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Ecological Structuring and Diversity of Crop Raider Communities in the Buffer Zone of Mont Sangbé National Park, Western Côte d'Ivoire

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ABSTRACT

Interactions between wildlife and agricultural systems represent a major challenge in the peripheral zones of protected areas. The Mont Sangbé National Park, located in Western Côte d'Ivoire, exemplifies this issue due to the high frequency of wildlife crop depredation affecting both subsistence and commercial farming. This study aims to characterize the composition, diversity, and structure of crop raider communities in this area, to identify dominant crop raider species and the most vulnerable crops. The survey was conducted among 120 farming households across three villages surrounding Mont Sangbé National Park. Data were collected between February and April 2022 through semi-structured interviews, direct observations and consultations with OIPR agents. Analyses focused on relative frequency, species richness, diversity indices and multivariate structuring. Results reveal a predominance of *Erythrocebus patas* and *Thryonomys swinderianus*, which together account for over one-third of the reported damage. Perennial and tuber crops exhibited high crop raider species richness, whereas a small number of crop raider species dominated short-cycle crops. Hill numbers and dominance indices confirmed these imbalances. Multivariate analyses revealed a coherent structuring of crop raider communities according to crop typology, with distinct functional groupings. These findings highlight the importance of differentiated agroecological management approaches tailored to the ecological specificities of both crops and crop-raider species.

Keywords Ecological structuring, Crop raider species diversity, Human–wildlife conflict, Multivariate analysis, Protected area buffer zones.

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INTRODUCTION

Interactions between wildlife and agricultural systems represent a major challenge in transitional zones between protected areas and cultivated lands. In West Africa, increasing pressure on natural resources, combined with the expansion of agricultural land, intensifies conflicts between humans and wild animals (Lamarque *et al.* 2009, Zumo 2024). These conflicts often manifest as crop depredation, affecting food security, rural household incomes, and biodiversity conservation (Linkie *et al.* 2007, Nyhus 2016).

Mont Sangbé National Park, located in the Man region of Côte d'Ivoire, exemplifies this dynamic. Surrounded by a densely populated and intensively cultivated buffer zone, the park hosts a diverse fauna that frequently interacts with both subsistence and commercial crops (Assui *et al.* 2023, Koffi *et al.* 2024, 2025).

A detailed understanding of the composition, diversity, and ecological structuring of crop raider communities is essential for developing appropriate agroecological management strategies. Ecological approaches based on diversity indices and multivariate analyses enable the characterization of faunal dynamics and the identification of the most vulnerable crops (Jost 2006, Legendre and Legendre 2012, Magurran 2021).

Despite the growing importance of wildlife-agriculture conflicts in buffer zones of protected areas, few studies have systematically quantified crop raider diversity and its ecological structuring across crop types. The lack of integrated data on species dominance, richness, and inter-crop dissimilarity limits the implementation of effective and differentiated management strategies. It is therefore crucial to identify the most harmful species, understand their distribution across crop types, and assess the complexity of faunal assemblages to guide sustainable agricultural practices.

This study seeks to characterize the composition, diversity, and structure of crop raider communities in the buffer zone of Mont Sangbé National Park, located in Western Côte d'Ivoire. The primary objective is to identify the most prevalent crop-raider species and the crops that are most susceptible to wildlife damage, considering the significant interactions between wildlife and agricultural systems. Specifically, the study aims to: Assess the species richness of crop raiders in relation to different crop types, quantify the ecological diversity of crop raider communities using robust indices ; analyze the relative dominance of harmful species associated with various crops and explore the multivariate structuring of faunal assemblages to illuminate ecological relationships and functional gradients among crops. These objectives will enhance our understanding of faunal dynamics in agricultural landscapes and inform the development of agroecological management strategies tailored to local conditions.

MATERIALS AND METHODS

Study site

The study was conducted in the buffer zone of Mont Sangbé National Park, located in the Man region in Western Côte d'Ivoire. Classified in 1976, the park spans 95,000 hectares and harbors remarkable biodiversity. It is surrounded by a 200,000-hectare inhabited buffer zone, where four ethnic groups (Yacouba, Toura, Mahou, Worodougou) coexist alongside a mosaic of subsistence and commercial crops. The research was carried out in rural areas surrounding Mont Sangbé National Park, a region where human–wildlife conflicts are particularly frequent (Koffi *et al.* 2024). The target population for this study consisted of 120 farming households, randomly selected from three villages around the park: Toulo (40 households), Sorotonan (40 households), and Kokialo (40 households), as illustrated in Fig. 1.

Data collection

Between February and April 2022, data were gathered through semi-structured interviews with farming household heads, complemented by field observations and consultations with technical agents from the Ivorian Office of Parks and Reserves (OIPR). Farmers listed crops affected by wildlife and identified the species responsible for crop raiding. Each crop was treated as a separate plot, and crop raider occurrence was defined as the number of species recorded per crop (Athya 2021, Wenda-Piesik and Piesik 2021). This method ensured an accurate representation of crop raider diversity and distribution. Species identification was validated through direct observation and expert input from OIPR agents, using morphological description guides (Kingdon *et al.* 2013, 2024, Kingdon and Happold 2024, Urban *et al.* 2020).

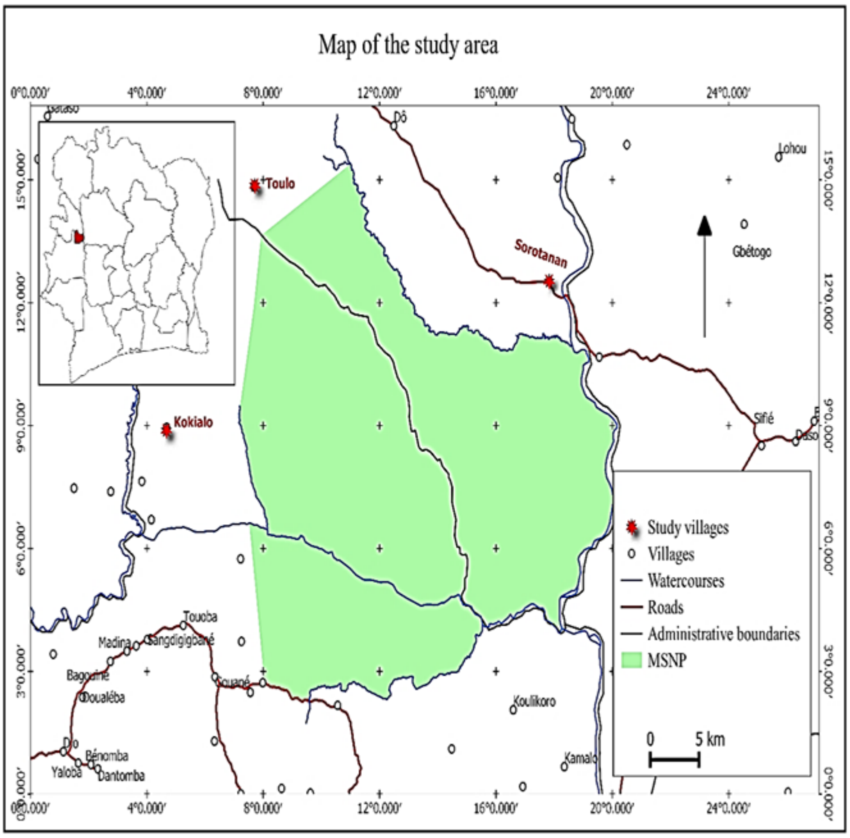

Fig. 1. The location of the study villages.

Data analysis

Relative frequency and species richness

The relative frequency of each crop raider species was calculated as its total abundance across all crops divided by the overall abundance of all recorded species, expressed as a percentage to indicate its ecological dominance. Species richness per crop type was determined by aggregating occurrence data and counting distinct taxa per crop using the specnumber function from the vegan package in R (version 4.4.3) (Dixon 2003, Oksanen *et al.* 2013). Relative frequencies were visualized using horizontal bar charts, and species richness was visualized using vertical bar charts to highlight diversity across crop types.

Crop raider diversity assessment using ecological indices

Assessing crop raider diversity requires ecological metrics that consider both species richness and the distribution of abundance. The Shannon index (H′) quantifies community entropy by integrating these two components, reflecting the uncertainty of randomly selecting an individual from the dataset (Shannon and Weaver 1949). The formula defines it:

$$H' = -\sum_{(i=1)}^{S} P_i \ln (P_i)$$

Where, pi is the proportion of crop raiders belonging to species i and S is the total number of crop raider species. A high value of H′ indicates a rich and evenly distributed crop raider community, whereas a low value reflects strong dominance or low diversity.

Pielou's evenness index (J′), based on the Shannon index, quantifies how evenly individuals are distributed across species by normalizing entropies with species richness (Chugani 2025). It is calculated as follows:

$$J' = \frac{H'}{\ln(S)}$$

Where, H′ represents the Shannon diversity index, while S denotes the richness of crop raider species. The value of J′ ranges from 0 to 1, a value approaching 1 suggests that individuals are evenly distributed among the crop raider species, whereas a value close to 0 indicates a strong dominance by one or a few species.

The Simpson index (D) estimates the likelihood that two randomly chosen individuals belong to different species, emphasizing the dominance of abundant taxa (Suf 2025). The formula defines it :

$$D = 1 - \sum_{i=1}^{S} P_i^2$$

Where, p_i is the proportion of individuals belonging to crop raider species i. The higher the value of D, the greater the diversity. Unlike the Shannon index, the Simpson index is less sensitive to rare crop raider species and places greater emphasis on the dominance of the most abundant crop raider species.

Additionally, A dominance index was computed for each crop as the ratio of the most abundant species to the total species abundance, revealing imbalances and resource monopolization. High values indicate strong dominance, while low values suggest a more evenly balanced community. The mathematical formula for the dominance index, as defined in your text, is as follows:

$$D = \frac{N_{max}}{N_{total}}$$

Where, D is the dominance index, N_{max} is the abundance of the most represented crop raider species in a given crop, and N_{total} is the total abundance of all crop raider species observed on that crop. If D = 1, it indicates that a single crop raider species overwhelmingly dominates the community. If D is low (close to 0), it reflects a more balanced distribution among crop raider species.

Finally, to compare crop raider community alpha diversity across crops, Hill numbers were calculated for orders q = 0, 1 and 2, representing species richness, Shannon-based diversity, and Simpson-weighted diversity. These indices express diversity as the effective number of species, enabling intuitive comparisons of community structure (Alberdi and Gilbert 2019, Chao *et al.* 2014). Below are the mathematical formulas for Hill numbers at orders q = 0, q = 1, and q = 2, which enable alpha diversity comparisons across communities:

—Hill number of order 0 (species richness)

$$^{0}D = S$$

Where, S is the total number of crop raider species present (species richness). This measure accounts only for presence/absence and does not consider the abundances of crop raider species.

—Hill number of order 1 (effective diversity based on Shannon)

$$^{1}D = \exp\left(-\sum_{i=1}^{S} p_i \ln(p_i)\right)$$

Where, p_i is the proportion of individuals belonging to crop raider species i. This value is the exponential of the Shannon index, making it interpretable as the effective number of equally abundant crop raider species.

—Hill number of order 2 (weighted diversity based on Simpson)

$$^{2}D = \frac{1}{\sum_{i=1}^{S} p_i^2}$$

This value is the inverse of the Simpson index and reflects diversity while accounting for the dominance of the most abundant crop raider species.

Diversity indices were calculated for each crop using abundance data and R (version 4.4.3). Classical indices (Shannon, Simpson, Pielou) were estimated using the vegan package, while Hill numbers for orders q = 0, 1 and 2 were calculated with the hill R package.

Vertical bar charts were used to show variations in taxonomic diversity across crop types. Dominance indices were also visualized to highlight imbalances in species distribution. Hill numbers were summarized in a comparative chart, distinguishing the three diversity orders and enabling cross-crop comparisons of crop raider community structure.

Multivariate analysis of crop raider community structure

Bray–Curtis distances were utilized to evaluate ecological dissimilarity among crop types, as they account for both species presence and relative abundance (Suf 2025). A heatmap illustrating these distances was created using the pheatmap function in R (version 4.4.3), incorporating average hierarchical clustering to group crops based on similarity. To delve deeper into ecological relationships, various ordination methods were employed, including Principal Coordinates Analysis (PCoA), which translates Bray–Curtis distances into principal axes, thereby unveiling patterns in faunal assemblages (Biology Insights 2025, Zelený 2021). Non-metric Multidimensional Scaling (NMDS) provides a flexible, rank-based visualization of dissimilarities, eliminating the need for linearity assumptions (Zelený 2021). Additionally, Principal Component Analysis (PCA) was applied to Hellinger-transformed data to mitigate the influence of rare species and emphasize significant ecological gradients (Legendre and Gallagher 2001). Collectively, these multivariate techniques provide a comprehensive and integrated perspective on crop raider community structure, thereby enhancing functional interpretations of crop–crop raider interactions.

RESULTS

Crop raider species frequency and impact on crops

We recorded 991 cases of crop damage attributed to crop raiders. Analysis of the 991 crop raider-related crop damage cases reveals a strong dominance by a few key species (Fig. 2). The patas monkey (*Erythrocebus patas*, Schreber 1774) (19.2%) and the grass cutter (*Thryonomys swinderianus*, Temminck 1827) (17.2%) together account for over one-third of incidents, making them the primary disturbance agents. These are followed by the red-headed quelea (*Quelea erythrops*, Hartlaub 1848) (10.4%) and the striped ground squirrel (*Xerus erythropus*, E. Geoffroy 1817) (8.5%), which also make significant contributions. Secondary species such as the green-bush squirrel (*Paraxerus poensis*, A. Smith 1830) (7.3%), the African savanna hare (*Lepus victoriae*, Thomas 1893) (5.8%), and the double-spurred francolin (*Francolinus bicalcaratus*, Linnaeus 1766) (5.6%) play a notable but lesser role. Intermediate taxa, including the northern giant pouched rat (*Cricetomys gambianus*, Waterhouse 1840), the warthog (*Phacochoerus africanus*, Gmelin 1788), and Maxwell's duiker (*Philantomba maxwellii*, C. H. Smith 1827), show lower frequencies (0.8%–4%). Rare species, such as the olive baboon (*Papio anubis*, Lesson 1827) and the pied crow (*Corvus albus*, Müller 1776), represent less than 0.3% of cases. Overall, crop damage is largely driven by gregarious, large-bodied species, especially rodents and primates, whose social and feeding behaviors intensify their impact.

Variation in crop raider alpha diversity across crop types

Crop raider species diversity varies significantly across different crop types. Perennial and tuber crops, such as cashew (with 18 species), cassava, and cocoa (with 12 species each), show high species richness, attracting a wide range of opportunistic crop raiders (Fig. 3). Maize and rice exhibit moderate diversity (11 species), while coffee and yams host 7 and 8 species, respectively. In contrast, short-cycle crops like beans (3 species), chili pepper, sweet potato, and sesame (4 species each) are less affected. These differences are linked to crop cycle duration, structural complexity, and permanence, which influence resource availability. Stable or complex systems tend to support greater crop raider diversity, whereas temporary or intensive crops limit the long-term establishment of crop raiders.

Ecological diversity of crop raider communities across crops

Diversity indices reveal significant variation in crop raider community structure across crop types (Fig. 4).

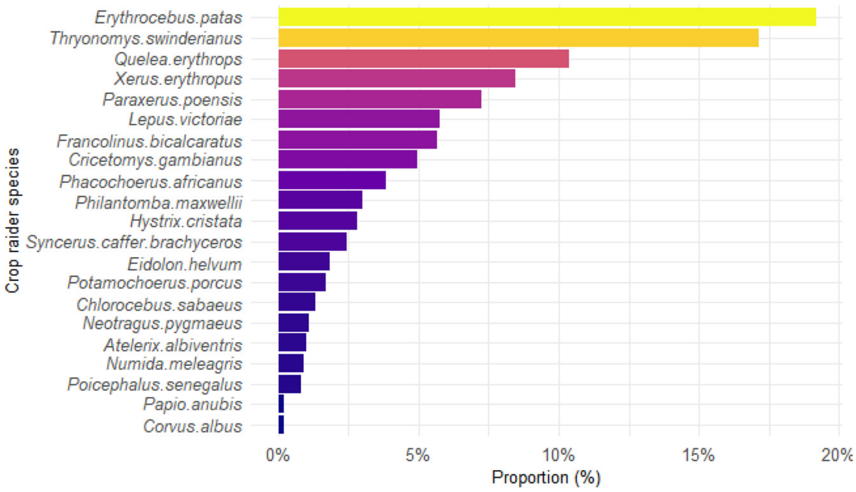

Fig. 2. Relative frequency of crop raider species.

The Shannon index (H′) is highest in cashew orchards (H′ = 2.256), indicating high diversity and evenness. Cassava (H′ = 1.955) and maize (H′ = 1.950) also show substantial diversity, while sesame (H′ = 1.074) and beans (H′ = 1.099) reflect strong dominance by a few species. The Simpson index (D) supports this pattern: Cashew (D = 0.8631), cassava and maize (D = 0.80) show high diversity, whereas sesame (D = 0.5625), chili pepper, and legumes display lower values, indicating dominance by a few taxa. Pielou's evenness index (J′) highlights distribution balance. Beans reach perfect evenness (J′ = 1) despite low richness, while rice (J′ = 0.66) shows the greatest imbalance. Tuber crops, cocoa and chili pepper exhibit intermediate values, suggesting more balanced crop raider distributions. Overall, perennial and structurally complex crops support more diverse and evenly distributed crop raider communities, whereas short-cycle or specialized crops concentrate crop raider pressure on a few dominant species.

Multidimensional crop raider diversity across crops: Insights from hill numbers

Hill numbers offer a comprehensive view of crop raider diversity through three metrics: Species

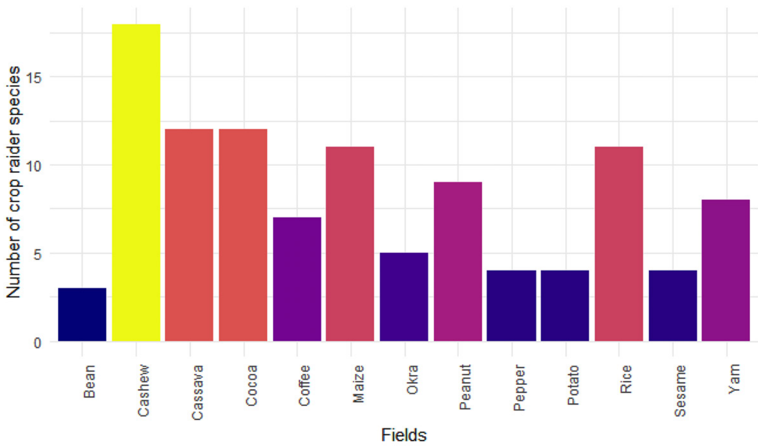

Fig. 3. Alpha richness per field.

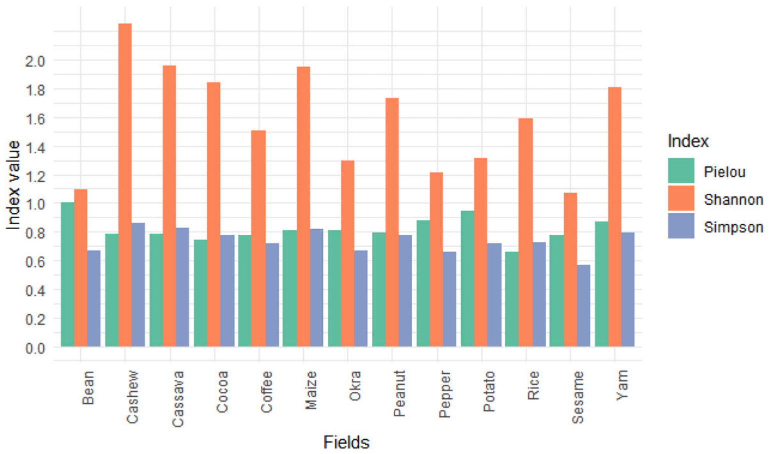

Fig. 4. Diversity indices by field.

richness ($Hill_0$), effective diversity ($Hill_1$), and dominance-weighted diversity ($Hill_2$) (Fig. 5). Beans show perfect evenness, with identical values across all indices ($Hill_0 = Hill_1 = Hill_2 = 3$), indicating a uniform crop raider distribution. In contrast, sesame ($Hill_0 = 4$, $Hill_2 = 2.29$) reflects strong dominance by a few species. Cashew, despite high richness ($Hill_0 = 18$), shows reduced effective diversity ($Hill_1 = 9.55$) and notable dominance ($Hill_2 = 7.31$), suggesting an unbalanced community. Intermediate crops, such as cassava, cocoa and yams, display a gradual decline from $Hill_0$ to $Hill_2$, indicating moderate dominance. Cereals (maize, rice) and coffee follow similar patterns, with $Hill_1$ values about one-third lower than $Hill_0$. The gap between $Hill_0$ and $Hill_2$ serves as a key indicator of dominance. Crops with small gaps (e.g., beans, sweet potatoes) exhibit greater ecological resilience, while those with large gaps (e.g., cashews, sesame) may require targeted crop raider management to reduce dominance and promote agroecological balance.

Species-specific dominance across crops

Crop raider dominance varies widely across crop types. Sesame shows the highest concentration of damage from a single species (62.5%), followed by okra and chili pepper (50%), indicating strong crop

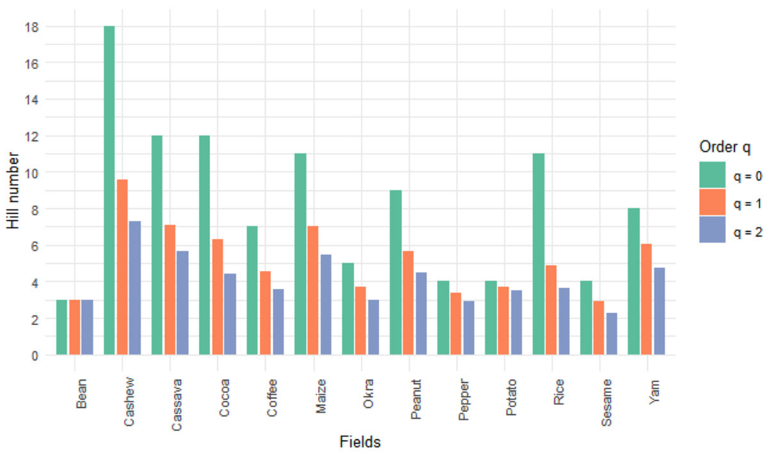

Fig. 5. Comparison of Hill numbers by order q.

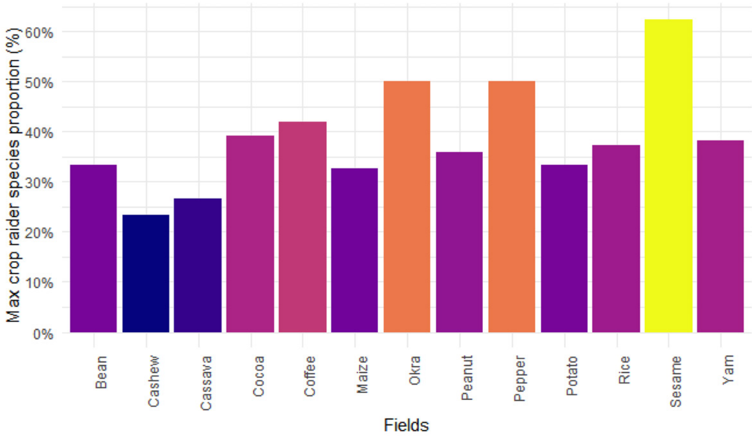

Fig. 6. Dominant species proportion by field.

raider specialization (Fig. 6). Coffee (41.9%) and cocoa (39.1%) also exhibit high dominance, though less extreme. Cassava (26.5%) and cocoa trees (23.3%) display more balanced crop raider distributions, suggesting greater functional diversity. Cereals, such as rice (37.4%) and maize (32.7%), along with yams (38.2%), exhibit moderate dominance levels. These disparities reflect the specialization capacity of certain crop raiders and have direct implications for crop-specific management strategies.

Multivariate structuring of crop raider communities

Crop raider community dissimilarity across crops (bray–curtis analysis)

Bray–Curtis dissimilarity analysis reveals strong variation in crop raider community composition across crops (Fig. 7). Beans show the highest dissimilarity with all other crops (≥ 0.977), indicating a highly distinct crop raider assemblage. In contrast, cassava and maize are the most similar (0.538), suggesting shared dominant species. Moderate similarities are observed between coffee and yam (0.600) and cassava and yam (0.682). The okra–pepper pair (0.417) forms the most homogeneous group. Conversely,

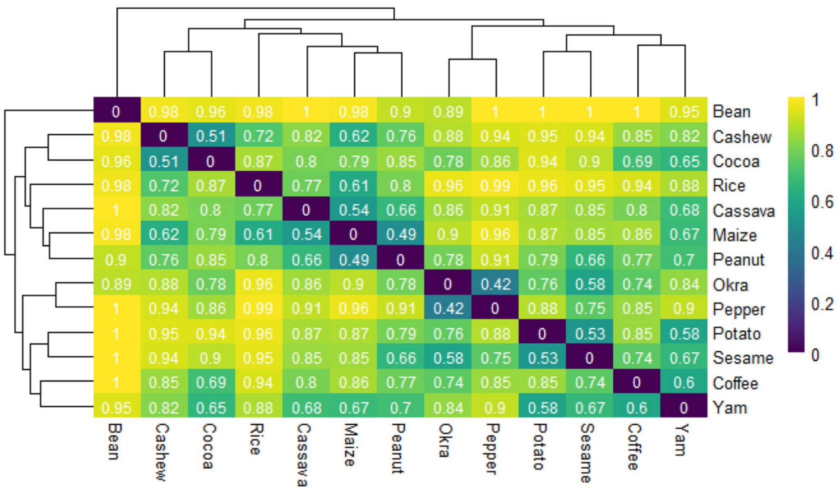

Fig. 7. Heatmap de bray–curtis.

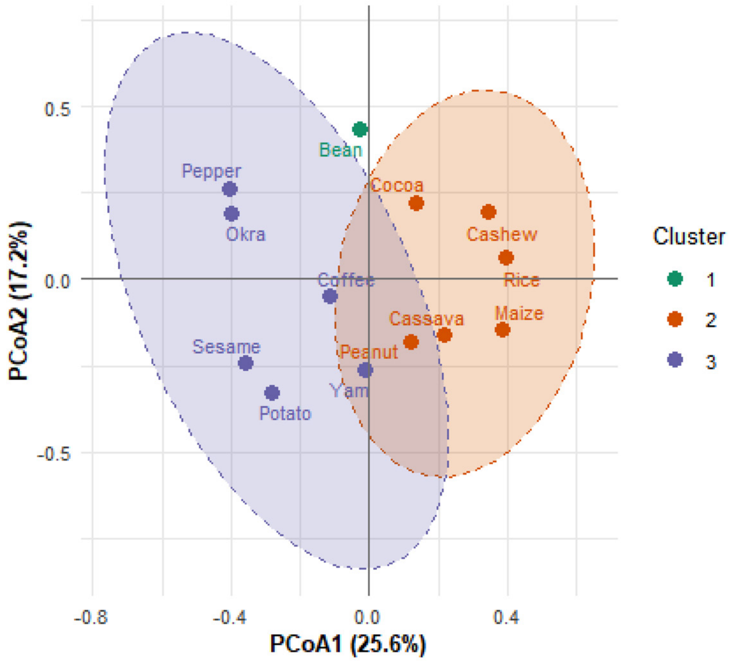

Fig. 8. PCoA (bray–curtis) with hierarchical clustering.

pairs like rice–pepper (0.987) and cashew–pepper (0.940) reflect highly distinct communities. These patterns underscore the need for crop-specific crop raider management in highly diverse systems, as well as shared strategies for ecologically similar crops.

Comparing PCoA and NMDS: Robust insights into crop raider community structure

PCoA and NMDS ordinations, employing Bray–Curtis distances, reveal consistent patterns in crop raider community structures across various crops, despite the differing algorithms used—PCoA being linear and variance-based, and NMDS being non-metric and rank-based. PCoA accounts for 42.8% of the cumulative variance and identifies three distinct crop groups: Cereals and tubers (including maize, rice and yams), legumes and perennials (such as beans, cashew, cocoa and coffee), and fruiting solanaceous crops (like okra and pepper) (Fig. 8). NMDS supports this structure,

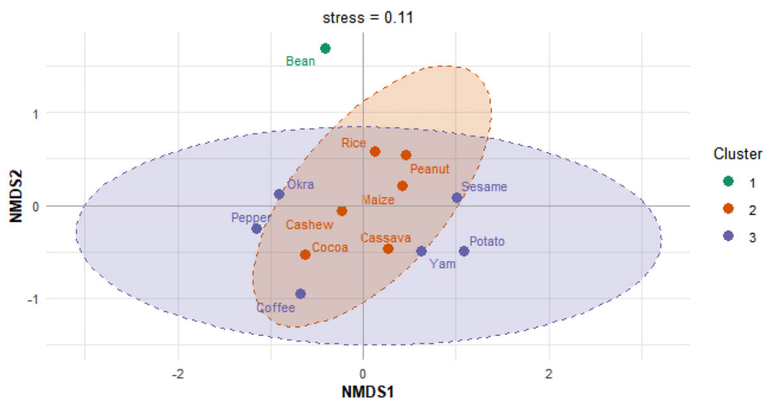

Fig. 9. NMDS (bray–curtis) with hierarchical clustering.

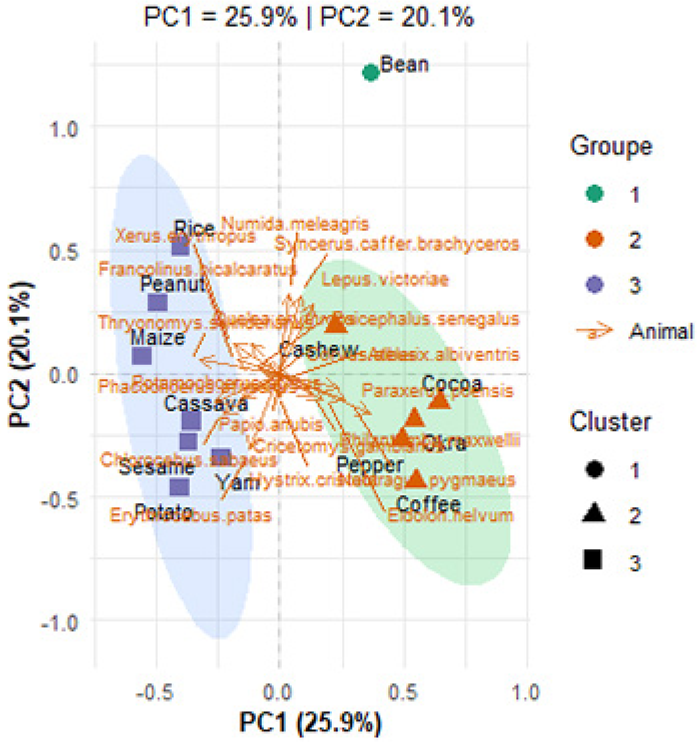

Fig. 10. PCA biplot: Crops vs crop raider species and field clusters.

with NMDS1 differentiating between solanaceous and perennial crops, as well as cereals and tubers, while NMDS2 isolates beans, highlighting its unique crop raider profile (Fig. 9). The convergence of these two methods enhances the reliability of the findings and underscores crop functional typology as a critical determinant of crop raider composition. This consistency advocates customized crop raider management strategies, suggesting general approaches for similar crops and specific methods for ecologically distinct varieties, such as beans.

Crop–crop raider interactions revealed by PCA

Principal Component Analysis (PCA) based on Hellinger-transformed data reveals structured interactions between crops and crop raider species (Fig. 10). The first two principal components explain 46.0% of the variance, providing strong ecological insight. Axis 1 separates tuber and cereal crops (cassava, maize, peanut, potato, rice, sesame, yam), associated with crop raiders like the grass cutter, the warthog and the green monkey (*Chlorocebus sabaeus*, Linnaeus 1766) from legumes and perennials (bean, cashew, cocoa, coffee, okra, pepper), linked to Maxwell's duiker, the green-bush squirrel, and The straw-colored fruit bat (*Eidolon helvum*, Kerr 1792). This reflects distinct trophic preferences. Axis 2 highlights beans as ecologically unique, dominated by the royal antelope (*Neotragus pygmaeus*, Linnaeus 1758), while crops like potatoes, coffee and yams show associations with generalist species (the olive baboon, the pied crow). The formation of two main clusters supports the idea that crop functional typology, cereals, tubers, legumes and perennials, is the key driver of crop raider composition. This structuring suggests that shared management strategies may be effective within crop groups, while specialized approaches are necessary for outliers, such as beans.

DISCUSSION

Analysis of agricultural crop raider community composition reveals a strong dominance by a few key species, notably the patas monkey and the grass cutter, which together account for over one-third of recorded cases. These two species, a gregarious primate and a large rodent, are known for their social behavior and mobility, which facilitate repeated and widespread incursions into cultivated areas (Akinola *et al.* 2015, De Jong and Butynski 2020). Their impact is amplified by their opportunistic exploitation of agricultural resources, particularly in orchards and perennial plantations.

Granivorous birds such as the red-headed quelea also play a significant role, especially in cereal crops. Colonies of Quelea, sometimes numbering in the millions, can cause massive losses in a very short time (McWilliam and Cheke 2004). Other species, such as the striped ground squirrel, the green-bush squirrel, and the double-spurred francolin, contribute to damage in a more localized manner, often targeting seedlings or tubers, reflecting the functional diversity within the crop raider community (Key 1990, Owolabi and Akinpelu 2020).

Species richness among crop raiders varies significantly across crop types. Perennial and tuberous crops such as cashew, cassava and cocoa host high alpha diversity, with up to 18 crop raider species recorded for cashew. This richness is attributed to the structural complexity and permanence of these agricultural systems, which offer varied and stable ecological niches (Magurran 2005, Tilman 1999). In contrast, short-cycle crops like beans and sesame attract fewer crop raider species but exhibit high species dominance, suggesting extreme specialization among certain crop raiders.

Biodiversity indices confirm these trends. The Shannon index reaches its highest value in cashew orchards, indicating high crop raider species diversity and relatively even distribution. Cassava and maize follow with similar values, while sesame and bean show the lowest values, reflecting strong dominance (Chao *et al.* 2014, Whittaker 1972). The Simpson index and Pielou's evenness corroborate these observations, highlighting a more balanced distribution of crop raider species in complex agricultural systems.

Hill numbers provide additional insight into the crop raider community structure. Bean illustrates perfect evenness, whereas sesame shows a significant loss in effective diversity, indicating marked dominance by a few crop raider species. Cashew, despite its high species richness, exhibits reduced effective diversity, suggesting an unbalanced crop raider community (Chao *et al.* 2014, Jost 2006). These discrepancies between indices serve as relevant indicators for assessing crop ecological resilience and guiding management strategies.

Multivariate structuring of crop raider communities, analyzed using Bray–Curtis dissimilarity, reveals strong heterogeneity among crops. Bean stands out with maximal dissimilarity from all other crops ($\geq$ 0.977), indicating a nearly exclusive crop raider community. Conversely, cassava and maize share dominant crop raider species, suggesting ecological similarities that could be leveraged for joint control strategies (Anderson *et al.* 2011, Legendre and Legendre 2012).

Ordination analyses (PCoA, NMDS) confirm the robustness of observed groupings. Three major clusters emerge: Cereals and tubers, legumes and perennials, and fruiting solanaceous crops. This functional structuring aligns with the trophic preferences of crop raiders and validates the use of these methods to inform control strategies (Clarke and Warwick 2001, Gotelli and Ellison 2004).

Finally, Principal Component Analysis (PCA) based on the Hellinger transformation highlights a clear distinction between tuber and cereal crops, associated with generalist crop raiders, and perennial and leguminous crops, which are targeted by more specialized species. This joint structuring of crops and crop raiders suggests that functional crop typology is the main determinant of crop raider community composition.

CONCLUSION

This study highlights the complexity and fine-scale structuring of crop raider communities within tropical agricultural systems. The results show that crop damage is predominantly caused by gregarious and large-bodied species, whose social and feeding behaviors amplify their impact on cultivated areas. Species richness varies significantly across crop types, with higher diversity observed in perennial and tuberous cropping systems, reflecting their ecological attractiveness. Biodiversity indices (Shannon, Simpson, Pielou, Hill) reveal contrasting dynamics between crops with high species dominance and those with more balanced distributions, underscoring the importance of vegetative structure and crop cycle in regulating crop raider communities. Multivariate analyses confirm that the functional typology of crops is the primary determinant of crop raider species composition, with coherent groupings among cereals, legumes, tubers, and solanaceous crops. These findings offer concrete perspectives for agroecological crop raider management: Crops sharing similar faunal crop raider assemblages may benefit from joint control strategies, while ecologically isolated crops, such as bean, require targeted approaches. By integrating ecological, statistical and functional dimensions, this study contributes to a deeper understanding of the interactions between harmful biodiversity and agricultural systems, paving the way for sustainable and differentiated management practices.

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