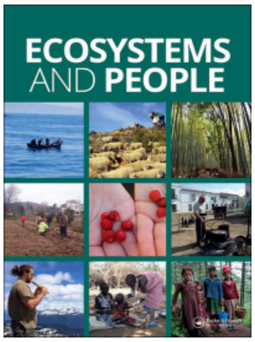

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Contrasting luxury effect on urban plant phylogenetic and taxonomic diversity in West African cities

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ABSTRACT

Urbanization is a driving factor for biodiversity loss and potential climate change by reducing carbon stocks. Understanding how urban development, as mitigated by socio-economic factors alters urban biodiversity is crucial for effective urban planning that maintains or improves environmental resilience. The luxury effect hypothesis predicts that wealthier parts of a city will have higher levels of biodiversity. This effect has been tested widely but we still have limited understanding of how wealth influences urban biodiversity in tropical regions of developing countries where plant species play profound sociocultural roles beyond aesthetics. This study investigates links between household income and the diversity of cultivated plants distribution within neighborhoods of two growing cities in Benin. We conducted a survey of 936 randomly selected households to record their socioeconomic characteristics and survey the cultivated plant species found in household gardens'. This enabled us to estimate household-level diversity metrics including taxonomic diversity and phylogenetic diversity. We found no global support for the luxury effect on phylogenetic diversity but rented properties had lower plant taxonomic diversity along with less phylogenetic diversity than privately owned houses. Taxonomic diversity is higher in the less urbanized areas while phylogenetic diversity is weakened. Household's cultural connection to plants has a negative effect on both diversity indices. Our results highlight the complex relationships between socioeconomic traits and urban plant diversity distribution in two tropical African cities, which only partly confirmed the luxury effect hypothesis. Disentangling these complex relationships can help city planners and policymakers to take informed decisions to promote sustainable cities.

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Introduction

Urbanization is locally intensifying effects of climate change such as increased temperature due to high levels of soils sealing, reduced air circulation due to buildings acting as barriers and the resulting urban heat island effect (Fokaides et al. 2016). This highlights the importance of urban vegetation for heat mitigation. To ensure that the heat mitigation potential of vegetation within cities can be maintained in the future, a diverse species composition is beneficial as it reduces the risk of vegetation loss due to diseases or stress induced due to weather extremes (Jamei et al. 2019; Djikpo et al. 2023). Therefore, there is a growing consensus among researchers that promoting biodiversity in urban areas is essential for maintaining healthy and sustainable urban ecosystems and related ecosystem services (Avolio et al. 2015; Behera et al. 2022). However, the factors that explain differences in biodiversity patterns within cities is so far not fully understood. One suspected driver is the social and economic status of the inhabitants of a city district. It has been observed that income inequality between urban residents is a major social and economic issue that has far-reaching implications for various aspects of human life, including health, education, and access to resources (Wilkinson and Pickett 2006; Saez and Zucman 2016). According to earlier studies, income inequality can also have significant impacts on urban biodiversity (Hope et al. 2008; Kuras et al. 2020). The relationship between income and urban biodiversity is complex and multifaceted, and has been studied for more than two decades (Hope et al. 2003; Chamberlain et al. 2019; Li et al. 2019; Blanchette et al. 2021; Danquah et al. 2023).

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Mean household income can be a strong predictor of biodiversity as well as an important proxy for other socioeconomic characteristics (Kuruneri-Chitepo and Shackleton 2011; Leong et al. 2018; Chamberlain et al. 2019). The luxury effect hypothesis suggests that households with higher income are more likely to have a higher biodiversity within their residences (Hope et al. 2003). The luxury effect has undergone extensive testing but was rarely tested in tropical regions of developing countries. This limits our ability to generalize the conclusions drawn for other parts of the world (Chamberlain et al. 2020). Most tests of the hypothesis used data from cities in industrialized nations where high level of urbanization can limit various mechanisms of species assembly and people's direct use of urban plants is often limited to aesthetics. It can be assumed that in the developing regions, where plant species hold significant socio-cultural significance beyond just their aesthetic value, the relationship between income and plant species diversity may differ from the findings for industrialized nations, which however, were also not uniform (Threlfall et al. 2022).

While, studies have suggested that higher-income neighborhoods tend to have higher levels of biodiversity (Hope et al. 2003; Bigirimana et al. 2012; Clarke et al. 2013; Methorst et al. 2021), others have found no significant relationship between income and biodiversity (Howes and Reynolds 2021). Padullés Cubino et al. (2019) highlighted that, there is no apparent effect of socioeconomic variables on taxonomic diversity in private yards. Besides, the outcome of the test of the luxury effect can be affected by the metrics used to assess urban biodiversity (Hess et al. 2006; Schmera et al. 2017). While taxonomic diversity is one commonly used metric, some researchers argue that functional diversity, which considers the functional traits of species (Petchey and Gaston 2006; Schmera et al. 2017) rather than just their taxonomic identity, may be a better indicator of ecosystem health and resilience in urban areas. For instance, species richness or taxonomic diversity does not take into account the relative abundance of each species, and is therefore not a reliable indicator for the overall diversity of an ecosystem and its services.

Taxonomic diversity alone may not fully represent ecosystem health or function (Soliveres et al., 2016). For instance, diverse ecosystem could still be unstable if it consists of non-native or disrupted species. Functional diversity metrics, more directly linked to ecosystem functioning, can supplement taxonomic diversity (Feld et al. 2014). However, data on functional diversity, especially for rare species, is often lacking. Many floras, particularly from under-researched regions, are underrepresented in studies, skewing our understanding towards the global North. Studying these underrepresented areas can reveal unique socio-cultural plant species meanings and improve our grasp of biodiversity-income relationships. Phylogenetic diversity serves as a proxy for functional diversity (Cadotte et al. 2012; Gerhold et al. 2015; Lososová et al. 2016; Schmera et al. 2017). It reflects evolutionary histories and relationships, offering insights into biodiversity patterns and the conservation value of evolutionarily distinct species (Faith 1992; Diniz-Filho et al. 2010). In urban planning, enhancing phylogenetic diversity by planting species with varied evolutionary histories can increase ecological resilience (Zhu et al. 2019). Balancing phylogenetic diversity with the luxury effect can lead to more resilient and diverse urban ecosystems (Lerman et al. 2023).

Overall, studies on urban biodiversity in Africa are rare. The limited evidence available is mainly focused on alien species in urban settings and the role of gender, age and income. For example, Bigirimana et al. (2012) showed the functional importance of urban gardens in providing shelter for native urban vegetation although they are also sources of alien species in Bujumbura, Burundi. Kuruneri-Chitepo and Shackleton (2011) reported higher density and species diversity in wealthy areas and lower in low-income districts of Eastern Cape, South Africa. In Anderson et al. (2020), the study reveals a significant ecological gradient in the City of Cape Town, with wealthier communities experiencing greater biodiversity, plant diversity, and ecosystem services, while poorer communities face limitations in green space and exhibit lower plant and trait diversity. The results underscore persistent environmental injustice in the city, mirroring historical apartheid planning. Furthermore, in Niger, commercial gardens on the outskirts of the city of Niamey that are managed by affluent, elderly gardeners with big families and a steady non-farming income had the greatest variety and abundance of plant species, particularly indigenous and long-lived species (Bernholt et al. 2009). However, these rare studies in Africa do not provide a direct and robust test of the Luxury effect. In contrast, it can be hypothesized that in urban areas in developing countries, contrary to the luxury effect, it may be more likely to find that poorer residents, who are more likely to use a diversity of plant species directly for their livelihood (medicine, food and culture), maintain a higher density and diversity of plants in their gardens (Bigirimana et al. 2012).

In this study, we provide a direct test of the luxury effect hypothesis and alternative hypothesis that poorer residents maintain a higher diversity of plants in their gardens, comparing two major growing but contrasted cities in West Africa. We investigated the effect of urban household's income on urban plant species diversity in different neighborhoods. To address the limitations related to the choice of the metrics of biodiversity, we used and compared two metrics representing plant taxonomic and phylogenetic diversity. The richness and diversity of urban plants, within this framework, are pivotal to biodiversity assessment. Urban plants contribute significantly to taxonomic diversity through the inclusion of native and adapted non-native species, increasing the species richness of a locale (Vigouroux et al. 2011). Furthermore, the incorporation of species from diverse evolutionary lineages enhances phylogenetic diversity, illustrating a broader spectrum of life's history (Schlaepfer et al. 2020). Such diversity among urban plants is crucial for sustaining local ecosystems, underpinning ecosystem services, and preserving genetic diversity, which, in turn, fosters resilience and adaptability within both human used and natural systems (Delahay et al. 2023). Besides income, we also examined whether ethnicity which is related to different socio-cultural knowledge affects the found biodiversity patterns.

Materials and methods

Study area

The study was conducted in two rapidly urbanizing cities, namely Cotonou (6°20' and 12°25'N) and Parakou (1° and 3°40'E) in the Republic of Benin, West Africa. Cotonou with 780,000 inhabitants is the largest city and the economic capital of Benin. The city is located in the southern coast, and is a major port city and serves as an essential gateway for international trade in the region. The average population density in Cotonou is 121.61 persons/km^2 with a growth rate of 10.1% (United Nations 2019). Cotonou, as an economic hub, attracts both internal and international migration, contributing to its population growth. Most of the socioeconomic activity of Cotonou is concentrated in the key activities of urban agriculture, small and medium-sized businesses, and various forms of trading. Cotonou experiences a tropical savannah climate, with two distinct wet and dry seasons. The city hosts numerous ethnic groups, including the Fon, Adja, Yoruba, and others, contributing to its vibrant cultural mosaic. Regarding land acreage, Cotonou's urban sprawl covers approximately 79 square kilometers. The urban landscape of Cotonou encompasses both modern and traditional elements. The city center features tall commercial buildings, bustling markets, and a wide array of services and amenities. Stepping away from the city center, the urban fabric transitions into residential areas with varying levels of socioeconomic status and infrastructure. The city's location near the coast and the presence of the Atlantic Ocean and several lagoons significantly influence local biodiversity patterns. Additionally, urban green spaces, including parks and gardens, may play a crucial role in supporting biodiversity within neighborhoods.

In contrast, Parakou is the largest city in northern Benin and serves as a key hub for trade, and transportation in the region. Unlike the coastal climate of Cotonou, Parakou experiences a more pronounced savannah climate with a dry season and one rainy season. The population in Parakou is 163,753 with a population density of 339.7 persons/km^2 (United Nations 2019). Parakou, while experiencing some internal migration, primarily sustains a more stable local population. The city is an important northern market town, dating from colonial times in the country. The major economic activities of Parakou are manufacturing, trade and services, which account for nearly 75% of the population (United Nations 2019). This is reinforced by agriculture, which accounts for nearly 16% of the workforce. Parakou, is a melting pot of cultures, with the Bariba, Fulani, and Dendi being some of the prominent ethnic communities, along with other minorities (Pdc 2004). Parakou's urban structure is distinct from that of Cotonou, with a mix of traditional and modern architecture. As a smaller city, Parakou spans around 35 square kilometers. The city center accommodates various commercial activities, while the surrounding neighborhoods consist of residential areas with diverse living conditions. In contrast to the coastal region, Parakou's biodiversity may be influenced by factors such as proximity to forest reserves, agricultural landscapes, and the local land use practices.

Sites selection and data collection

We collected urban plant diversity and socioeconomic data in the two cities using a random sample of 936 households. We used an in-person direct structured questionnaire survey encoded under kobotoolbox, an open-source suite of tools for field data collection (Nampa et al. 2020). The households were chosen from different wards within the urban area. We implemented a categorical approach to measure income, with respondents providing income ranges rather than precise mean income values. This was necessitated by the practical consideration that respondents often expressed mean income within a specified range. The selection of households was carried using road-level random sampling. On each road within the selected neighborhoods, we systematically selected every third house to participate in our study. In addition, only houses with gardens were selected. This approach ensured that households were chosen in a consistent manner, minimizing any potential bias in our sample. Only plant species that were intentionally introduced by humans were included in the study analysis, and they were identified taxonomically, typically at the family, genus, and species levels. This approach allowed us to examine the human-mediated component of biodiversity and its relationship to the luxury effect theory. For each household we estimated plant taxonomic and phylogenetic diversity to capture the variety and contribution of urban plants and the evolutionary relationships among these species in an urban setting. Respondents were queried directly to ascertain whether the plant species observed were spontaneous or intentionally planted. Additionally, ethnicity (to capture ethnic diversity in the city level), building types (straw building, single family house, duplex and high-rise building) as different categories or classifications of buildings based on their design (as an urbanization attribute), and land tenure (rented or ownership house) were collected as additional explanatory variables. Respondent household plot area was recorded and their knowledge about the Urban Heat Island (UHI) effect were also collected as environmental knowledge (Table A4, Supplementary material S2). The study specifically focused on cultivated or planted plant species within each household. These plant surveys were conducted by a team of researchers between January and March 2023.

Estimating species and phylogenetic diversity

We estimated species abundance by recording all plant species within each household plot and counted the number of individuals for each species. We then built a household plot by species abundance matrix where each row represents a specific household plot while each column corresponds to the recorded species from our survey (Swenson et al. 2012). We estimated Chao1 diversity as a metric of taxonomic diversity. This index estimates the total species in a community, emphasizing true diversity, especially for less common species. Sample size and species distribution influence its reliability (Chao et al. 2014). Chao1 was computed with the "estimateR" function in the "vegan" package (Oksanen et al. 2022), using a species-abundance matrix at the household level. To estimate phylogenetic diversity (PDI), the V.PhyloMaker2 package (Jin and Qian 2022) was used to prune the mega phylogeny of the tree of life to fit the species-abundance matrix of the recorded plant species at the household level. Based on the phylogenetic tree, phylogenetic diversity was computed using "picante" package (Kembel et al. 2010) applying the "phylo.maker" function in R, version 4.2.3 (R Core Team 2023).

Statistical analysis

We first explored the multicollinearity between the predictor variables using the "check_collinearity" function in the "performance" package (Lüdecke et al. 2021) in R4.2.3 (R Core Team 2023) based on the independent variables PDI and Chao1. The variance inflation factor (VIF) values were below the commonly recommended threshold of 5 (Lüdecke et al. 2021), indicating no substantial collinearity issues among the predictor variables (Fig A2, supplementary material S2). Therefore, all variables initially included in the models remained in the analysis

We developed a general linear mixed effect model using the "nlme" package (Pinheiro & Bates 2000) in R to test for significant effect of socio-economic (mean income, education level, land tenure, and knowledge of the urban heat island), demographic attributes (house size, age, gender of respondents) and urbanization attributes (building types, level of urbanization) on phylogenetic and taxonomic diversity (Table A2, supplementary material S2). District was included as a random effect to account for the non-independence of households within the same district (unknown heterogeneity effects), as multiple households per district may share similar characteristics. Households and socio-economic characteristics, demographic and urbanization attributes were used as fixed factors. Shapiro-Wilk normality test was used to check the for residuals of the best models fit for the Phylogenetic diversity ($W = 0.88$, $p < 0.005$) and for the taxonomic diversity ($W = 0.73$, $p < 0.005$). We developed several candidate models by including interaction terms (Table A3). The most saturated model was selected by iteration-based model convergence. It was observed that model including more than three ways interactions tended to not converge due to singularity. Therefore, the complex model which was identified included two key interactions including mean income and cities, note that here the cities are not just the names of cities but two cities with contrasted traits mainly different in terms of population density, level of urbanization and land size. We then selected the most representative models by performing multi-model inference analyses using the "dredge" function of the "MuMIn" package (Barton 2012). Each model's suitability was assessed based on the Akaike Information Criterion corrected for small sample sizes (AICc), selecting models with ΔAICc <2 as the most plausible (Burnham & Anderson, 2004; Johnson & Omland, 2004). Additionally, considering the disparities in ethnic diversity and contrasting urbanization levels between the two cities, we introduced the cities as a factor to investigate variations in the luxury effect within different urbanization levels. Specifically, we tested the theoretical relevance of the luxury effect and how knowledge of the urban heat island could affect this hypothesis by targeting three-way interactions involving these parameters and controlling for sociodemographic parameters and ecological knowledge of the households. We employed model averaging to integrate multiple models for multi-model inference using the "model.avg" function from the "MuMIn" package (Barton2012). The conditional average of the parameter estimates was reported (Table A1, A2, supplementary material S1), as it provides a balanced representation by accounting for model uncertainty and incorporating model weights. This approach ensures that the results are robust and reliable, reflecting the most supported models in our analysis (Barton 2012).

Results

The results presented here are based on the conditional averages of the best-supported models. This approach allows for a more robust inference by incorporating model uncertainty into the parameter estimates. The parameter estimates reported in our results reflect these conditional averages, providing a comprehensive view of the relationships between the explanatory variables and the diversity metrics.

Relation between socio-demographic traits and plant diversity

The linear mixed-effects models analysis revealed insightful patterns regarding the predictors' significance in predicting both taxonomic and phylogenetic diversity. Our findings indicated that gender, ethnicity, residence time and tenancy were robust predictors significantly shaping both phylogenetic and taxonomic diversity. Male-headed households exhibited lower phylogenetic diversity ($\beta = -0.181 \pm 0.066$, $p = 0.006$, Table A1), and marginally reduced taxonomic diversity compared to female-headed households ($\beta = -0.143 \pm 0.078$, $p = 0.067$, Table A2). Additionally, ethnic groups such as the Dendi (β =-0.515 ± 0.150, $p = 0.001$)), Fon ($\beta = -0.224 \pm 0.118$, $p = 0.056$, Table A2), Goun ($\beta = -0.271 \pm 0.140$, $p = 0.053$, Table A2) and Nago ($\beta = -0.222 \pm 0.131$, $p = 0.091$, Table A2) consistently tended to have lower taxonomic diversity as compared to the reference group, Bariba ethnic groups who has high degree of connection to plant in the studied systems (Figure 1d). Land tenure significantly affected both phylogenetic (Figure 2) diversity and Taxonomic (Figure 3) diversity within neighborhood compound with households under rented properties having lower phylogenetic ($\beta = -0.176 \pm 0.068$, $p = 0.009$, Table A1) and taxonomic diversity ($\beta = -0.197 \pm 0.066$, $p = 0.003$, Table A2) than households under private ownership. We found no significant effect of education levels on both diversity indices (Figures 2, 3).

We also found contrasting effects between taxonomic and phylogenetic diversity. For instance, while household income positively influenced taxonomic diversity ($\beta = 0.289$, $p = 0.027$), its effect on phylogenetic diversity was negligible (Figure 3). Similarly, urbanization significantly increased taxonomic diversity ($\beta = 0.475$, $p = 0.033$) but did not affect phylogenetic diversity (Figure 3). Household that leaves for a long time period in their compounds tended to have a negative phylogenetic diversity of plants in their gardens ($\beta = -0.065 \pm 0.031$, $p = 0.035$, Table A1). Interaction effects, such as those between mean income, levels of education, level of urbanization and Urban heat island knowledge, further influenced both diversity measures (Figure 2), highlighting complex relationships not captured by main effects alone. For instance, higher mean income combined with well educated (university or secondary level of education) households living in less urbanized area tended to exhibit higher taxonomic ($\beta = -0.469 \pm 0.236$, $p = 0.047$, Table A2) diversity with a higher evolutionary history of plant diversity in their yard ($\beta = -0.514 \pm 0.239$, $p = 0.032$, Table A1). Wealthier household with high education levels also spared significantly an increasing cultivated plant phylogenetic diversity ($\beta = -0.237 \pm 0.104$, $p = 0.023$, Table A1, Figure 1a) as well as a marginal significant effect on plant taxonomic diversity they had in their gardens ($\beta = -0.183 \pm 0.103$, $p = 0.076$, Table A2). Conversely, knowledge of urban heat islands interacts with educational attainment, indicating varied impacts on biodiversity metrics across different urbanization levels (Figures 2, 3). While wealthier household in less urbanized area tended to significantly exhibit a marginal increasing of cultivated plant taxonomic diversity in their gardens ($\beta = -0.366 \pm 0.216$, $p = 0.090$, Table A2, Figure 1b), household with positive knowledge of urban heat island negatively influenced the phylogenetic diversity ($\beta = -0.233 \pm 0.097$, $p = 0.016$, Table A1, Figure 1c) as well as the taxonomic diversity of plant they include in their yards ($\beta = -0.334 \pm 0.095$, $p = 0.001$, Table A2, Figure 1d).

Discussion

The study provides no global direct support for the luxury effect hypothesis on the phylogenetic diversity but rented properties had lower plant taxonomic diversity along with less phylogenetic diversity than privately owned houses. This indicates that socio-economic status may not be the primary determinant influencing both types of diversity metrics. Instead, our findings point toward other nuanced socio-demographic factors specific to neighborhoods that could play a more

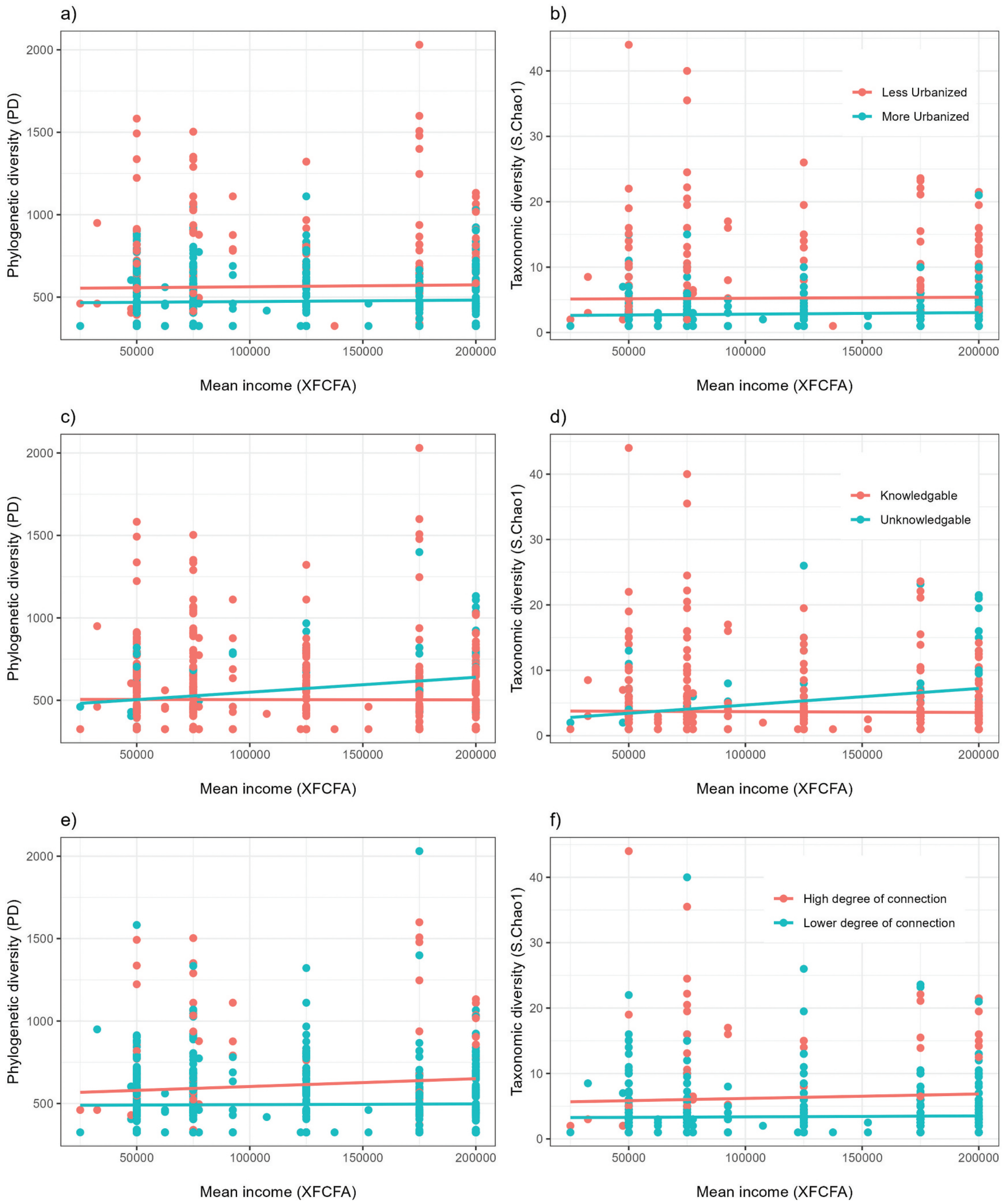

Figure 1. Single interaction of household mean income with level of urbanization (less urbanized standing for and more urbanized standing for) effect on a): phylogenetic diversity (PD) and b): taxonomic diversity (S.chao1); household mean income with knowledge of urban heat island (knowledgeable and unknowledgeable) effect on c): phylogenetic diversity (PD), d): taxonomic diversity (S.chao1); household mean income with degree of connection to plants (lower degree of connection which here stand for ethnic groups that have negative influence on both diversity indexes, high degree of connection which stand for ethnic groups that positively significance on both indexes effect on e): phylogenetic diversity (PD), f): taxonomic diversity (S.chao1).

significant role in shaping these diversity patterns while interacting with the economic status of households.

Drivers of plant diversity in urban settings

Our study highlights the significant influence of various socioeconomic factors on both phylogenetic diversity and taxonomic diversity. These factors include mean income, level of urbanization, education level, gender, ethnicity, land tenure, residence time and the broad knowledge of urban heat island of the respective interviewed households in our study areas. Despite the known “luxury effect”, which links wealth with higher biodiversity (Hope et al. 2003; Chamberlain et al. 2019; Li et al. 2019) due to better resources and knowledge (Grove et al. 2014), we

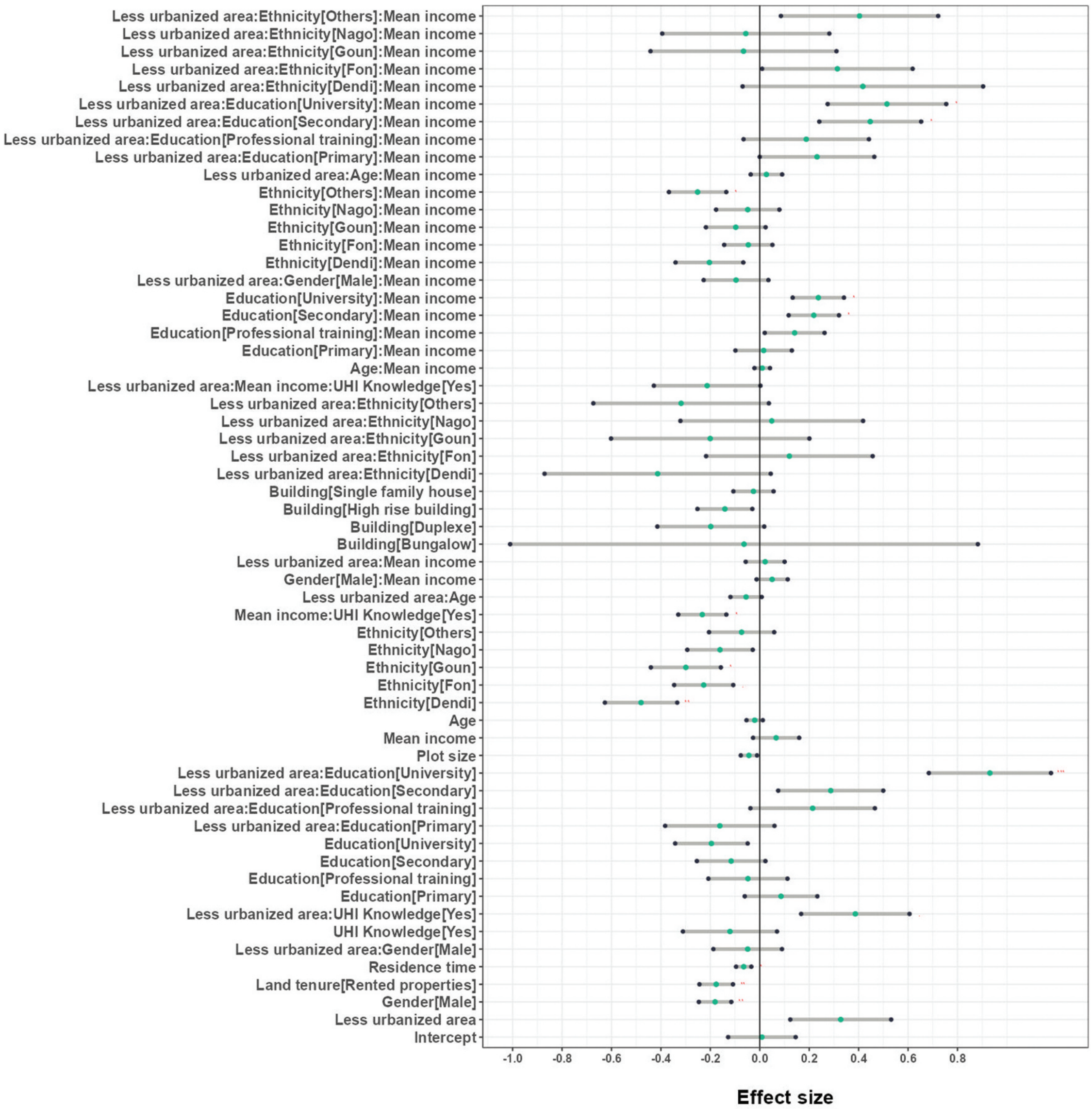

Figure 2. Effect respondent mean income, age and gender, ethnicity (Fon, Dendi, Nago, Goun, others), education levels (no education, professional training, primary, secondary, university), household plot area (land area), household building type, household resident time and the household respondent knowledge about urban heat island (UHI knowledge) on household phylogenetic diversity (PD); and interaction effect of the of respondent age and gender, ethnicity (Fon, Dendi, Nago, Goun, others), education levels (no education, professional training, primary, secondary, university), household plot area (land area), household building type, household resident time and the household respondent knowledge about urban heat island (UHI knowledge) on household phylogenetic diversity (PD) of cultivated of plant species communities in their yard. ***$p < 0.001$; **$p < 0.01$: *$p < 0.05$.

found no effect of household mean income on phylogenetic diversity indexes. Rather, we observed a significant effect for the taxonomic diversity. This discrepancy underscores the necessity of comparing different metrics to identify the underlying factors influencing biodiversity. The choice of the diversity metrics is crucial. For instance, while some metrics may reveal significant effects where others do not, highlighting the need for comprehensive comparisons to understand the factors at play. When accounting for evolutionary diversity, the impact of income on diversity might be obscured. This suggests that even wealthier households, despite their intention to enhance plant diversity in their gardens, may not fully understand the combinations of plant species that maximize evolutionary diversity. Evolutionary diversity is essential for urban ecosystems because it reflects the breath of evolutionary history represented by different species. This diversity can enhance ecosystem resilience, functionality and stability, contributing to more robust and adaptable urban green spaces. Wealthier households might invest in a variety of plants yet fail to achieve optimal phylogenetic diversity due to the lack of awareness of knowledge about which plant combination contributes most effectively to evolutionary diversity,

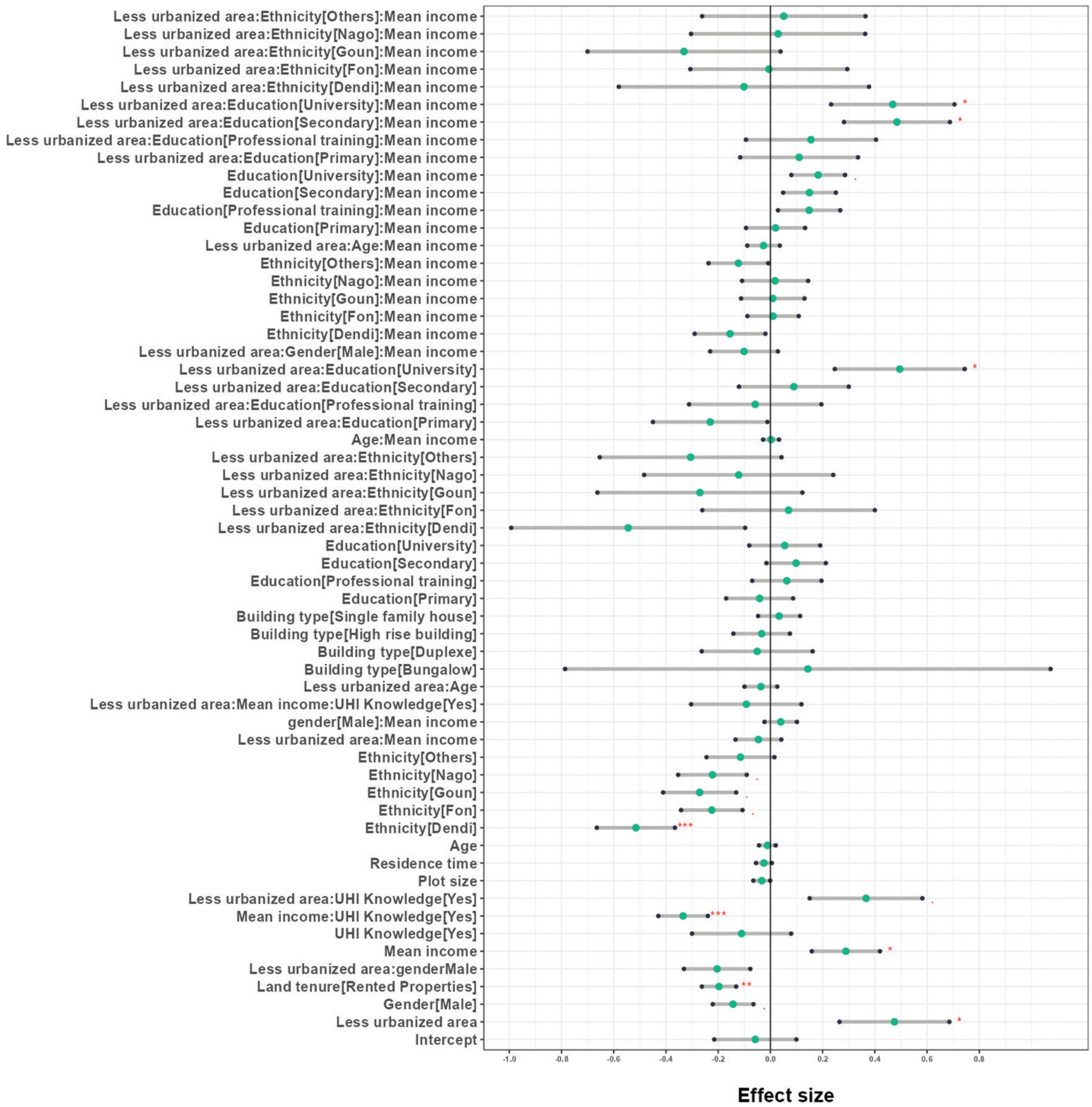

Figure 3. Main effect of respondent mean income, age, gender, ethnicity (Fon, Dendi, Nago, Goun, others), education levels (no education, professional training, primary, secondary, university), household plot area (land area), household building type, household resident time and the household respondent knowledge about urban heat island (UHI knowledge) on household taxonomic diversity (S.Chao1); and interaction effect of the of respondent age and gender, ethnicity (Fon, Dendi, Nago, Goun, others), education levels (no education, professional training, primary, secondary, university), household plot area (land area), household building type, household resident time and the household respondent knowledge about urban heat island (UHI knowledge) on household taxonomic diversity (S.Chao1) of cultivated plant species communities in their yard. ***$p < 0.001$; **$p < 0.01$: *$p < 0.05$.

highlighting the complexity of plant diversity management and the importance of informed decision-making in cultivating diverse urban gardens.

Here, we found a strong effect of household mean income on both diversity indexes considered in our study for household with knowledge of Urban Heat Island. The assessment of urban heat island knowledge in our study might have been flawed since participants with only a vague idea of the concept may have answered with yes, while at the same time their long-term decisions related to planting and caring for plants may have been hardly affected by this vague knowledge. Income which is measured here as the monthly income might not fully capture wealth which could also exist due to other factors. For instance, assets, investments, inheritance, and access to resources such as land or education significantly contribute to overall wealth and financial security (Saez and Zucman 2016). Interestingly, households in less urbanized areas exhibited higher taxonomic diversity in their gardens but showed no significant effect on phylogenetic diversity. However, the highest levels of education (secondary or university) in this area significantly enhances both phylogenetic and taxonomic diversity of the cultivated plants. Additionally, this trend is further amplified in wealthier households within these low urbanized areas. The observed effect of wealth on biodiversity in less urbanized areas supports the 'luxury effect', which posits that wealthier households have more resources to invest in their gardens, leading to greater plant diversity (Chamberlain et al. 2019). This effect is particularly pronounced in areas with less urban development, where space and opportunities for gardening are more abundant. The lack of a significant effect on phylogenetic diversity in less urbanized areas, except among the most educated households, suggests that while general plant diversity can be achieved through basic horticultural practices, achieving phylogenetic diversity requires more specialized knowledge and effort. This finding underscores the importance of education in promoting not just the quantity but the quality of biodiversity.

Our finding highlights a crucial urban structural dimension concerning plant diversity. Specifically, rented properties tend to feature gardens with reduced plant diversity. Tenancy might more accurately reflect accumulated wealth disparities. Tenants, who typically have less accumulated wealth than homeowners, are more likely to reside in properties with lower plant diversity. This distinction underscores the importance of considering various forms of wealth (Keister and Moller 2000) and their impact on urban biodiversity. Intriguingly, historical links between income and plant species as symbols of social status have been identified (Grove et al. 2014). However, our findings propose that wealth plays a more substantial role in influencing cultivated plant diversity. Income might be a relatively new factor, emerging later in a household's tenure, while decisions about plant diversity in gardens may be shaped over years. Furthermore, the negative effect of tenancy arrangements on both diversity indexes supports the idea that ownership and investment in property contribute to higher biodiversity in urban settings (Elmqvist et al. 2003; Andersson et al. 2007; Aronson et al. 2017). Thus, the security and sense of ownership associated with private home ownership may contribute to a greater investment in cultivated plant diversity within urban settings. However, Andersson et al. (2007) emphasized that long-term residence provides the temporal stability needed for plant communities to thrive and diversify. We found that households that remain in their compounds for extended periods tend to exhibit negative phylogenetic diversity in their gardens. This phenomenon may be attributed to several factors. Long-term residents often favor certain plant species for aesthetic or cultural reasons, leading to a more homogeneous plant community. Additionally, the prolonged presence of specific plant species can reduce the introduction of new, phylogenetically diverse species. This trend aligns with findings from various studies that emphasize how urban and residential areas can influence plant diversity patterns. For example, non-native plants, often selected for their ornamental value, can dominate gardens, thereby reducing overall phylogenetic diversity and affecting ecological balance (Zhu et al. 2019; Delahay et al. 2023)

Key social traits, as expected, play an important role in developing attachment, and these were found to be gender-sensitive. It is interesting that we found male-respondent in our study households, tend to have lower plant diversity than households led by women. This, is consistent with discussions on gendered divisions of labor and decision-making processes within households (Agarwal 2009; Wolch et al. 2014). The negative impact of male ownership on both diversity indexes may be indicative of a greater interest among women in gardening and landscaping. Our findings indicating a negative impact of male ownership on taxonomic diversity align with residents' yard preferences. In fact, the desire for visually appealing and easily maintained landscapes, often associated with traditional gendered roles in gardening, could shed light on the observed pattern (Larson et al. 2009). Moreover, the link between environmental considerations and various yard types suggests that women, typically more environmentally conscious, could play a key role in shaping taxonomic diversity as well as the evolutionary history of plants in their yard by prioritizing eco-friendly landscaping. This result suggests that promoting gender equity and empowering women within households may contribute to increased biodiversity (Tengö et al. 2017).

Moreover, we found a significant influence of ethnicity on urban biodiversity patterns. Research by Hope et al. (2003) demonstrated that ethnic diversity positively contributes to the abundance and diversity of urban trees. In our study, ethnicity is considered as the degree of familiarity and deep-rooted connection that households have with plants. This includes traditional knowledge and cultural practices related to plant use. For example, ethnic groups with a strong connection to medicinal plant knowledge, such as the Bariba ethnic group, tend to cultivate a greater variety of plants in their gardens (Koura et al. 2011; Salako et al. 2014). The significant associations between ethnicity and biodiversity patterns indicate the potential role of cultural and social factors in shaping household behaviors and attitudes towards biodiversity (Hope et al. 2003; Kabisch et al. 2016; Blanchette et al. 2021; Danquah et al. 2023). This may be attributed to cultural practices, socioeconomic disparities, or specific ecological knowledge and preferences (Lubbe et al. 2010; van Heezik et al. 2013; Blanchette et al. 2021).

The lack of support for the luxury effect for the phylogenetic diversity in this study challenges a common assumption in urban ecology and suggests that the relationship between wealth and plant diversity might not be as straightforward or universal as previously thought, rather the type of metric of the diversity is important. Despite the lack of support for the luxury effect in the current study, there is evidence in the literature showing connections between different drivers of diversity (Threlfall et al. 2022). This raises questions on the complexity of urban ecosystems and the multifaceted relationships between sociodemographic factors and biodiversity. In many urban and peri-urban areas, cultivated gardens are key components of green infrastructure, contributing significantly to overall biodiversity and ecological functioning. Studies have shown that cultivated plant diversity in urban gardens can enhance wider biodiversity by providing habitats and resources for various species, including pollinators, birds, and small mammals (Smith et al. 2006; Goddard et al. 2010). These gardens play a crucial role in supporting urban ecological networks and maintaining ecosystem services. While our study may indeed be more specific in its focus compared to other luxury effect studies (Hope et al. 2003; Chamberlain et al. 2020), this specificity is particularly relevant in the context of understanding plant diversity in human-modified landscapes, such as residential areas. We here excluded spontaneously growing species which have distinct ecological and cultural significance in urban environments. Indigenous plantings play a crucial role in maintaining local biodiversity and cultural heritage, and their exclusion represents a notable limitation in study design and we acknowledge that this choice may limit the generalizability of our results to ecosystems that include a more diverse range of species, including those not under direct human management (Kendal et al. 2012). Future research should integrate indigenous species to offer a more comprehensive understanding of urban ecosystem dynamics (Pincetl 2010). Our research employed a cross-sectional design, which allows us to identify associations but not causation. Long-term changes in biodiversity may require longitudinal studies that track households over time. Socioeconomic influences on biodiversity may differ in diverse geographic and cultural settings. While biodiversity is influenced by a multitude of factors beyond those considered in this study, the interplay of ecological, climatic, and anthropogenic variables is intricate, and we acknowledge that our study may not capture the full complexity of these interactions to uncover the trends, hold true universally and which are more context-dependent

Conclusion

This study represents a pioneering effort in understanding the interplay between socioeconomic factors and urban plant diversity distribution in gardens within the context of expanding West African cities. By examining various factors such as mean income, education, residence time, and ownership, we identified their profound influence on biodiversity patterns. We found no support for the luxury effect on plant diversity in residential yards. Furthermore, this research shed light on the multifaceted impact of gender, ethnicity, age and urban structural dimension on biodiversity. Female-respondent in the households, in particular, harbored higher plant diversity in their gardens, indicating the importance of cultural and social factors in shaping ecological variations. A compelling finding emerged, indicating that long-term residence in households is associated with a decline in biodiversity. While the negative impact of residence time on biodiversity is contrary to the notion of a sense of place attachment fostering biodiversity conservation, it is essential to recognize the complexity of factors influencing biodiversity in these urban settings. The integration of context-specific conservation strategies emerged as a key recommendation from this study. By promoting sustainable behaviors within households and addressing socio-economic disparities, we can lay a strong foundation for effective biodiversity conservation. Empowering women and incorporating environmental education into curricula holds great promise for nurturing a culture of conservation in West African cities. These findings pave the way for a more nuanced and tailored approach to biodiversity conservation within urban neighborhoods, ensuring that urban planning strategies align with the socio-demographic dynamics of each community.

The implications of these findings underscore the need for proactive, long-term conservation efforts, along with the active management and preservation of biodiversity-rich areas. We advocate for a comprehensive approach that takes into account the complex interactions between socioeconomic factors and biodiversity to foster environmental resilience. Ultimately, understanding the role of socioeconomic factors and promoting sustainable behaviors are paramount for successful biodiversity conservation in the dynamic and rapidly growing urban environments of West Africa. As this study has opened new avenues for exploration, further research is encouraged to deepen our knowledge and inform the development of effective policies by conservation biologists and urban planners alike.

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Author's contribution

EBOA and OGG designed the study. EBOA performed fieldwork, analyzed the data and wrote the first draft of the manuscript. OGG, FF contributed substantially revisions to the manuscript with editorial assistance from MAO and AAO. All authors gave final approval for publication.

Data availability statement

Data in WASCAL are open access and are made available upon the receipt of an official request to the institution through the Data Management Department.

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