CLUSTERING LOCAL PLANTS IN THE RIPARIAN ZONE OF THE KAMPAR RIVER, INDONESIA: TOWARDS AN AGRICULTURAL MANAGEMENT STRATEGY

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Abstract. Agriculture plays a vital role of biodiversity management strategies aimed at developing sustainable agricultural and food systems. Riparian vegetation management strategies are essential for the sustainability of agricultural systems, particularly through the selecting suitable plant species. The objective of this study is to analyze the riparian vegetation of the Kampar River basin and clustering species. The study was conducted in the riparian area of the Kampar River, Indonesia, across eight stations. The methods included phytosociological relevés, cluster analysis, and ecophysiological indicator analysis. The study identified 38 dominant plant species in the riparian area of the Kampar River Basin on podsolic soils, grouped into five main clusters. On peatlands, 26 plant species were identified, organized into three clusters based on similarities in chemical and physical properties of soil and mesoclimatic factors. The identification and use of local plants that are well-adapted can be used to develop riparian vegetation management strategies and support sustainable agriculture in the riparian zone of the Kampar River Basin.
Keywords: *agroforestry, bioresource management, riparian vegetation, species diversity, sustainable agriculture*

Introduction

Agriculture plays a vital role in biodiversity strategies and initiatives aimed at promoting sustainable agricultural and food systems (Boix-Fayos and de Vente, 2023; Titisari et al., 2023). The rapid decline in water availability for agricultural production has led to significant changes in cropping systems. Effective management strategies are crucial to sustaining agricultural systems. The adoption of techniques that improve crop water use efficiency, enhance soil health, select appropriate plant species, and conserve soil moisture could strengthen agricultural sustainability (Ingrao et al., 2023; Korneeva et al., 2023; Nilahyane et al., 2023; Bharati and Uhlenbrook, 2024; Titisari et al., 2024a, b). In this context, riparian buffer zones play a critical role in maintaining water quality and supporting ecosystem services that support sustainable

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agriculture (Prado et al., 2022; Gay et al., 2023; Larsen et al., 2023). Within agricultural landscapes, riparian areas serve as transitional ecotones between agricultural and freshwater habitats.

Currently, riparian systems around the world are experiencing significant degradation due to habitat alteration, overexploitation, dam construction, climate change, pollution, flow modification, and invasive species, all of which negatively impact biodiversity, ecosystem services, and human well-being (Gu and Li, 2024; Mohan and Joseph, 2024). Riparian vegetation helps to regulate water temperature, filter sediments, balance water nutrient levels, stabilize banks and adjacent lands, and provide habitat for both aquatic and terrestrial species (Lind et al., 2019; Luke et al., 2019; Riis et al., 2020; Pielech, 2021). Riparian borders create distinct ecosystems within agricultural landscapes, characterized by inherent complexities that promote pollination and pest management (Cole et al., 2015; Pywell et al., 2015; CRCD, 2020), which can ultimately influence crop yields.

Numerous studies have emphasized the importance of riparian ecosystems. However, research on the effective management of riparian ecosystems in tropical agriculture remains limited. Flores et al. (2021) investigated flooded and non-flooded riparian forest ecosystems in Brazil’s National Park, highlighting the vulnerability of riparian forests within tropical savanna ecosystems to widespread wildfires. Pielech (2021) studied plant species richness in riparian forests at local and regional scales across multiple watersheds in Poland. Wu et al. (2023) examined the effects of riparian zones on water quality and agricultural non-point source pollution (NPSP), concluding that riparian buffer zones are an effective method for ensuring water safety, controlling NPSP, and creating suitable habitats for both terrestrial and aquatic species.

In analyzing riparian plant vegetation, Konatowska and Rutkowski (2019), Kim et al. (2019), and Ziaja et al. (2021) employed phytosociological relevés methods. However, their research was limited to specific communities and did not explore species proximity based on soil biophysical conditions and mesoclimatic factors. Here mesoclimatic refers to the climate characteristics of a localized area within a region typically intermediate in scale, influenced by geographical features like hills and bodies of water and can impact local vegetation. Therefore, this study aims to analyze the riparian vegetation of the Kampar River Basin and cluster species based on biological, physical, and chemical soil conditions as well as mesoclimatic factors, so that it can be a reference in identifying local plants that have potential to applied in agroforestry systems and studying phylogenetic relationships between species.

Method

Study area

The study was conducted in the riparian area of the Kampar River, Indonesia. The research locations comprised 8 stations (*Fig. 1*). The basis for selecting these villages is their high level of dependence on river basins, particularly for agriculture, plantation land, and fishing. Each sampling site’s coordinates are shown in *Table 1*.

Phytosociological relevés

To characterize the riparian vegetation in the study area, a phytosociological relevé analysis was conducted from May to August 2024 using the Zurich-Montpellier method

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(Braun-Blanquet, 2013). The coverage of each species was estimated using an abundance/dominance scale. At each site, surveys were distributed along transects perpendicular to the water flow, covering both the riverbed and the active riverbanks up to the levee edge. The transect line was established 1 km long along the river and 3 m from the riverbank. Data were georeferenced, digitized, and analyzed using QGIS software (QGIS Development Team, 2024). All original layers (in vector and raster formats) and field maps were georeferenced to the WGS84_UTM32N projected coordinate system (EPSG 32632). Multivariate statistical analysis of the phytosociological data was performed using STATSOFT®. Graphs were created using Microsoft Excel (2021) and STATSOFT. Plant association nomenclature was determined using a dichotomous key and the scientific species names recommended by Pignatti et al. (2019) for plant identification.

Table 1. *The coordinates of each sampling site*

Sampling sites	Coordinates
Pulau Belimbing-Kampar	0°19’30.2”N 100°56’26.9”E
Teluk Kenidai-Kampar	0°22’14.7”N 101°13’05.8”E
Gema-Kampar	0°18’20.2”N 102°15’49.8”E
Mentulik-Kampar	0°15’04.2”N 102°52’08.4”E
Muaro Sako-Pelalawan	0°16’11.8”N 101°41’25.6”E
Pulau Kapal-Pelalawan	0°17’36.1”N 102°16’58.0”E
Teluk Meranti-Pelalawan	0°18’20.2”N 102°15’49.8”E
Kuala Kampar-Pelalawan	0°15’04.2”N 102°52’08.4”E

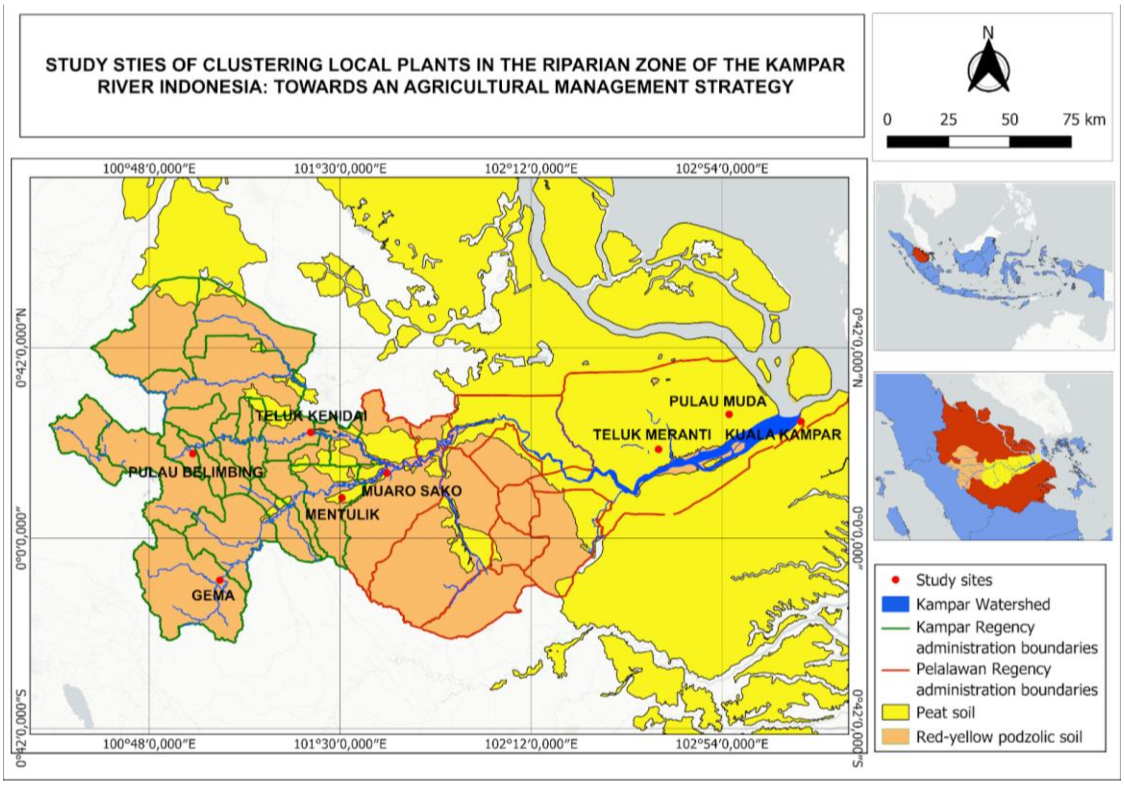

Figure 1. *Study area*

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Cluster analysis

After the data obtained from the phytosociological relevés were collected, statistical techniques, specifically cluster analysis, were applied to understand species distribution patterns. The criteria used are chemical and physical biological variables. Chemical variables include nutrient levels (nitrogen, phosphorus), pH, and soil organic carbon content. Physical variables include soil type (dryland and peatland). Through cluster analysis, similarities and differences within plant communities were identified, grouping the main vegetation types. The cluster analysis was performed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) and chord distance coefficients (Legendre and Gallagher, 2001) through R software version 3.6.1 (R Core Team, 2024). A hierarchical clustering algorithm was applied to form plant groups. In this method, each plant is initially considered a single cluster, and then the most similar clusters are progressively merged until all plants are grouped into one large cluster.

Ecophysiological indicator analysis

Ecophysiology combines ecology and physiology to describe how an organism's physiological processes are influenced by environmental factors such as temperature, humidity, and light. This analysis includes: (a) the Landolt Index, consisting of 7 indices (Landolt et al., 2010), which describes the influence of environmental factors on plant community growth: temperature requirements (T), light requirements (L) indicator for light ranges from species that grow exclusively in deep shade, receiving only 1–30% of full sunlight (L-number = 1), to species that require full sunlight or at least 50% of full light exposure to thrive (L-number = 5), soil nutrient availability (N), for nitrogen/nutrients cover species only growing on the poorest soils (N-number = 1) to species only growing on excessively nitrogen (nutrient)-rich soils (N-number = 5), soil pH (R), soil aeration (D), soil moisture (F), in terrestrial plants, the for soil moisture ranges from species that grow exclusively on dry soils (M-number = 1) to those that thrive only in wet, low-oxygen (hypoxic) soils (M-number = 5), and humus content (H). Each environmental factor is evaluated with five scores, where 1 means low, and 5 means high. In this study, we assigned plant species to two different habitat groups (dryland/podzolic soil and peatland) Then analyzed using the PCA score statistical test; (b) the Ecological Maturity Index (EIM), which measures the degree of disturbance in plant communities by considering phytosociological class information, species abundance, and karyotype (Giupponi et al., 2015, 2017, 2019). These disturbances can be either biotic or abiotic, and this index accounts for modern concepts of ecological succession and vegetation dynamics (Taffetani and Rismondo, 2009); (c) the Exotic Component Index (IE), which assesses the percentage of exotic species abundance (Canullo and Campetella, 2013; Giupponi et al., 2013); and (d) vegetation height (VH), which refers to the average height of vegetation cover, calculated as the mean maximum height of trees, shrubs, and plants based on their percentage land cover (Fogliata et al., 2021).

Result and discussion

Clustering of riparian plant species on podsolic soil in the Kampar watershed

In the Kampar Watershed with podsolic soil, 38 plant species were identified. Cluster analysis grouped the relevés into five main vegetation types (clusters), which are labeled with Roman numerals (I, II, III, IV, V) as shown in the following dendrogram (*Fig. 2*).

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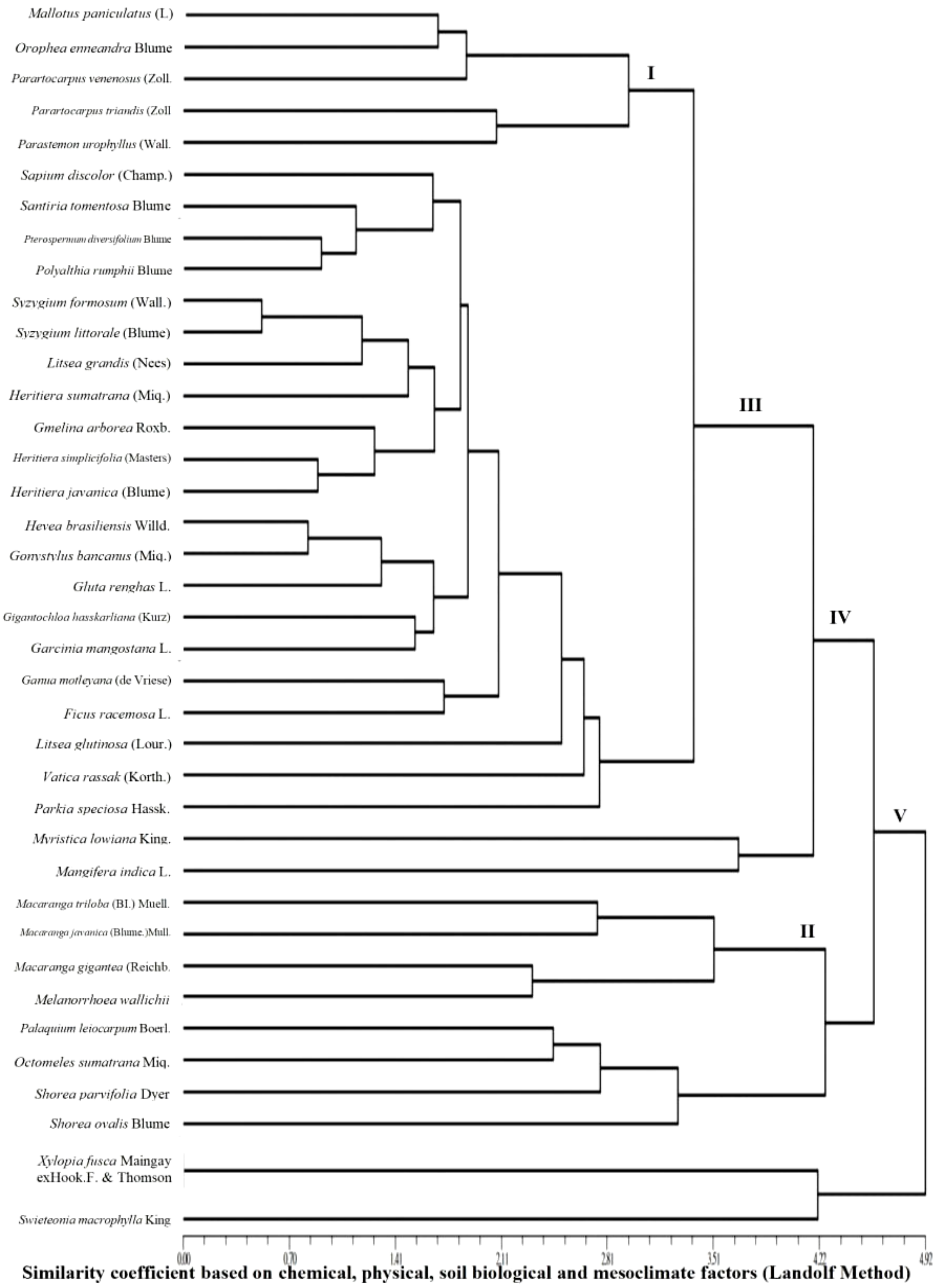

Figure 2. *Dendrogram of riparian species proximity on podsolic soil based on chemical, physical, biological soil factors, and mesoclimatic conditions*

In Cluster I, the primary cluster, several species are grouped together, including *Durio carinatus* Mast., *Durio zibethinus* Rumph. ex Murray, *Dyera lowii* Hook. f., *Drypetes brownii* Vahl, *Dysoxylum gaudichaudianum* (A. Juss.) Miq., among others.

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These species have relatively low Euclidean coefficients (less than 1.0), indicating that they are highly similar to one another. This group has a close relationship, possibly in terms of taxonomy or ecological characteristics, such as the chemical, physical, and biological properties of the soil. *Durio carinatus* Mast. and *Durio zibethinus* Rumph. ex Murray are members of the *Durio* genus, which belongs to the Malvaceae family, a group of higher plants with relatively high species diversity (Mursyidin et al., 2022). Their genetic resources are estimated to include 27 species (Kurniadinata et al., 2019). Individuals of the *Durio* species can co-exist in the same location, forming large populations (Thorogood et al., 2022). However, based on morphological similarities, such as calyx structure, filament arrangement, and anther architecture, Mursyidin et al. (2023) found that *Durio zibethinus* is more closely related to *Durio lowianus*. Meanwhile, *Durio carinatus* is more closely related to *Durio lanceolatus*; both species share primitive traits, such as straight pistil stalks and flowers located on their branches (Naufal, 2021). Additionally, according to the findings of Fikriyya et al. (2023), *Durio* species are considered to have a high importance index for riparian areas, meaning they play a dominant role in riparian ecosystems.

Cluster II: This group includes species such as *Melanorrhoea wallichii* Hook. f, *Sapium discolor* (Champ. ex Benth.) Müll. Arg., *Palaquium leiocarpum* Boerl., and others. The differences among these species are relatively greater compared to those in the first cluster, with Euclidean coefficients ranging from approximately 1.5 to 2.0. These three species are commonly found in tropical Southeast Asia. *Melanorrhoea wallichii* and *Palaquium leiocarpum* are frequently found in tropical rainforests, while *Sapium discolor* tends to inhabit slightly drier areas and can sometimes grow in secondary forests (Olander and Wilkie, 2018). These plants belong to the class Magnoliopsida (dicots), which is characterized by flowering plants with two seed leaves. Although they belong to different families, *Melanorrhoea wallichii* in Anacardiaceae, *Sapium discolor* in Euphorbiaceae, and *Palaquium leiocarpum* in Sapotaceae, they are all tall trees used commercially in the timber and latex industries (Villar et al., 2020; Tölke et al., 2021).

Melanorrhoea wallichii Hook. f, part of the Anacardiaceae family, is a large evergreen tree widely distributed in dry and peat swamp forests of Sumatra, though it is commonly found in peat swamp forests (Purwaningsih, 2011). *Palaquium leiocarpum* is typically found in mixed swamp forests or dipterocarp forests. Several species within this group are endangered due to deforestation and overexploitation. For instance, *Melanorrhoea wallichii* has experienced population declines in some regions due to illegal logging and extraction of its latex, making its protection crucial. Despite its endangered status, this species plays a vital role as a riparian plant in both terrestrial and aquatic ecosystems (Partomihardjo et al., 2020).

Cluster III: This cluster consists of species such as *Macaranga triloba* (BI.) Muell. Arg., *Shorea parvifolia* Dyer, and others. The Euclidean coefficient for this group ranges from 2.0 to 2.8, indicating lower similarity compared to the previous clusters. Mirmanto (2014) noted that these species are pioneer types with high adaptability to environmental conditions. In line with the findings of Sofiah et al. (2018), *Macaranga triloba* and *Shorea parvifolia* have the highest importance value index in the tropical forests of Kalimantan. According to Sarah et al. (2015), areas dominated by Euphorbiaceae species are typically secondary forests. These plants help prevent erosion as they act as buffer trees and have strong water absorption capabilities, making them ideal for riparian planting (Syukur, 2020).

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Macaranga triloba and *Shorea parvifolia* are two species frequently found together in lowland dipterocarp forests, particularly in Southeast Asia. The relationship between these species is primarily ecological, as they share the same forest habitat and have overlapping ecological niches. However, they differ in their roles as pioneer and climax species. *Shorea parvifolia* often grows in areas with stable soil nitrogen dynamics, supporting its slow growth and long-term establishment. On the other hand, *Macaranga triloba* benefits from disturbed soils with more dynamic nitrogen cycles, particularly following events like logging or forest fires, which enable it to grow rapidly. The contrast in nitrogen usage and light requirements between these species highlights how they partition resources within the same forest ecosystem, promoting biodiversity by occupying different ecological niches within the same area.

Cluster IV: This cluster consists solely of *Ficus racemosa* L., *Litsea glutinosa*, *Vatica rassak*, *Parkia speciosa*, *Myristica lowiana*, and *Mangifera indica*, all of which exhibit a very high Euclidean coefficient, approximately 4.0. The species within this cluster demonstrate a preference for soils rich in organic matter with moderate to high water content. *Ficus racemosa* and *Litsea glutinosa* typically grow in areas close to water sources, indicating a similar preference for soil moisture. The presence of *Mangifera indica* may suggest soils with good drainage but that still receive sufficient water from the Kampar River, as mango trees can thrive in soils with moderate moisture levels.

Cluster V: This cluster groups species such as *Shorea ovalis* Blume, *Mangifera indica* L., and *Garcinia nigrolineata* Planch. ex T. Anderson, among others, with Euclidean coefficients ranging from 3.0 to 4.0, indicating that while there are similarities among them, the degree of similarity is not as high as in other clusters. *Shorea ovalis* Blume belongs to the Dipterocarpaceae family, *Mangifera indica* L. to Anacardiaceae, and *Garcinia nigrolineata* Planch. ex T. Anderson to Guttiferae. These species share ecological similarities, such as thriving in tropical environments with nutrient-rich soils and preferring warm temperatures, typically ranging from 24°C to 35°C (Zivković et al., 2024). Given the relatively lower level of similarity found within this cluster, there are notable differences among these species, particularly in terms of soil characteristics. *Shorea ovalis* prefers deep, well-drained, slightly acidic soils, commonly found in tropical rainforests. Such soils are often rich in organic matter, which supports the development of its extensive root system (Purwaningsih and Kintamani, 2018). *Mangifera indica* thrives in various soil types, from clay to sandy soils, provided they are well-drained. This species tolerates slightly alkaline soils but prefers neutral to slightly acidic conditions (Hussain et al., 2021). In contrast, *Garcinia nigrolineata* grows well in moist, well-drained soils with high organic content (Cahyanto et al., 2017; Khamphukdee et al., 2022).

The use of dendrograms in vegetation analysis helps to reveal the complex interactions between species and their environment. This approach provides insights into interspecies competition, vertical stratification in forests, and symbiotic relationships (Lee et al., 2021). From the resulting dendrogram, we can observe groups of species that are ecologically similar and share the same habitat. Species classified within the same branch typically have similar ecological requirements, such as light conditions, soil moisture, or nutrient availability. In contrast, species located on different branches suggest that they occupy different ecological niches or may be involved in significant competitive interactions.

For example, if certain hardwood species are found within the same cluster in the dendrogram, it may indicate that these species share similar adaptive strategies to

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environmental factors such as drought or dense canopy cover. On the other hand, species found on different branches may demonstrate a more specific specialization for unique habitat conditions, such as tolerance to salinity or preference for certain soil types. Research by Pang et al. (2023) found that the proximity of species in a dendrogram can predict species distribution patterns in the field, particularly in the context of forest succession or riparian plant communities. These patterns offer valuable insights into the processes of regeneration and the maintenance of biodiversity in natural ecosystems.

Based on this clustering, a Principal Component Analysis (PCA) score was derived using similarity coefficients based on soil chemical, physical, and biological factors, as well as mesoclimate variables. This clustering was applied to the riparian plant species on mineral soils in the Kampar Watershed area (*Fig. 3*).

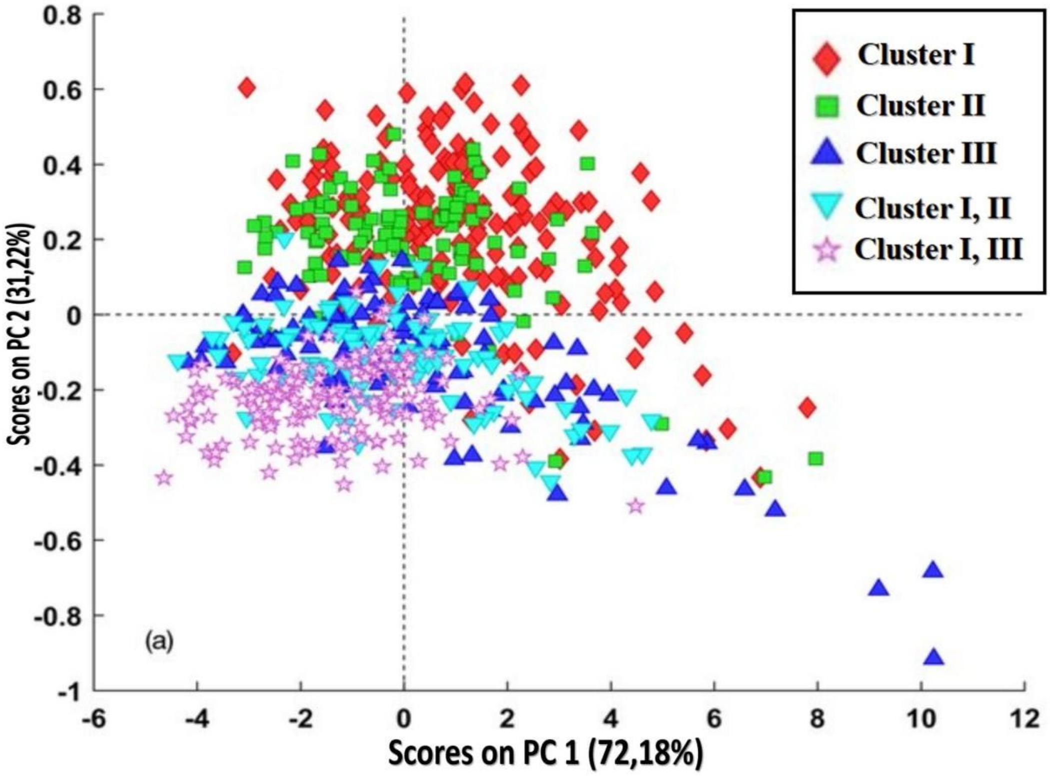

Figure 3. *PCA of riparian vegetation on mineral soils in the Kampar watershed*

Based on the five levels of riparian vegetation clusters identified on mineral soils, two main axes were revealed to have the most significant influence on the proximity of species, separating the data based on observed variables (soil chemical, physical, biological, and mesoclimatic factors). Specifically, 72.18% of the variation in PC1 was attributed to soil chemical or physical variables, such as pH and nutrient content, while 31.22% of the variation in PC2 was related to biological or mesoclimatic variables, such as temperature and humidity. Cluster I appears widely dispersed, indicating high variability along PC1. Cluster II demonstrates tighter grouping with less variability along PC1 but more dispersion along PC2. Cluster III is grouped below and along the negative side of PC1. Clusters I, II, and I, III represent hybrid groups that show overlapping characteristics between these clusters.

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Based on the findings of this study, several riparian plants are recommended for agroforestry cultivation, combined with agricultural crops, in the riparian zones of mineral soils within the Kampar Watershed. These include: *Archidendron pauciflorum* (Jengkol), *Baccaurea macrocarpa* (Tampui), *Baccaurea motleyana* (Rambai), *Durio carinatus* (Durian), *Durio zibethinus* (Durian), *Garcinia mangostana* (Mangosteen), *Hevea brasiliensis* (Rubber), *Mangifera indica* (Mango), *Parkia speciosa* (Petai), *Syzygium formosum* (Water Apple), and *Santiria tomentosa* (Kedondong) (*Fig. 4*).

Figure 4. *Examples of riparian plants on mineral soils in the kampar Watershed*

Clustering of Riparian Plant Species on Peat Soils in the Kampar Watershed

Based on cluster analysis, 26 riparian plant species on peat soils were grouped into three main types of vegetation, identified with Roman numerals (I, II, III) (*Fig. 5*).

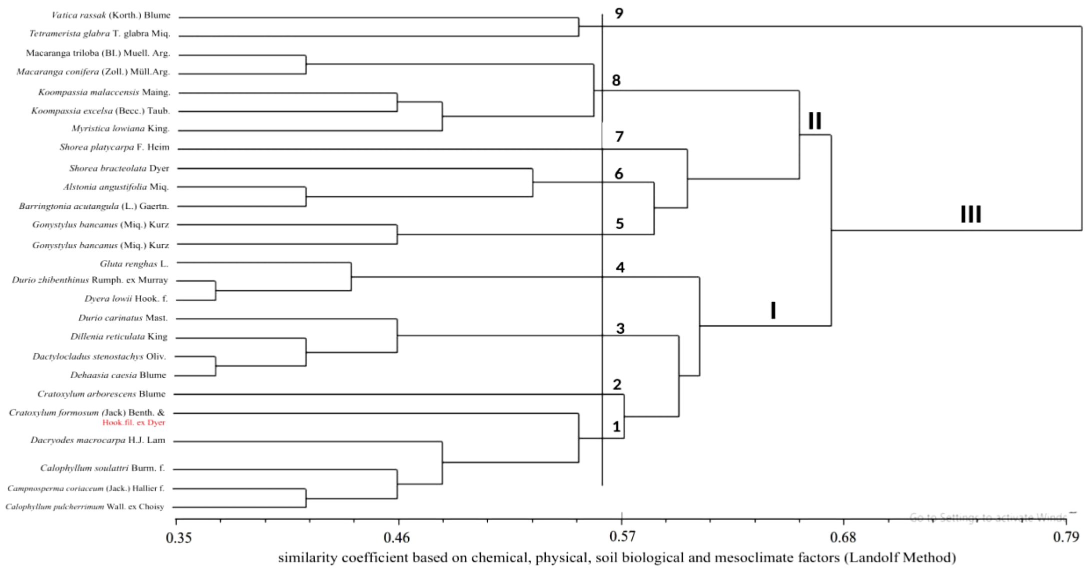

Figure 5. *Dendrogram of riparian species proximity on peat soils based on soil chemical, physical, biological, and mesoclimatic factors*

In Cluster I, several plant species were found with similarity coefficients ranging from 0.46 to 0.68, indicating that this group has a smaller degree of difference and a greater level of similarity compared to other groups. Cluster I consists of *Gonystylus bancanus*, *Gluta renghas*, *Durio zibethinus*, *Durio carinatus*, *Dyera lowii*, *Dillenia*

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reticulata, *Dactilocladus stenistachys*, and *Dehaasia caesia*. *Gonystylus bancanus*, a member of the Thymelaeaceae family, is often found associated with other plants, including *Dyera lowii* (Triono et al., 2009), which is also part of the same cluster in this study. The plants in Cluster I are primarily tree species that dominate peatlands, most of which thrive in soils with slightly acidic to neutral pH levels, ranging from 4 to 6 (Ainy et al., 2018; Amrullah et al., 2023). Meso-climatically, these plants grow in areas with high humidity, such as tropical rainforests, which experience high annual rainfall with relatively even distribution throughout the year (Nurfadilah et al., 2023).

In Cluster II, several plant species were found with slightly higher similarity coefficients (0.68–0.79), indicating that they exhibit greater environmental differences compared to species in Cluster I but still share more similarities than species in Cluster III. The species in Cluster II include *Koompassia malaccensis*, *Koompassia excelsa*, *Macaranga conifera*, *Macaranga triloba*, *Tetrameristra glaba*, and *Vatica rassak*. These plants exhibit relatively high similarity in terms of adaptation to environmental factors such as soil chemistry, physics, biology, and mesoclimate. According to Amirta et al. (2017) and Fujii et al. (2018), these species are able to adapt to nutrient-poor conditions, particularly through the presence of mycorrhizae, which enhance phosphate uptake from nutrient-deficient soils. These plants generally grow in soils with slightly acidic to neutral pH levels (4.5–6.5), particularly in ultisol and oxisol soils commonly found in tropical rainforests. Typically, the forests where these plants grow have low nutrient availability but are rich in organic matter (Rosalina et al., 2014). However, based on findings by Yule and Gomez (2009), Fujii et al. (2018), *Koompassia excelsa* and *Vatica rassak* are more often found in well-drained soils and can survive in areas that experience periodic flooding. On the other hand, *Macaranga conifera* and *Macaranga triloba* are more adaptive to soils that are slightly more moist or even waterlogged for extended periods, as observed in the field in peat swamp areas.

Cluster III exhibits a higher degree of variation compared to other clusters, based on soil chemical, physical, biological, and mesoclimatic factors. This cluster consists of species such as *Cratoxylum arborescens*, *Cratoxylum formosum*, and *Calophyllum pulcherrimum*. The plants in Cluster III represent the most heterogeneous group, reflecting their ability to survive in more diverse or extreme environmental conditions. Species in this cluster are generally found in soils with high organic content, such as tropical rainforests and peat swamps. The soils in their habitats typically range from slightly acidic to neutral, with pH levels between 4.5 and 6.5 (Nonpunya et al., 2014). However, *Cratoxylum formosum* is more tolerant of drier soil conditions, often found in upland forests and sandy soils, while *Cratoxylum arborescens* and *Calophyllum pulcherrimum* are more commonly found in moist or peat swamp soils (Yin Bok et al., 2023). According to findings by Atabani and César (2014), these plants grow in tropical climates with high annual rainfall (above 2000 mm per year) and stable average temperatures throughout the year (around 25°C–30°C), conditions that are crucial for supporting photosynthesis and growth in humid environments such as peat swamps.

Based on the three levels of riparian vegetation clusters (I, II, III) identified on mineral soils, two primary axes were revealed that most significantly influence species proximity, separating the data based on observed variables (soil chemical, physical, biological, and mesoclimatic factors) (*Fig. 6*).

Specifically, 92.17% of the variation in PC1 is attributed to soil chemical or physical variables, such as pH and nutrient content, while 41.31% of the variation in PC2 is related to biological or mesoclimatic variables, such as temperature and humidity.

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Cluster I shows the greatest variation and is spread across a wide range of PC1 and PC2 scores (ranging from below -0.0005 to nearly 0.01), indicating that this group has a broader distribution or greater variation in their environmental adaptations. In contrast, Clusters II and III appear to have a more limited distribution, clustering around the same PC1 score, between 0 and 0.0005.

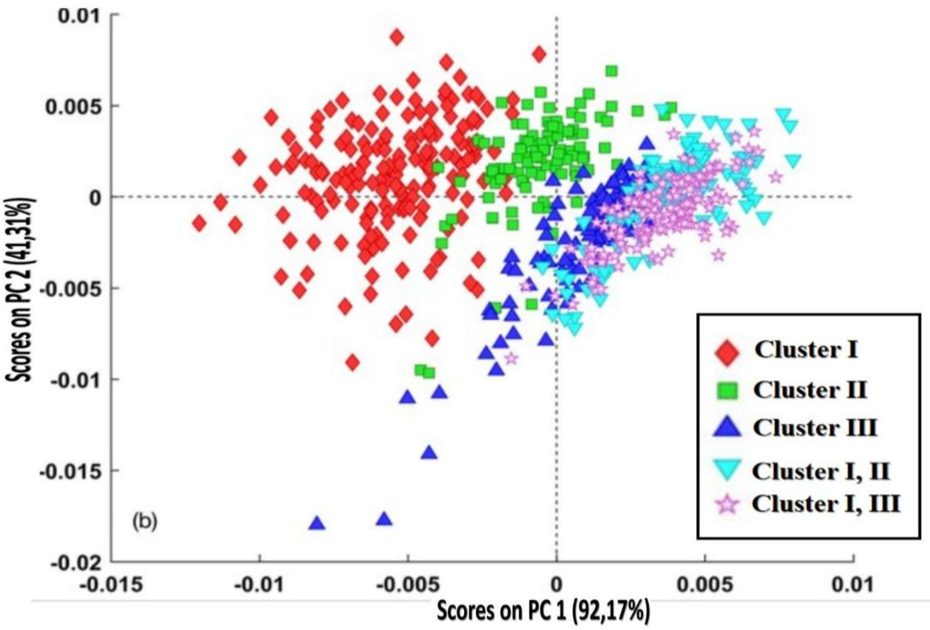

Figure 6. *PCA of riparian vegetation on peat soils in the Kampar watershed*

Based on these findings, several riparian plants are recommended for agroforestry cultivation, in combination with agricultural crops, in the riparian zones of peat soils within the Kampar Watershed. These include: *Artocarpus altilis* (Breadfruit), *Averrhoa bilimbi* (Bilimbi), *Baccaurea motleyana* (Rambai), *Hevea brasiliensis* (Rubber), *Koompassia excelsa* (Sialang), *Koompassia malaccensis* (Sialang), *Mangifera indica* (Mango), *Psidium guajava* (Guava), and *Syzygium polyanthum* (Indonesian Bay Leaf) (*Fig. 7*).

Comparison of riparian vegetation between peat and mineral soils in the Kampar watershed

The composition of vegetation is influenced by environmental factors, including soil type, which in turn affects the types of plants including the distribution and density of species that thrive in a given area (Fikriyya et al., 2023b; Pramadaningtyas et al., 2023). This phenomenon was observed at the research site, where the riparian zone of the Kampar Watershed contains two distinct soil types: peat soil and mineral soil, leading to differences in vegetation composition across the Kampar Watershed (*Fig. 8*).

In riparian zones on mineral soils, larger trees are found less frequently. Along the riparian edge, the vegetation appears lower and more dispersed, consisting of palm trees and small shrubs. This indicates plant adaptations to drier soil conditions and lower water fluctuations. The distance of the vegetation from the river is approximately 800 meters from the riverbank, suggesting that this area may not be directly affected by

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regular flooding, supporting the growth of more drought-tolerant plants. In contrast, the vegetation on peat soil riparian zones is located about 1100 m from the river, with much denser and more diverse vegetation, characterized by closely clustered large trees of distinctive species, along with denser understory plants.

***Figure 7.** Examples of riparian plants on peat soils in the Kampar watershed*

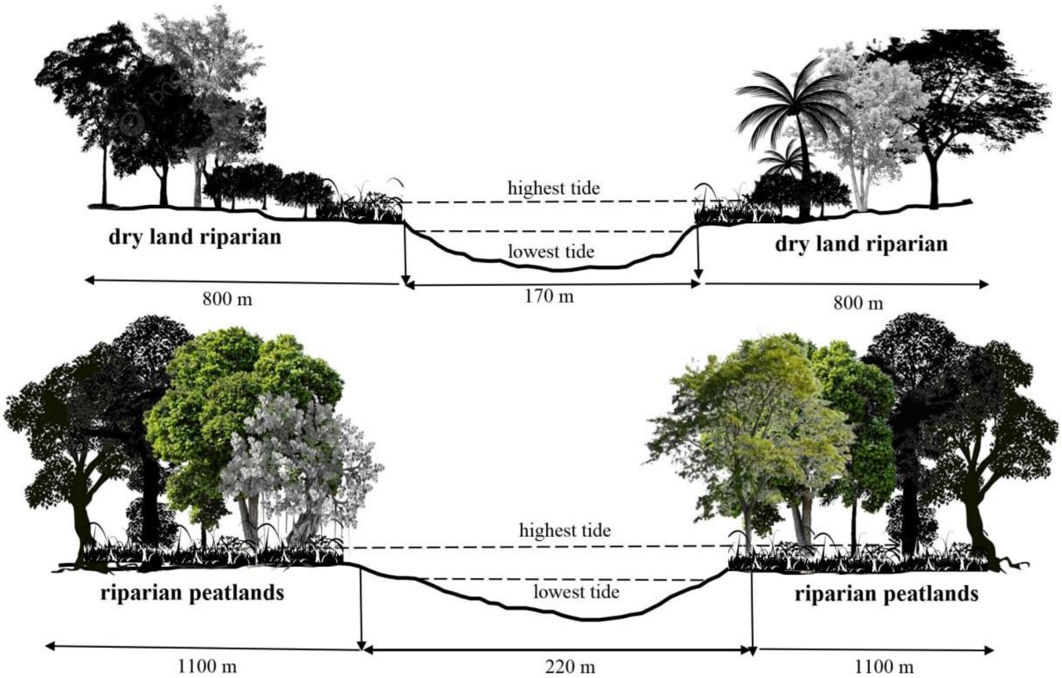

***Figure 8.** Comparison of two riparian profiles: dry land (mineral soil) riparian vs. peatland riparian in the Kampar watershed*

In addition to the differences in vegetation composition, soil conditions also affect the width of the river. Rivers flowing through peatlands are wider, creating a larger floodplain with greater tidal fluctuations. The riverbanks on peat soils are more gently sloped compared to dry land riparian zones, allowing for more area to retain water during floods. This influences the types of vegetation that can grow and survive under such conditions. According to Craft et al. (2022), Garsetiasih et al. (2022), Pschenyckyj et al. (2023), the plant vegetation was directly influenced by the characteristics of peat hydrology, peat chemistry, and peat organic matter. Riparian plants need to adapt to

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flooding and waterlogging in order to thrive in peat soils, as these areas are known for their water retention capacity. This results in denser vegetation, a richer ecosystem, and greater hydrological stability. In contrast, riparian zones on mineral soils (dry land) are drier, with smaller tidal fluctuations and sparser vegetation.

Practical implications for agricultural management

Clustering of local plants contributes to sustainable agricultural practices, including conservation, and socio-economic benefits. Native plant clustering in riparian zones can guide agricultural land use by integrating species that provide natural soil stabilization, water filtration, and erosion protection. Native species, such as certain grasses, shrubs, or trees, have root systems that stabilize soil, reduce erosion, and limit sediment runoff (Asima et al., 2022; Roy et al., 2023). It can help prevent land degradation around the Kampar watershed, where intensive agriculture can lead to riverbank degradation and water pollution from agricultural runoff. Beside that, riparian zones that utilize clusters of native plants can serve as protective buffer zones. By filtering runoff before it reaches agricultural lands, these buffers help in maintaining water quality and regulating river flow, especially during rainy seasons. This practical buffer system could be proposed as a model for local farmers and land managers to reduce crop loss from flooding, suggesting a cost-effective alternative to engineered barriers.

Therefore, agroforestry, or incorporating trees and shrubs into farmland, is increasingly recognized for its benefits. The plant clusters identified in the study could act as stepping stones for a complete agroforestry system. These clusters can improve soil structure, enhance moisture retention, and create shaded areas, benefiting areas facing extreme weather (Rolo et al., 2023; Chavez et al., 2024). Adopting agroforestry based on the study’s clustering findings for the Kampar watershed could increase resilience to climate variability while enhancing crop yields. Moreover, many local plants in the Kampar riparian zone have potential economic value. For example, plants used commercially in the timber and latex industries are beneficial to improve the local economy. The clustering strategy provides supporting biodiversity while offering an additional source of income. It can strengthen local economies, reduce poverty, and offer a more sustainable way to manage the land.

Conclusion

This study identified 38 plant species, organized into five main clusters, growing in the riparian zones of the Kampar Watershed on podzolic soils, and 26 plant species, organized into three main clusters, growing in the riparian zones of the Kampar Watershed on peat soils. The vegetation clusters were grouped based on similarities in soil chemical, physical, and biological properties, as well as mesoclimatic factors. The findings of this study indicate that local plant species hold great potential for application in sustainable agroforestry systems, which not only support food security but also play a crucial role in conserving riparian ecosystems. The management of local plants in riparian zones can help maintain water quality, reduce erosion, and support biodiversity, especially in addressing the challenges of environmental degradation caused by climate change and human activities. Utilizing local plants that are well-suited to specific environmental conditions can contribute to creating more sustainable agricultural management strategies in the riparian zones of the Kampar Watershed. Further research is required to establish an acceptable riparian management approach, taking into

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account several elements like ecological, economy, socio-culture, water footprint, and multi-stakeholder participation. Furthermore, it is essential to investigate suitable habitats for plants ideal for riparian clustering, based on their biology behavior.

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