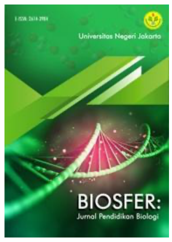
Biosfer: Jurnal Pendidikan Biologi, 18(2), 230-248 (2025)

Biosfer: Jurnal Pendidikan Biologi

Journal homepage: http://journal.unj.ac.id/unj/index.php/biosfer



Flora diversity and soil nutrients in Samudra University Arboretum: development of a conservation learning module based on environmental and climate education

Sri Jayanthi[1*], Zulfan Arico[2], Wendy Achmmad Mustaqim[2], Saudah[3]

[1] Biology Education, Faculty of Teacher Training and Education, Samudra University, Indonesia
[2] Biology, Faculty of Science and Technology, Samudra University, Indonesia
[3] Biology Education, Faculty of Teacher Training and Education, University of Serambi Mekkah, Banda Aceh, Indonesia.

*Corresponding author: srijayanthi@unsam.ac.id

ARTICLE INFO

Article history
Received: 14 May 2025
Revised: 21 May 2025
Accepted: 28 May 2025

Keywords:
Arboretum
Climate support
Conservation
Flora diversity
Soil nutrients.

ABSTRACT

Climate change has long been an important global issue caused by large-scale environmental changes. In the context of green spatial planning, arboretums are important elements that contribute to improving the quality of urban environments and maintaining the balance of local ecosystems. This study aims to explore the flora diversity of the Samudra University Arboretum and analyze soil macronutrient content to assess the relationship between soil fertility levels and the vegetation growing on it. These findings are expected to be utilized as contextual learning media in biology education on environment, ecosystem and biodiversity materials that will foster understanding and awareness of the importance of protecting the environment, conservation, sustainable spatial management, introduction to the impacts of climate change. Observations were made using the inventory method, with data analysis focused on the content of macro nutrients in the soil taken from the arboretum land. The research location was at the Ocean University Arboretum; the research was conducted in June-November 2023. From the results of the study found 16 species with a total of 437 individuals. The most abundant species was Alysicarpus vaginalis with 92 individuals, followed by Ottochloa arnottiana with 55 individuals and Spermacoce sp. with 45 individuals. The species with the highest cover were Alysicarpus vaginalis and Digitaria sp., each at 220%, indicating significant dominance in the observed plant community. From the results of this study, it is recommended that schools, especially at the middle and high school levels, integrate visits and learning activities at the arboretum into the biology curriculum, because the arboretum can function as an outdoor natural laboratory that supports hands-on understanding of biodiversity, ecology, morphology, and plant conservation.

INTRODUCTION

Climate change has long been an important global issue caused by large-scale environmental changes (Xie et al., 2024). One of the main factors is land cover change, loss of shade diversity and greenhouse effect, and urbanization (Lopes et al., 2025; Rahmawaty et al., 2021a; Rahmawaty et al., 2021b; Giles-Corti et al., 2020). Plant diversity is currently experiencing a reduction in species resulting in associated declines in ecosystem services (Zhou et al., 2024; Suwardi et al., 2023). The potential ecological consequences of biodiversity loss have received widespread attention worldwide (Mi et al., 2022).

Currently about one-third of the 300,000-450,000 vascular plant species are facing extinction due to various anthropogenic activities (Diribsa, 2024; Dunn, 2017), including overharvesting, exploitation through agricultural practices and urbanization, environmental pollution, land use change, presence of invasive species, and global climate change (Prakash & Verma, 2022; Prakash, 2021; Prakash, 2017; Kumar & Verma, 2017; Ren et al., 2017). Arboretums are also one of the environments in which several fauna live, and the distribution patterns of plants in these communities are influenced by small-scale heterogeneity in habitat conditions (Xue et al., 2019).

The arboretum as an ecosystem has many benefits, such as enrichment and protection, so that it becomes a research centre (Affandi et al., 2020; BGCI, 2023; Chen & Sun, 2018). Arboretums also play a role in absorbing carbon and producing oxygen, alternative green open spaces, a place for various animals to find food, breed and shelter, and other benefits, thus the existence of arboretums can be further utilized to optimize their function as carbon stocks and CO2 absorption which has a significant impact in dealing with climate change and small-scale conservation (Ansari et al. 2024; Wulandari et al., 2020; Li et al., 2020a).

In urban areas, arboretums can be used as a solution to fulfill green open space, biodiversity conservation, climate change mitigation, and water catchment areas (Li et al., 2020b; Zhou et al., 2020; Dimobe et al., 2019a; Arico and Jayanthi, 2019; Jayanthi and Arico, 2017). However, suboptimal land management and spatial planning policies have the potential to have significant direct or indirect impacts on climate change and hotter urban temperatures (Ariani et al., 2021; Di Pietro et al., 2023).

The lack of integration between green space management and environmentally sustainable urban planning often leads to a decrease in air quality and an increase in the urban heat island (UHI) phenomenon, which worsens urban environmental conditions (Cetin, 2019; Chen et al., 2016; Dang et al., 2023; Kim and Brown, 2021; Tam et al., 2015). Recent research has demonstrated the role of tree canopy cover in moderating UHI impacts (Lopes et al., 2025). Ziter et al. (2019) found that even small urban green spaces can dramatically reduce temperatures. Interconnected networks of green spaces, both at the neighborhood and city level, provide a range of benefits such as energy savings, reduced air and noise pollution, stormwater management, reduced likelihood of flooding, improved urban quality, and enhanced livability (Gargiulo and Zucaro, 2023). These networks can also promote the protection and enhancement of undeveloped and neglected natural areas in spatial planning (Hiemstra et al. 2017).

Their findings showed that areas with significant tree canopy cover experienced temperature reductions of up to 4°C compared to areas with no vegetation. In this context, the presence of a well-managed arboretum provides benefits beyond aesthetic functions. Arboretums that feature biodiversity can serve as refuges for local and rare species, enriching urban ecosystems (Burch et al., 2018; Iwaniec and Cook, 2019). Additionally, the diversity of plant species can enhance air quality, mitigate pollution, and optimize rainwater absorption, ultimately contributing to a reduction in flood risk. Moreover, the arboretum also has great potential as a natural laboratory in biology education, where students can learn firsthand the concepts of ecology, plant adaptation, interaction of living things, and the importance of conservation in a contextual and applicable manner. The utilization of the arboretum as a sustainable green open space needs to be encouraged through proactive management policies, so that it not only contributes to climate change mitigation and improving environmental quality, but also to strengthening ecological literacy in biology education (Mursyid et al. 2025).

In this study, conservation has a very important role in biology education because it provides a holistic understanding of the relationship between living things and their environment (Sagoff, 2022). Through the conservation approach, students not only learn theoretical concepts about biodiversity, ecosystems, and life cycles, but are also invited to realize the importance of preserving nature for the sustainability of life (Cardinale et al. 2019). Biology education integrated with conservation values encourages the formation of environmental awareness, ecological responsibility, and critical thinking skills in dealing with environmental issues, such as climate change and habitat destruction (Akinwumi, 2023).

This research aims to explore the diversity of flora in the Samudra University Arboretum and analyze the macro nutrient content of the soil to examine the relationship between soil fertility and the vegetation growing on it. The findings are expected to be utilized as contextual learning media in biology education on environment, ecosystem, and biodiversity materials that will foster understanding and awareness of the importance of protecting the environment, conservation, sustainable spatial management, and introduction to the impacts of climate change.

METHODS

Study area

The research was conducted at Samudra University Arboretum with coordinates 4°26'56.8 "N 97°58'35.7" E which has an area of 1000 m2. This arboretum is a mini conservation area managed by the Faculty of Agriculture of Samudra University and has various types of native vegetation in it. The research was conducted from June to November 2023 (Figure 1).

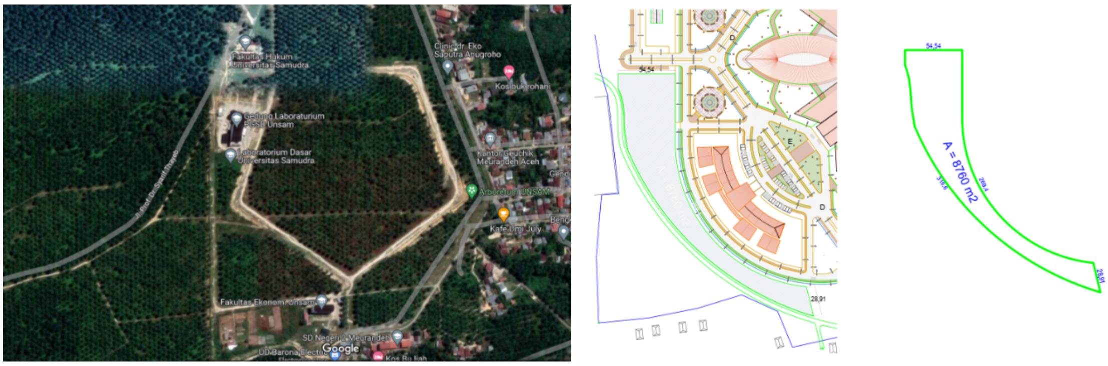


Figure 1. Map of Samudra University Arboretum, Aceh Province, Indonesia, as a research area

Procedures

Observations were made on the Arboretum land in the Samudra University area using the inventory method and 1x1 meter observation plots of 5 plots (Brambach, 2019). The selection of locations for soil sampling was carried out by purposive sampling by determining three observation points on each research object. Before sampling, the soil surface was cleaned of litter, grass, or other cover plants. Soil samples were taken at the tillage layer with a depth of 0-20 cm, then put in plastic and taped, considering that most nutrients are at this depth. This procedure was carried out three times in the observed field. Furthermore, on the arboretum land, soil physical and chemical factors were measured. Soil samples that have been collected from each research object are then analyzed to determine the content of macro nutrients, namely C, N, P, K, Mg, Na, Ca, and soil pH. Plants were then identified using the plant identification book Flora of the mountains of Java and internationally recognized plant identification websites such as powo.science.kew.org, indonesiaplants.org and gbif.org. For plant status monitoring, the website www.iucnredlist.org was used. In collecting vegetation data, all plants in the arboretum area were taken specimens and stored using newsprint and glass plastic and doused with 70% alcohol. Species composition was calculated based on the number of plant species found (Khoiri et al. 2023).

The results of this activity can be used as a biology learning module for grade X high school students, especially in environmental, ecosystem, and biodiversity materials. Through a local environment-based approach that is safer to access, students can learn directly about the importance of plants in maintaining the balance of ecosystems and the environment, as well as conservation values. By making the arboretum a natural laboratory, students not only understand biological theory, but are also trained to think critically, make scientific observations, and foster concern for the surrounding environment.

Data Analysis Techniques

In this study, data analysis focused on the content of macronutrients in soil taken from the arboretum land. Data were obtained through soil sampling at three observation points determined by purposive sampling at each research object. Samples were taken from the tillage layer with a depth of 0-20 cm, because this layer is considered to contain the highest nutrients. After the samples were collected, laboratory analysis was conducted to measure the content of macronutrients such as carbon (C), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sodium (Na), calcium (Ca), as well as soil pH values. In addition, it is important to consider broader ecological factors that affect soil health, such as organic matter content and microbial activity, which can also play an important role in soil fertility (Shiwakoti et al. 2019). In addition, measurements of soil physico-chemical factors were also taken to support the interpretation of the analytical results. The results obtained from the laboratory were then analyzed descriptively to determine the level of soil fertility at each observation point and used as a basis for assessing soil quality in the Samudra University arboretum area (Mpia et al., 2023; Fendorf, 2017).

RESULTS AND DISCUSSION

Characteristics of vegetation in the arboretum area

The results of the study found 16 species with a total of 437 individuals. The most abundant species was *Alysicarpus vaginalis* with 92 individuals, followed by *Ottochloa arnottiana* with 55 individuals and *Spermacoce sp.* with 45 individuals. Other species that are also quite abundant include *Axonopus compressus* (36 individuals), *Digitaria sp.* (33 individuals), *Phyllanthus urinaria* (28 individuals), and *Mimosa pudica* (21 individuals). In addition, there were also *Urena cf. lobata* (19 individuals), *Tylophora indica* (18 individuals), *Cyperus mindorensis* (15 individuals), *Lygodium microphyllum* and *Spermacoce exilis* with 13 individuals each. Other species recorded were *Steinsmia laxa* (12), *Elephantopus scaber*, *Grona triflora*, and *Melastoma malabathricum* with 7 individuals each, and *Clidemia hirta* (6 individuals). Species found in small numbers include *Cyperus sp.* and *Lindernia antipoda* with 3 individuals each, *Lindernia sp.* and *Psidium guajava* with 2 individuals each (Figure 3, Table 1).

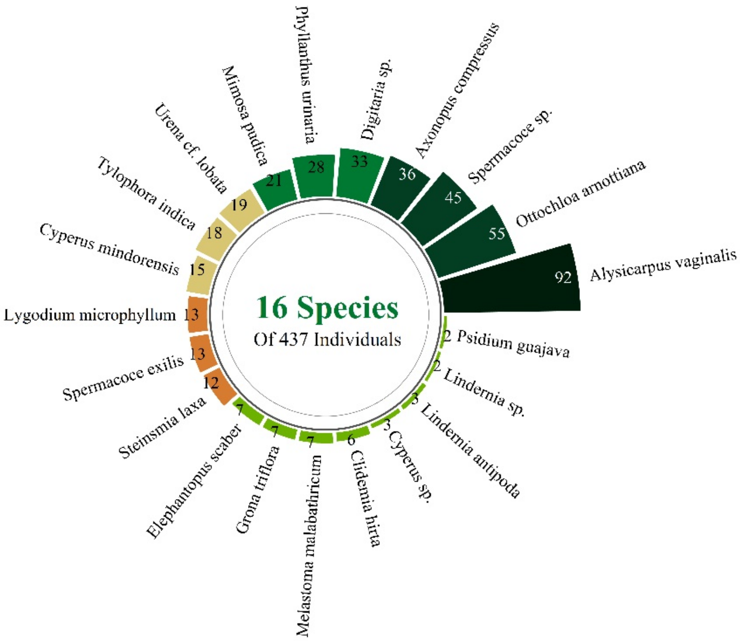


Figure 2. Inventory Species found in Samudra University Arboretum

The finding of 16 species with a total of 437 individuals in the arboretum area not only shows the richness of local biodiversity but also has important value in the context of education and conservation. This species inventory can be used as a contextual learning resource in environmental education, especially in understanding ecological dynamics, plant adaptation to environmental conditions, and the role of plants in maintaining ecosystem balance (Doup, 2018). In the world of education, especially in learning biology, these results can be used to strengthen students' understanding of biodiversity, interactions between living things and their environment, and other ecological concepts (Correia et al. 2020). This material can also be developed into project-based or inquiry-based learning media, such as making herbariums, observing plant morphology, and field studies in the arboretum environment. In addition, the arboretum as a research location has the potential to become a natural laboratory that supports educational conservation programs, such as making scientific plant name labels, observing vegetation growth, and practicing ecological restoration. Thus, the results of this study are not only scientifically important, but also strategic in supporting conservation-based education and increasing students' awareness of the importance of maintaining biodiversity (Sugiarto et al. 2023).

Species diversity in arboretum areas is significantly influenced by environmental conditions that favor the growth of certain plant species. Various studies highlight how these conditions shape species distribution and diversity, reflecting the ecological dynamics at play in an ecosystem. For example, the University of North Sumatra Arboretum houses as many as 50 plant species with a moderate diversity index, indicating the existence of selective environmental conditions that support the growth of certain plants, especially medicinal plants (Rahmawaty et al., 2019). Research by Wulandari et al. (2020) in the Riau University Arboretum showed that this arboretum has a complete vegetation composition in all strata, from seedlings to mature trees, with the number of seedling individuals reaching 349. The species diversity index in all strata was high, which has an important role in supporting the green campus program through its ecological function as a carbon sink and carbon dioxide store. Meanwhile, the Ruhande Arboretum recorded 28 genera and 844 individual plants, with species diversity influenced by forest regeneration history and environmental factors such as soil composition (Mugunga et al., 2022).

In addition, allelopathic effects of tree species also shape the vegetation structure in the arboretum. Research shows that coniferous tree species tend to inhibit vegetation growth to a greater extent than broadleaf species, indicating that soil pH and nutrient availability are critical environmental factors (Ito and Ito, 2022). The diversity found in arboreta emphasizes the importance of conservation efforts, as some species are endangered. Effective arboretum management can increase species richness as well as the ecological resilience of the area (Haastrup et al., 2022).

The decrease in the number of species found can be influenced by many factors, namely environmental conditions that are less favorable for vegetation growth, such as the availability of light, soil moisture, soil microbes, and low nutrient content (Bogati et al. 2022; Abdul Rahman et al. 2021; Siebielec et al. 2020; Lamaoui et al. 2018), ultimately damaging vital ecosystem services (Kashyap et al., 2018; Singh et al., 2023). Other studies have shown that environmental factors such as nutrient availability, light and soil moisture play an important role in shaping plant community dynamics and influencing species richness levels (Harefa et al., 2025; Noor et al., 2021). This phenomenon was noted in a study in alpine meadows and the Burgundy region of France, which showed a 13% decrease in species richness as the nutritional preferences of the plant community changed over time (Burón et al., 2024). Soil moisture also influences plant diversity, as its interaction with nutrient availability can create conditions that favor only certain species, leading to a decrease in biodiversity across different habitat types (Höckendorff et al., 2021). In addition, anthropogenic activities such as vegetation pruning, land clearing, and arboretum arrangement also have the potential to disrupt the natural habitat of plants (Dar et al. 2022).

The diversity of species found in the arboretum reflects the selective influence of environmental conditions on certain plant species. This indicates that both areas with open and closed canopy cover have a tendency to favor the dominance of certain species. In particular, areas with open canopy cover are more likely to allow the growth of shade intolerant species, which show adaptation to high light intensity and typical microclimate conditions (Sutedjo & Warsudi, 2017; Rohmadi et al., 2018).

Vegetation cover in the Arboretum area

The species with the highest cover were *Alysicarpus vaginalis* and *Digitaria sp*., each at 220%, indicating significant dominance in the observed plant community. Next, *Ottochloa arnottiana* had 202% cover, followed by *Axonopus compressus* and *Phyllanthus urinaria* which had 155% cover each. *Lygodium microphyllum* showed a cover of 95%, while *Spermacoce exilis* had a cover of 85%. Other species such as *Clidemia hirta* and *Spermacoce sp.* covered an area of 75% each, followed by *Tylophora indica* and *Urena cf. lobata* with 65% cover. *Steinsmia laxa*, *Cyperus mindorensis*, and *Cyperus sp.* showed cover between 45% to 49% each. Species with lower cover include *Grona triflora* and *Mimosa pudica* (42%), *Elephantopus scaber* (40%), and *Melastoma malabathricum* (35%). Meanwhile, *Lindernia antipoda* and *Lindernia sp.* had only 5% cover each, and *Psidium guajava* was the species with the lowest cover of 2% (Figure 3, Table 1).

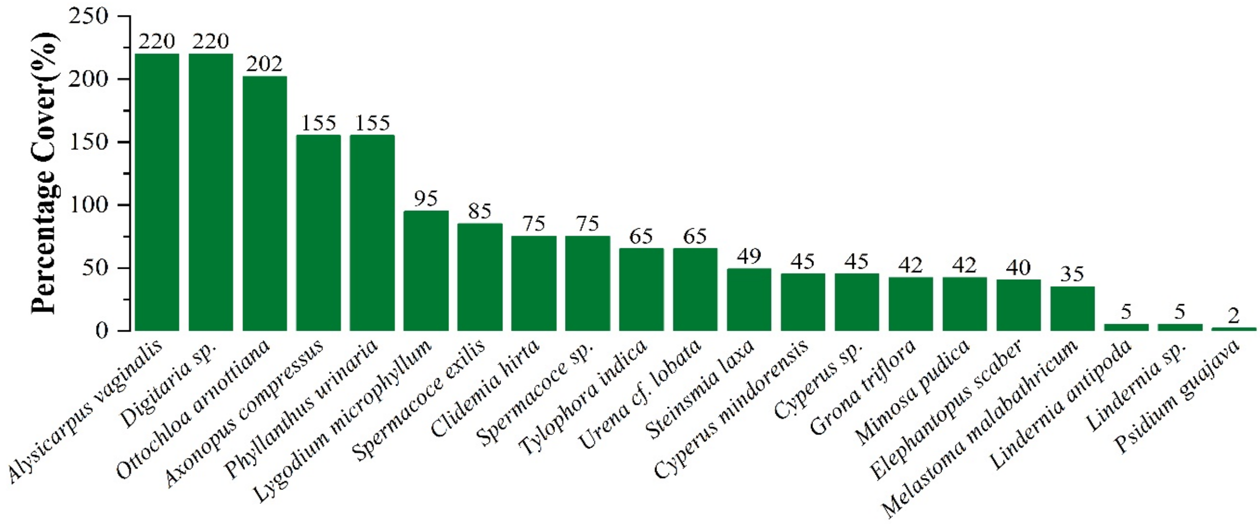


Figure 3. Percentage Cover of Ocean University Arboretum Flora

Findings on vegetation cover reflect the dominance distribution and ecological adaptation of species in the arboretum environment. This vegetation cover serves as an important indicator in assessing ecosystem health and the effectiveness of conservation functions in planned green areas. In the context of education, particularly biology education, these cover data can be utilized as real learning materials to introduce ecological concepts such as community structure, species dominance, plant adaptation to microclimate, and interspecies relationships (Puspitasari et al., 2023). The arboretum, with its varied vegetation cover, can serve as a natural laboratory that supports observation-based learning activities, data collection, and in-depth ecological analysis. In addition, this information is highly relevant in conservation education, as it helps students understand the importance of maintaining vegetation diversity to sustain ecosystem services such as carbon sequestration, microclimate regulation, habitat provision, and biodiversity protection (Pietrzak-Zawadka & Zawadka, 2018)

Arboretum vegetation cover serves as a vital indicator of ecological characteristics and conservation functions in planned green areas, reflecting the health and diversity of plant species that are important for maintaining ecological balance, providing ecosystem services such as air and water purification, carbon sequestration, providing habitat for neighbourhood animals, and improving the quality of life in urban areas through recreational space and aesthetic value (Wysocki, 2019), while moderating the local climate by influencing temperature and humidity that are crucial in urban environments (Cheng et al., 2019). In terms of supporting services, arboretums can improve soil fertility and soil organic carbon storage (Chen et al. 2018; Lange et al. 2015; Eisenhauer et al. 2018).

Vegetation in arboretums generally consists of various species of trees, shrubs, shrubs, and understory plants that are collected for educational, research, preservation, herbal medicine, and aesthetic values (Muhlisin et al. 2021; Palliwoda et al. 2017; Lacy and Shackleton, 2017). The composition of vegetation cover in the arboretum is strongly influenced by microclimatic conditions, soil type, topography, and biological interactions between species (Solfiyeni et al. 2022). Dense tree canopy cover will create more humid and shady environmental conditions, so that only shade-tolerant species are able to thrive. Species that have a high tolerance to shade generally direct more biomass to the leaves and branches, in an effort to maximize light absorption and support optimal growth in low light conditions (Ntawuhiganayo et al., 2020). Dense vegetation plays an important role in increasing soil moisture retention, thus creating more stable and favorable microclimate conditions for understory species. This more humid environment significantly reduces drought stress, allowing herbaceous species to maintain better water status and improve photosynthetic performance compared to plants growing in open areas (Urban and Lessambo, 2022; Siddiq et al. 2019).

In contrast, areas with open cover tend to be inhabited by light-intolerant species that are more common in newly cleared land (Mariton et al., 2022; Nomura et al., 2019; Seymoure et al., 2023). The diversity of canopy structures also creates complex vertical layers of vegetation, supporting high biodiversity, especially for supporting fauna such as birds, insects and small mammals. These vegetation cover patterns reflect not only natural ecological conditions, but also the influence of human management and planning (Solfiyeni et al, 2024).

Soil Fertility Level in the Arboretum area

The findings of plant species inventories at research sites, such as arboretums, not only provide an overview of the richness of biodiversity, but also open up great opportunities for environmental education and conservation. The diversity of plant species found reflects the complex ecological interactions between soil and vegetation, as explained by Gavrilescu (2021) that soil is the main nutrient and water provider for plants, while plants influence soil quality through root structure and organic matter inputs (Blume et al., 2016).

In the context of education, the results of this inventory can be used as a contextual learning resource at various levels, especially in the fields of biology, ecology and geography. Students can learn firsthand how certain plant species adapt to local soil characteristics, and how plants play a role in improving soil structure and fertility. Using the arboretum as a natural laboratory will strengthen students' observation, classification and analysis skills, in line with the principles of inquiry-based learning and environment-based learning. In terms of conservation, the presence of various inventoried species can be used as a basis for developing local conservation strategies, such as planting endemic or rare species in similar locations, or developing conservation-based educational areas. By understanding the mutual interactions between plants and soils (Creamer et al., 2022; Lehmann et al., 2020), communities and learners can be involved in science-based ecosystem restoration, sustainable soil management and biodiversity conservation programs.Furthermore, the use of soil quality indicators such as those described by Bünemann et al. (2018) and Norris et al. (2020) opens up opportunities for STEM (Science, Technology, Engineering, and Mathematics) based curriculum development, where students not only learn plant species, but also take physical, chemical, and biological measurements of soil, and quantitatively analyze the data to assess the viability and fertility of an ecosystem (Table 2).

Table 1
Species found in Samudra University Arboretum, Aceh Province, Indonesia.

Location	Plot Number	Species Name	Number of species	Collection number	Cover (%)	Plot Name	Number
Arboretum	1	*Mimosa pudica*	6	WRA 047	40	A1	1
	1	*Phyllanthus urinaria*	4	WRA 048	5	A1	2
	1	*Grona triflora*	9	WRA 049	70	A1	3
	1	*Lindernia sp.*	3	WRA 050	5	A1	4
	1	*Steinsmia laxa*	13	WRA 051	60	A1	5
	1	*Ottochloa arnottiana*	9	WRA 052	80	A1	6
	1	*Digitaria sp.*	17	WRA 053	90	A1	7
	1	*Spermacoce sp.*	1	WRA 054	2	A1	8
	1	*Lindernia antipoda*	3	-	5	A1	9
	1	*Spermacoce exilis*	2	-	5	A1	10
	1	*Axonopus compressus*	55	WRA 057	95	A1	11
	2	*Mimosa pudica*	10	-	60	A2	1
	2	*Tylophora indica*	2	WRA 055	5	A2	2
	2	*Grona triflora*	14	-	80	A2	3
	2	*Ottochloa arnottiana*	20	-	90	A2	4
	2	*Steinsmia laxa*	6	-	75	A2	5
	2	*Digitaria sp.*	13	-	85	A2	6
	2	*Axonopus compressus*	45	-	75	A2	7
	3	*Mimosa pudica*	6	-	40	A3	1
	3	*Steinsmia laxa*	3	-	45	A3	2
	3	*Axonopus compresus*	18	-	65	A3	3
	3	*Digitaria sp.*	15	-	45	A3	4
	3	*Alysicarpus vaginalis*	7	WRA 061	35	A3	5
	3	*Ottochloa arnottiana*	17	-	35	A3	6
	4	*Melastoma malabathricum*	7	WRA 062	40	A4	1
	4	*Ottochloa arnottiana*	13	-	95	A4	2
	4	*Alysicarpus vaginalis*	21	-	25	A4	3

	4	*Clidemia hirta*	1	WRA 063	20	A4	4
	4	*Phyllanthus urinaria*	4	-	2	A4	5
	4	*Axonopus compressus*	5	-	8	A4	6
	4	*Urena cf. lobata*	2	WRA 064	2	A4	7
	5	*Psidium guajava*	1	-	1	A5	1
	5	*Lygodium microphyllum*	3	-	4	A5	2
	5	*Cyperus sp.*	1	-	1	A5	3
	5	*Ottochloa arnottiana*	17	-	97	A5	4
	5	*Alysicarpus vaginalis*	19	-	65	A5	5
	5	*Axonopus compressus*	8	-	35	A5	6
	5	*Elephantopus scaber*	7	-	7	A5	7
	5	*Cyperus mindorensis*	3	-	5	A5	8
Basic Laboratory	1	*Mimosa pudica*	11	-	35	L1	1
	1	*Steinsmia laxa*	4	-	30	L1	2
	1	*Ottochloa arnottiana*	8	-	65	L1	3
	1	*Grona triflora*	32	-	85	L1	4
	1	*Crotalaria pallida*	1	-	1	L1	5
	1	*Melastoma malabathricum*	2	-	3	L1	6
	1	*Axonopus compressus*	7	-	35	L1	7
	1	*Calopogonium mucunoides*	2	WRA 068	3	L1	8
	1	*Paspalum conjugatum*	1	WRA 069	7	L1	9
	2	*Mimosa pudica*	23	-	60	L2	1
	2	*Melastoma malabathricum*	12	-	45	L2	2
	2	*Ottochloa arnottiana*	23	-	70	L2	3
	2	*Axonopus compressus*	10	-	35	L2	4
	2	*Chromolaena odorata*	1	-	2	L2	5
	2	*Steinsmia laxa*	17	-	50	L2	6
	3	*Melastoma malabathricum*	7	-	25	L3	1
	3	*Centrosema pubescens*	9	WRA 071	25	L3	2
	3	*Axonopus compressus*	10	-	45	L3	3
	3	*Chrysopogon aciculatus*	7	WRA 064	20	L3	4

3	*Grona triflora*	36	-	85	L3	5
3	*Digitaria sp.*	13	WRA 072	15	L3	6
3	*Fimbristylis sp.*	1	WRA 073	1	L3	7
3	*Mimosa pudica*	13	-	25	L3	8
4	*Axonopus compressus*	74	-	95	L4	1
4	*Steinsmia laxa*	11	-	35	L4	2
4	*Mimosa pudica*	4	-	15	L4	3
4	*Ottochloa arnottiana*	16	-	40	L4	4
4	*Grona triflora*	13	-	30	L4	5
4	*Elephantopus scaber*	1	-	1.5	L4	6
5	*Mimosa pudica*	21	-	30	L5	1
5	*Ottochloa arnottiana*	1	-	1	L5	2
5	*Fimbristylis sp.*	1	WRA 073	1	L5	3
5	*Axonopus compressus*	24	-	95	L5	4
5	*Grona triflora*	28	-	70	L5	5
5	*Uraria lagopodioides*	3	-	15	L5	6

Notes: Ecological data in Samudra University Arboretum area

Table 2
Chemical Physics Analysis of Samudra University Arboretum soil, Aceh Province, Indonesia.

Type of Analysis	Value	Quality Standard Value (MOA, 2009)
C-Organic (%)	1,29	Low
N-Total (%)	0,11	Low
P-Bray I (ppm P)	6,85	Very Low
K-dd (me/100g)	0,15	Very Low
pH	5,19	Acid
Na (me/100mg)	0,30	Normal
Ca (me/100mg)	2,36	Normal
Mg (me/100mg)	0,57	High

Note: Chemical Physics Analysis Data (2023)

The results of the analysis of soil chemical properties showed that the content of C-Organic (1.29%) and N-Total (0.11%) was in the low category, while phosphorus levels (P-Bray I) of 6.85 ppm and exchangeable potassium (K-dd) of 0.15 me/100g were classified as very low based on MOA 2009. The soil pH value of 5.19 indicates acidic conditions. Meanwhile, sodium (Na) and calcium (Ca) contents of 0.30 and 2.36 me/100mg respectively, were in the normal category, and magnesium (Mg) content of 0.57 me/100mg was categorized as high. These results reflect poor soil conditions and require nutrient improvement and liming to increase productivity (Powlson, 2020).

From the data above, it can be seen that the topsoil is a layer that is vulnerable to change. Topsoil is highly susceptible to changes caused by a variety of external factors, including weather conditions, agricultural practices, and climate change due to human activity. This layer, often referred to as topsoil, plays an important role in plant growth and overall soil health. Its vulnerability to change is influenced by several key aspects. Weather factors such as rainfall and temperature fluctuations significantly affect soil structure, especially during spring thaws and heavy rains (Bryk et al., 2017). Increased rainfall can reduce soil moisture content and air permeability, which in turn negatively affects crop conditions (Bryk et al., 2017). In addition, agricultural practices such as the use of heavy machinery in tillage can cause mechanical deformations that increase soil density and reduce pore size, which is important for water retention (Kokieva et al., 2021). Compaction due to agricultural machinery also impacts soil structure, affecting aeration and the ability of soil to store water (Zhang & He, 2024). On the other hand, human-induced climate change accelerates soil degradation through erosion, organic matter loss and pollution, further threatening topsoil integrity (Meyer-Drawe, 2022).

Arboretum's Link to Biology Learning

In learning biology, the arboretum has great potential as a real and applicable educational tool. Arboretum is a plant conservation area specifically designed to support educational, research, conservation, and scientific recreation activities (Muhlisin et al., 2021). In the context of biology education, arboretums can be used as outdoor natural laboratories that allow students and college students to learn directly about biodiversity, plant morphology, classification, adaptation, and plant ecology. Knowledge of arboretums is considered important in providing understanding to the public to participate in plant conservation (Ram, 2023; Lepczyk et al., 2017; Smith et al., 2018). This is in line with the learning objectives of biology which not only emphasize on understanding concepts but also strengthening ecological awareness and conservation values. As a conservation area, the arboretum can be a place of direct observation for students to get to know endangered or endemic plant species. This allows for biology learning based on field data and scientific approaches, where students are trained to conduct species identification, adaptation analysis, and simple ecological studies. The arboretum also provides plant collections from various ecosystems, which serve as concrete teaching materials to enrich the understanding of concepts such as genetic diversity, species, and ecosystems (Almeida et al., 2024; Fay and Christenhusz, 2016).

In biology learning, this can support the application of inquiry-based learning, project-based learning, and problem-based learning methods by raising real conservation issues as project topics. Furthermore, the existence of an arboretum enables the strengthening of students' science literacy in ecology and environmental conservation topics through a hands-on and evidence-based approach (Smith, 2016; Kovács et al., 2021).

The arboretum is also an interdisciplinary educational medium that integrates biology with geography, sociology, and environmental education, while encouraging student involvement in real actions such as conservation campaigns and ecosystem restoration. Through its strategic role in providing seed sources, genetic preservation, and conservation education, the arboretum also supports the implementation of a biology curriculum that is adaptive to global environmental issues (Wambugu et al., 2023; Rahmawaty et al., 2020; Oldfield et al., 2019). Arboretums are not only a place to learn about plants, but also a means of building students' environmental awareness and ecological responsibility. Thus, arboretum development needs to be seen not only as a conservation effort, but also as an integral part of contextual, meaningful, and future-oriented biology learning (Gargiulo et al., 2023; Hiemstra et al., 2017).

Survey Results Recommendations on Conservation Education in Biology

From the results of this study, it is recommended that schools, especially at the middle and high school levels, integrate visits and learning activities in the arboretum into the biology curriculum, because the arboretum can function as an outdoor natural laboratory that supports direct understanding of biodiversity, ecology, morphology, and plant conservation. To support this integration, educational institutions and biology teachers need to develop contextual learning modules based on observation and exploration in the arboretum with an inquiry-based learning or project-based learning approach, addressing themes such as rare species conservation, plant adaptation, and ecosystem restoration. Teachers also need to receive training on utilizing the arboretum as a learning resource, including species identification skills, preparation of student conservation projects, and integration of environmental literacy in learning. Collaboration between schools and arboretum managers is essential to optimally facilitate student learning, field trips and research activities, which can also include internships or student volunteering programs in real conservation activities. Schools need to encourage students to conduct conservation campaigns, popular science writing, and ecological projects based on data from visits to the arboretum, so as to strengthen science literacy and shape the character of environmental care. Local governments and education offices are expected to provide support in the form of facilities, funding, educational visit policies, and recognition of arboretum-based learning as part of the formal education process. In addition, project-based assessment in ecology and conservation topics also needs to be improved, with the arboretum as a location for data collection and project implementation integrated with biology curricular assessment.

CONCLUSION

Arboretums play an important role in biology lessons for students as a hands-on learning medium that allows them to understand the concept of ecosystem restoration through the provision of quality seed sources that are suitable for local ecological conditions. By observing plant collections in the arboretum, students can learn cultivation techniques, vegetative propagation, and species adaptation to various environmental conditions in a real and contextualized manner. In addition, the arboretum provides a platform for students to participate in conservation-oriented educational and recreational activities, thus fostering ecological awareness and a caring attitude towards the environment from an early age. Through this experience, students not only master biological theory, but also develop practical skills and social responsibility in biodiversity conservation. Therefore, the development and preservation of arboretums should be an important part of biology education programs in schools as an effort to support the formation of students' conservation knowledge, skills and attitudes for a sustainable future.

ACKNOWLEDGMENT

The research team would like to thank the Institute for Research, Community Service and Quality Assurance of Universitas Samudra for the funding provided through the Lector research scheme with Number 650/UN54.6/PG/2023 for the 2023 fiscal year.

REFERENCES

Abdul Rahman, N. S. N., Abdul Hamid, N. W., & Nadarajah, K. (2021). Effects of abiotic stress on soil microbiome. *International Journal of Molecular Sciences*, 22, 9036. https://doi.org/10.3390/ijms22169036

Affandi, S. D., Halimatussadiah, A., & Asrofani, F. W. (2020). Visitors' preferences on the characteristics of Bogor Botanical Gardens. *Sustainability*, *12*(22), 9489. https://doi.org/10.3390/su12229489

Akinwumi, I. O. (2023). Biology education: A panacea to global environmental challenges. *European Journal of Training and Development Studies*, *10*(2), 44–56. https://doi.org/10.37745/ejtds.2014/vol10n24456

Almeida, T. M. H. d., Coelho, M. A. N., & Peixoto, A. L. (2024). Rio de Janeiro Botanical Garden: Biodiversity conservation in a tropical arboretum. *Journal of Zoological and Botanical Gardens*, *5*(3), 378–394. https://doi.org/10.3390/jzbg5030026

Ansari, M. H., Bijani, M., Abbasi, E., & Goli, I. (2024). Determinants of local community participation in forest fire management in the northern Iran. *International Journal of Disaster Risk Reduction,* 107, 104478. https://doi.org/10.1016/j.ijdrr.2024.104478

Ariani, N. M., Wijaya, M. I. H., & Priambudi, B. N. (2021). Understanding Spatial Planning Policies in Responding to Urban Heat Island Using GIS Analysis in The Kendal Industrial Area. 887(1), 012021. https://doi.org/10.1088/1755-1315/887/1/012021

Arico, Z., & Jayanthi, S. (2024). Forest carbon storage potential of Gunung Leuser National Park Tenggulun Resort as climate change mitigation effort. Elkawnie: *Journal of Islamic Science and Technology,* 2(2), 143–152. https://doi.org/10.22373/ekw.v2i2.2660

Baveye, P. C. (2021). Soil health at a crossroad. *Soil Use and Management*, *37*(2), 215–219. https://doi.org/10.1111/sum.12703

BGCI (Botanic Gardens Conservation International), (2023). About BGCI database. *Available online*: https://www.bgci.org/about/botanic-gardens-and-plant-conservation/

Blume, H.-P., Brümmer, G. W., Fleige, H., Horn, R., Kandeler, E., Kögel-Knabner, I., Kretzschmar, R., Stahr, K., & Wilke, B.-M. (2016). Soil-plant relations. In Soils as a Key Component of the Critical Zone (pp. 409–484). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-30942-7_9

Bogati, K., & Walczak, M. (2022). The impact of drought stress on soil microbial community, enzyme activities and plants. Agronomy, 12, 189. https://doi.org/10.3390/agronomy12010189

Brambach, F. (2019). Diversity, composition, and biogeography of trees in tropical mountain forests of Sulawesi, Indonesia (Doctoral dissertation). Gottingen University.

Bryk, M., Kołodziej, B., Słowińska-Jurkiewicz, A., & Jaroszuk-Sierocińska, M. (2017). Evaluation of soil structure and physical properties affected by weather conditions in the fall-cold-semi-season. *Soil and Tillage Research*, 170, 66–76. https://doi.org/10.1016/j.still.2017.03.004

Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T. W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J. W., & Brussaard, L. (2018). Soil quality – A critical review. *Soil Biology and Biochemistry*, 120, 105–125. https://doi.org/10.1016/j.soilbio.2018.01.030

Burch, S., Hughes, S., Romero-Lankao, P., Schroeder, H., Elmqvist, T., Bai, X., Frantzeskaki, N., Griffith, C., Maddox, D., & McPhearson, T. (2018). Governing urban sustainability transformations. In T. Elmqvist, X. Bai, N. Frantzeskaki, C. Griffith, D. Maddox, & T. McPhearson (Eds.), The Urban Planet: Knowledge towards Sustainable Cities (pp. 303–326). Cambridge University Press.

Burón, M., Porcher, E., Fédoroff, É., Berrod, L., Vallet, J., Bardet, O., Martin, G., & Machon, N. (2024). Rapid declines in species diversity and occurrence of common plant species are related to nutrient availability and soil moisture in open habitats. *Journal of Vegetation Science*, *35*(6). https://doi.org/10.1111/jvs.13316

Cardinale, B. J., Primack, R. B., & Murdoch, J. D. (2019). Conservation biology. Oxford University Press. https://doi.org/10.1093/hesc/9781605357140.001.0001

Cetin, M., 2019. The effect of urban planning on urban formations determining bioclimatic comfort area's effect using satellitia imagines on air quality: a case study of Bursa city. Air Qual. *Atmos. Health* 12, 1237–1249. https://doi.org/10.1007/ s11869-019-00742-4

Chaubey, O. P., Sharma, A., & Krishnamurthy, G. (2015). Ex-situ conservation of indigenous, threatened and ethno-medicinal diversity of forest species. *International Journal of Bio-Science and Bio-Technology*, *7*(3), 9–22. https://doi.org/10.14257/IJBSBT.2015.7.3.02

Chen, G., & Sun, W. (2018). The role of botanical gardens in scientific research, conservation, and citizen science. Plant Diversity, 40, 181–188. https://doi.org/10.1016/j.pld.2018.07.006

Chen, S., Wang, W., Xu, W., Wang, Y., Wan, H., Chen, D., Tang, Z., Tang, X., Zhou, G., Xie, Z., Zhou, D., Shangguan, Z., Huang, J., He, J. S., Wang, Y., Sheng, J., Tang, L., Li, X., Dong, M., ... Bai, Y. (2018).

Plant diversity enhances productivity and soil carbon storage. *Proceedings of the National Academy of Sciences*, *115*(16), 4027–4032. https://doi.org/10.1073/pnas.1700298114

Cheng, L., Zhang, Y., & Sun, H. (2019). Vegetation cover change and relative contributions of associated driving factors in the ecological conservation and development zone of Beijing, China. *Polish Journal of Environmental Studies*, *29*(1), 53–65. https://doi.org/10.15244/pjoes/102368

Correia, D. B., Soares, T. R. C., Santos, L. G. dos, Landim, H. S., Teixeira, P. H. R., Nascimento, C. A. do, Fernandes, N. de S., Lima, E. E., Oliveira, B. A. de, Cruz, G. V., Pereira, C., Freitas, L. C. de, Amaro, B. B. D. F., Lima, L. A. de, Silva, J. R. de L. S., Cordeiro, G. A. da S., Cordeiro, M. L. A., Oliveira, A. H. de, Silva, L. A. M. da, & Torres, C. M. G. (2020). A educação ambiental e sua importância na conservação de espécies ameaçadas de extinção. Research, *Society and Development*, *9*(12). https://doi.org/10.33448/rsd-v9i12.11416

Creamer, R. E., Barel, J. M., Bongiorno, G., & Zwetsloot, M. J. (2022). The life of soils: Integrating the who and how of multifunctionality. Soil Biology and Biochemistry, 166, 108561. https://doi.org/10.1016/j.soilbio.2022.108561

Dang, T.T., Oanh, T.T.K., Thanh, H.L., Nguyen, T.N., 2023. Impacts of foreign direct investment on economic development: does institutional quality matter? *Econ. Sociol. J.* 7 (6). https://doi.org/10.28991/ESJ-2023-07-06-05

Dar, S. A., Nabi, M., Dar, S. A., & Ahmad, W. S. (2022). Influence of anthropogenic activities on the diversity of forest ecosystems. In Towards sustainable natural resources: Monitoring and managing ecosystem biodiversity (pp. 33-49). *Cham: Springer International Publishing*

Di Pietro, G., Marziali, E., Montaldi, C., & Zullo, F. (2023). Land Surface Temperature and Urban Policies: The Ferrara City Case Study. *Sustainability,* 15(24), 16825. https://doi.org/10.3390/su152416825

Dimobe, K., Gessner, U., Ouédraogo, K., & Thiombiano, A. (2022). Trends and drivers of land use/cover change in W National Park in Burkina Faso. *Environmental Development,* 44, 100768. https://doi.org/10.1016/j.envdev.2022.100768

Diribsa, G. C. (2024). The assessment of the role of parks and botanical gardens in Ethiopia. Preprints. https://doi.org/10.20944/preprints202401.1068.v1

Doup, M. L. (2018). Using an outdoor activity on local plant biodiversity to teach conservation ecology and promote environmentally responsible behaviors. *American Biology Teacher*, *80*(5), 359–364. https://doi.org/10.1525/abt.2018.80.5.359

Drobnik, T., Greiner, L., Keller, A., & Grêt-Regamey, A. (2018). Soil quality indicators – From soil functions to ecosystem services. *Ecological Indicators*, *94*, 151–169. https://doi.org/10.1016/j.ecolind.2018.06.052

Dunn, C. P. (2017). Biological and cultural diversity in the context of botanic garden conservation strategies. *Plant Diversity*, *39*(6), 396–401. https://doi.org/10.1016/j.pld.2017.10.003

Eisenhauer, N., Hines, J., Isbell, F., van der Plas, F., Hobbie, S. E., Kazanski, C. E., Lehmann, A., Liu, M., Lochner, A., Rillig, M. C., Vogel, A., Worm, K., & Reich, P. B. (2018). Plant diversity maintains multiple soil functions in future environments. eLife, 7, e41228. https://doi.org/10.7554/eLife.41228

Esparza Olguín, L. G., Martínez, A. M., Hernández García, G., & Martínez Romero, E. (2020). Jardín botánico y arboretum: Estrategias de conservación forestal en paisajes antropizados del trópico mexicano. *Revista Mexicana de Ciencias Forestales*, *11*(60), 50–77. https://doi.org/10.29298/rmcf.v11i60.724

Farhat, N., Elkhouni, A., Zorrig, W., Smaoui, A., Abdelly, C., & Rabhi, M. (2016). Effects of magnesium deficiency on photosynthesis and carbohydrate partitioning. *Acta Physiologiae Plantarum*, *38*(6), 145. https://doi.org/10.1007/s11738-016-2165-z

Fay, M. F., & Christenhusz, M. J. M. (2016). Plant conservation and botanic gardens. *Royal Botanic Gardens*, 1–15. https://doi.org/10.1002/9780470015902.a0023748

Fendorf, S. (2017). Soils. Soils: An Open Access Journal, 1(1), 7. https://doi.org/10.3390/soils1010007

Gargiulo, C., & Zucaro, F. (2023). A method proposal to adapt urban open-built and green spaces to climate change. *Sustainability*, *15*(10), 8111. https://doi.org/10.3390/su15108111

Gavrilescu, M. (2021). Water, soil, and plants interactions in a threatened environment. Water, 13(19), 2746. https://doi.org/10.3390/w13192746

Giles-Corti, B., Moudon, A. V., Lowe, M., Adlakha, D., Cerin, E., Boeing, G., Higgs, C., Arundel, J., Liu, S., Hinckson, E., Salvo, D., Adams, M. A., Badland, H., Florindo, A. A., Gebel, K., Hunter, R. F., Mitáš, J., Oyeyemi, A. L., Puig-Ribera, A., Queralt, A., Santos, M. P., Schipperijn, J., Stevenson, M., Van Dyck, D., Vich, G., & Sallis, J. F. (2022). Creating healthy and sustainable cities: What gets measured, gets done. *The Lancet Global Health,* 10(6), e782–e785. https://doi.org/10.1016/S2214-109X(22)00070-5

Haastrup, N. O., Bolaji, O. W., Narudeen, T. A., Babalola, Y. O., Jeminiwa, O. R., Oladipupo-Alade, E. O., Oyedele, M., Lawal, M. O., & Bolaji, O. O. (2022). Description and composition of tree species in a tertiary institution agricultural faculty arboretum, Ibadan, South-West Nigeria. *Journal of Applied Science and Environmental Management*, *26*(6), 1163–1172. https://doi.org/10.4314/jasem.v26i6.25

Harefa, D. N., Warwu, S. S., Waruwu, D. R. Y., & Ndraha, A. B. (2025). The impact of planting distance on nutrient and light competition in spinach plants (Amaranthus spp.). *Flora: Jurnal Kajian Ilmu Pertanian dan Perkebunan*, *2*(1), 168–176. https://doi.org/10.62951/flora.v2i1.262

Hiemstra, J. A., Saaroni, H., & Amorim, J. H. (2017). The urban heat island: Thermal comfort and the role of urban greening. In D. Pearlmutter, C. Calfapietra, R. Samson, L. O'Brien, S. K. Ostoić, G. Sanesi, & R. A. del Amo (Eds.), The urban forest: Cultivating green infrastructure for people and the environment (pp. 7–19). Springer. https://doi.org/10.1007/978-3-319-50280-9_2

Höckendorff, S., Peintinger, M., Fiedler, F., Stift, M., & van Kleunen, M. (2021). Declines in occurrence of plants characteristic for a nutrient-poor meadow habitat are partly explained by their responses to nutrient addition and competition. *Ecology and Evolution*, *11*(9), 4058–4070. https://doi.org/10.1002/ece3.7306

Imaningsih, W., Susilawati, I. O., Fadillah, M. R., Saroh, I., & Maulida, S. (2021). Pengelolaan jasa ekosistem hutan riparian permaculture. UrbanGreen Central Media.Phoebus, P., Rutledge, M. L., & Sadler, K. C. (2018). Meeting the giants in our midst: Developing an interactive online arboretum guide to promote ecological literacy. *American Biology Teacher*, *80*(8), 572–576. https://doi.org/10.1525/abt.2018.80.8.572

Ito, K., & Ito, M. (2022). Variation in allelopathic influence among wide range of tree species (pp. 285–295). https://doi.org/10.1201/9780367813673-24

Iwaniec, D. M., Cook, E. M., Barbosa, O., & Grimm, N. B. (2019). The framing of urban sustainability transformations. *Sustainability*, *11*, 573. https://doi.org/10.3390/su11030573

Janzen, H. H., Janzen, D. W., & Gregorich, E. G. (2021). The 'soil health' metaphor: Illuminating or illusory? Soil Biology and Biochemistry, 108167. https://doi.org/10.1016/j.soilbio.2021.108167

Jayanthi, S., & Arico, Z. (2017). Effect of vegetation density on forest litter productivity of Gunung Leuser National Park. Elkawnie: *Journal of Islamic Science and Technology,* 3(2). https://doi.org/10.22373/ekw.v3i2.1888

Kashyap, P.L., Srivastava, A.K., Tiwari, S.P., Kumar, S., Gupta, S., Sharma, D., Gupta, M., 2018. Microbes for Climate Resilient Agriculture, First Edition. Edited Climate Change Impact On Plant Diseases: *Opinion, Trends And Mitigation Strategies* 41–56

Khoiri, I., Sadjati, E., & Lestari, I. (2023). Identify the types of white-sapped trees in the Lancang University Arboretum. *Prosiding Seminar Nasional S.R.I*, *1*(1), 161–175. https://doi.org/10.31938/psnsri.v1i1.539

Kim, S.W., Brown, R.D., 2021. Urban heat island (UHI) intensity and magnitude estimations: a systematic literature review. *Sci. Total Environ.* 779, 146389. https://doi.org/10.1016/j.scitotenv.2021.146389

Kokieva, G. E., Sokolova, V. A., Maksimovich, K. Y., Dzjasheev, A.-M. S., Ivanov, A. A., Golubev, V. V., & Melbert, A. A. (2021). Seedbed preparation of the upper soil layer. *IOP Conference Series: Earth and Environmental Science*, *848*(1), 012172. https://doi.org/10.1088/1755-1315/848/1/012172

Kovács, Z., Csergő, A. M., Csontos, P., & Höhn, M. (2021). Ex situ conservation in botanical gardens – Challenges and scientific potential preserving plant biodiversity. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *49*(2), 12334. https://doi.org/10.15835/nbha49212334

Kumar, A., & Verma, A. K. (2017). Biodiversity loss and its ecological impact in India. *International Journal on Biological Sciences*, *8*(2), 156–160. https://moocs.mkclibrary.ac.in/pluginfile.php/11320/mod_resource/content/1/IDC-Unit-3-Biodiversity%20loss-PGS.pdf

Lacy, P. D., & Shackleton, C. (2017). Aesthetic and spiritual ecosystem services provided by urban sacred sites. *Sustainability*, *9*, 1628. https://doi.org/10.3390/su9091628

Lamaoui, M., Jemo, M., Datla, R., & Bekkaoui, F. (2018). Heat and drought stresses in crops and approaches for their mitigation. *Frontiers in Chemistry*, *6*, 1–14. https://doi.org/10.3389/fchem.2018.00026

Lange, M., Eisenhauer, N., Sierra, C. A., Bessler, H., Engels, C., Griffiths, R. I., Mellado-Vázquez, P. G., Malik, A. A., Roy, J., Scheu, S., Steinbeiss, S., Thomson, B. C., Trumbore, S. E., & Gleixner, G. (2015). Plant diversity increases soil microbial activity and soil carbon storage. *Nature Communications*, *6*, 6707. https://doi.org/10.1038/ncomms7707

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2020). The concept and future prospects of soil health. *Nature Reviews Earth & Environment*, *1*, 544–553. https://doi.org/10.1038/s43017-020-0080-8

Lepczyk, C. A., Aronson, M. F. J., Evans, K. L., Goddard, M. A., & Lerman, S. B. (2017). Biodiversity in the city: Fundamental questions for understanding the ecology of urban green spaces for biodiversity conservation. *BioScience*, *67*(9), 799–807. https://doi.org/10.1093/biosci/bix079

Li, M., Cui, Y., Fu, Y., Li, N., Tang, X., Liu, X., & Run, Y. (2020a). Simulating the potential sequestration of three major greenhouse gases in China's natural ecosystems. *Forests,* 11(2), 128. https://doi.org/10.3390/f11020128

Li, Z., Cheng, X., & Han, H. (2020b). Future impacts of land use change on ecosystem services under different scenarios in the ecological conservation area, Beijing, China. *Forests,* 11(5), 584. https://doi.org/10.3390/f11050584

Lopes, H. S., Vidal, D. G., Cherif, N., Silva, L., & Remoaldo, P. C. (2025). Green infrastructure and its influence on urban heat island, heat risk, and air pollution: A case study of Porto (Portugal). *Journal of Environmental Management*, *376*, 124446. https://doi.org/10.1016/j.jenvman.2025.124446

Mariton, L., Kerbiriou, C., Bas, Y., Zanda, B., & Le Viol, I. (2022). Even low light pollution levels affect the spatial distribution and timing of activity of a "light tolerant" bat species. *Environmental Pollution*, *305*, 119267. https://doi.org/10.1016/j.envpol.2022.119267

Meyer-Drawe, K. (2022). Soil change under different scenarios. In Elsevier eBooks. https://doi.org/10.1016/B978-0-12-822974-3.00123-3

Mi, J., Ou, J., Liu, H., Shi, J., Chen, D., & Bai, Y. (2022). The loss of plant species diversity dominated by temperature promotes local productivity in the steppe of eastern Inner Mongolia. *Ecological Indicators,* 139, 108953. https://doi.org/10.1016/j.ecolind.2022.108953

Mpia, L., Hasbiadi, H., R., M., & Handayani, F. A. (2023). Identification of soil chemical characteristics and evaluation of soil fertility status on pineapple plantation in Walambeno Wite Village, Parigi Sub-District, Muna District. *Agroteksos*, *33*(3), 1113–1120. https://doi.org/10.29303/agroteksos.v33i3.1004

Mugunga, C. P., Mindje, M., Cyuzuzo, H. A., Uwiringiyimana, J., & Mind'je, R. (2022). Tree species diversity in a naturally regenerated secondary forest in the Ruhande Arboretum, Rwanda. *International Journal of Forestry Research*, *2022*, 1–11. https://doi.org/10.1155/2022/9707130

Muhlisin, Iskandar, J., Gunawan, B., & Cahyandito, M. F. (2021). Vegetation diversity and structure of urban parks in Cilegon City, Indonesia, and local residents' perception of its function. *Biodiversitas*, *22*, 2589–2603. https://doi.org/10.13057/biodiv/d220706

Mursyid, H., Suryanto, P., Fadhilla, S., Silmia, B., & Wibowo, F. A. C. (2025). Diversity and Ecophysiological Performance of Coffee under Dry-Field and Homegarden Agroforestry in Yogyakarta*. Jurnal Sylva Lestari,* 13(1), 75–89. https://doi.org/10.23960/jsl.v13i1.1005

Nathan, M. V. (2017). Soils, plant nutrition and nutrient management. University of Missouri Extension. https://mospace.umsystem.edu/xmlui/handle/10355/59216

Nomura, M., Ohlemüller, R., Lee, W. G., Lloyd, K. M., & Anderson, B. J. (2019). Can we predict which species win when new habitat becomes available? bioRxiv, 562959. https://doi.org/10.1101/562959

Noor, A. W. N. W., Mariyono, M., Junaidi, J., & Probojati, R. T. (2021). Optimization of Various Planting Spacings and Number of Plants per Hole on the Growth and Yield of Corn (Zea mays L.). *JINTAN: Jurnal Ilmiah Pertanian Nasional*, *1*(2), 173. https://doi.org/10.30737/jintan.v1i2.1783

Norris, C. E., Bean, G. M., Cappellazzi, S. B., Cope, M., Greub, K. L. H., Liptzin, D., Rieke, E. L., Tracy, P. W., Morgan, C. L. S., & Honeycutt, C. W. (2020). Introducing the North American project to evaluate soil health measurements. *Agronomy Journal*, *112*(5), 3195–3215. https://doi.org/10.1002/agj2.20234

Ntawuhiganayo, E., Uwizeye, F. K., Zibera, E., Dusenge, M. E., Ziegler, C., Ntirugulirwa, B., Nsabimana, D., Wallin, G., & Uddling, J. (2020). Traits controlling shade tolerance in tropical montane trees. *Tree Physiology*, *40*(2), 183–197. https://doi.org/10.1093/treephys/tpz119

O'Donnell, K., & Sharrock, S. (2018). Botanic gardens complement agricultural gene bank in collecting and conserving plant genetic diversity. *Biopreservation and Biobanking*, *16*(5), 384–390. https://doi.org/10.1089/bio.2018.0028

Oldfield, S. F., Olwell, P., Shaw, N., & Havens, K. (2019). Conservation of plant species. In Plant Conservation: Why It Matters and How It Works (pp. 41–57). Springer, Cham. https://doi.org/10.1007/978-3-319-96974-9_4

Palliwoda, J., Kowarik, I., & von der Lippe, M. (2017). Human-biodiversity interactions in urban parks: The species level matters. Landscape and Urban Planning, 157, 394–406. https://doi.org/10.1016/j.landurbplan.2016.09.003

Pietrzak-Zawadka, J., & Zawadka, J. (2018). The Forest Arborets and Their Activities for Forest and Nature Education. 64(1), 11. http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.agro-7a98f7a9-9e03-4ee8-bc73-065af0f5eea1

Powlson, D. S. (2020). Soil health—Useful terminology for communication or meaningless concept? Or both? Frontiers of Agricultural Science and Engineering, 7, 246–250. https://doi.org/10.15302/J-FASE-2020326

Prakash, S. (2017). Climate change and need of biodiversity conservation: A review. International *Journal of Applied Research*, *3*(12), 554–557. https://www.allresearchjournal.com/archives/2017/vol3issue12/PartH/6-8-83-494.pdf

Prakash, S. (2021). Impact of climate change on aquatic ecosystem and its biodiversity: An overview. *International Journal of Biological Innovations*, *3*(2), 312–317. https://doi.org/10.46505/IJBI.2021.3210

Prakash, S., & Verma, A. (2022). Anthropogenic activities and biodiversity threats. *International Journal of Biological Innovations*, *4*(1), 94–103. https://ssrn.com/abstract=4048276

Puspitasari, M., Udiansyah, U., & Suyanto, S. (2023). Structure and dominance of stands in the arboretum of the forestry faculty of Lambung Mangkurat University. *Jurnal Sylva Scienteae,* 6(2), 269. https://doi.org/10.20527/jss.v6i2.8539

Rahmawaty, Frastika, S., Marpaung, R. M. E., Batubara, R., & Rauf, A. (2019). Short communication: Use of Geographic Information System for mapping of Aquilaria malaccensis land suitability in North Sumatra, Indonesia. *Biodiversitas*, *20*, 2561–2568. https://doi.org/10.13057/biodiv/d200918

Rahmawaty, Frastika, S., Rauf, A., & Batubara, R., & Harahap, F. S. (2020). Land suitability assessment for Lansium domesticum cultivation on agroforestry land using matching method and geographic information system. *Biodiversitas*, *21*, 3683–3690. https://doi.org/10.13057/biodiv/d210835

Rahmawaty, Harahap, M. M., Kurniawan, H., & Rauf, A. (2021a). Land use changes monitoring over a period of ten years in Panjang Island, Pangkalan Susu, Langkat, North Sumatra. *IOP Conference Series: Earth and Environmental Science*, *782*(3), 032008. https://doi.org/10.1088/1755-1315/782/3/032008

Rahmawaty, Harahap, M. M., Rauf, A., & Kurniawan, H. (2021b). Changes in dryland-forest cover in several sub-regencies in Deli Serdang Regency. IOP Conference Series: *Earth and Environmental Science*, *752*(1), 012041. https://iopscience.iop.org/article/10.1088/1755-1315/912/1/012093/pdf

Rahmawaty, R., Samosir, J. B., Batubara, R., & Rauf, A. (2019). Diversity and distribution of medicinal plants in the Universitas Sumatera Utara Arboretum of Deli Serdang, North Sumatra, Indonesia. *Biodiversitas*, *20*(5). https://doi.org/10.13057/biodiv/d200539

Rahmawaty, Rauf, A., Harahap, M. M., & Kurniwan, H. (2022). Land cover change impact analysis: An integration of remote sensing, GIS and DPSIR framework to deal with degraded land in Lepan Watershed, North Sumatra, Indonesia. *Biodiversitas*, *23*, 3000–3011. https://doi.org/10.13057/biodiv/d230627

Ram, H. (2023). Increasing extinction of species of plants in India – Alarming situation. *Research Hub*, *10*(2), 95–102. https://doi.org/10.53573/rhimrj.2023.v10n02.020

Ren, Y., Qu, Z., Du, Y., Xu, R., Ma, D., Yang, G., Shi, Y., Fan, X., Tani, A., Guo, P., Ge, Y., & Chang, J. (2017). Air quality and health effects of biogenic volatile organic compounds emissions from urban green spaces and the mitigation strategies. *Environmental Pollution,* 230, 849–861. https://doi.org/10.1016/j.envpol.2017.06.049

Rohmadi, S., Rayadin, Y., Matius, P., & Ruslim, Y. (2018). The presence and diversity of liana herbs as a food source for wildlife in the coal mining reclamation area of PT Kideco Jaya Agung, Paser, East Kalimantan. *Dipterocarp Ecosystem Research*. *4*(2), 71–82. https://doi.org/10.20886/jped.2018.4.2.71-82

Sagoff, M. (2022). Conservation biology. In H. LaFollette (Ed.), International encyclopedia of ethics (2nd ed., pp. 1–10). Wiley-Blackwell. https://doi.org/10.1002/9781444367072.wbiee125.pub2

Seymoure, B., Dell, A., Hölker, F., & Kalinkat, G. (2023). A framework for untangling the consequences of artificial light at night on species interactions. Philosophical Transactions of the Royal Society B: Biological Sciences, 378. https://doi.org/10.1098/rstb.2022.0356

Shiwakoti, S., Shiwakoti, S., Zheljazkov, V. D., Gollany, H. T., Kleber, M., & Xing, B. (2019). Effect of tillage on macronutrients in soil and wheat of a long-term dryland wheat-pea rotation. *Soil and Tillage Research*, *190*, 194–201. https://doi.org/10.1016/j.still.2019.02.004

Siddiq, Z., Zhang, Y. J., Zhu, S. D., & Cao, K. F. (2019). Canopy water status and photosynthesis of tropical trees are associated with trunk sapwood hydraulic properties. *Plant Physiology and Biochemistry*, *139*, 724–730. https://doi.org/10.1016/j.plaphy.2019.04.031

Siebielec, S., Siebielec, G., Klimkowicz-Pawlas, A., Gałązka, A., Grządziel, J., & Stuczyński, T. (2020). Impact of water stress on microbial community and activity in sandy and loamy soils. *Agronomy*, *10*, 1429. https://doi.org/10.3390/agronomy10091429

Singh, Brajesh K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J.E., Liu, H., Trivedi, P., 2023. Climate change impacts on plant pathogens, food security and paths forward. *Nat. Rev. Microbiol.* 21, 640–656. https://doi.org/10.1038/s41579-023-00900-7

Smith, P. (2016). Building a global system for the conservation of all plant diversity. *The Journal of Botanic Garden Horticulture*, *14*, 5–13. https://doi.org/10.24823/SIBBALDIA.2016.208

Smith, W. S., da Silva, F. L., de Amorim, S. R., & Stefani, M. S. (2018). Urban biodiversity: How the city can do its management? *Biodiversity International Journal*, *2*(2), 246–251. https://doi.org/10.15406/bij.2018.02.00068

Solfiyeni, S., Syamsuardi, Chairul, & Mukhtar, E. (2022). Impacts of invasive tree species Bellucia pentamera on plant diversity, microclimate and soil of secondary tropical forest in West Sumatra, Indonesia. *Biodiversitas*, *23*(6), 3135–3146. https://doi.org/10.13057/biodiv/d230641

Solfiyeni, Winata, F., Mildawati, & Marisa, H. (2024). Vegetation composition, structure and association at site invaded by Calliandra houstoniana in Bung Hatta Grand Forest Park, West Sumatra, Indonesia. *Biodiversitas*, *25*, 3608–3616. https://doi.org/10.13057/biodiv/d251022

Sugiarto, S., Imran, Z., & Widayanti, S. (2023). Manifestation of the ecosystem learning model for biodiversity to improve competency-based environmental education. *BIODIVERS - BIOTROP Science Magazine*, *2*(1), 65–73. https://doi.org/10.56060/bdv.2023.2.1.1997

Sutedjo, & Warsudi. (2017). Assessing the invasive potential of Acacia mangium (Acacia mangium Willd.) in the Bukit Soeharto Research and Education Forest. *ULIN: Jurnal Hutan Tropis*, 1*(*1). https://doi.org/10.32522/ujht.v1i1.795

Suwardi, A. B., Navia, Z. I., Mubarak, A., & Mardudi, M. (2023). Diversity of home garden plants and their contribution to promoting sustainable livelihoods for local communities living near Serbajadi protected forest in Aceh Timur region, Indonesia. *Biological Agriculture & Horticulture,* 39(3), 170–182. https://doi.org/10.1080/01448765.2023.2182233

Tam, B.Y., Gough, W.A., Mohsin, T., 2015. The impact of urbanisation and the urban heat island effect on day to day temperature variation. *Urban Clim.* 12, 1–10. https://doi.org/10.1016/j.uclim.2014.12.004

Urban, J., & Lessambo, F. I. (2022). Effect of forest canopy density on water status and photosynthesis of 14 herbaceous species in temperate forest. EGU General Assembly Abstracts. https://doi.org/10.5194/egusphere-egu22-12769

Wambugu, P., Nyamongo, D., & Kirwa, E. (2023). Role of seed banks in supporting ecosystem and biodiversity conservation and restoration. *Diversity*, *15*(8), 896.

https://doi.org/10.3390/d15080896
Wulandari, S. (2020). Arboretum as carbon stock and carbon dioxide uptake to support the realization of green campus at Riau University. *International Journal of Ecophysiology*, *2*(1), 11–17. https://doi.org/10.32734/ijoep.v2i1.3983
Wysocki, C. (2019). Funkcjonowanie szaty roślinnej w warunkach miejskich = The functioning of plant cover in urban conditions. *Przegląd Geograficzny*, *91*(3), 421–434. https://doi.org/10.7163/przg.2019.3.7
Xie, J., Zhou, S., Chung, L. C. H., & Chan, T. O. (2024). Evaluating land-surface warming and cooling environments across urban–rural local climate zone gradients in subtropical megacities. *Building and Environment,* 251, 111232. https://doi.org/10.1016/j.buildenv.2024.111232
Xue, W., Bezemer, T. M., & Berendse, F. (2019). Soil heterogeneity and plant species diversity in experimental grassland communities: Contrasting effects of soil nutrients and pH at different spatial scales. *Plant and Soil*, *442*(1–2), 497–509. https://doi.org/10.1007/s11104-019-04208-5
Zhang, H., & He, T. (2024). Risiko pemadatan tanah atas berdasarkan respons struktur tanah yang berbeda terhadap tekanan pemadatan. *Agronomy*, *15*(1), 78. https://doi.org/10.3390/agronomy15010078
Zhou, T., Liang, G., Reich, P. B., Delgado-Baquerizo, M., Wang, C., & Zhou, Z. (2024). Promoting effect of plant diversity on soil microbial functionality is amplified over time. *One Earth*, *7*(12), 2139–2148. https://doi.org/10.1016/j.oneear.2024.10.004
Ziter, C.D., Pedersen, E.J., Kucharik, C.J., Turner, M.G., 2019. Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. Proc. Natl. Acad. *Sci. U.S.A.* 116 (15), 7575–7580. https://doi.org/10.1073/pnas.1817561116