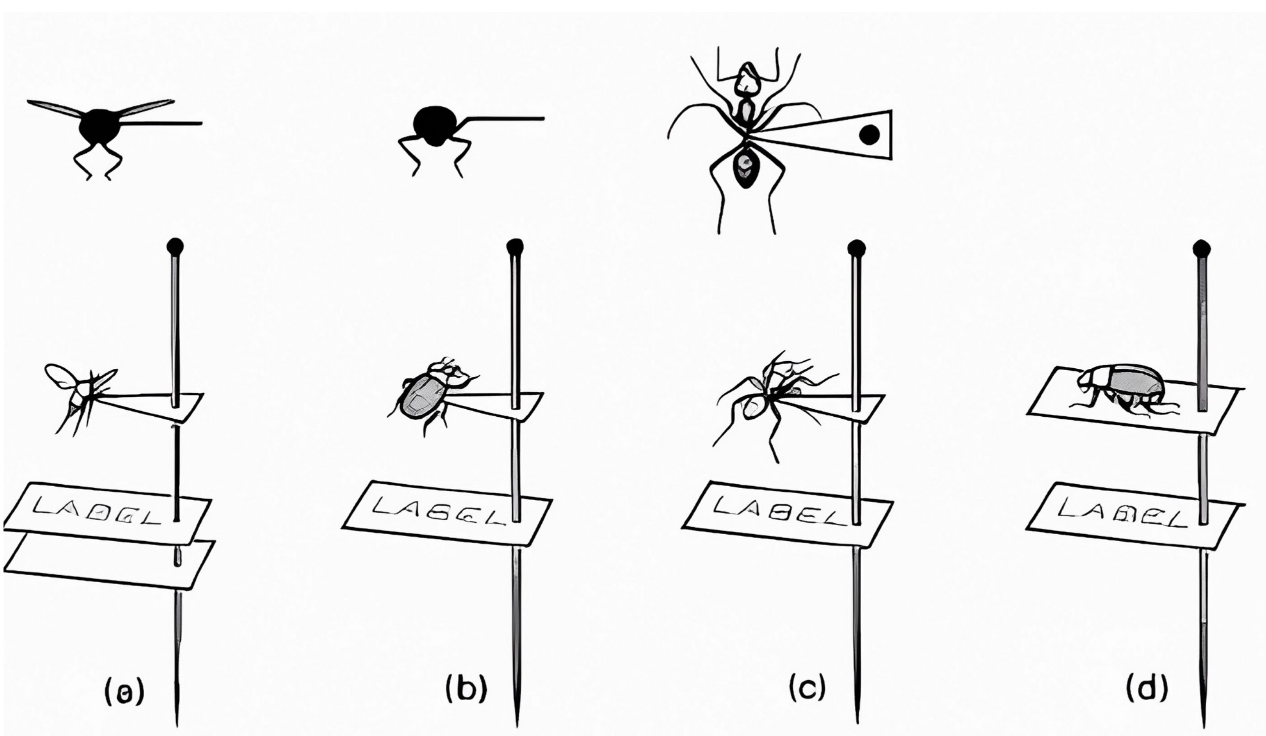

Figure 4. Point mount for sample identification (Source: Gullan & Cranston 2010).

The data are integrated to calculate the Shannon-Wiener index and Simpson index (Santorufo et al. 2012), where the equation for each index is as follows:

$$H = -\sum P_i \ln P_i$$

$$D = \sum (P_i)^2$$

where H is Index Shannon-Wiener, D is Index Simpson, and P_i is percentage of individuals of species i from the total number of individuals found.

High diversity is indicated by high Shannon-Wiener index values and low Simpson index values. Each individual of every taxa (evenness) was evaluated by Menhinick index and Pielou index (Magurran 2004). The similarity of soil macroarthropod groups was measured using the similarity index and the ratio of diversity index values at each location will be tested using Duncan's test with a p value of 0,05 (Kilowasid et al. 2012).

Results

Macroarthropod Community in Green Open Space in Kendari City

The soil macroarthropod community found in the green open spaces of Kendari City were 3505 individuals. The individuals found were divided into 12 orders of the Phylum Arthropod, namely 6 orders of the Insect class (insects), 1 order of the Archnida class (spiders), 1 order of the Chilopoda class (centipedes), and 4 orders of the Diplopoda class (millipedes). The orders of the Insect class identified were Isoptera, Hymenoptera, Coleoptera, Dermaptera, Isopoda and Diptera. The order of the Archnida class was Aranae, the order of the Chilopoda class was Scolopendromorpha, and the orders of the Diplopoda class were Spirostreptida, Glomerida, Polydesmida, Spirobolida. The order of each soil macroarthropod taxa found in green open spaces is less than the results of Ferreire et al, (2018), which found 19 orders of soil arthropod taxa in green open spaces in the cities of São Paulo and Osaco, Brazil, including Hymenoptera, Hemiptera, Orthoptera, Neuroptera, Blattodea, Thysanoptera, Dermaptera, Coleoptera, Acariformes, Araneae, Isopoda, Amphipoda, Geophilomorpha, Lepidoptera, Diptera, Siphonaptera, Mallophaga, and Ixodida.

The orders collected from the Green Open Spaces have a number of different families; the families of the order Isoptera were Rhinotermitida and Termitidae, the family of Hymenoptera was Formicidae; the families of the order Coleoptera were Staplaylinidae, Lampiridae, Lucanidae, and Scirtidae; the family of the order Dermaptera was Chelisochidae; the family of the order Scolopendromorpha was Cryptopida; families of the order Aranae were Oonopidae, Dictinidae, Dysderidae, Clubionidae, Pylodromidae, Salticidae, Lycosidae, Dysderidae, Gnaphosidae, Tetragnathidae, Thomisidae; the family of the order Glomerida was Gloremidae, the families of the order Polydesmida were Polydesmidae and Paradoxomatidae, the family of the order Spirobolida was Spirobolidae. The orders Isopoda, Diptera, and Hemiptera were identified up to the order level only. The genus number found in each green open spaces is presented in Table 1.

Table 1 showed that the three green open spaces had different genus numbers, where the locations with the most genus numbers were Nanga-nanga botanical garden with 26 genus, Baruga forest with 25 genus, and Mayor's park with 21 genus. Ants (Formicidae: Hymenoptera) have the most genus numbers found at each research location point (Figure 5). This was in line with the research of Siquiera et al. (2016) which stated that Hymenoptera was the most abundant group in three green open spaces. Differences in the results obtained can be caused by physicochemical factors of the environment (Benckiser 2019), vegetation characteristics (Jokimäki & Huhta 1998), the presence or absence of plants (Lara et al. 2009; Alvarez et al. 2019), colonization ability and dispersal of organisms (Delabie et al. 2007; Santos et al. 2016).

Table 1. Genus number of the Order from soil macroarhtropods in Green Open Spaces

Taxa	Baruga Forest	Nanga-nanga Botanical Garden	Mayor's Park
Hymenoptera (Ants)	10	11	12
Isoptera (Termites)	6	2	1
Coleoptera (Beetles)	1	1	2
Dermaptera (Earwig)	1	0	0
Scolopendromorpha (Centipedes)	1	0	0
Aranae (Spiders)	4	9	4
Diplopoda (Millipedes)	2	3	2
Total	25	26	21

Figure 5. *Odontomachus* sp. (Formicidae: Hymenoptera), one of ant that found in the three Green Open Spaces. A: Anterior side; B: Lateral side

Macroarthropod Diversity in Green Open Space in Kendari City

The highest diversity index was shown by Baruga forest, Nanga-nanga botanical garden and Mayor's park respectively (Table 2). It can be assumed that Baruga forest has a higher diversity of soil macroarthropod species compared to other locations. The diversity index is in contrast to the dominance index which is seen in the results of the study that the highest dominance index is in the Nanga-nanga botanical garden, Baruga forest, and Mayor's Park, respectively.

A high dominance index parameterizes the presence of a species or genus that is much more abundant than other species. *Protohamitermes* sp. (Isoptera: Rhonotermitidae) was a termite species that has a relative density of 31,7% of all total individuals found in the Nang-nanga botanical garden, thus showing dominance over other species. Menhinick index (Menhinick, 1964) as an index that explains the relative abundance of a community shows that the highest value is in Baruga forest.

Macroarthropod Abundance in Green Open Space in Kendari City

Hymenoptera was the most abundant taxa found in the entire green open spaces of Kendari City which was 60,29%, followed by isoptera 24,94%, aranae 12,01%, glomerida 0,74%, coleoptera 0,57%, spirostreptida 0,49%, spirobilida 0,37%, polydesmida 0,26%, and in the last place were diptera, dermaptera, scolopendromorpha, and isopods < 1% (Table 3).

Table 2. Index Diversity in Green Open Space

Location	H'	Di	DMn	P	E
Baruga Forest	2,49	0,146	0,05	0,77	0,41
Nanga-nanga Botanical Garden	2,40	0,152	0,71	0,73	0,33
Mayor's Park	2,35	0,12	0,61	0,75	0,32

Description: H'= Index Shannon-Wiener; Di= Index Simpson; DMn= Index Menhinick; P= Index Pielou; E= Index Similarity.

Table 3. Composition and abundance ranking of soil macroarthropods

TAXA	Rank	N	Densities	Relatively Densities (%)
Hymenoptera	1	2113	84,52	60,29
Isoptera	2	874	34,96	24,94
Araneae	3	421	16,84	12,01
Glomerida	5	26	1,04	0,74
Coleoptera	6	20	0,8	0,57
Spirostreptida	7	17	0,68	0,49
Spirobolida	8	13	0,52	0,37
Polydesmida	9	9	0,36	0,26
Diptera	10	3	0,12	0,09
Dermaptera	10	3	0,12	0,09
Scolopendromorpha	10	3	0,12	0,09
Isopoda	10	3	0,12	0,09
Total		**3505**	**140,8**	**100**

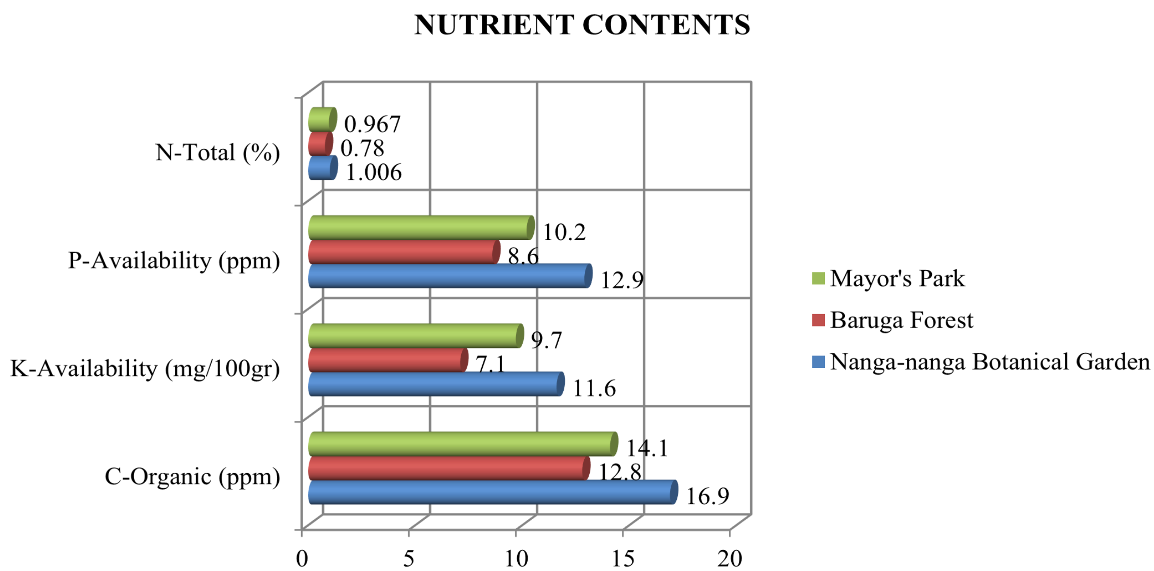

Figure 6. Analysis result of macro nutrient content in Green Open Space of Kendari City

The abundance of ants (Hymenoptera: Formicidae) was found to be the highest one in Mayor's Park with a relative densities of 77,42% of the total fauna collected from the study site, even though in terms of vegetation densitiy and diversity the area was much lower than Baruga forest and Nanga-nanga botanical garden, with relative densities of 68,55% and 42,38%. The results of this study were in line with the results obtained by Ozanne et al. (2000) who explained that the abundance of soil arthropods is greater in small forests because it is related to the characteristics of the vegetation, where small forests have sapling development and have more shrub growth than in large forests.

The genus Odontomachus and Pachyconyla were found in all study sites. This showed that both genera have a wide distribution in green open spaces. Odontomachus is known as one of the "nest architects" so that it can maintain colonies in seasonal changes, this was proven by Pamoengkas et al. (2020) who stated that the densities and distribution of odontomachus did not change significantly due to seasonal changes. In line with the results of Wetterer's research (2016), Pachycondyla has a very wide distribution and high densities in both natural and disturbed forests. Furthermore, Baveye et al. (2016) stated that Pachycondyla can live in a wide variety of habitats, including dry forests, tropical rainforests, urban areas, botanical gardens, grassy areas, chocolate plantations, coffee, riparian tropical forests, and many more. Thus, both the densities and distribution of Odontomachus and Pachycondyla were not significantly affected by abiotic characteristics.

Environmental Conditions and Nutrient Contents of Green Open Spaces of Kendari City

Environmental characteristics in Baruga forest were located at an altitude of 23 meters above sea level with a topography of 0,2o, has a high enough coverage so that the light intensity in the area was the lowest compared to other locations. This was indicated by the figure of light intensity which was much lower than other locations with an average of 641,4 candela, where this figure was significantly different from other locations p>0,05. The low light intensity was supported by vegetation conditions dominated by trees > 20 cm in diameter. The soil texture in the Baruga forest after testing with the sense method showed a dusty loam texture. The dusty loam texture was a sign that this location can store water longer so that it has an impact on soil moisture. It can be seen that soil moisture in Baruga Forest was the highest with an average of 71,1%, this figure was significantly different from other locations p>0,05.

Environmental characteristics at Nanga-nanga botanical garden located 112 meters above sea level with topography 25o, has medium coverage so that the light intensity in the area was quite high with an average of 1041,2 candela, where this figure was significantly different from other locations p>0,05. The soil texture at Nanga-nanga botanical garden after testing with the sense method showed a dusty loam texture. The dusty loam texture was a sign that this location can store water longer so that it has an impact on soil moisture, however, the botanical garden has a fairly low average humidity of 15,12%, this was due to the steep topographical condition so that water run off was faster and causes low water storage.

The Mayor's Park was a green open spaces that is utilized as a recreational and entertainment park by the people of Kendari City. This location was located at an altitude of 12 meters above sea level which was lower than the Baruga forest. The topography in this area was 0,5o. Vegetation in this area was dominated by trees with a diameter of >15 cm which were lined up lengthwise so that it has an impact on high light intensity. This was indicated by the light intensity figured of 841,6 candela. The soil texture in this area was dusty loam, however, it appears that the soil moisture in this area was low with an average of 15,26%, this is due to the lack of coverage at that location so that high light intensity increases the evaporation of water from the soil. Thus soil moisture can decrease.

The nutrient content in the three research locations showed differences from each other (Figure 6). The botanical garden had the highest nutrient content compared to the Baruga forest and Mayor's Park ($p<0,05$). However, nitrogen has the smallest number among other nutrients because nitrogen was a nutrient with high mobility, so it was very fast to evaporate and leach, especially supported by high soil temperatures and low air humidity (Wu et al. 2021). The amount of P-available in botanical garden soil was more due to the lack of P leaching process from the soil in natural forests caused by the presence of plants in the area, so that P remains in the soil. The available K contained in the soil of the Nanga-nanga botanical garden was 11,6%, the loss of available K in the soil was caused by the leaching process (Wu et al. 2021). Nutrients N and P are not only consumed by plants, but also by animals. From total nitrogen consumed, 20% was utilized by animals and 80% was returned to the environment as feces. Thus, the content of nutrients in the soil was not only important for plants, but also important for the existence of soil fauna (Foth, 1994).

Soil macrofauna have different reactions to the effects of soil chemical properties. The most affected nutrients are organic C and N. The high content of N, P, K, and organic C was not positively correlated with its biodiversity and abundance such as Hymenoptera and Coleoptera, but positively correlated with the abundance of Isoptera (Ayuke et al. 2009; Bufebo et al. 2021).

Conclusion

The soil macroarthropod community in green open spaces of Kendari City consists on 4 classes, 12 orders, 27 families, and 54 genera. The highest diversity of soil macroarthropods is in Baruga forest, Nanga-nanga botanical Garden, and Mayor's Park, respectively. The highest relative abundance of soil macroarthropods was shown by Family Formicidae (Ants), followed by Isoptera (Termites), Aranae (Spiders), and the lowest were Dermaptera (Cocopet), Scolopendromorpha (Centipedes), and Isopoda (Dead woodlice). The highest nutrient contents were in Nanga-nanga botanical garden, Mayor's park, and Baruga forest, respectively. Environmental characteristics in the green open spaces show significant differences in terms of vegetation, altitude and topography.

References

Alvarez-Garreton, C., Lara, A., Boisier, J. P., & Galleguillos, M. (2019). The impacts of native forests and forest plantations on water supply in Chile. *Forests*, *10*(6), DOI: 10.3390/f10060473.

Ayuke, F. O., Karanja, N. K., Muya, E. M., Musombi, B. K., Mungatu, J., & Nyamasyo, G. H. N. (2009). Macrofauna diversity and abundance across different land use systems in Embu, Kenya. *Tropical and Subtropical Agroecosystems*, *11*(2), 371-384.

Baveye, P. C., Baveye, J., & Gowdy, J. (2016). Soil "ecosystem" services and natural capital: critical appraisal of research on uncertain ground. *Frontiers in Environmental Science*, *4*, 41, DOI: 10.3389/fenvs.2016.00041.

Benckiser, G. (2019). Plastics, micro-and nanomaterials, and virus-soil microbe-plant interactions in the environment. *Plant Nanobionics: Volume 1, Advances in the Understanding of Nanomaterials Research and Applications*, 83-101, DOI: 10.1007/978-3-030-12496-0_4.

Berg, M., Peter de Ruiter, W. Didden, M. Janssen, T. Schouten, and H. Verhoef. 2001. Community Food Web, Decomposition and nitrogen mineralization in stratified scots pine forest soil, *Oikos* 94: 130-142.

Brussaard, L., 2012. Ecosystem services provided by the soil biota. In: Wall, D.H., BehanPelletier, V., Ritz, K., Jones, T.H., Six, J., Strong, D.R., van der Putten, W.H. (Eds.), Soil Ecology and Ecosystem Services. Oxford University Press, Oxford, pp. 45–58.

Bufebo, B., Elias, E., & Getu, E. (2021). Abundance and diversity of soil invertebrate macro-fauna in different land uses at Shenkolla watershed, South Central Ethiopia. *The Journal of Basic and Applied Zoology*, *82*, 1-12, DOI: 10.1186/s41936-021-00206-1.

Carter, M. R., and E. G. Gregorich. 2008. Soil Sampling and Analysis Methods. Second Edition. CRC Press. USA. Hal: 24-46.

Delabie, J. H., Jahyny, B., do Nascimento, I. C., Mariano, C. S., Lacau, S., Campiolo, S., Stacy, M. P., & Leponce, M. (2007). Contribution of cocoa plantations to the conservation of native ants (Insecta: Hymenoptera: Formicidae) with a special emphasis on the Atlantic Forest fauna of southern Bahia, Brazil. *Biodiversity and Conservation*, *16*, 2359-2384.

Dindal, D. L. 1990. Soil Biology Guide. Wiley. New York.

Ferreira, M. L., 1 , L. C. de Souza, D. de Melo Conti, C. C. Quaresma, A. R. Tavares, K. G. da Silva, C. T. Kniess, and P. B. de Camargo, 2018, Soil biodiversity in urban forests as a consequence of litterfall management: implications for são paulo's ecosystem services, *Sustainability* 10 (684): 1-13.

Foth, H. D. 1994. *Dasar-dasar Ilmu Tanah*. Erlangga. Jakarta. Pp. 22-32.

Fulong, Li., Lin, B., and Kun, M. (2023). Green Space Settlement Landscape Optimization Strategy Under the Concept of Ecological Environment Restoration. *Journal of King Saud University-Science*, DOI: 10.1016/j.jksus.2023.102539.

Goulet, H., and J. T. Huber. 1894. Hymenoptera of the World: an Identification Guide to Families. Agriculture Canada. Canada.

Gullan, P. J. and P. S. Cranston. 2010. *The insects*. Wiley-Blackwell. UK.

Haaland, C., Konijnendijk van den Bosch, C., 2015. Challenges and strategies for urban green-space planning in cities undergoing densification: a review. Urban For. Urban Green. 14 (4), 760–771, DOI: 10.1016/j.ufug.2015.07.009

Hashimoto, Y. and H. Rahman. 2010. Inventory and Collection. Research and Education Component. Malaysia.

Jokimäki J., E. Huhta, J. Itämies, and P. Rahko, 1998, Distribution of arthropods in relation to forest patch size, edge, and stand characteristics, *Can. J. For. Res.* 28: 1068–1072.

Kilowasid, L. M. H., T.S Syamsudin, E. Sulistiawaty, and F.X. Susilo. 2012. Ecological diversity of soil fauna as ecosystem engineers in small-holder cocoa plantation in South Konawe, Southeast Sulawesi, *J Trop Soil*, 17 (2): 173-180.

Lara, A., Little, C., Urrutia, R., McPhee, J., Álvarez-Garretón, C., Oyarzún, C., Soto, D., & Arismendi, I. (2009). Assessment of ecosystem services as an opportunity for the conservation and management of native forests in Chile. *Forest Ecology and Management*, *258*(4), 415-424.

Lavelle, P. and A. Spain. 2001. *Soil Ecology*. Kluwer Academics, The Netherlands.

Magurran, A. E. 2004. Measuring Bilogical Diversity. Blackwell Publishing. USA.

Menhinick, E. P. 1964. A comparison of some species-individuals diversity indices applied to samples of field insects. Ecology 45: 859-861.

Mohammed, M. 1999. Keys To The Terrestrial Invertebrates. Malaysia Sbah University. Malaysia.

Ozanne, C. M. P., Speight, M. R., Hambler, C., & Evans, H. F. (2000). Isolated trees and forest patches: patterns in canopy arthropod abundance and diversity in Pinus sylvestris (Scots Pine). *Forest Ecology and Management*, *137*(1-3), 53-63.

Pamoengkas, P., Rachmat, H. H., & Khalifa, N. (2020). The growth of shorea leprosula at various planting distances and slopes in gunung dahu research forest, Bogor, Indonesia. *Biodiversitas Journal of Biological Diversity*, *21*(9), DOI: 10.13057/biodiv/d210959.

Rab, M. A., Nasta, P., Armindo, R. A., Beverly, C. R., Reynolds, W. D., & Romano, N. (2023). Empirical equations for estimating field capacity in dryland cropping soils of southeastern Australia. Soil and Tillage Research, 234, 105816, DOI: 10.1016/j.still.2023.105816.

Ramírez, B. H., Cortés-B, R., Pinzón, O. P., Gómez, L., Jacquin, S., Hernández, E., Quimbayo, L. A., & Bogotá-A, R. G. (2023). Cloud forests of the Orinoco River Basin (Colombia): Variation in vegetation and soil macrofauna composition along the hydrometeorological gradient. *Biotropica*, DOI: 10.1111/btp.13203.

Ring, Z., Damyanovic, D., & Reinwald, F. (2021). Green and open space factor Vienna: A steering and evaluation tool for urban green infrastructure. *Urban Forestry & Urban Greening*, *62*, DOI: 10.1016/j.ufug.2021.127131.

Ruiz, N. and P. Lavelle. 2008 . *Soil Macrofauna Field Manual*. FAO. Rome.

Sánchez-Bayo, F., Wyckhuys, K.A., 2019. Worldwide decline of the entomofauna: a review of its drivers. Biol. Conserv. 232, 827, DOI: 10.1016/j.biocon.2019.01.020.

Santorufo, L., C. A. M. Van Gestel, A. Rocco, G. Maisto. 2012. Soil invertebrates as bioindicator of urban soil quality. *Environmental Pollution* 161: 57-63.

Santos-Silva, L., Vicente, R. E., & Feitosa, R. M. (2016). Ant species (Hymenoptera, Formicidae) of forest fragments and urban areas in a Meridional Amazonian landscape. *Check List*, *12*(3), 1885-1885.

Swift, M.J., A.M.N. Izac. and M. van Noordwijk. 2004. Biodiversity and Ecosystem Services in Agricultural Landscapes—Are We Asking The Right Questions? *Agriculture, Ecosystems and Environment* 104: 113–134.

Siqueira, G. M., de França Silva, Ê. F., Moreira, M. M., de Araújo Santos, G. A., & Silva, R. A. (2016). Diversity of soil macrofauna under sugarcane monoculture and two different natural vegetation types. *African Journal of Agricultural Research*, *11*(30), DOI: 10.5897/AJAR2016.11083.

Tho, Y. P. 1992. Termites of Peninsular Malaysia. FRIM. Kuala Lumpur.

van Klink, R., Bowler, D.E., Gongalsky, K.B., Swengel, A.B., Gentile, A., Chase, J.M., 2020. Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. Science 368, 417–420, DOI: 10.1126/science.aax9931.

Wagner, D.L., Grames, E.M., Forister, M.L., Berenbaum, M.R., Stopak, D., 2021. Insect decline in the anthropocene: death by a thousand cuts. Proc. Natl. Acad. Sci. U. S. A. 118 (2), DOI: 10.1073/pnas.2023989118.

Wenying, Y. 2000. Pictorial Keys to Soil Animals China. Science Press. Beijing, New York.

Wetterer, J. K. (2016). Geographic range of Pachycondyla harpax (Fabricius)(Hymenoptera, Formicidae). *Sociobiology*, *63*(1), 623-627, DOI: 10.13102/sociobiology.v63i1.764.

Wu, A., Hu, X., Wang, F., Guo, C., Wang, H., & Chen, F. S. (2021). Nitrogen deposition and phosphorus addition alter mobility of trace elements in subtropical forests in China. *Science of The Total Environment*, *781*, 146778, DOI: 10.1016/j.scitotenv.2021.146778.

Yu, S., Yu, B., Song, W., Wu, B., Zhou, J., Huang, Y., Wu, J., Zhao, F., Mao, W., 2016. View-based greenery: a three-dimensional assessment of city buildings' green visibility using Floor Green View Index. Landsc. Urban Plan. 152, 13–26, DOI: 10.1016/j.landurbplan.2016.04.004.