HAYATI
Journal of Biosciences

Vol. 32 No. 2, March 2025 459-471
DOI:10.4308/hjb.32.2.459-471
ISSN: 1978-3019
EISSN: 2086-4094

Research Article

Sustaining Biodiversity and Ecological Roles in a Heritage Landscape: The Role of Coffee Agroforestry in Kluncing, Indonesia

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ARTICLE INFO

Article history:
Received September 3, 2024
Received in revised form October 29,2024
Accepted November 26, 2024

KEYWORDS:
Agroforestry,
Birds,
Butterfly,
Cofee,
Insects,
Kluncing

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ABSTRACT

This study investigates the role of coffee agroforestry in sustaining biodiversity and ecosystem functions in Kluncing, Ijen, Indonesia. By quantifying bird, butterfly, and coffee insect diversity using the Shannon-Wiener index, it evaluates ecological dynamics and their implications for sustainable land management. Bird communities demonstrated the highest diversity (2.911), indicating ecosystem stability, while butterflies (2.481) and coffee insects (1.841) exhibited lower diversity, reflecting habitat and resource limitations. Trophic network modeling using NetworkX identified keystone species like *Collocalia linchi* (21.9% relative abundance) among birds and the Formicidae family (29.8% relative abundance) among coffee insects, emphasizing their critical roles in ecosystem balance. Canonical Correspondence Analysis (CCA) highlighted the influence of environmental factors on species distribution. Species such as *Ariadne ariadne* and *Delias belisama* were sensitive to humidity and temperature, while *Collocalia linchi* favored areas with higher light intensity. The findings underscore the importance of tailored management practices to address species-specific responses to microclimatic variations. Sustainable agroforestry management is vital for preserving biodiversity, maintaining ecosystem stability, and ensuring agricultural productivity. This study also highlights challenges posed by habitat degradation and climate change, emphasizing the need for adaptive strategies to safeguard this unique agroforestry landscape.

1. Introduction

Agroforestry systems have long been recognized as a sustainable approach to managing agricultural land. These systems not only provide adequate crop yields, but also support the overall sustainability of ecosystems. Coffee agroforestry, in particular, is crucial in tropical regions, such as Indonesia, where biodiversity plays a vital role in maintaining ecological balance. This biodiversity encompasses various species of flora and fauna that interact within the agroforestry ecosystem, contributing to ecosystem functions, such as natural pest control, soil fertility enhancement, and the conservation of endangered species (Perfecto *et al*. 2014; Béat *et al*. 2015; Anastase *et al* 2018). By monitoring and analyzing species diversity, we can understand the dynamics within agroforestry ecosystems and how species interactions influence ecosystem functions. Kluncing, a coffee plantation

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in Bondowoso Regency, Indonesia, is a significant geosite within the Ijen Mountain area, which features coffee agroforestry. This area is ecologically, socially, and economically vital to the local community. Coffee agroforestry in Kluncing enables the community to continue living in an area recognized as a world heritage site, making sustainable land management crucial. This agroforestry system supports the local economy and helps preserve natural heritage rich in biodiversity (Haggar *et al*. 2019). The existence of this system is essential because if the economic and social needs of the community are not met, the pressure on conservation areas will increase, ultimately threatening the environmental sustainability and livelihoods of the local population (Mukhlis *et al*. 2022).

However, significant challenges have emerged with modern agricultural practices, particularly in Kluncing, where coffee monoculture and intensification of agriculture, such as expanding coffee plantations and continuous pesticide use, are increasingly common. Although these practices aim to enhance short-term productivity, they often come at the expense of biodiversity and long-term ecosystem health (Zhao *et al*. 2018; Botelho *et al*. 2021). For instance, the excessive and prolonged use of chemical pesticides in Kluncing has disrupted the balance of local fauna, especially insects, which play critical roles in natural pest control. In addition, land expansion for coffee monoculture threatens previously dominant species, leading to a significant decline in biodiversity. The reduction in biodiversity due to agricultural intensification diminishes the land's ability to support essential ecosystem functions such as natural pest control and soil fertility maintenance (Zhao *et al*. 2018; Botelho *et al*. 2021). This issue is particularly acute in constrained areas, such as Kluncing, where limited space demands careful management to ensure long-term sustainability.

In addition to threats from agricultural intensification, habitat degradation due to uncontrolled land-use changes in restricted areas, such as Kluncing, presents a severe problem. When land is opened for various economic activities without considering the ecological balance, populations of previously abundant species can drastically decline (Perfecto *et al* 2014; Benkendorf and Whiteman 2021; Botelho *et al* 2021). This population decline disrupts the balance of local ecosystems and can trigger wider imbalances, including pest outbreaks or invasive species that can damage coffee crops (Johnson *et al*. 2020; Cecília and Silva 2020). These negative effects can exacerbate environmental degradation and endanger the sustainability of agroforestry as a viable system. Therefore, it is crucial to consider how land use changes can be managed sustainably to balance economic needs and environmental preservation.

Moreover, land use changes in Kluncing exacerbated habitat degradation. Local studies have shown that the expansion of land for coffee monoculture and uncontrolled forest conversion has accelerated the loss of native species and triggered pest outbreaks, such as in the coffee berry borer (*Hypothenemus hampei*) (Johnson *et al*. 2020; Cecília and Silva 2020). The shifts in rainfall patterns and increasing temperatures driven by global climate change have further destabilized this ecosystem, putting additional pressure on species that are sensitive to microclimatic changes, such as temperature and humidity (Checa *et al*. 2014). Therefore, implementing ecologically informed adaptation strategies in Kluncing is crucial to balance agricultural productivity and environmental conservation.

To address these challenges, research focusing on faunal diversity interactions within the agroforestry system of Kluncing is essential. This research aimed to document the existing species and understand how interactions between these species contribute to ecosystem stability and health. This information is expected to be used to develop concrete solutions for sustainable land management that supports agricultural productivity while preserving the critical biodiversity necessary to balance local ecosystems. This study aims to evaluate the role of coffee agroforestry in sustaining biodiversity and ecosystem functions within the heritage landscape of Kluncing, Ijen, Indonesia. The research objectives were to quantify the diversity of bird, butterfly, and coffee insect species using the Shannon-Wiener diversity index, providing insights into species distribution and ecosystem health.

Additionally, the study employed trophic network modeling to explore predator-prey dynamics and identify keystone species that play critical roles in maintaining ecosystem stability. Canonical Correspondence Analysis (CCA) assesses the relationships between species distribution and environmental factors, such as temperature, humidity, and light intensity, to further understand the interactions between species and their environment. The expected outcomes of this study are to provide a better understanding of how coffee agroforestry can be managed more sustainably, not only for economic benefits, but also for ecological interests and the preservation of natural heritage.

2. Materials and Methods

This study employed a comprehensive data collection method to monitor the diversity of fauna within the Kluncing Cofee agroforestry system (7°57'56"S, 114°01'32"E; Figure 1). In the Kluncing coffee agroforestry system, the vegetation comprises coffee plants and shade trees, which are crucial for regulating the microclimate and supporting biodiversity. Common shade tree species include *Gliricidia sepium* and *Erythrina subumbrans*, which provide canopy cover to mitigate temperature fluctuations and enhance soil moisture retention. This agroforestry system follows a mixed cropping pattern in which coffee is intercropped with shade trees in a scattered arrangement rather than structured rows.

Bird observations were conducted using the point count method with a 20-meter radius, which allowed for the detection and recording of bird species within the designated area. We used Nikon Prostaff 3S binoculars to ensure observation accuracy, and a Canon 550D camera with a Canon III USM telephoto lens for detailed visual documentation. Bird observations were conducted using the point count method with a 20-meter radius. A total of five point-count stations were established across the study area, each spaced at least 100 m apart to minimize overlap. At each station, observations lasted for 20 min, during which all bird species seen or heard within a 20-meter radius were recorded. This approach allowed for a thorough survey of the bird community while minimizing habitat disturbance.

Yellow bowl traps were used to monitor coffee insects, placed 1.5 meters above the ground, directly beneath the coffee plant canopy. The traps were filled with soap and 70% alcohol to effectively capture and preserve the specimens for further analysis. Butterflies were captured using 30 cm diameter hanging van Sommersen traps baited with ripe bananas. After 24 h, the captured butterflies were pinned (attached to a board with pins) to preserve their shapes and structures. This pinning process was conducted within 24 h of capture to ensure that the specimens remained in good condition. After pinning, butterflies were identified based on their morphological characteristics and were thoroughly documented. In addition to fauna observations, we also measured the environmental parameters in each plot. Temperature and humidity were measured using a UT 333 hygrometer, while light intensity was measured using a Lutron LX-103 lx meter. These measurements were taken to provide an overview of the microclimatic

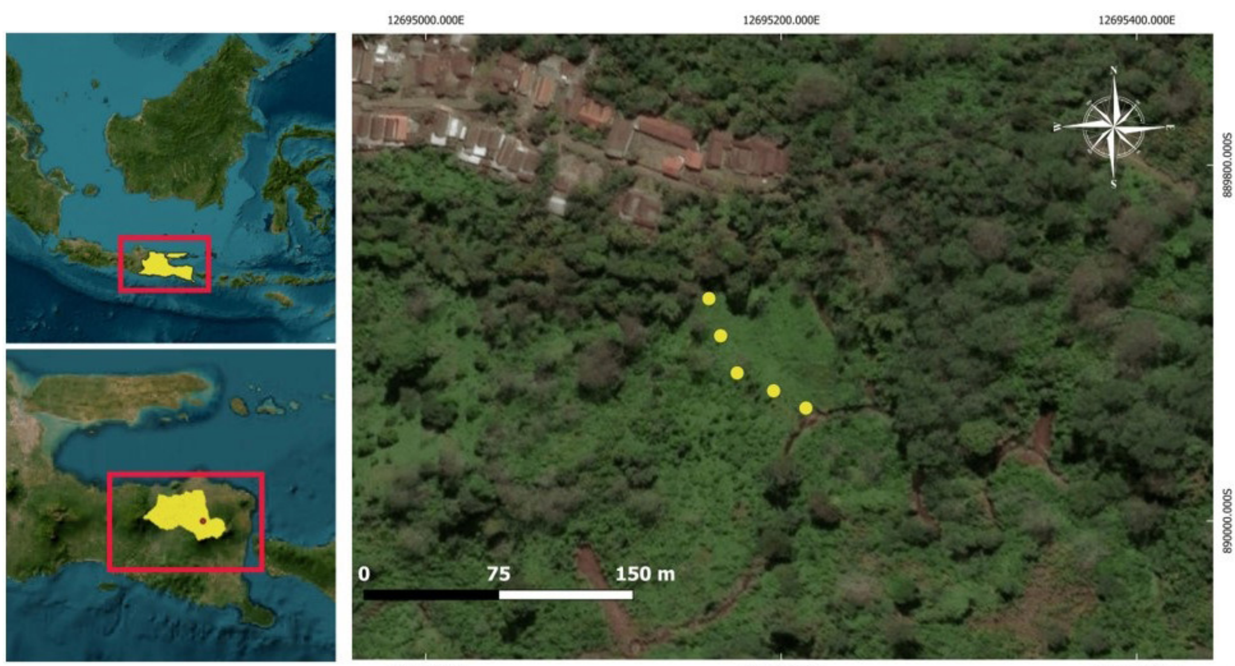

Figure 1. Map of the research study

conditions that might influence the presence and activity of fauna in the agroforestry system.

The trophic network diagram was constructed using NetworkX and Matplotlib libraries in Python to visualize predator-prey interactions within the agroforestry ecosystem. NetworkX created a graph where species were represented as nodes and their interactions (e.g., predator-prey relationships) were represented as edges. The strength and direction of these interactions were modeled based on the ecological roles of the species. The spring layout algorithm in NetworkX arranges the nodes to reflect the relationships more clearly, with connected nodes being attracted to each other and unconnected nodes repelling each other. Matplotlib was then employed to generate and customize the visual representation of the network, including using different colors to categorize species based on their trophic roles, such as predators, herbivores, and omnivores.

We constructed a keystone species model diagram using the NetworkX and Matplotlib libraries in Python to visualize predator-prey relationships between birds and coffee insects within the agroforestry ecosystem. This diagram depicts the interactions between bird species acting as predators and coffee insects as their prey, focusing on identifying the keystone species that significantly influence the ecological network. For both models, the network layout was arranged using the spring_layout algorithm from the NetworkX library, which modeled interactions between nodes as physical forces, such as springs, where connected nodes attract each other and unconnected nodes repel each other.

To evaluate the relationships between bird and coffee insect species with environmental factors, we conducted a Canonical Correspondence Analysis (CCA). CCA was used to identify patterns of association between environmental variation and species distribution within the agroforestry ecosystem. Environmental factors, such as temperature, humidity, and light intensity, were measured at five sampling spots per plot to ensure adequate representation of microclimatic conditions across the study area. CCA analysis was performed using Python sci-kit-learn and matplotlib libraries for result visualization, and the first step involved normalizing the environmental data to ensure balanced scales among the various variables. Next, CCA analysis was conducted to identify the two principal components (CCA Component 1 and CCA Component 2). CCA results were visualized as a biplot, with a green dot representing each species and blue arrows representing environmental variables.

3. Results

3.1. Species Diversity

The Shannon-Wiener diversity index results indicated varying levels of biodiversity across bird, butterfly, and coffee insect communities (Table 1). A higher Shannon-Wiener index value, such as 2.911 for the bird community, reflects greater species diversity and a more even distribution among species. This suggests a healthy and stable ecosystem where different species coexist, without a few species dominating the community. In contrast, lower values, such as 2.481 for butterflies and 1.841 for coffee insects, indicate less diversity, which could mean that a few species dominate, potentially because of limited resources or specialized habitat requirements. These lower values suggest a potential ecological imbalance or reduced resilience in these communities, which makes them more vulnerable to environmental changes.

Species diversity analysis using the Shannon-Wiener index and relative abundance distribution provided deep insights into the dynamics of the studied agroforestry ecosystem. The high Shannon-Wiener index value for the bird community (2.91) suggests that this ecosystem supports high diversity, reflecting a more even distribution among bird species. This is crucial because high diversity in bird communities can enhance ecosystem stability, contribute to the sustainability of ecosystem functions, and create complex interactions among diverse species. Overall, the relative abundance distribution showed that despite dominant species, most species in both communities had low relative abundance (Figures 2 and 3). The 'others' category, which includes species with relative abundance below 2%, highlights the importance of considering less dominant species, which, although they contribute little, still play a role in maintaining ecosystem diversity and function.

The analysis of the relative abundance distribution of coffee insect families within the agroforestry ecosystem revealed a clear dominance of the

Table 1. Shannon-wiener index and relative diversity of bird, butterfly, and coffee insect communities

Community	Shannon Wiener index	Relative diversity (The highest)
Bird Community	2.91	*Collocalia linchi*: 21.90%
Butterfly Community	2.48	*Delias belisama*: 14.30%
Coffee Insect Community	1.84	Formicidae: 29.80%

Formicidae family, with a relative abundance of 29.8% (Figure 4). This dominance highlights the significant role of ants in coffee ecosystem dynamics, both as predators and species that can influence the distribution and abundance of other species. The relatively high abundance of the Cicadellidae and Aphididae families at 18.0% and 12.8%, respectively, also provides insight into the conditions of this ecosystem.

3.2. Interaction Model

The trophic network diagram model provides an important visual representation of ecological interactions within the agroforestry ecosystem, highlighting how different species contribute to overall ecosystem functions (Figure 5). Using colors to categorize species based on their ecological roles effectively explains the complexity and dynamics of

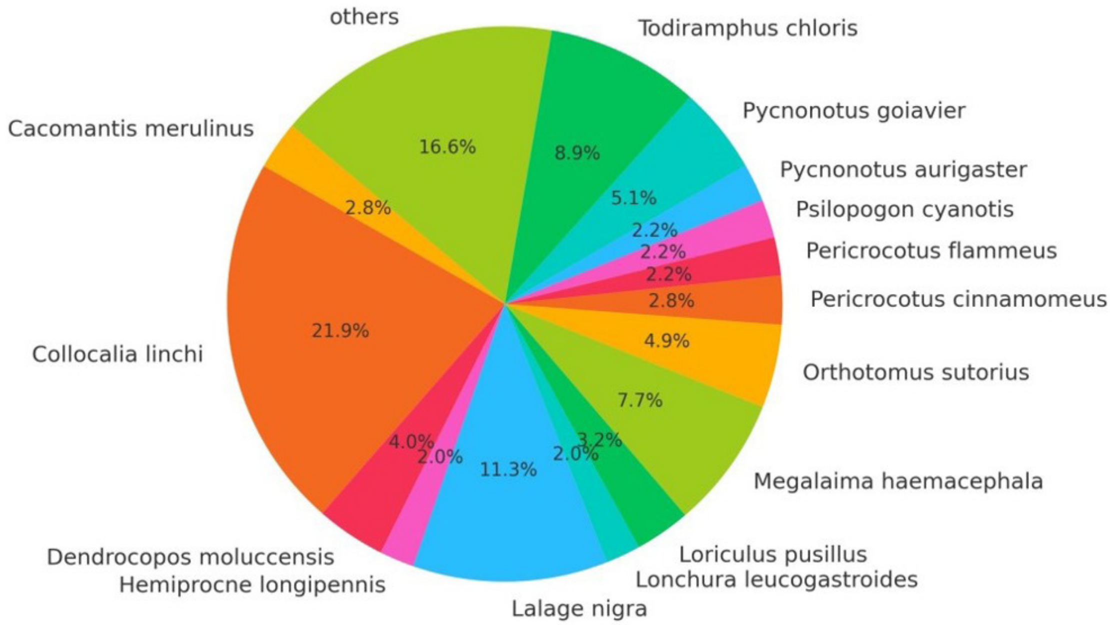

Figure 2. Relative diversity of bird species

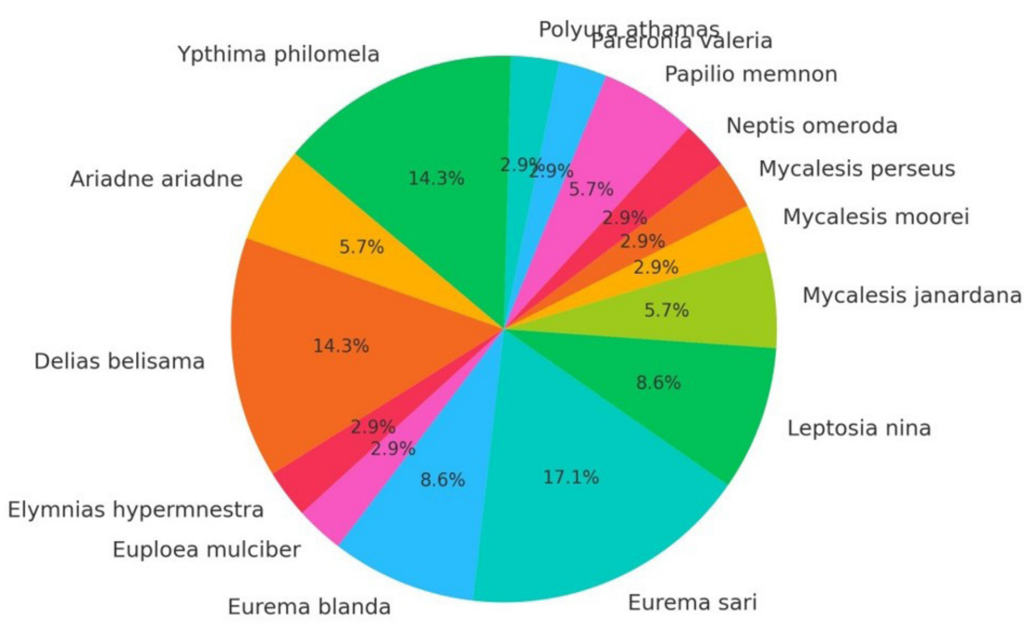

Figure 3. Relative diversity of butterfly species

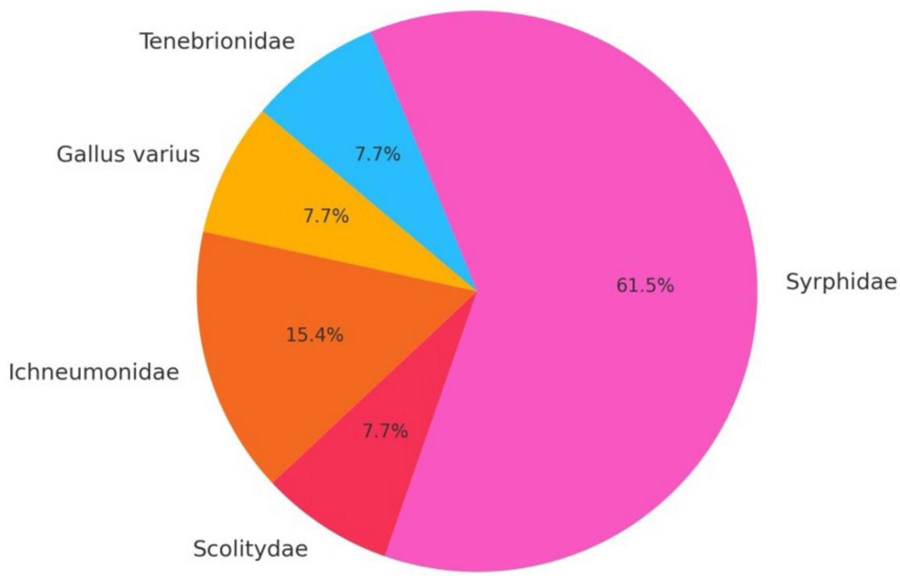

Figure 4. Relative diversity of coffee insect species

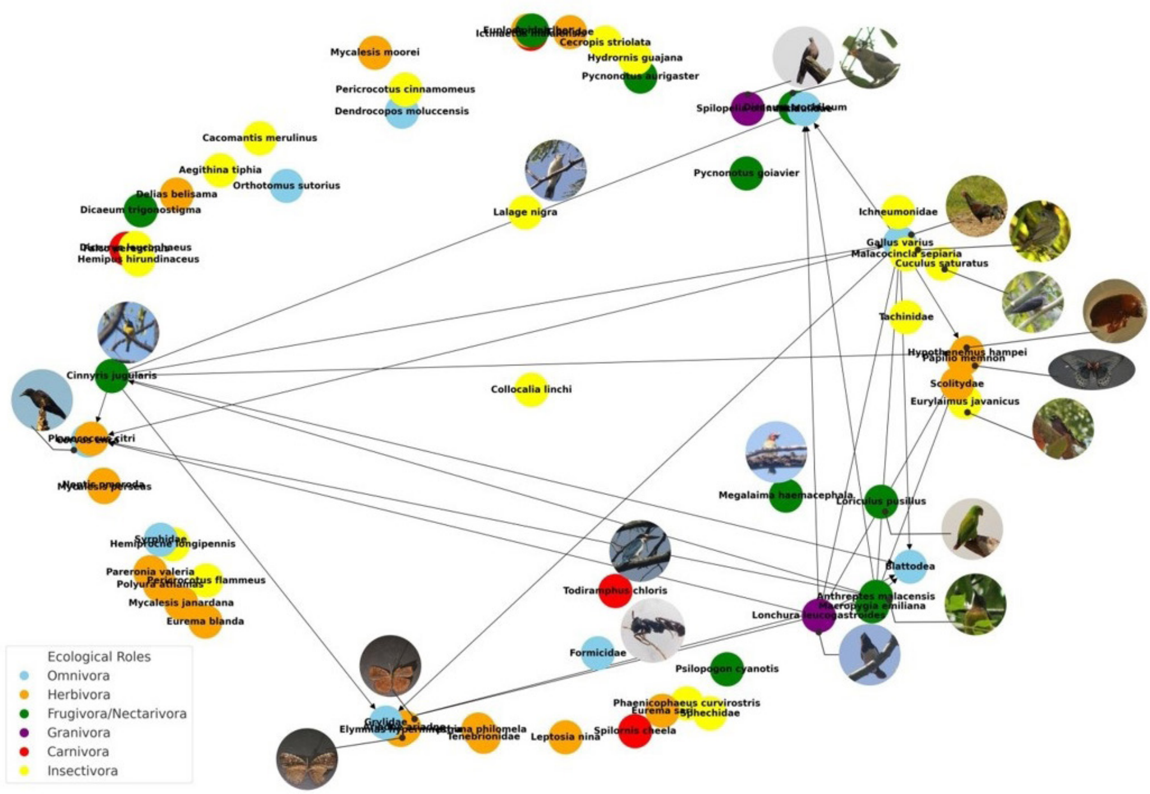

Figure 5. Trophic interaction modeling using networkX library for ecological roles

the existing trophic interactions. Omnivorous species, such as *Gallus varius*, Blattodea, and Gryllidae, play critical roles in this ecosystem.

The presence of herbivores is represented in oranges, emphasizing the importance of understanding and managing these species in coffee production (Figure 5). As herbivores, they can cause direct damage to plants, which can negatively impact crop yields. Therefore, the effective management of these herbivore populations is crucial for maintaining the productivity and health of coffee agroforestry. Frugivores/Nectarivores, such as *Anthreptes malacensis* and *Cinnyris jugularis*, are represented in green, indicating their role in pollination and seed dispersal (Figure 5).

The dominance of different ecological roles within the coffee agroforestry system provides significant insight into how resource availability influences species distribution. Among the bird species, insectivores, such as *Collocalia linchi*, dominate, representing 21.90% of the bird community. This high dominance can be linked to the abundance of insect populations, particularly coffee pests, supported by diverse vegetation within the agroforestry system. Shade trees such as *Gliricidia sepium* and *Erythrina subumbrans* offer habitats that promote insect proliferation, thus supporting insectivorous species that play crucial roles in natural pest control. In the coffee insect community, the Formicidae family, which serves as a predator, had a relative abundance of 29.80%. This reflects the significant role of ants in regulating pest populations, which is critical in agroforestry systems. Trees with nectar sources and other vegetation types within the agroforestry system support the survival and foraging activities of these ants, highlighting the mutualistic relationships between vegetation and fauna. For butterflies, *Delias belisama* dominated the community, with a relative abundance of 14.30%. The success of this species may be attributed to the availability of flowering plants and fruit trees within the agroforestry system, which provides essential nectar resources. The presence of diverse plant species fosters a stable habitat for pollinators, underscoring the role of agroforestry systems in promoting pollination services and enhancing biodiversity.

3.2. Trophic Network Diagram

This trophic network diagram illustrates the basic interactions between species within the agroforestry ecosystem and highlights the critical roles of carnivorous and insectivorous species in maintaining population balance within this ecosystem. The presence of carnivorous species underscores the importance of apical predators in the structure of ecological communities. Insectivorous species, such as *Aegithina tiphia* and *Hemipus hirundinaceus*, represented in yellow, play an essential role in controlling insect populations.

3.3. Modeling in Evaluating the Impact of Trophic Disturbances

Figure 6 clearly illustrates the central roles of *G. varius* and *L. leucogastroides* in maintaining ecological balance within the coffee agroforestry system. These keystone species contribute significantly to ecosystem stability by controlling prey populations and ensuring plant regeneration through seed dispersal. The impact of loss of *Gallus varius* or *Lonchura leucogastroides* was evaluated by comparing the interaction network before and after their loss. The evaluation considered changes in species diversity, the number of interactions, and network structure. The analysis showed that after considering the previous keystone species in terms of relative diversity values, *G. varius*, and *L. leucogastroides*, no other species met the criteria for having a high number of interactions (threshold ≥ 3). Visualization of the original trophic network demonstrates the complexity of ecological interactions within the agroforestry ecosystem, with the keystone species *G. varius* and *L. leucogastroides* playing a central role (see Figure 6). *G. varius*, as an omnivore, has six interactions with other species, reflecting its flexibility in utilizing various food sources and its influence in controlling insect and plant populations. *L. leucogastroides*, as a granivore, plays a significant role in seed dispersal and plant regeneration. The presence of these keystone species ensures a strong and stable interaction network, which helps to maintain ecosystem balance and support biodiversity. Conversely, network visualization without keystone species showed a drastic reduction in interactions and network diversity. The loss of *G. varius* and *L. leucogastroides* led to a decreased network connectivity from 0.12 to 0.02 and the loss of clustering within the network (the connectivity decreased from 0.22 0.00).

3.4. Environmental Factors Interaction with Species Diversity and Abundance

The Canonical Correspondence Analysis (CCA) displayed in this diagram provides essential insights into how environmental variables influence the distribution and abundance of species within the studied agroforestry ecosystem (Figure 7). The decision to analyze only 12 species in the Canonical Correspondence Analysis (CCA) was based on their ecological significance and relative abundance within

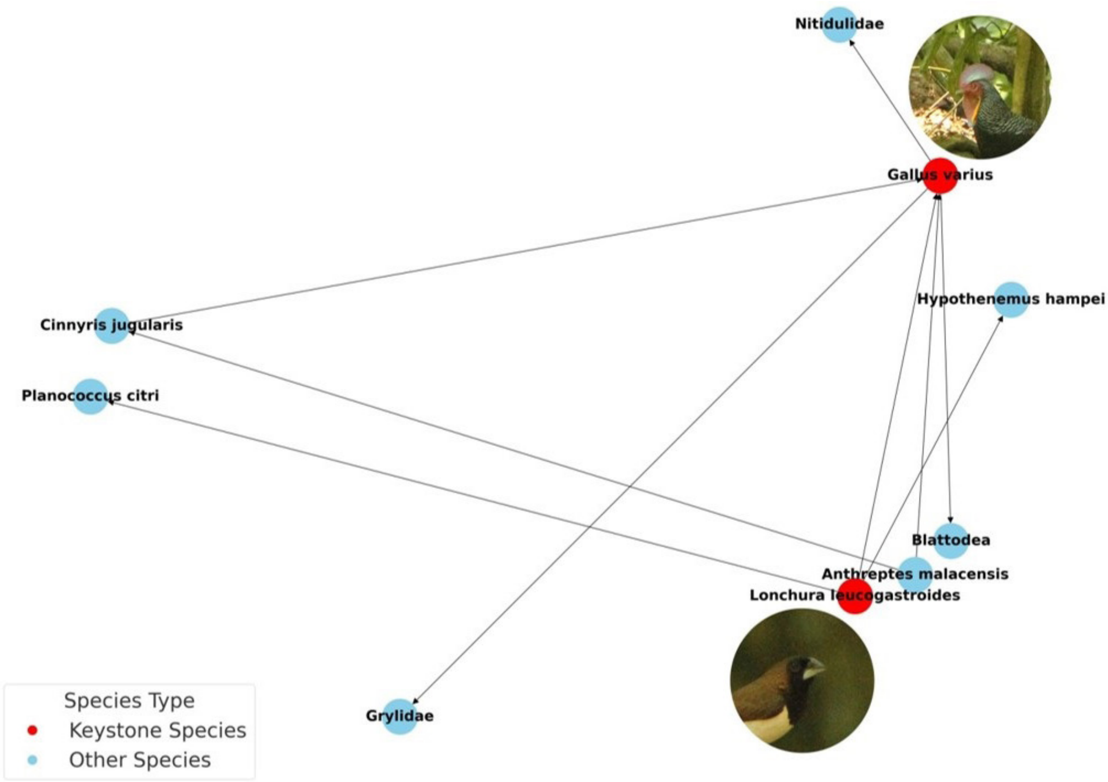

Figure 6. Trophic network model showing the impact of keystone species (*G. varius* and *L. leucogastroides*) on the interaction network. Removing these species significantly reduces connectivity and disrupts ecological balance, as reflected by the decreased clustering coefficient and network stability

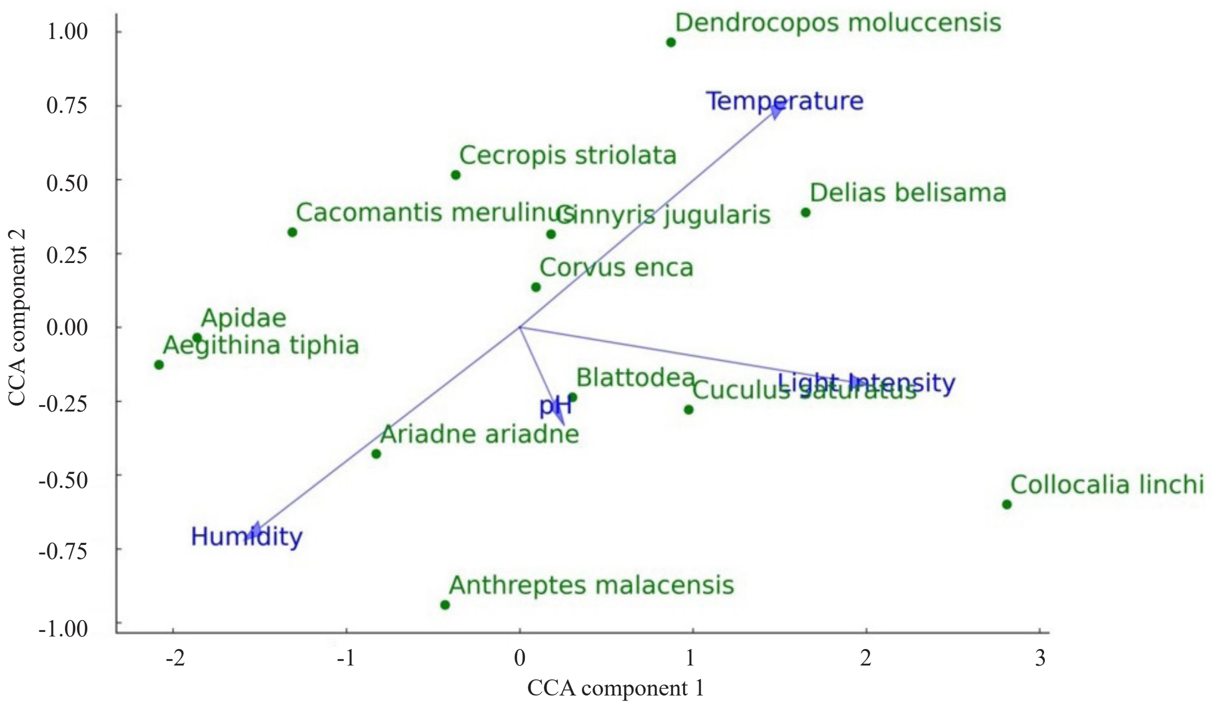

Figure 7. CCA plot of environmental factors' impact on species diversity and abundance

the study site. These species were selected because they represent the most dominant or ecologically important species in the coffee agroforestry system. The analysis aimed to highlight the key players that significantly influence the structure and functioning of the ecosystem by focusing on the most abundant species. These species have been shown to have strong interactions with environmental variables such as temperature, humidity, and light intensity, making them ideal indicators for understanding how microclimatic changes affect species distribution. Using blue arrows to represent environmental factors, such as humidity, light intensity, temperature, and pH, CCA allows us to understand how each variable affects species communities.

Figure 7 provides a critical visualization of how environmental factors influence species distribution within the coffee agroforestry system. The blue arrows in the CCA plot represent the environmental variables humidity, light intensity, temperature, and pH. The direction and length of these arrows indicate the strength and correlation of these factors with species distribution. Species such as *Ariadne ariadne* and *Delias belisama* were located close to the humidity arrow, suggesting that humid conditions strongly influenced their abundance. This implies that these species are sensitive to changes in moisture levels and that fluctuations in humidity could significantly affect their populations. The proximity of *Collocalia linchi* to the light intensity arrow indicates its preference for environments with higher light exposure. This species is commonly found in open areas within agroforestry systems, where sunlight is abundant. Temperature variations strongly influenced the species located near the temperature arrow. For instance, fluctuations in daily or seasonal temperatures can impact activity patterns, reproduction, and survival rates.The position of Blattodea near the pH arrow suggests that soil acidity or alkalinity significantly affected their distribution. Changes in soil pH, whether due to natural or anthropogenic factors, can alter habitat suitability for this species.

Given the role of agroforestry systems in maintaining biodiversity, understanding the ecological preferences and responses of these dominant species is crucial for developing sustainable land-management strategies. For instance, *Collocalia linchi* serves as an effective insectivore in coffee agroforestry, helping to control pest populations, while Formicidae's dominance as coffee pest predators highlights their role in natural pest management. By examining how these species respond to specific environmental conditions, such as increased light in more open areas or higher humidity levels under dense canopy cover, this analysis provides valuable insights for optimizing agroforestry management practices.

Moreover, using CCA in this context underscores the complexity of agroforestry ecosystems and the importance of understanding species-environment interactions. These results suggest that managing environmental variables, such as maintaining an appropriate canopy density for light regulation or ensuring microclimatic stability to control humidity, can help sustain biodiversity and promote ecological resilience in agroforestry systems. As climate change continues to alter weather patterns, the ability to adapt agroforestry practices to support species sensitive to environmental change has become increasingly important. Thus, this analysis offers practical implications for enhancing the ecological and agricultural sustainability of coffee agroforestry in Kluncing.

4. Discussion

The relative abundance is essential because it reflects a healthy and stable ecosystem where various bird species j show the dominance of *Collocalia linchi* at 21.9%, which may indicate that this species is highly adapted to the existing agroforestry environment (see figure 2, Iswandaru *et al*. 2020; Putri *et al*. 2020). This dominance should be noted because highly dominant species can alter community structure and reduce functional diversity in the long term. Other species, such as *Dendrocopos moluccensis* and *Cacomantis merulinus*, although not as dominant as *C. linchi*, still show a significant presence, which can add another dimension to the dynamics of this ecosystem. Although most species in both communities have low relative abundances, their ecological roles remain crucial for the stability and resilience of the ecosystem. Species with relative abundance below 2%, categorized as 'others,' are often less dominant but can serve essential functions, such as filling specialized ecological niches or acting as prey for higher trophic levels. For example, these less abundant species may enhance ecosystem resilience by supporting functional diversity, which ensures that ecosystem processes such as nutrient cycling and pest control continue, even when dominant species face environmental stressors. In agroforestry systems, such as Kluncing, these species, despite their lower numbers, contribute to the maintenance of biodiversity and help buffer the ecosystem against potential disturbances such as climate variability and habitat changes.

Conversely, the butterfly and coffee insect communities showed lower diversity levels, with index values of 2.48 and 1.84, respectively. The lower index values indicate the dominance of certain species, such as *Delias belisama* (Figure 3, 14.3%), among butterflies, reflecting specialization to specific habitats or resources available in this ecosystem (Wibisana *et al*. 2024). A similar situation occurs in the coffee insect community, where the dominance of certain species may reflect more specific and less varied environmental conditions, as well as indicate symptoms of imbalance, such as the emergence of herbivorous communities that are considered pests in large numbers (Muhammad *et al*. 2022; Haryadi *et al*. 2024). Overall, the relative abundance distribution showed that despite the dominant species, most species in both communities had low relative abundance (Figure 4). This may indicate challenges in resource availability or intense competition between these species (Matthews and Whittaker 2015; Frost *et al*. 2016). Formicidae have complex interactions with various other organisms, including mutualistic relationships with specific plant and insect species, and a role in pest control (Haryadi *et al*. 2024; Lutinski *et al*. 2024). The high abundance of this family may indicate that the agroforestry system provides an environment that supports the activity and reproductive success of ants, which in turn can affect the overall balance of the ecosystem.

Cicadellidae, often known as plant disease vectors through their feeding activity, can serve as indicators of specific environmental pressures or the availability of abundant resources for them (Brodbeck *et al*. 2017; Vaidya *et al*. 2017; Haggar *et al*. 2019). Aphididae, also known as a significant agricultural pest, particularly in coffee, indicate that this ecosystem supports a considerable population of aphids, which may require management interventions to prevent adverse impacts on coffee production (Anastase *et al*. 2018). The presence of Coccinellidae, with a relative abundance of 8.5%, is also noteworthy, as these beetles often act as natural biological control agents against aphids (Aphididae) and other pests (Anastase *et al*. 2018; Iverson *et al*. 2021). The significant presence of Coccinellidae suggests that this agroforestry system has the potential for more natural biological control, which could reduce the need for chemical pesticides. Thripidae, with a relative abundance of 6.4%, also added diversity to the coffee insect community. Thrips are pests that can damage coffee plants, particularly during the flowering phase; therefore, their significant abundance suggests that they could pose a potential threat to crop yields if not adequately managed (Ravelo *et al*. 2019; Shimales *et al*. 2023).

Omnivorous species, such as *Gallus varius*, Blattodea, and Gryllidae, play critical roles in this ecosystem. Omnivores have a flexible diet that allows them to adapt to various plant and animal food sources (Yashmita-Ulman *et al*. 2018; Almeira 2020; Campera *et al*. 2022). This flexibility plays an essential role in controlling the populations of other species, including pests, thus helping maintain ecosystem balance. Their diverse presence across different trophic levels indicates their role as essential links in the food chain that can influence the dynamics of other communities (Benkendorf and Whiteman 2021). Herbivores such as *Hypothenemus hampei* (Coffee Berry Borer) and *Planococcus citri* (mealybug) directly affect the health of coffee plants (Johnson *et al*. 2020; Cecília and Silva 2020). Nectarivores/frugivores are essential for supporting plant regeneration and biodiversity in agroforestry ecosystems. These species not only assist in the reproduction of coffee plants through pollination, but also seed dispersal, which can help in vegetation recovery and maintain the diverse structure of the ecosystem (Nurqamareena *et al*. 2018; Suripto *et al*. 2020).

The presence of carnivorous species such as *Falco peregrinus* (peregrine falcon) and *Ictinaetus malaiensis* (black eagle) underscores the importance of apex predators in the structure of ecological communities. As predators, they play a role in controlling the populations of smaller animals, which in turn helps prevent overpopulation and maintain ecosystem balance. The presence of carnivores at higher trophic levels also indicates that this agroforestry ecosystem is complex and supports a long food chain, which is often a sign of ecosystem health (Salazar *et al*. 2014; Cardona *et al*. 2024). Insectivorous species play an essential role in the control of insect populations. This is highly relevant in coffee agroforestry, where natural pest control can help reduce dependence on chemical pesticides (Rohman *et al*. 2020). The role of insectivores in maintaining insect population balance is crucial for preventing crop damage and maintaining land productivity (Nyffeler *et al*. 2018). The complex interactions among carnivores, insectivores, omnivores, herbivores, and frugivores/nectarivores demonstrate that a healthy agroforestry ecosystem is supported by a variety of species with complementary ecological roles (Béat *et al*. 2015; Benkendorf and Whiteman 2021). Species diversity is essential for ecosystem balance and ensures that various ecosystem functions, such as natural pest control, pollination, and seed dispersal, can proceed effectively. This diagram (Figure 5) reinforces the notion that species diversity is critical for maintaining the health and productivity of agroforestry systems.

The loss of keystone species, such as *G. varius* and *L. leucogastroides*, led to a significant reduction in network connectivity, demonstrating that removing these species can disrupt ecosystem structure and stability. A decrease in the network clustering coefficient indicates a breakdown in species interactions, which can trigger imbalances in population dynamics and weaken the ecosystem's resilience to external disturbances. These findings align with the general ecological theory that keystone species play a disproportionately large role in maintaining the structure of ecological communities, and that their loss can lead to cascading effects throughout the ecosystem (Hale and Koprowski 2018; Srinivas *et al*. 2024).

Loss of *G. varius* and *L. leucogastroides* led to decreased network connectivity. This reflects how losing keystone species can disrupt the ecosystem structure, reduce species interactions, and diminish ecosystem stability. This decline can result in imbalances in the populations of other species, increase the risk of ecological disturbances, and reduce the ability of the ecosystem to recover from environmental changes and other disruptions (Hale and Koprowski 2018).

The direction and length of the arrows in the CCA diagram indicate the strength and direction of each environmental variable's influence on the main components. For example, species such as *Ariadne ariadne* and *Delias belisama* are located close to the direction of the humidity and temperature arrows, indicating that humidity and temperature levels strongly influence their abundance in the environment. These findings suggest that these species may be more sensitive to fluctuations in microclimatic conditions, such as changes in rainfall patterns or temperature, which could affect their survival and distribution within the ecosystem (Checa *et al*. 2014). *Collocalia linchi*, located closer to the light intensity arrow, indicates a preference for environments with higher light intensity. This could indicate that this species is often found in open or less shaded areas within the agroforestry system, where sunlight is more intense (Winarni *et al*. 2022). This preference underscores the importance of considering plant arrangements and vegetation in agroforestry to support suitable habitats for certain species. The Blattodea family, located near the pH variable, showed a strong relationship between abundance and soil acidity levels. This may indicate that Blattodea prefers or is more tolerant to slightly alkaline soil conditions, which could affect their distribution within the agroforestry ecosystem. Changes in pH, whether due to natural factors or human intervention, may significantly impact the population of this species, and thus should be considered in land management (Das 2021).

Overall, this CCA is useful for identifying species that are more sensitive to specific environmental changes, thereby providing valuable insights into ecosystem dynamics within agroforestry (Jiang *et al*. 2014). Understanding species sensitivity to environmental variables is crucial for ecological science and for the development of more effective conservation strategies. With this information, conservation actions and land management can be targeted to protect species that are more vulnerable to environmental changes and maintain the overall ecosystem balance (Palma *et al*. 2015). These results can also serve as a foundation for optimizing the design and management of agroforestry to be more sustainable, taking into account the ecological needs of the various species present.

This study demonstrates that the coffee agroforestry system in Kluncing, Ijen is vital for maintaining faunal diversity. The analysis results indicated that the bird community had the highest Shannon-Wiener diversity index (2.911), reflecting a highly diverse and balanced ecosystem. The butterfly and coffee insect communities showed lower diversity index values at 2.481 and 1.841, respectively, indicating the presence of dominant species and limitations in available habitats and resources. The trophic interactions among the species in this ecosystem also underscore the importance of each species in maintaining ecosystem balance. *C. linchi* birds dominate with a relative abundance of 21.9%, showing excellent adaptation to agroforestry conditions. The butterfly *D. belisama* showed dominance with a relative abundance of 14.3%, while the ant family Formicidae dominated the coffee insect community with a relative abundance of 29.8%. This study also highlights the challenges faced by this ecosystem, particularly in the context of land use changes and the impacts of global climate change. Uncontrolled habitat degradation and agricultural intensification could threaten the sustainability of agroforestry and biodiversity in Kluncing. The implementation of sustainable land management strategies is therefore crucial, not only to support agricultural productivity, but also to preserve biodiversity, which is critical for ecosystem balance.

Acknowledgments

We want to express our sincere gratitude to the Institute for Research and Community Service (Lembaga Penelitian dan Pengabdian kepada Masyarakat) of Universitas Jember for supporting this research through the Research Group (KeRis - DiMas) 2024 grant (Contract Number: 2880/UN25.3.1/LT/2024). We also thank Ijen Geopark and Mr. Harsono for granting necessary research permits. Special appreciation goes to Ayu Lestari, Ahmad Rifqi Hanafi, Auralia Sakinah, Galang Prasetya Efendi, Nadifa, and Ifa for their invaluable bird and butterfly research assistance. We are also grateful to Michele and Jihan Lutvia for their assistance with insect research.

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