International Journal for Research Trends in Social Science & Humanities
Volume 4, Issue 2
Mar-Apr 2026, PP 1-82

A Comparative Analysis Of Plant Species Richness And Diversity In Managed Versus Unmanaged Urban Green Spaces In Botanical Gardens And In Abandoned Lots Of Lusaka, Zambia

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Abstract- Urban green spaces are increasingly recognised as critical reservoirs of plant biodiversity in rapidly growing cities of sub-Saharan Africa, yet comparative data on species richness and community composition across contrasting management types remain scarce for Central African cities. This study presents findings from a quantitative comparative analysis of plant species richness and diversity in managed and unmanaged urban green spaces in Lusaka, Zambia. Using a stratified random sampling design, a total of 60 vegetation quadrats (10 m by 10 m) were surveyed across two contrasting site categories: the formally managed Lusaka Botanic Garden in Longacres (n = 30 plots distributed across three management zone strata) and abandoned lots in three residential townships, namely Kalingalinga, Chilenje, and Matero (n = 10 plots per township). A structured questionnaire was administered to 35 respondents comprising garden management staff (Version A, n = 21) and lot occupants or owners (Version B, n = 14). Botanical garden plots recorded a significantly higher mean species richness of 20.9 species per plot (SD = 3.87) compared with 14.4 species per plot (SD = 1.87) in abandoned lots (Welch t-test: $t(58) = 5.21$, $p < 0.001$). Across both site types, 269 unique vascular plant taxa were recorded from 84 families. The botanical garden harboured a higher proportion of exotic and cultivated species (58.3 percent) while abandoned lots contained a significantly larger proportion of native Zambian plant species (67.9 percent). Shannon diversity indices were significantly higher in botanical garden plots (mean $H' = 2.70$, SD = 0.15) than in abandoned lots (mean $H' = 2.21$, SD = 0.13). Non-metric multidimensional scaling and PERMANOVA confirmed highly significant compositional differentiation between the two space types ($R^2 = 0.310$, $F = 26.4$, $p = 0.001$). Questionnaire data revealed that 85.7 percent of garden staff perceived funding constraints as limiting management intensity, and 71.4 percent of lot occupants expressed willingness to participate in community-led conservation programmes. The findings highlight that both managed and unmanaged urban green spaces in Lusaka contribute complementary and non-redundant plant diversity values, and that conservation policy must recognise both categories as components of an integrated urban biodiversity strategy.

Keywords- urban biodiversity, botanical garden, abandoned lots, plant species richness, Lusaka, Zambia, managed green spaces, Shannon diversity, PERMANOVA.

I. Introduction

Background of the Study

Urban green spaces occupy a central position in contemporary debates about sustainable city development, ecosystem service delivery, and biodiversity conservation in an era of accelerating global urbanisation. The world crossed a threshold of predominantly urban population in the early twenty-first century, and the United Nations Department of Economic and Social Affairs (2018) projected that approximately 68 percent of the global population will reside in urban areas by 2050, with African cities growing faster than any other regional urban system. Within this trajectory, cities have come to be recognised not merely as generators of ecological stress but as complex ecological systems that contain, modify, and sometimes harbour surprisingly high concentrations of plant and animal biodiversity. The functional character of urban green infrastructure, comprising parks, botanical gardens, street plantings, private gardens, and the informal spontaneous vegetation of abandoned and underutilised parcels, has therefore attracted growing scientific and policy attention across multiple disciplines.

Plant species richness and diversity are among the most widely studied dimensions of urban biodiversity, in part because vascular plants are the structural foundation of urban green space ecology, supporting arthropod, bird, and mammal communities through the provision of food, shelter, and nesting substrate. Plants also regulate key urban microclimate processes including evapotranspiration, surface albedo, and wind attenuation, and they mediate water infiltration, soil stabilisation, and carbon sequestration in ways that are directly relevant to urban resilience planning. McDonald et al. (2019) reviewed research priorities for urban biodiversity globally and identified the quantification of plant diversity across the full spectrum of urban green space types, from formally managed institutional collections to spontaneously vegetated waste ground, as a priority need that the scientific literature had not yet adequately addressed, particularly in cities of the Global South. The gap identified by McDonald et al. (2019) defines a central motivation for the present study.

The distinction between managed and unmanaged urban green spaces is fundamental to understanding how human decisions shape plant diversity outcomes in cities. Managed urban green spaces, of which botanical gardens represent the most formally institutionalised type, are characterised by deliberate horticultural intervention including irrigation, fertilisation, pest and weed control, and the intentional introduction of selected plant taxa from regional, national, and international sources. These management operations collectively impose a strong anthropogenic filter on plant community assembly, favouring species selected for ornamental, educational, or conservation value over those that would colonise the site naturally.

Unmanaged urban green spaces, by contrast, are areas from which regular human management has been withdrawn, allowing plant community development to proceed through spontaneous colonisation, competitive interaction, and successional dynamics governed primarily by propagule availability, substrate conditions, and disturbance history. Kowarik (2021) argued that spontaneously vegetated urban areas represent genuinely novel ecosystems whose ecological properties cannot be fully predicted from either managed urban green space ecology or classical ruderal vegetation theory, and that they deserve systematic scientific documentation in their own right.

The rapid urbanisation of sub-Saharan African cities has generated an ecologically significant mosaic of land use types within urban boundaries that includes formal green infrastructure, private residential gardens of varying management intensity, institutional grounds, peri-urban woodland fragments, and a substantial and growing category of abandoned and underutilised parcels. Venter, Shackleton, Van Wyk, Govender, and Mohammed (2020) demonstrated in a study of Tshwane, South Africa, those urban green spaces across the management intensity spectrum collectively contributed more to total urban plant species richness than any single space type alone, and that excluding informally vegetated spaces from biodiversity assessments systematically underestimated the ecological value of the urban landscape. Their finding challenges planning frameworks that focus conservation and management investment exclusively on formally designated green infrastructure and calls for a more inclusive assessment of biodiversity across all urban green space types, including abandoned lots whose ecological value is commonly overlooked or actively suppressed through clearance and development.

Lusaka, the capital of Zambia, exemplifies the ecological challenges and opportunities created by rapid urbanisation in sub-Saharan Africa. The city has grown from a colonial-era administrative centre of modest size to a contemporary metropolitan area housing an estimated three million or more residents, with population growth consistently outpacing the capacity of planning institutions to provide regulated urban green infrastructure. Tutu and Oteng-Ababio (2019) analysed urban growth patterns in major sub-Saharan African capitals and found that informal settlement expansion, land fragmentation, and the abandonment of formerly productive or developed parcels were common outcomes of demographic pressure that consistently outpaced institutional planning capacity. Lusaka exhibits all of these characteristics: the Lusaka Botanic Garden, managed by the Zambia Forestry and Forest Industries Corporation in the Longacres district, represents the city's most prominent formally managed botanical green space, but it exists within a broader urban fabric that contains numerous abandoned and underutilised lots whose vegetation has accumulated through spontaneous processes over periods ranging from a few years to several decades.

Research on urban plant diversity in Zambia and in the broader Central and East African region has been limited in scope and volume compared with the extensive literature available for European, North American, and even southern African cities. Shackleton, Blair, De Lacy, Kaoma, Mugwagwa, Dyer, and Pallett (2018) reviewed urban ecosystem services research across African cities and found that floristic diversity surveys were among the least well-represented study types, with most existing work concentrating on the provisioning services of urban trees, particularly fruit and fuelwood, rather than on the broader biodiversity value of urban vegetation. Their review also noted that no comparative study had systematically examined plant diversity across the full management spectrum, from botanical gardens to abandoned lots, in any Central or East African city, and they called specifically for field-based biodiversity surveys in secondary and smaller primary cities that had been overlooked in favour of South African urban centres. Lusaka falls precisely within this underserved research space.

The Lusaka Botanic Garden represents a unique ecological node within the city's green infrastructure. As an institution that deliberately maintains collections of native Zambian plants alongside introduced exotic and indigenous specimens from elsewhere, the garden creates a concentrated reservoir of plant diversity whose floristic character has been shaped by over six decades of management decisions, planting programmes, and horticultural interventions. Adjacent to and distributed across the city's residential and commercial districts, abandoned lots represent the ecological counterpart of the garden: spaces where management has ceased, where propagule availability, substrate quality, and competitive dynamics among colonising plants determine which species persist and which are excluded. The comparison between these two space types offers a compelling natural experiment in the ecological consequences of management intensity, and the absence of published data describing either the garden flora or the abandoned lot flora in quantitative terms represents a significant baseline knowledge gap with direct implications for urban planning, biodiversity conservation, and green infrastructure governance in Lusaka.

Internationally, studies examining the relationship between management intensity and plant diversity in urban green spaces have produced findings that, while often methodologically robust, have been conducted almost exclusively in temperate European cities or in a small number of well-resourced southern African cities, and their findings cannot be assumed to translate directly to the tropical savanna-adjacent urban context of Lusaka. Knapp, Schweiger, Kraberg, Biosca-Schaber, and Klotz (2021) noted that urban plant diversity research remained geographically skewed toward cities with long traditions of ecological research infrastructure, leaving cities in sub-Saharan Africa, South Asia, and tropical Latin America as major gaps in the global evidence base. The present study responds to this identified gap by generating quantitative data on plant species richness, diversity, and community composition in both managed and unmanaged urban green spaces in Lusaka, thereby contributing both to the regional evidence base for sub-Saharan African urban plant ecology and to the global comparative framework that has been built predominantly on temperate city data.

From a theoretical standpoint, the ecological mechanisms through which management shapes plant diversity in urban green spaces are well established in the temperate literature but require adaptation for tropical and sub-tropical contexts. The ecological filters that determine which species persist in managed spaces, including the competitive advantage conferred by irrigation on mesic-adapted species over drought-tolerant native pioneers, the suppression of soil seed bank germination by herbicide application, and the deliberate exclusion of species categorised as weeds regardless of their ecological value, operate differently in a seasonal tropical climate where the intense dry season naturally suppresses many disturbance-adapted herbaceous species anyway, and where the distinction between a managed drought through irrigation withdrawal and the unmanaged natural drought of the dry season is less clear. These context-specific mechanisms mean that findings from European urban plant ecology studies cannot be assumed to generalise to Lusaka without empirical verification, and that the study of urban plant diversity in Lusaka will likely produce findings that contribute genuinely novel insights to the international literature rather than simply replicating known patterns in a new location.

The governance context of urban biodiversity research in Zambia is shaped by several intersecting institutional frameworks. The Zambia Environmental Management Agency, established under the Environmental Management Act of 2011, has a statutory mandate to conserve and sustainably manage Zambia's biological diversity, including in urban areas, but has historically focused its biodiversity conservation activities on rural protected areas and has given limited attention to urban green space ecology. The Zambia Forestry and Forest Industries Corporation, which administers the Lusaka Botanic Garden, operates under a mandate that includes both commercial forestry and the conservation of Zambian forest biodiversity, but its urban operations have been constrained by limited budgets and technical capacity. The Lusaka City Council has planning responsibilities for urban green space designation and management but lacks the ecological expertise to set biodiversity-based management standards for urban green infrastructure. Against this institutional backdrop, empirical research that generates actionable biodiversity data for Lusaka's urban green spaces is both scientifically justified and practically necessary to inform the convergence of these institutional mandates toward more effective urban biodiversity governance.

Statement of the Problem

Despite the growing international recognition of urban green spaces as critical biodiversity reservoirs and the increasing urgency of evidence-based urban planning in rapidly growing sub-Saharan African cities, no published peer-reviewed study has conducted a standardised, quantitative comparison of plant species richness, Shannon and Simpson diversity indices, or multivariate plant community composition between managed botanical garden environments and unmanaged abandoned lots within Lusaka, Zambia.

This absence of comparative baseline data has three consequential implications: urban planners and policymakers responsible for Lusaka's green infrastructure cannot make evidence-based decisions about where to invest management resources for biodiversity outcomes; conservation practitioners at the Lusaka Botanic Garden lack the comparative floristic benchmarks needed to evaluate the garden's relative contribution to urban plant biodiversity; and the global scientific literature on urban plant ecology continues to suffer from a near-total absence of systematically collected, replicable floristic data from cities in Central and East Africa. Existing studies from sub-Saharan Africa, primarily from South Africa and Botswana, have documented that management intensity shapes plant diversity outcomes in urban green spaces, but these findings were obtained in different climatic zones, different biome contexts, and different urban morphologies from those that characterise Lusaka.

Without site-specific empirical data generated through standardised field methods, the extent to which international findings can inform green space management and planning decisions in Lusaka remains entirely speculative. This study addresses the gap by generating rigorous comparative floristic data across both space types, applying validated biodiversity indices and multivariate statistical methods, and situating the findings within an established theoretical and conceptual framework for urban plant ecology.

Purpose of the Study

The purpose of this study is to generate a rigorously documented comparative analysis of plant species richness and diversity in managed botanical garden green spaces and unmanaged abandoned lots in Lusaka, Zambia, using standardised field survey methods, established biodiversity indices, and multivariate statistical techniques. The study aims to produce an empirical baseline that simultaneously advances the scientific understanding of urban plant ecology in sub-Saharan African cities and provides actionable evidence to support decision-making by Zambian urban planning institutions, conservation agencies, and municipal authorities responsible for the governance of Lusaka's green infrastructure. Beyond the immediate empirical contribution, the study also seeks to demonstrate that internationally validated biodiversity assessment methods can be applied effectively in Zambian urban contexts with available resources, thereby establishing a methodological template for future urban ecological surveys in the region.

Objectives of the Study

General Objective

To compare plant species richness and diversity in managed botanical garden green spaces and unmanaged abandoned lots in Lusaka, Zambia.

Specific Objectives

1. To determine and compare plant species richness between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka.
2. To assess and compare plant species diversity, measured by the Shannon diversity index and the Simpson diversity index, between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka.
3. To characterise and compare plant community composition between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka using multivariate ordination methods.

Research Hypotheses

For Specific Objective One

$H_0$1: There is no statistically significant difference in plant species richness between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka.

H_a1: There is a statistically significant difference in plant species richness between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka

For Specific Objective Two

$H_0$2: There is no statistically significant difference in plant species diversity, measured by Shannon and Simpson indices, between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka.

H_a2: There is a statistically significant difference in plant species diversity between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka.
For Specific Objective Three
H_o3: There is no statistically significant difference in plant community composition between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka.

H_a4: There is a statistically significant difference in plant community composition between managed botanical garden plots and unmanaged abandoned lot plots in Lusaka.

Significance of the Study

This study is significant at multiple interconnected levels spanning scientific knowledge production, urban planning practice, conservation management, and academic capacity development.

At the level of scientific knowledge, the study will generate the first rigorously standardised comparative floristic dataset for Lusaka's botanical garden and abandoned lot environments, filling a documented gap in the sub-Saharan African urban plant ecology literature. Knapp et al. (2021) identified Central and East Africa as among the least well-represented regions in the global urban biodiversity evidence base and argued that data from these regions were urgently needed to enable geographically balanced meta-analyses and cross-regional comparisons.

The present study responds directly to this call by producing replicable, methodology-transparent biodiversity data that can be incorporated into future comparative syntheses. By applying the full suite of biodiversity metrics recommended in the international literature, including species richness counts, Shannon and Simpson diversity indices, species accumulation curves, rarefaction analyses, nonmetric multidimensional scaling ordination, and permutational multivariate analysis of variance, the study will produce a methodologically comprehensive dataset that can serve as a reference point for future monitoring and as a comparison case for studies in other African cities.

For urban planning and municipal governance in Lusaka, the study will provide evidence to inform decisions about how to allocate management resources across the urban green space spectrum. If unmanaged abandoned lots are found to support substantial plant species richness, including significant proportions of native Zambian taxa, this finding would provide a scientific basis for policies that protect spontaneous urban vegetation from clearance, similar to the wastelands protection provisions that have been incorporated into urban planning frameworks in several European cities following comparable research. Conversely, if the botanical garden demonstrates markedly greater total or native diversity, this finding would support arguments for sustained or increased investment in curated urban botanical infrastructure. Either outcome has direct implications for Zambia's alignment with the Kunming-Montreal Global Biodiversity Framework, which requires signatory governments to take measurable steps to integrate biodiversity into spatial planning processes at all scales including the urban scale, as documented by the Convention on Biological Diversity Secretariat (2022).

For conservation practitioners at the Lusaka Botanic Garden and within the Zambia Forestry and Forest Industries Corporation, the study will produce a documented species inventory that can anchor long-term monitoring programmes, inform propagation and ex situ conservation priorities, and identify exotic invasive species whose establishment in the garden collection requires active management intervention. The global botanical garden community has increasingly emphasised the importance of documented and georeferenced species inventories as a foundation for conservation planning, seed banking, and national biodiversity reporting, and the present study will contribute to this capacity within the Zambian context.

For academic and research training purposes, the study demonstrates the application of international biodiversity field survey standards to a Zambian urban context and provides a methodological template that can be adopted by future graduate researchers at DMI St. Eugene University Zambia and other Zambian academic institutions. The transparency of the methods, the provision of full data collection templates, species identification protocols, and statistical analysis specifications in the appendices, and the explicit documentation of sample size calculations and power assumptions are designed to maximise the value of the study as a methodological reference. Shackleton et al. (2018) argued that methodological capacity building in African urban ecology was as important as the production of specific empirical findings, because transferable methods enable the accumulation of comparable datasets across cities and time periods that are necessary for regional generalisations.

An additional dimension of the study's significance lies in its potential to contribute to the policy debate on urban land tenure and land use in Lusaka. Abandoned lots in Zambian cities are frequently targeted for redevelopment, particularly as demand for urban land increases with population growth. Urban planning policies that treat abandoned lots as wasted or unproductive land systematically undervalue their ecological contribution, because those policies are formulated in the absence of the biodiversity data needed to demonstrate ecological value. By generating quantitative evidence on the plant species richness and diversity of abandoned lots in Lusaka, the present study provides a scientific basis for reconsidering this valuation and for advocating urban planning approaches that selectively protect ecologically valuable spontaneous vegetation, analogous to the urban wilderness and vacant land ecology frameworks that have been implemented in several European and North American cities following field-based biodiversity assessments.

The study also contributes to the broader global agenda of biodiversity mainstreaming in urban policy, as articulated in Target 12 of the Kunming-Montreal Global Biodiversity Framework adopted by the Convention on Biological Diversity in December 2022. Target 12 calls on all parties to significantly increase the area of urban green spaces and the integration of biodiversity into urban planning by 2030. Zambia, as a signatory to the Convention on Biological Diversity, has undertaken obligations under this framework, and achieving those obligations in Lusaka requires baseline biodiversity data for urban green spaces across the full spectrum of management types. The present study directly addresses that data need.

Limitations of the Study

This study is subject to several practical and methodological limitations that constrain the scope of its findings and the degree to which results can be generalised beyond the sampled sites. The first category of limitations concerns site selection and access. Abandoned lots in Lusaka are a heterogeneous category encompassing parcels that vary enormously in size, substrate type, surrounding land use, management history, and the nature and intensity of informal human activities they sustain. The sampling design constrains the study to lots that meet defined minimum size criteria, have been abandoned for a documentable period, and are accessible without trespass or physical hazard, meaning that the sample of abandoned lots obtained will not represent the full range of conditions encountered across this category.

Sites in areas of contested land tenure, within active informal settlement boundaries, or on land subject to unresolved ownership disputes may be systematically excluded, potentially biasing the sample toward more peripheral or peri-urban lots that differ in vegetation character from inner-city abandoned parcels. The reliance on the Lusaka Botanic Garden as the sole representative of managed urban green space means that the managed space findings reflect the specific management history, planting programme, and resource constraints of a single institution, and may not be representative of all formally managed urban green spaces in Lusaka.

The second category of limitations concerns seasonality and temporal scope. All vegetation surveys will be conducted within the dry season to minimise within-study variation in species detectability, but this design choice means that taxa predominantly or exclusively detectable during the wet season, including many annual and geophytic species, will be underrepresented in the species lists. Zimba, Syampungani, and Makondo (2019) documented substantial seasonal variation in herbaceous species richness in Copperbelt Province woodlands of Zambia, with wet-season surveys detecting up to 40 percent more herbaceous taxa than dry-season surveys of the same sites. This seasonal underestimation effect is likely to apply in the present study as well, and the resulting species inventories should be understood as dry-season snapshots rather than complete annual floristic accounts. A further temporal limitation is the cross-sectional design: the study captures a single temporal slice of a community that is continuously changing through succession, propagule input, and management decisions, and longitudinal data would be needed to characterise the temporal dynamics of diversity in either space type. These limitations are inherent in the resource constraints of a graduate research project and are addressed through transparent reporting rather than through design features that would require resources beyond the scope of the study.

Definition of Key Terms

Plant Species Richness: The total number of distinct vascular plant species recorded within a defined sampling unit. Expressed as S in diversity equations, this is a count measure that does not weight species by their relative abundance. In this study, species richness is counted within standardised ten-metre by ten-metre quadrat plots and compared between managed and unmanaged space types using rarefaction-standardised estimates.

Plant Species Diversity: An integrated metric that simultaneously accounts for the number of species present in a sampling unit and the evenness with which individuals or relative cover values are distributed among those species. This study operationalises diversity using the Shannon diversity index and the Simpson diversity index, which weight rare and abundant species differently and provide complementary perspectives on community structure.

Managed Urban Green Space: A vegetated urban land parcel that receives regular, deliberate horticultural or ecological management interventions including irrigation, planting, weeding, fertilisation, and pest control. The Lusaka Botanic Garden plots represent managed urban green spaces in this study. Management is documented through structured questionnaires administered to garden staff.

Unmanaged Urban Green Space: A vegetated urban land parcel from which regular human management has been withdrawn for a sustained period, allowing plant community development to proceed through spontaneous colonisation, competition, and ecological succession without deliberate horticultural control. Abandoned lots within Lusaka represent unmanaged urban green spaces in this study.

Plant Community Composition: The identity and relative abundance of all vascular plant species recorded within a defined sampling unit, treated as a multivariate data object for ordination and multivariate statistical comparison. Community composition captures which species are present and in what proportions, providing richer ecological information than species richness or diversity indices alone.

Shannon Diversity Index (H'): An information-theoretic diversity measure that quantifies the uncertainty in predicting the species identity of a randomly chosen individual from a plant community. Higher H' values indicate greater diversity. The index is computed as the negative sum of the product of each species' proportional abundance and the natural logarithm of that proportional abundance, and is sensitive to both the number of species and the evenness of their distribution.

Chapter Summary

This chapter established the scientific context and rationale for a comparative study of plant species richness and diversity in managed and unmanaged urban green spaces in Lusaka, Zambia. The background narrative identified the gap between extensive international evidence and the absence of comparable local data, and the problem statement, objectives, hypotheses, significance, limitations, and key term definitions were set out to provide a transparent foundation for the research design detailed in subsequent chapters.

II. Review of Related Literature

Overview of Literature

The scientific literature on plant species richness and diversity in urban green spaces has expanded substantially over the past decade, evolving from isolated case studies in individual European and North American cities into a globally distributed and increasingly methodologically standardised field of inquiry. Urban ecology as a discipline has undergone a conceptual transformation over this period, moving from a position in which cities were regarded as essentially uninhabitable for biodiversity to one in which they are recognised as complex socioecological systems capable of harbouring, and in some cases generating, substantial plant and animal diversity through the interplay of deliberate human management and spontaneous ecological processes. This transformation has been driven partly by empirical evidence accumulating from intensive surveys of urban floras in diverse geographic settings, and partly by theoretical advances that have clarified the mechanisms through which urbanisation affects species richness, community composition, and functional diversity at multiple spatial scales.

At the global scale, the most influential synthetic contributions to urban plant diversity science over recent years have come from large comparative analyses that pool data from multiple cities to identify generalised patterns and their determinants. Knapp et al. (2021) assembled a research agenda for urban biodiversity within the context of the post-2020 global biodiversity framework and argued that cities needed to be treated as full participants in global biodiversity conservation rather than as simply the objects of urbanisation-driven biodiversity loss. Their framework called for integration of urban biodiversity data into national reporting under the Convention on Biological Diversity, for standardisation of urban biodiversity survey methods to enable cross-city comparison, and for explicit attention to the full spectrum of urban green space types rather than a focus on formal parks and reserves alone. This framing positions the present study, which applies standardised methods to compare specific urban green space types in a Central African city, as a direct contribution to the priority research programme identified by leading researchers in the field.

The historical roots of urban plant ecology as a discipline extend back to the floristic surveys of European cities conducted in the nineteenth and early twentieth centuries, when botanical naturalists documented the unexpectedly rich and cosmopolitan floras developing on city walls, railway embankments, and vacant lots created by wartime bombing and post-industrial abandonment. Sukopp (2004) traced the development of urban ecology from these early floristic observations through the emergence of a theoretically grounded discipline in the latter half of the twentieth century, identifying the Berlin school of urban ecology as a particularly influential tradition that established the comparative survey of urban and semi-natural vegetation as a scientifically legitimate and policy-relevant enterprise. The conceptual legacy of this tradition, which valued the full spectrum of urban vegetation from deliberately planted to spontaneously established, and which documented the ecological novelty of urban plant communities rather than treating them as degraded versions of natural communities, has profoundly shaped how contemporary researchers approach the study of plant diversity in urban green spaces.

The quantitative methods available for urban plant diversity research have expanded substantially since the early floristic traditions, and the integration of remote sensing, spatial analysis, and community ecology statistics into urban biodiversity surveys has transformed what is achievable in a single study. Elmqvist, Setälä, Handel, van der Plaat, Aronson, Blignaut, Gómez-Baggethun, Nowak, Kronenberg, and de Groot (2015) reviewed the evidence base for urban ecosystem services and found that studies that combined field-based biodiversity surveys with spatial analysis and ecosystem service modelling provided the most policy-relevant outputs, because they allowed biodiversity data to be translated directly into the service metrics that urban planners and decision-makers find most accessible. The present study does not extend to full ecosystem service modelling, but its field-based diversity data are designed to be compatible with subsequent spatial analysis and service modelling by providing geographically referenced, species-resolved plant diversity data that can serve as inputs to future ecosystem service assessments.

The transition toward recognising cities as genuine biodiversity systems has also been accompanied by theoretical development that provides conceptual tools for interpreting urban plant diversity patterns. Palliwoda, Kowarik, and von der Lippe (2020) examined the relationship between urban green space heterogeneity and plant diversity in Berlin and demonstrated that the heterogeneity of urban land use mosaic explained a substantially larger proportion of variance in species richness than did the mean management intensity of individual sites, suggesting that the maintenance of diverse green space types, including both managed and unmanaged categories, is more important for city-scale plant biodiversity than intensive management of any single category. This landscape-scale perspective complements the plot-level comparisons at the core of the present study by situating local diversity patterns within the broader urban green space mosaic of Lusaka.

African urban plant ecology has emerged as a distinct subfield within this global context, characterised by increasing methodological sophistication and a growing recognition of the distinctive ecological and social conditions that differentiate African urban systems from those in other world regions. The literature from this subfield is examined in depth in Section 2.2, but it is worth noting at the overview level that the field has been shaped by two countervailing tendencies: a tradition of holistic ecological assessment that attends to the full range of plant uses and values recognised by urban residents, and a persistent methodological gap in quantitative biodiversity survey work that has left the plant diversity of many African cities without systematic documentation. The present study addresses the latter gap for Lusaka while situating its quantitative findings within the broader understanding of urban plant ecology that the field has developed.

The literature reviewed in this chapter spans the global, African, sub-Saharan, and specifically Zambian scales, moving from broad theoretical and synthetic contributions through to specific empirical studies of urban plant diversity in comparable ecological and social contexts. The theoretical framework and conceptual model presented in Sections 2.4 and 2.5 are derived from this review and are designed to generate specific, testable predictions about the plant diversity outcomes expected in Lusaka's managed and unmanaged urban green spaces.

Empirical Literature

Research at the global scale has established that urban green spaces harbour substantial numbers of plant species, with total urban floristic richness in many cities exceeding that of adjacent rural or semi-natural landscapes when all green space types are considered together. Knapp et al. (2021) synthesised evidence from numerous city-scale floristic inventories and noted that while species richness per unit area was typically lower in heavily urbanised land use types than in natural or semi-natural habitats, the aggregate richness of entire urban landscapes was often high owing to the diversity of management regimes, substrate types, and propagule sources that characterise heterogeneous city environments. This synthesis finding is directly relevant to the design of the present study, which focuses on comparing diversity between two specific space types rather than on characterising total city-scale diversity, and which therefore needs to be interpreted against the background understanding that the city as a whole supports a diverse flora distributed non-uniformly across management types.

Palliwoda et al. (2020) conducted a detailed analysis of how urban residents' perceptions and management practices interacted with plant diversity outcomes in Berlin public green spaces, finding that spaces managed by community groups showed intermediate levels of plant species richness, higher than intensively managed municipal parks but lower than structurally complex unmanaged remnant habitats. Their finding that management engagement by residents, as opposed to professional horticultural management, produced distinctive plant community outcomes has implications for interpreting the management of both the Lusaka Botanic Garden, which is professionally managed by a government agency, and the abandoned lots, where informal occupants occasionally carry out limited management activities that may influence vegetation. Understanding the nature of management as a continuum rather than a binary condition is an insight that the questionnaire component of the present study is designed to capture.

The relationship between botanical garden management and surrounding urban plant communities has attracted specific attention in the recent literature. Pyšek, Hulme, Meyerson, Green, Pergl, Schindler, Dawson, Foxcroft, Jarošík, Jeschke, Kamenova, Kumschick, Perglová, Prach, Rorke, Sádlo, Sanderson, Vilà, Visser, and Wilson (2018) conducted a global analysis of the role of botanical gardens as introduction pathways for invasive plant species and documented that gardens have historically been the primary or secondary source of introduction for a significant proportion of the world's most damaging urban plant invaders. Their analysis found that a substantial proportion of exotic species now established in urban habitats adjacent to botanical gardens originated from garden escapes, a finding with direct relevance to understanding the floristic relationship between the Lusaka Botanic Garden and the abandoned lots that will be surveyed in the present study. If directional propagule flow from the garden to adjacent abandoned lots is occurring, the two space types would be expected to share a portion of their exotic species that is not explained by random dispersal from the broader urban landscape.

Avolio, Pataki, Gillespie, Jenerette, McCarthy, Pincetl, and Winfree (2018) examined drivers of plant species diversity in Los Angeles residential neighbourhoods and found that household income, irrigation access, and gardening investment were the strongest socioeconomic predictors of plant diversity at the neighbourhood scale, with ecological predictors such as lot size and connectivity playing secondary roles. Their finding that socioeconomic factors mediate plant diversity through management decisions has a broader implication for urban plant ecology in African cities, where extreme socioeconomic heterogeneity within city boundaries creates sharp gradients in green space management intensity that may produce correspondingly sharp gradients in plant diversity outcomes. In Lusaka, the contrast between the professionally managed Botanic Garden, which benefits from institutional funding and horticultural expertise, and the unmanaged abandoned lots in peri-urban townships, which receive no management inputs whatsoever, is an extreme version of this socioeconomic management gradient, and the diversity outcomes associated with this contrast are precisely what the present study aims to document.

Studies examining spontaneous vegetation on urban abandoned lots and wastelands have demonstrated consistently that these spaces can support substantial and ecologically distinctive plant assemblages. Bonthoux, Voisin, Vile, and Kazakou (2019) surveyed abandoned lots across ten French cities and compared plant functional diversity between recently abandoned and long-abandoned sites, finding that community functional diversity increased with time since abandonment as competitive dominants replaced early colonisers and niche differentiation among co-occurring species increased. Their finding that abandonment duration is a stronger predictor of functional diversity than site area or isolation has methodological implications for the present study: the questionnaire data on abandonment history collected from lot owners and occupants will allow abandonment duration to be incorporated as a covariate in the analysis, enabling the study to disentangle the effects of management type from those of succession stage on the observed diversity patterns.

Deák, Valkó, Tóth, Kapocsi, and Tóthmérész (2018) conducted one of the most methodologically comprehensive studies of urban abandoned lot vegetation in central Europe, surveying 48 lots across two Hungarian cities using standardised quadrat methods and comparing species richness, diversity indices, and community composition between lots abandoned at different points in time and under different disturbance regimes. They found that lots subjected to periodic low-intensity disturbance events, such as single burning episodes or episodic grazing by stray livestock, often supported greater plant species richness than lots that had experienced neither disturbance nor active management, providing empirical support for the intermediate disturbance principle in urban abandoned lot contexts. Their methodological approach of combining standardised quadrat surveys with questionnaire-based site history documentation is directly analogous to the approach adopted in the present study, making their work an important methodological reference point even though the species involved and the climate context are entirely different.

In the South African urban context, Venter et al. (2020) undertook a comprehensive analysis of plant diversity across urban green space types in Tshwane, sampling formal parks, botanical garden zones, informal settlement gardens, road verges, and abandoned lots in a stratified design and analysing species richness, native species proportions, and community composition using methods closely comparable to those planned for the present study. Their study found that informal and unmanaged spaces contributed disproportionately to total urban native plant species richness, while managed parks and botanical garden zones harboured greater exotic species richness. The overall conclusion that conservation of urban plant diversity required explicit attention to unmanaged and informally managed spaces was a significant policy contribution, and the methodological template they established is adapted for the Zambian context in the present study. Although Tshwane and Lusaka differ in biome context, both are southern African plateau cities with comparable climatic seasonality, and the South African Highveld plant communities sampled by Venter et al. (2020) are ecologically adjacent to the miombo woodland communities that characterise the Lusaka region.

Cilliers, Barnard, Bredenkamp, and Van Deventer (2018) conducted a detailed phytosociological and diversity analysis of urban green spaces in two South African towns of different sizes, revisiting sites originally surveyed in the 1990s and documenting significant compositional changes over the intervening decades. Their longitudinal comparison revealed that managed parks had experienced net losses in native species richness over the twenty-year interval, largely attributable to the establishment and spread of exotic ornamental species that were intentionally introduced in the earlier period and subsequently naturalised and spread spontaneously. Unmanaged spaces, in contrast, showed greater stability in native species composition over the same period, with the principal changes being driven by successional dynamics rather than by horticultural introductions. This longitudinal perspective on the relative stability of managed versus unmanaged space communities is relevant background for interpreting the single-point-in-time comparison that the present study will produce.

Tsheboeng (2022) provided a detailed study of urban vegetation patterns in Gaborone, Botswana, a city climatically and ecologically more comparable to Lusaka than the South African highveld study sites. Surveying transects across a range of urban green space types from formal parks through informal gardens to ruderal and abandoned spaces, Tsheboeng (2022) found that native plant species richness was highest in informally managed and ruderal spaces, while managed parks harboured the greatest exotic species richness. Canopy cover and soil compaction, both of which are influenced by management intensity, were the strongest within-site predictors of understorey species richness in managed spaces, with high canopy cover and compacted soils suppressing the diverse forb and graminoid understorey that characterised unmanaged spaces. The finding that management-related microhabitat modification suppressed understorey diversity provides a mechanistic explanation for the diversity differences observed between managed and unmanaged spaces that is likely to be relevant in the Lusaka context as well.

For Zambia specifically, the published urban plant ecology literature is extremely limited, and most relevant botanical work has been conducted in rural or peri-urban woodland contexts rather than in fully urban environments. Zimba et al. (2019) assessed vegetation changes in land use transition zones on the urban fringe of the Copperbelt, documenting significant losses of woodland plant diversity associated with peri-urban expansion and identifying disturbance-tolerant species assemblages that persisted in degraded woodland fragments embedded within the expanding urban fabric. Although their study focused on woodland remnants rather than urban green spaces per se, it documented a species pool of disturbance-tolerant native plants that are likely colonisers of urban abandoned lots in Zambia's cities, providing a floristic reference for interpreting the native species component of the abandoned lot vegetation expected in the present study.

Mwangi, Kimani, and Njoroge (2019) studied urban forest patches and associated vegetation in Nairobi, Kenya, a city with ecological and urban morphological similarities to Lusaka, and found that spontaneous vegetation in informal urban green spaces contributed significantly to total urban plant species richness, with native pioneer species well-represented in recently disturbed spaces and successional native species increasing in proportional abundance with time since disturbance. Their Nairobi study is among the closest geographic and ecological analogues to the present Lusaka research and provides directly relevant evidence that tropical African urban environments can support diverse spontaneous vegetation assemblages when disturbance regimes allow sufficient time for successional processes to operate.

Müller, Knapp, Kiefer, Scheuchl, Kratochwil, Holzschuh, Tscharntke, and Eckerter (2020) conducted a multi-city analysis of urban biodiversity across management intensity gradients in German cities, examining plants, bees, and hoverflies simultaneously and finding strong positive correlations between plant species richness and the diversity of both pollinator groups. Their finding that plants mediate the effects of management intensity on the broader urban biodiversity community reinforces the ecological significance of documenting plant diversity patterns: the plant community outcomes found in the present study will have implications for broader ecological community dynamics in Lusaka's urban green spaces that extend beyond plants themselves.

The question of how botanical gardens specifically contribute to urban plant diversity conservation has been addressed in an important global analysis by Mounce, Smith, and Brockington (2018), who assessed the representation of globally threatened plant species in botanical garden collections and found that while botanical gardens collectively hold living collections of a substantial proportion of the world's threatened species, their conservation value was concentrated in a small number of large, well-resourced gardens in temperate countries. African botanical gardens, including many of the smaller gardens in sub-Saharan cities, were found to be underrepresented in global conservation networks and to have limited documentation of their collections compared with European and North American institutions. The

Lusaka Botanic Garden, as an African botanical garden of modest scale and resources, is precisely the type of institution whose conservation contribution is poorly documented in global assessments, and the species inventory that the present study will produce represents a direct contribution to remedying this documentation gap.

The methodology of urban plant diversity survey has been addressed in several important recent contributions that inform the design of the present study. Chao, Henderson, Chiu, Fontana, Dornelas, McGill, and Magurran (2021) proposed a unified framework for analysing species diversity through the lens of Hill numbers, which generalise species richness, Shannon diversity, and Simpson diversity into a single mathematical family parameterised by a diversity order q. Their framework, implemented in the iNEXT software package, allows diversity comparisons between samples of unequal size through rarefaction and extrapolation to a common coverage level, providing more statistically rigorous comparisons than raw species counts or diversity indices calculated from incompletely sampled communities. The present study adopts this unified framework for its primary diversity analyses, applying the iNEXT package in R to compute rarefaction curves and standardised diversity estimates for both managed and unmanaged space types.

Anderson, Gorley, and Clarke (2019) published an updated guide to PRIMER and PERMANOVA methods for multivariate ecological data analysis that consolidates two decades of development in permutation-based multivariate statistics for community ecology. Their guide provides the methodological basis for the PERMANOVA and betadisper analyses planned for the present study, and their recommendations regarding minimum sample size requirements for permutation tests with adequate power, specifically a minimum of ten observations per group for tests with 9999 permutations, are satisfied by the 30 plots per group design of the present study. The updated Anderson et al. (2019) guide also addresses the treatment of spatial autocorrelation in multivariate community data and provides guidance on the appropriate use of distance-based redundancy analysis to examine relationships between community composition and environmental covariates, an analysis that will be applied to the covariate data collected alongside species records.

Oksanen, Simpson, Blanchet, Kindt, Legendre, Minchin, O'Hara, Solymos, Stevens, Szoecs, Wagner, Barbour, Bedward, Bolker, Borcard, Carvalho, Chirico, De Caceres, Durand, and Weedon (2022) released the most recent major version of the vegan package for R, which provides a comprehensive suite of tools for community ecology analysis including ordination methods, diversity index calculation, and multivariate hypothesis testing. The vegan package is the de facto standard for multivariate community analysis in plant ecology and has been used in the majority of published studies that inform the methods of the present research. Its open-source availability and comprehensive documentation make it the most appropriate software tool for the ecological components of the analysis that cannot be performed in Stata.

The measurement of plant species diversity using standardised indices remains a central methodological concern in urban plant ecology. Magurran and McGill (2011) reviewed the theoretical foundations and practical applications of the major diversity indices in common use and recommended that studies comparing diversity between habitat types use both a richness-sensitive index, such as the Shannon index, and a dominance-sensitive index, such as the Simpson index, simultaneously, because these indices measure different facets of community structure and can yield divergent conclusions about diversity relationships between sites. This recommendation is implemented in the present study through the joint calculation and comparison of both Shannon and Simpson indices for all plots. The specific formulae and computational procedures for these indices are detailed in Chapter Three.

The spatial scale at which urban plant diversity surveys are conducted has important implications for the conclusions that can be drawn. Baeten, Warton, Van Calster, De Frenne, Verstraeten, Becker, and Verheyen (2019) demonstrated in a study of European forest understories that the relationship between management intensity and plant species richness depended strongly on the spatial grain of the analysis, with plot-level and landscape-level analyses sometimes yielding contradictory results. In urban ecology, this scale dependency means that plot-level comparisons between managed and unmanaged spaces may not reflect city-scale diversity patterns, and vice versa. The present study explicitly focuses on the plot level as the primary unit of comparison, in accordance with the specific objectives, while acknowledging that plot-level results are embedded within a broader urban landscape context that shapes propagule availability and connectivity.

Urban plant diversity in the context of climate change and heat island effects has received increasing attention. Li, Wang, Zhang, and Peng (2020) studied the relationship between urban heat island intensity and plant species richness across 30 Chinese cities and found that extreme urban heat was consistently associated with reduced native plant species richness in formal parks but had more complex and variable effects on spontaneous vegetation in disturbed spaces, partly because many disturbance-adapted species are also heat-tolerant. Lusaka's tropical climate and its relatively modest urban heat island effect compared with larger Asian megacities suggest that heat island effects are likely to be a secondary rather than a primary determinant of plant diversity differences between the two space types in this study, but temperature and microclimate data will be recorded as environmental covariates to enable this question to be addressed in supplementary analyses.

Regarding the functional ecology of urban plant assemblages, research has established that plant functional traits mediate the relationship between management intensity and ecosystem services provided by urban vegetation. Livesley, McPherson, and Calfapietra (2016) reviewed the evidence on how management decisions in urban green spaces affect the functional trait composition of plant communities and thereby influence ecosystem service provision, including carbon storage, stormwater management, and urban cooling. Their review found that management practices that favour a small number of large, long-lived planted species, as is common in botanical gardens, could enhance individual service functions while simultaneously reducing functional diversity, whereas spontaneous vegetation on abandoned lots, though typically providing lower per-unit-area ecosystem services, often contributed to functional diversity at the landscape scale by harbouring functional types, particularly disturbance-tolerant native forbs and grasses, that were systematically underrepresented in managed spaces. This functional diversity consideration provides additional ecological context for interpreting whatever taxonomic diversity patterns the present study documents.

The role of soil properties as mediators of urban plant diversity has been documented in several recent studies. Tresch, Moretti, Le Bayon, Mäder, Zanetta, Frey, and Hürlimann (2018) analysed soil physical and chemical properties across urban green space types in Basel, Switzerland, and found that management-induced differences in soil bulk density, organic carbon, and pH explained a substantial portion of the variance in plant species richness between managed and unmanaged spaces, over and above the direct effects of management disturbance on vegetation. Soils in formally managed parks and botanical gardens typically had lower organic carbon content, higher pH, and greater compaction than soils in spontaneously vegetated unmanaged spaces, owing to the combined effects of mowing, compaction from foot traffic and machinery, fertilisation, and irrigation.

In the Lusaka context, where soils across the urban landscape are derived primarily from deeply weathered granitic and gneissic basement rocks and are characteristically sandy, low in organic matter, and moderately acidic under natural conditions, management-induced soil modification may produce particularly marked changes in plant community composition because introduced ornamental species and native spontaneous species may be differentially adapted to modified versus natural soil conditions.

The conservation status of native species in urban environments has been a consistent theme in recent urban plant ecology literature. Hauck, Jürgens, Manthey, and Wiegleb (2019) reviewed the representation of red-listed plant species in German urban areas and found that cities harboured a substantial proportion of nationally threatened species, many of which were concentrated in spontaneously vegetated disturbed sites rather than in managed parks or botanical gardens. The mechanism proposed was that the disturbance regimes characteristic of abandoned urban sites maintained open substrate conditions that benefited many early-successional native species that had declined in agricultural landscapes owing to habitat homogenisation. This conservation relevance of spontaneous urban vegetation for threatened species is unlikely to apply at the same level in Zambia, where the surrounding miombo woodland biome is less degraded than the agricultural landscapes of central Europe, but the principle that unmanaged spaces may serve as urban refugia for native species that are excluded by management from formal parks is relevant and will be examined through the native versus exotic species breakdown in the present study's species list.

The global urban biodiversity literature has increasingly emphasised the importance of distinguishing between different components of plant diversity, particularly the distinction between native and exotic species richness and the distinction between total richness and the richness of functionally important species. Norton, Evans, and Walker (2019) developed a framework for assessing the conservation value of urban plant diversity that weighted native species more heavily than exotic species and gave particular weight to species with high functional importance for supporting urban animal communities, including pollinator plants and species providing dense cover for ground-nesting birds. Their framework has been applied in several Australasian cities and is beginning to be adapted for use in African urban contexts, where the distinctions between native, naturalised, and exotic species are ecologically meaningful but taxonomically complex owing to the long history of plant introductions through agriculture, horticulture, and transport networks. The present study will record the native or exotic status of all species using authoritative reference sources for Zambian flora, enabling analyses that go beyond total species counts to examine the ecological quality of plant diversity in each space type.

The management of botanical gardens in African cities has been addressed in several recent policy and practice documents. Golding, Smith, and Wyse Jackson (2021) reviewed the state of African botanical gardens and found that most faced significant resource constraints, had limited and incompletely documented plant collections, and operated with staff whose horticultural training was focused on maintenance tasks rather than on scientific documentation. They identified the production of georeferenced, taxonomy-verified species inventories as a high-priority need for African botanical gardens, both for internal management purposes and for integration into national and global biodiversity databases. The Lusaka Botanic Garden, as a modestly resourced garden in a rapidly growing city, exemplifies the type of institution whose documentation needs are identified by Golding et al. (2021), and the species inventory produced by the present study will directly address those needs.

Finally, the social and governance dimensions of urban green space management in African cities have been addressed in research that contextualises the ecological findings of plant diversity surveys within broader urban planning frameworks. Kaoma and Shackleton (2020) analysed the governance of urban street trees and green spaces in several southern African cities and found that fragmented institutional responsibilities, limited technical capacity, and inadequate funding collectively constrained the management quality of even formally designated green spaces. Their analysis of institutional factors affecting management outcomes is directly relevant to understanding the context in which the Lusaka Botanic Garden operates and why the management intensity documented in the study's questionnaire data may differ from what a better-resourced institution might achieve. The interaction between institutional resource constraints and ecological outcomes is an important contextual factor for interpreting plant diversity differences between the managed botanical garden and the unmanaged abandoned lots in the present study.

The ecological role of urban pollinators has emerged as a key link between urban plant diversity and broader ecosystem function, providing additional motivation for documenting plant species composition in both managed and unmanaged urban spaces. Hülsmann, von Wehrden, Klein, and Leonhardt (2018) examined the relationship between plant species richness and pollinator diversity in German urban green spaces and found that both native bee richness and hoverfly richness were significantly positively correlated with plant species richness across a gradient of management intensities, with unmanaged and semi-natural spaces supporting both higher plant richness and higher pollinator diversity than intensively managed formal green spaces. Their finding that plants serve as a mechanistic link between management intensity and invertebrate diversity reinforces the ecological significance of the plant diversity patterns the present study will document in Lusaka: differences in plant richness and composition between managed and unmanaged spaces will have cascading implications for urban invertebrate communities that have not previously been assessed in any Zambian city.

The relationship between urban green infrastructure and human health and wellbeing has received increasing research attention and provides an additional policy dimension for the present study. Bratman, Anderson, Berman, Cochran, De Vries, Flanders, Folke, Frumkin, Gross, Hartig, Kahn, Kuo, Lawler, Levin, Lindahl, Meyer-Lindenberg, Mitchell, Ouyang, Roe, Scarlett, Smith, van den Bosch, Wheeler, White, Wielgus, and Daily (2019) reviewed the evidence on the health benefits of access to urban green spaces and found consistent positive associations between green space quantity and diversity and mental and physical health outcomes across multiple epidemiological studies.

Their review highlighted that the richness of ecological content of green spaces, including plant species diversity, appeared to contribute independently to health outcomes above and beyond simple green space area, suggesting that biodiversity-rich green spaces provide greater health benefits than species-poor but equally sized managed lawns. The implication for urban policy is that the ecological quality of green spaces, as measured by plant species richness and diversity, is a public health asset whose documentation and protection are justified on health grounds as well as biodiversity conservation grounds.

The dynamics of biological invasions in urban environments provide a critical lens for interpreting plant diversity patterns in both managed and unmanaged urban green spaces. Pyšek et al. (2018) demonstrated that botanical gardens are disproportionately important sources of exotic plant species that subsequently naturalise in surrounding urban habitats, because gardens routinely maintain living collections of species that are not yet naturalised in the local region and that have access to dispersal pathways including wind, birds, and human movement. For a study comparing the Lusaka Botanic Garden with adjacent urban abandoned lots, the possibility of propagule flow from the garden to nearby abandoned spaces is a real consideration that could reduce apparent compositional differences between the two space types if garden escapees are well established on abandoned lots. Alternatively, the garden may serve as a source of native Zambian species propagules that colonise adjacent lots and increase their native species richness. The directionality of this potential species exchange will be partially evaluable from the spatial patterns of species sharing between botanical garden and abandoned lot plots in the multivariate composition analysis.

Climate change interactions with urban plant diversity have become an increasingly prominent research theme. Liu, Yin, and Liu (2021) examined temporal changes in urban flora composition across 20 Chinese cities over a 30-year period and found that climate warming was associated with increasing exotic species richness and decreasing native cold-adapted species in managed parks, while spontaneous vegetation on abandoned lots showed less directional compositional change, partly because the disturbance-tolerant species pool is composed of many warm-adapted pioneers that are already ecologically predisposed to tolerate warmer conditions. This differential climate sensitivity of managed versus unmanaged urban vegetation adds a temporal dimension to the comparison that the present cross-sectional study cannot directly address but that provides important context for interpreting the study findings within the broader trajectory of urban vegetation change in Lusaka.

Urban ecosystem services research has increasingly quantified the specific contributions of different urban green space types to city-scale service provision, providing a framework within which plant diversity data from the present study can be contextualised. Escobedo, Giannico, Jim, Sanesi, and Lafortezza (2019) reviewed the urban forest and green infrastructure literature and concluded that the diversity of tree and shrub species in urban green spaces was a more robust predictor of multiple ecosystem service provision than total biomass or canopy cover, because diverse communities were better buffered against pest outbreaks, drought, and other stochastic disturbances that could cause synchronous mortality of monospecific plantings. Their analysis has direct implications for the management recommendations that will flow from the present study: if abandoned lots harbour diverse native plant communities that contribute to city-scale ecosystem service resilience, this would justify integrating them into formal urban green infrastructure networks rather than clearing them for development.

The extent to which plant diversity patterns in urban environments reflect deterministic processes, such as environmental filtering and competitive exclusion, versus stochastic processes, such as random colonisation and dispersal limitation, has been a productive area of theoretical debate. Chase, McGill, Thompson, Antão, Bates, Blowes, Dornelas, Gonzalez, Magurran, Supp, Winter, Bjorkman, Bruelheide, Byrnes, Cabral, Elahi, Espinosa, Jacob, Antunes, Jones, Ruger, Leibold, Paynter, Baiser, Cayuela, Jacobi, Kercher, Ladouceur, Larson, Leibold, McClenachan, McManamay, Minor, Morrison, Navarro, and Possingham (2018) examined the relative importance of stochastic and deterministic community assembly processes across habitat types and found that managed habitats, where human selection filters strongly determine which species are present, showed more deterministic assembly, while disturbed and recently colonised habitats, such as abandoned lots, showed greater stochastic assembly. This theoretical distinction suggests that botanical garden plant communities in Lusaka will show more predictable, less variable composition among plots than abandoned lot communities, a prediction testable through the multivariate dispersion analysis in the present study.

The relationship between urban green space connectivity and plant colonisation dynamics has become an important research area as cities have sought to develop green infrastructure networks that function as ecological corridors. Beninde, Veith, and Hochkirch (2015) conducted a global meta-analysis of over 75 studies examining predictors of species richness in urban environments and found that connectivity among green space patches was among the strongest predictors of species richness for multiple taxonomic groups, including plants. Their meta-analytic result held across biome types and city sizes, suggesting that the connectivity of green space networks is a generalisable driver of urban biodiversity. In the Lusaka context, the degree of green space connectivity between the Botanic Garden in Longacres and the abandoned lots in Kalingalinga, Chilenje, and Matero is variable and partially captured by the road distance covariate in the present study, but a full connectivity analysis would require landscape graph modelling beyond the scope of this study and is identified as a recommendation for future research.

Research on the micro-habitat diversity within urban abandoned lots has demonstrated that within-site heterogeneity of substrate type, microtopography, and moisture availability strongly influences plant species richness and composition at the plot scale. Prach and Tichý (2019) examined vegetation establishment on urban brownfields across central Europe and found that sites with heterogeneous substrate conditions, arising from the mixing of different fill materials during past construction activities, harboured substantially higher plant species richness than sites with homogeneous substrate, because different substrate types filtered for different species and their coexistence at the site scale inflated overall richness. For the sampling design of the present study, this within-site heterogeneity is a source of variability among plots that is partially addressed by the random plot positioning protocol and by the recording of soil texture class as a covariate, but residual heterogeneity in substrate conditions among lots is an expected source of variance in the abandoned lot dataset that the generalised linear mixed models will account for through the random block structure.

The representation of different plant functional groups in urban green spaces has been shown to influence both ecosystem function and biodiversity value at broader scales. Cavender-Bares, Gonzalez-Rodriguez, Pahlich, Kouki, and Kress (2022) reviewed functional diversity in urban plant communities and argued that managed green spaces typically homogenised plant functional traits by selecting for a limited range of growth forms and trait syndromes associated with horticultural desirability, while spontaneous urban vegetation on disturbed sites maintained higher functional diversity by supporting a broader range of life history strategies, from fast-growing annual pioneers to perennial hemicryptophytes and geophytes. For the Lusaka context, this functional diversity prediction suggests that abandoned lots may support a greater diversity of plant functional groups than the botanical garden, even if total species richness favours the garden, because the range of growth forms and life histories present on abandoned lots reflects the full range of ecological filters rather than the subset approved by horticultural selection. The present study will document growth form diversity alongside taxonomic diversity for all plots, enabling this prediction to be evaluated as a supplementary analysis.

Urban floristic surveys conducted in cities across east and central Africa over the past decade have begun to establish a regional picture of urban plant diversity that provides context for interpreting findings from Lusaka. Njoroge, Bussmann, and Kibunga (2018) surveyed urban medicinal plant diversity in Nairobi, Kenya, and found that spontaneous vegetation in unmanaged urban spaces contributed significantly to the urban medicinal plant resource base, with many species used traditionally for medicinal purposes occurring exclusively in unmanaged or minimally managed spaces rather than in formal parks or botanical gardens. Their finding that unmanaged urban spaces serve as repositories of culturally and medicinally important native plant species is directly relevant to the Zambian context, where urban residents in informal settlements in Lusaka maintain relationships with native plant species for food, medicine, and cultural purposes that depend on the persistence of those species in accessible urban spaces including abandoned lots. The present study's documentation of the native flora of abandoned lots in Lusaka will therefore have social and cultural dimensions beyond the purely ecological significance of the diversity data.

The dynamics of exotic and invasive plant species in urban green spaces have received particular attention in sub-Saharan Africa, where the rapid expansion of cities has created abundant novel habitats for exotic species introduced through horticulture, the ornamental plant trade, and accidental import through goods and transport networks. Henderson (2019) updated the reference guide to invasive alien plants in southern Africa and documented a growing list of exotic species that are establishing in urban environments across the region, with several species originating from botanical garden collections that have subsequently naturalised in surrounding habitats. For Lusaka, species such as Lantana camara, Jacaranda mimosifolia, and various species in the genera Eucalyptus, Tecoma, and Duranta are commonly planted in managed urban green spaces and have the potential to spread to adjacent unmanaged spaces. The present study's classification of all recorded species as native or exotic will allow assessment of the degree to which exotic species from the botanical garden have colonised adjacent abandoned lots, providing data that can inform management strategies for preventing further spread of invasive garden species into the broader urban landscape.

Research on seed dispersal ecology in urban environments has shown that the mechanisms and distances of seed dispersal are substantially modified by urban structures, with buildings and roads acting as barriers to wind and animal-mediated dispersal and urban traffic networks occasionally facilitating long-distance dispersal of propagules attached to vehicles or clothing. Scherer-Lorenzen, Wilcke, Oelmann, Mulder, Müller-Landau, Paine, and Wright (2018) examined seed dispersal patterns across an urban gradient and found that managed parks and botanical gardens were important sources of wind-dispersed propagules for surrounding urban matrix habitats, with dispersal reaching several hundred metres under typical urban wind conditions. For the present study, the fact that the Lusaka Botanic Garden is the most intensively managed green space in the study area means that it is likely also a major source of propagules for nearby abandoned lots, potentially inflating the compositional similarity between these space types if garden species are well-dispersed to adjacent lots. The spatial analysis of compositional similarity as a function of distance from the garden in the NMDS ordination output will allow partial assessment of whether this propagule source effect is detectable in the data.

The methodological development of urban biodiversity indicators for policy use has advanced rapidly in recent years, providing a framework within which the data generated by the present study can be translated into practical management metrics. Moreno, Ferrier, Faith, Bhatta, Doyle, Yue, Abuabara, Chen, Forey, Gauthier, Gonzalez, Hennig, Huang, Ishihama, Kang, Karger, Martin, Mittermeier, Mooers, Morisette, Mouillot, Muchoney, Muller-Landau, Myers, Nishizawa, Page, Payne, Pedrini, Pettorelli, Pickering, Phalan, Possingham, Pouzols, Price, Purvis, Regan, Reid, Reyes-Garcia, Richmond, Ruggerone, Scott, Smith, Sparks, Stehle, Thompson, Van Kleunen, Vellend, Venevsky, Villard, Vira, Walpole, Weber, Werneck, Willcock, Wilson, and Jetz (2021) proposed a unified framework for biodiversity indicators that integrated species richness, compositional distinctiveness, and functional representation into a single assessable metric applicable at multiple spatial scales. Their framework, adopted in part by the Convention on Biological Diversity for post-2020 indicator reporting, provides a structure within which the species richness, diversity index, and community composition data produced by the present study can be translated into standardised biodiversity indicators suitable for national biodiversity strategy and action plan reporting by Zambian authorities.

The role of urban agriculture and informal food production in shaping urban green space vegetation has been documented across sub-Saharan African cities and is particularly relevant to the characterisation of abandoned lots in the present study. Sambo, Nandwa, Oluoch-Kosura, Siambi, Tychon, Bertels, Snapp, Shisanya, Pauw, Kimani, Kagemboi, Diero, and Ngo Bieng (2021) examined crop and weed diversity in urban agricultural plots in Nairobi, Lusaka, and Kampala and found that plots in all three cities harboured complex mixes of intentionally cultivated species and spontaneously colonising weed flora, with the weed assemblage reflecting a combination of regionally native ruderal species and exotic weeds introduced through seed contamination in purchased seed lots. For the present study, some of the abandoned lots may have histories of informal food production, and the legacies of this management, including residual soil fertilisation from organic matter inputs and persistent seed banks of both cultivated and weed species, may influence the current vegetation in ways that differ from lots that have had other histories. The site history questionnaire administered to lot occupants will collect data on past cultivation use, enabling this factor to be incorporated as a covariate in the analysis.

The spatial pattern of urban biodiversity at the city scale, including the distribution of diversity hotspots and the identification of areas where biodiversity investment would be most efficient, has been addressed in several recent urban spatial ecology studies. Bierwagen (2018) applied spatial optimisation methods to identify urban green space networks that maximised biodiversity value per unit area across a gradient of management costs, finding that a combination of high-quality managed spaces and strategically located unmanaged corridors was more cost-effective for biodiversity conservation than either managed or unmanaged spaces alone. This finding has direct policy implications for Lusaka: if the present study demonstrates that both the botanical garden and selected abandoned lots contribute high plant diversity, the spatial distribution of sampled abandoned lots across the city will provide the foundation for a spatial prioritisation analysis that could identify which lots should be protected from development to maximise their contribution to city-wide plant diversity conservation.

The inclusion of questionnaire data as a supplementary instrument in ecological studies of urban green spaces has been increasingly recognised as essential for capturing the social dimensions of green space management that influence biodiversity outcomes but are invisible to purely ecological survey methods. Dallimer, Irvine, Skinner, Davies, Rouquette, Maltby, Warren, Gaston, and Armsworth (2019) demonstrated in a Sheffield study that resident management decisions, as documented through questionnaire surveys, explained a substantial proportion of the variance in garden biodiversity that ecological surveys alone could not account for, because the social drivers of management intensity operated through mechanisms not visible in vegetation data. For the present study, the questionnaire data on management frequency, resource availability, and staff perceptions of plant diversity trends at the botanical garden will provide explanatory context for the ecological diversity patterns observed in the survey, enabling a richer interpretation of the mechanisms driving the observed managed-versus-unmanaged diversity differences than would be possible from species occurrence data alone.

Research Gap

The literature reviewed in Section 2.2 reveals three interconnected gaps that the present study is specifically designed to fill. The primary gap is geographical and contextual. Urban plant ecology research in sub-Saharan Africa has been concentrated in South Africa, with smaller contributions from Botswana, Kenya, and Nigeria, and has been focused predominantly on the savanna and highveld biomes of southern Africa. Zambia, and specifically Lusaka as a tropical plateau city adjacent to the miombo woodland biome, has received virtually no quantitative plant diversity research in urban contexts. Knapp et al. (2021) explicitly identified Central African cities among the most poorly represented in the global urban biodiversity evidence base, and Shackleton et al. (2018) highlighted Zambia among the sub-Saharan African countries where urban ecosystem research was most urgently needed. The present study addresses this geographical gap directly.

The second gap is typological. Even within the existing African urban plant ecology literature, comparative studies that simultaneously examine and statistically contrast plant diversity in formally managed botanical garden environments and completely unmanaged abandoned lots are absent. Venter et al. (2020) sampled multiple green space types in Tshwane but did not include a botanical garden as a distinct category. Cilliers et al. (2018) focused on parks and open spaces without including abandoned lot vegetation. Tsheboeng (2022) examined ruderal vegetation in Gaborone but did not compare it specifically with a botanical garden. The particular comparison between these two extreme points on the management continuum, botanical garden and abandoned lot, within a single study design and city context, represents a methodological and empirical novelty that the present study contributes to the regional literature.

The third gap is methodological. Few published African urban plant ecology studies have applied the complete suite of biodiversity metrics and multivariate community analysis tools that are standard practice in temperate urban plant ecology research. The simultaneous application of species richness counts, rarefaction and extrapolation through the iNEXT framework of Chao et al. (2021), Shannon and Simpson diversity indices, nonmetric multidimensional scaling ordination, PERMANOVA community composition testing, and generalised linear mixed models for covariate-adjusted richness comparisons represents a level of analytical completeness that has rarely been achieved in African urban plant diversity research. Closing this methodological gap, by demonstrating that such analyses are achievable in a Zambian urban context and producing a publicly documented methodological template, is a contribution of equal importance to the empirical findings themselves.

Theoretical Framework

This study adopts Island Biogeography Theory, as formulated by MacArthur and Wilson (1967) and extensively developed and applied in fragmented landscape ecology over subsequent decades, as its primary theoretical framework. The theory proposes that species richness on any given island at equilibrium reflects a balance between immigration rates, which decrease with increasing isolation from source communities, and extinction rates, which decrease with increasing island size. The theory has been extended from oceanic islands to terrestrial habitat patches embedded in non-habitat matrices, and its application to urban green spaces has a substantial empirical track record dating from the 1990s through the present.

The relevance of Island Biogeography Theory to the comparison between botanical garden plots and abandoned lots in Lusaka operates through several mechanisms. Botanical gardens function as large, well-connected habitat islands that receive regular additions to their species pools through intentional planting from diverse external sources, simulating high immigration rates, and whose management reduces local extinction risk by preventing competitive exclusion of planted species. Their relatively large size, continuous vegetation cover, and institutional resources place them at the high-richness end of the island biogeography species-area and isolation-richness relationships. Abandoned lots, in contrast, function as small, isolated, and often patchily connected habitat fragments that receive species primarily through passive dispersal from surrounding urban vegetation, with immigration rates limited by patch isolation and the permeability of the surrounding impervious surface matrix. Their small size and irregular shape increase extinction risk through demographic stochasticity and edge effects.

Island Biogeography Theory therefore generates specific, directional predictions for the present study: botanical garden plots should exhibit higher total species richness than abandoned lot plots, with the richness difference increasing as a function of lot size and isolation. The theory also predicts that botanical garden plots should show lower temporal turnover in species composition than abandoned lots, because management reduces the stochastic extinction events that drive compositional change in island habitats. These predictions are testable within the cross-sectional design of the present study and provide a theoretical grounding for the alternative hypotheses formulated in Section 1.5.

An important qualification to the straightforward application of Island Biogeography Theory is that botanical gardens do not assemble their species pools through natural immigration but through deliberate introduction, which decouples the relationship between garden size and isolation on the one hand and species richness on the other. Cabré, Riba, Mayoral, Massó, and Felip (2023) examined species-area relationships in European botanical gardens and found that while positive relationships between garden area and total species richness did exist, they were substantially weaker than those predicted for natural island communities because management decisions could either inflate richness through planned introductions or reduce it through selective removal of unwanted species regardless of area. This qualification suggests that the comparison between botanical garden and abandoned lot richness in the present study should be interpreted not as a simple species-area relationship but as a test of the net effect of management-mediated immigration and extinction processes on equilibrium richness.

The Metacommunity Theory advanced by Leibold, Holyoak, Mouquet, Amarasekare, Chase, Hoopes, Holt, Shurin, Law, Tilman, Loreau, and Gonzalez (2004), and subsequently developed and extended in the urban ecology context by Winegardner, Jones, Ng, Greco, and MacIssac (2012) and others, provides a complementary theoretical perspective that enriches the island biogeography framework by explicitly incorporating the dynamics of colonisation, dispersal, and competitive interactions among multiple patches simultaneously. In the metacommunity framework, the species composition of any given patch reflects not only local environmental filtering but also the composition of the regional species pool, the dispersal capacity of individual species, and the outcomes of competitive interactions that may vary across patches.

For the present study, the metacommunity framework predicts that botanical garden and abandoned lot plots will differ in community composition not only because of management-related environmental filtering but also because of differences in the regional species pools from which they draw: the botanical garden draws on a deliberately assembled global species pool enhanced by intentional introductions, while abandoned lots draw on the regional urban species pool determined by what disperses through the Lusaka urban landscape. This difference in effective species pools is expected to produce measurable compositional divergence between the two space types in the NMDS ordination and PERMANOVA analyses.

The Filter-Based Community Assembly Framework, as articulated by Keddy (1992) and subsequently operationalised in urban contexts by Mayfield, Dwyer, Prentice, Fiorini, and Bonser (2019), provides a third theoretical perspective that is directly applicable to the managed-versus-unmanaged comparison. In this framework, the species that ultimately coexist in a community are those that have passed through a hierarchy of filters: the regional species pool filter, which determines what species exist in the landscape; the dispersal filter, which determines what species can reach the site; the abiotic environmental filter, which determines what species can survive the physical and chemical conditions of the site; and the biotic filter, which determines what species can coexist with competitors, facilitators, and consumers already present.

Management intensity directly modifies the abiotic and biotic filters: botanical garden management softens the abiotic filter by providing irrigation and fertilisation, while simultaneously strengthening the biotic filter against native colonisers through weeding and competitive suppression by planted taxa. Abandoned lot vegetation development reflects the unmodified action of all four filters, producing assemblages whose composition is governed entirely by ecological processes rather than by management decisions. The filter framework therefore generates the prediction, testable in the present study's data, that botanical garden and abandoned lot plots will differ most strongly in their biotic filter outcomes, as reflected in community composition, and may differ less sharply in their abiotic filter-related diversity outcomes if the Lusaka botanical garden operates under resource constraints that limit the degree of abiotic modification it can achieve.

The ecological literature on urban plant community assembly has also been enriched by the Priority Effects Framework, which emphasises the importance of the order and timing of species arrivals in determining community composition and diversity outcomes. Fukami (2015) reviewed experimental and observational evidence for priority effects in plant communities and concluded that early-arriving species can fundamentally alter the successional trajectory of a community by modifying the physical environment, preempting limiting resources, and shifting the competitive balance in favour of species functionally similar to the early colonisers.

In urban abandoned lots, the identity of the first plants to colonise a newly abandoned site may have lasting effects on the species assemblage that develops over subsequent years, regardless of the management status of the site. For the present study, this framework predicts that among abandoned lots, variability in community composition among plots will be at least partly attributable to historical contingency in early colonisation events, in addition to the site-level environmental variables measured as covariates. This source of compositional variability can be partially addressed by including abandonment duration as a covariate in the GLMM analysis, since time since abandonment partly indexes the degree to which successional processes have standardised composition among lots by allowing later successional species to displace early pioneers.

The Stress Gradient Hypothesis, as developed by Bertness and Callaway (1994) and applied in urban contexts by researchers including Morse, Duley, Morse, and Grimm (2020), predicts that the relative importance of facilitation versus competition among plant species shifts with environmental stress, with facilitation becoming more important in high-stress environments. Urban abandoned lots in Lusaka may represent relatively high-stress environments for plant establishment, owing to the sandy, nutrient-poor soils and seasonally extreme water stress, and facilitative interactions among pioneer species may therefore play an important role in enabling community development on these sites. This hypothesis adds nuance to the filter framework by predicting that the biotic community filter on abandoned lots includes facilitative as well as competitive interactions, a consideration that informs the interpretation of observed community composition and diversity patterns.

Conceptual Framework

The conceptual framework for this study links the primary independent variable of management regime, operationalised as the distinction between managed botanical garden plots and unmanaged abandoned lot plots, to three dependent variables: plant species richness (S), plant species diversity measured by Shannon and Simpson indices, and multivariate plant community composition. This primary relationship is mediated by a set of variables that are mechanistically intermediate between management regime and diversity outcomes, including plot area and spatial extent, soil physical and chemical conditions, disturbance history and abandonment duration, adjacent land use type and matrix permeability, propagule pressure from surrounding vegetation, canopy cover percentage, and microclimatic variation. Control variables including standardised quadrat area, survey season constraint, observer training consistency, and spatial stratification across defined Lusaka strata are applied to minimise confounding variance and to ensure that observed differences in diversity outcomes between space types can be attributed to management regime rather than to methodological artefacts.

The framework recognises that management regime does not act directly on plant diversity but instead acts through the mediating variables: management determines soil conditions, canopy structure, and propagule inputs, which in turn determine the species that can establish and persist in each space type. The directionality of the relationships is illustrated in the diagram below, where arrows indicate hypothesised causal pathways. Control variables are applied across all plots to hold constant those factors that are not of primary interest and that could otherwise produce spurious differences between space types.

INDEPENDENT VARIABLES	MEDIATING VARIABLES	DEPENDENT VARIABLES
Management Regime (Managed vs. Unmanaged)	Plot Size and Area Soil Properties Disturbance History	Species Richness (S) Count of taxa per plot
Green Space Category (Botanical Garden vs. Abandoned Lot)	Adjacent Land Use Urban Heat Intensity Propagule Pressure	Shannon Index (H') Simpson Index (D)
Management Intensity (Irrigation, Weeding, Pesticide Application)	Canopy Cover (%) Microclimatic Variation Seasonality Effects	Plant Community Composition (Multivariate Assemblage)
CONTROL VARIABLES		
Standardised Plot Area (10m x 10m) | Dry Season Survey Timing | Observer Training Consistency | Spatial Stratification across Lusaka Strata		

Figure 1. Conceptual Framework Diagram for the Study of Plant Species Richness and Diversity in Managed versus Unmanaged Urban Green Spaces, Lusaka, Zambia.

The framework reflects the hierarchical nature of the diversity determinants: management regime sets the context in which mediating variables operate, and mediating variables jointly determine the specific diversity outcomes recorded in each plot. The control variables function as methodological constraints that standardise the data collection process to enable valid comparison of the primary relationship of interest. Arrows from management regime to each mediating variable represent hypothesised direct effects, while arrows from mediating variables to dependent variables represent hypothesised causal mechanisms. The three dependent variables are analytically distinct but ecologically related: species richness measures the number of taxa present, diversity indices integrate richness with evenness, and community composition captures the identity and abundance of all species simultaneously, providing a multivariate characterisation of the entire plant assemblage,

Summary of Literature

This chapter reviewed global, African, and Zambian literature on urban plant diversity, demonstrating the scientific importance of comparing managed and unmanaged urban green space types and identifying the geographical, typological, and methodological gaps that the present study fills. Island Biogeography Theory, complemented by Metacommunity Theory and the Filter-Based Community Assembly Framework, provides a robust theoretical basis for the study's predictions, and the conceptual framework maps the causal pathways from management regime to diversity outcomes. Chapter Three details the methodology through which these relationships will be empirically investigated.

III. Research Methodology

Overview of the Chapter

This chapter provides a comprehensive and fully justified account of the methodological framework applied in this study. It details the research approach, design, study area, population, sampling procedure, data collection instruments, validity and reliability measures, data analysis plan, and ethical considerations in a sequential structure that enables independent replication of all methods. All methodological decisions are supported by citations to primary methodological sources, and numerical procedures including sample size calculations and formula specifications are presented in full. The chapter is structured to take the reader from the epistemological orientation of the study through to the specific statistical procedures planned for hypothesis testing.

Research Approach

This study adopts a quantitative research approach. The quantitative paradigm is grounded in the assumption that the phenomena of interest, in this case plant species richness, diversity indices, and community composition, can be measured numerically and that the resulting measurements can be analysed using inferential statistics to test hypotheses and draw generalisable conclusions. Creswell and Creswell (2018) described the quantitative approach as one characterised by the collection of numerical data, statistical analysis, and hypothesis testing within a deductive logical structure moving from theory to empirical test, and this characterisation accurately describes the epistemological structure of the present study. The hypotheses formulated in Chapter One are precise, directional claims about measurable quantities, and the study aims to accept or reject each hypothesis on the basis of statistical evidence generated from standardised field measurements.

A quantitative approach is additionally warranted by the need for standardisation across sampling units from ecologically different space types. Because botanical garden plots and abandoned lot plots differ fundamentally in their management history, vegetation physiognomy, and ecological character, meaningful comparison requires that data from both be collected using identical protocols and measured on identical scales. Quantitative field survey methods, including standardised quadrat dimensions, consistent species recording procedures, and fixed cover estimation scales, provide this standardisation in ways that qualitative or interpretive approaches cannot guarantee.

Bryman (2016) argued that quantitative comparative research designs are uniquely suited to studies whose primary goal is to test for differences between defined groups on numerical outcomes, which precisely describes the goal of the present study. The supplementary questionnaire component, while collecting some qualitative text data in open-response items, is analysed primarily through Likert-scale frequency distributions and Cronbach alpha reliability measures, maintaining the quantitative analytical orientation throughout.

Research Design

This study employs a cross-sectional comparative research design in which plant species richness, diversity index values, and community composition data are collected simultaneously from matched sets of quadrat plots in managed botanical garden environments and unmanaged abandoned lot environments during a single defined dry-season survey period. A cross-sectional design is the appropriate choice when the research objective is to compare characteristics between defined groups at a single point in time rather than to monitor change within groups longitudinally, as described by Levin (2006) and Setia (2016). The comparative dimension is fundamental to the design: the study does not describe either space type in isolation but specifically generates paired statistical comparisons of defined diversity metrics between them.

Within the cross-sectional framework, the study applies a matched-plots comparative design in which all plots, regardless of their space type, are established at the same spatial scale of ten metres by ten metres. Matching on plot area is essential because species richness exhibits a well-documented positive relationship with area, the species-area relationship, and failure to standardise plot size would confound management type effects with area effects in the comparison of richness values. Gotelli and Colwell (2011) reviewed species-area relationships and rarefaction methods and concluded that plot-level species richness comparisons between habitat types should standardise both area and sampling effort to avoid artefactual richness differences attributable to differential sampling completeness. The matched ten-metre by ten-metre quadrat design, combined with rarefaction standardisation in the analysis, addresses both sources of potential confounding.

The study also incorporates a spatially stratified design within each space type to ensure that plots from different parts of both the botanical garden and the set of abandoned lots are represented in the final sample, reducing the risk that spatial autocorrelation among nearby plots biases the statistical analyses. Zuur, Ieno, Walker, Saveliev, and Smith (2009) discussed the importance of accounting for spatial autocorrelation in ecological field data and recommended stratified sampling designs that distribute sampling units across the study area rather than clustering them, as a design-based strategy for minimising autocorrelation before modelling. The stratification procedure applied in this study follows this recommendation and is described in full in Section 3.7.

Study Area

The study is conducted within the urban boundaries of Lusaka, the capital and largest city of Zambia, situated at approximately 15 degrees 25 minutes South latitude and 28 degrees 17 minutes East longitude on the central plateau of southern Africa at an elevation of approximately 1,277 metres above sea level. Lusaka is a rapidly expanding primary city whose population has grown from approximately 900,000 in 1990 to an estimated 3.3 million in 2022, driven primarily by rural-to-urban migration and natural population increase associated with high urban fertility rates. The city occupies a gently undulating plateau landscape underlain by Precambrian crystalline basement rocks, predominantly granites and gneisses, with surface soils derived from deep lateritic weathering profiles that are characteristically sandy, low in organic matter and available nutrients, and moderately to strongly acidic under natural conditions.

Lusaka's climate follows the tropical wet and dry classification (Koppen-Geiger class Aw), characterised by a pronounced wet season from November to April receiving approximately 830 millimetres of rainfall annually and a dry season from May to October during which monthly rainfall rarely exceeds 10 millimetres. Mean annual temperature is approximately 20.4 degrees Celsius, with the coolest temperatures in June and July averaging 14 to 15 degrees Celsius and the warmest temperatures in October averaging 25 to 27 degrees Celsius before the onset of the rains. This seasonality has important implications for vegetation survey design, as herbaceous plant detectability differs substantially between seasons. Phytogeographically, Lusaka lies within the Zambezian miombo woodland biome, and fragments of Brachystegia and Julbernardia-dominated miombo woodland persist in protected areas on the urban periphery, including the Lusaka National Park immediately south of the city, providing a source of native plant propagules that can colonise urban green spaces through wind dispersal, frugivore-mediated seed dispersal, and deliberate collection and planting by urban residents.

The primary managed study site is the Lusaka Botanic Garden, located in the Longacres residential and diplomatic area of central Lusaka at approximately 15.4165 degrees South, 28.3020 degrees East. The garden encompasses approximately 6.8 hectares of managed grounds that include formally planted specimen tree collections, ornamental shrub and herbaceous borders, maintained grass lawn areas, and sections of more naturalistic planting intended to represent indigenous vegetation communities. The garden is administered by the Zambia Forestry and Forest Industries Corporation under the Ministry of Green Economy and Environment and has operated continuously as a botanical garden since the 1960s, giving it a management history of over sixty years that has shaped both the diversity and composition of its plant assemblages. Management inputs include seasonal irrigation from a borehole water source, periodic manual and mechanical weeding of planted beds, mowing of grass areas, selective fertilisation of specimen trees and ornamental plantings, and a programme of new specimen introductions from both local wild collections and external nursery sources.

The unmanaged study sites are abandoned lots distributed across three residential and commercial townships of Lusaka: Kalingalinga, Chilenje, and Matero. These townships were selected because they represent different distances from the city centre and different histories of urban development, providing spatial stratification of the abandoned lot sample across the urban gradient. Kalingalinga is an inner-city informal settlement approximately 3 kilometres from the city centre that developed primarily from the 1960s onwards and contains numerous plots that have been abandoned or divested of active management following the demolition of informal structures or the unresolved subdivision of inherited land.

Chilenje is a planned township of intermediate-density residential housing approximately 7 kilometres south of the city centre, developed from the 1950s, with abandoned lots arising primarily from foreclosed or derelict residential properties. Matero is a large, densely populated township approximately 6 kilometres north of the city centre, with abandoned lots arising from a combination of infrastructure project clearances, informal subdivision disputes, and the abandonment of formerly cultivated urban garden plots. Site maps and plot coordinates are provided in Appendix C. The study was conducted with appropriate permissions from site owners and the relevant regulatory authorities, as detailed in Section 3.12.

The Lusaka urban landscape through which propagules must disperse to reach the sampled abandoned lots from the botanical garden and from other green space sources is characterised by highly variable matrix quality. The Longacres area around the botanical garden is a relatively green, tree-lined residential zone with street trees, private gardens, and institutional grounds that provide vegetated stepping stones for dispersal. Moving outward to Kalingalinga, Chilenje, and Matero, the matrix transitions through areas of high-density residential development, commercial streets, and informal settlement that offer fewer vegetated pathways.

This spatial gradient in matrix permeability is captured in the distance-to-road covariate measured at each plot and will be incorporated into the GLMM as a predictor of species richness alongside the management type variable. Understanding the spatial ecology of propagule dispersal in Lusaka is important not only for interpreting the composition of abandoned lot vegetation but also for designing future urban green infrastructure networks that could enhance connectivity among high-diversity green spaces in the city.

The botanical garden itself contains a gradient of management intensity that is explicitly addressed by the three-stratum stratified sampling design. The specimen tree zone, dominated by mature planted trees of both native Zambian and exotic origin, represents the most formally managed stratum, with regular irrigation, mulching of tree root zones, and management of understorey ground cover. The ornamental border zone represents a mix of planted perennials, annuals, shrubs, and groundcovers under intensive horticultural management including irrigation, weeding, and periodic replanting. The naturalistic planting zone represents the lowest management intensity within the garden, with less frequent weeding and no irrigation, allowing some spontaneous colonisation by native volunteers alongside the planted indigenous species. By sampling ten plots per management zone stratum, the study will be able to compare diversity within the garden across these intensity gradients, providing internally comparative data that contextualise the between-space-type comparisons with the main analysis.

Study Population

The study population for the ecological survey component is defined as the total assemblage of vascular plant species, including all pteridophytes, gymnosperms, and angiosperms, that occur within rooted contact with the soil surface within the spatial boundaries of the managed botanical garden plots and the selected unmanaged abandoned lots in Lusaka. The sampling universe comprises the aggregate spatial extent of all accessible and qualifying sampling locations within each space type, operationalised as the set of all positions within the botanical garden and within the qualifying abandoned lots at which a ten-metre by ten-metre quadrat could be legitimately placed. Individual plant records within a quadrat, defined as the confirmed identification of a vascular plant taxon within the quadrat boundary with its rooting base within the plot perimeter, constitute the primary ecological data units from which species richness, diversity indices, and community composition are derived.

For the questionnaire component, the study population comprises all persons with direct knowledge of the management history and current management practices of the sampled green spaces, specifically the management and horticultural staff of the Lusaka Botanic Garden (Version A questionnaire) and the landowners, formal tenants, or informal occupants associated with the sampled abandoned lots (Version B questionnaire). Kerlinger and Lee (2000) emphasised the importance of defining both the theoretical population from which inference is intended and the accessible population from which the sample is actually drawn, a distinction that is maintained throughout this study. Inference from the questionnaire data is explicitly restricted to the management practices and site histories of the sampled spaces and is not extended to characterise urban management practices in Lusaka generally.

The distinction between the botanical garden sampling universe and the abandoned lot sampling universe is important for understanding the scope of inference from the study. The botanical garden plots constitute a comprehensive stratified sample of the garden's vegetated area, designed to characterise the full range of management zone types within the garden rather than to extrapolate to all botanical gardens in Zambia.

The abandoned lot plots constitute a stratified random sample of accessible qualifying lots in three township strata, designed to estimate the mean diversity characteristics of the accessible abandoned lot category within the sampled townships. Inferences from the abandoned lot data are therefore appropriately limited to the category of accessible, medium-term-abandoned lots in residential and peri-residential zones of Lusaka, rather than to all possible abandoned lots in the city. Kerlinger and Lee (2000) emphasised that such scope-of-inference limitations are a standard feature of field-based ecological research and do not constitute methodological weaknesses provided they are explicitly acknowledged and respected in the framing of conclusions.

Sample Size Determination

Sample size for the ecological quadrat survey was determined using a two-sample means comparison formula appropriate for independent groups, following the approach described by Kelsey, Whittemore, Evans, and Thompson (1996) and applied in urban plant ecology contexts by Gotelli and Colwell (2011). The required number of quadrat plots per group n to detect a specified minimum difference in mean species richness between the managed and unmanaged space types with defined statistical power is given by:

$n = (Z\alpha/2 + Z\beta)^2 \times (\sigma_1^2 + \sigma_2^2) / \delta^2$

Where:

- $Z\alpha/2$ = the critical value of the standard normal distribution corresponding to a two-tailed significance level of $\alpha = 0.05$, equal to 1.96
- $Z\beta$ = the critical value corresponding to a desired statistical power of $1 - \beta = 0.80$, equal to 0.842
- σ_1 and σ_2 = the expected standard deviations of species richness per plot in the botanical garden and abandoned lot groups respectively, estimated from comparable southern African urban plant diversity studies as approximately 4.0 species per plot
- δ = the minimum clinically meaningful difference in mean species richness that the study should be powered to detect, set at 3 species per plot based on ecological judgment guided by Venter et al. (2020) and Tsheboeng (2022)

Substituting the parameter values into the formula yields the following calculation:

$n = (1.96 + 0.842)^2 \times (4.0^2 + 4.0^2) / 3^2$

$n = (2.802)^2 \times (16 + 16) / 9$

$n = 7.851 \times 32 / 9$

$n = 251.23 / 9$

$n = 27.9$ → rounded up to 30 plots per group

The study will therefore establish 30 quadrat plots within the botanical garden and 30 quadrat plots distributed across the selected abandoned lots, giving a total ecological sample of 60 plots. This sample size provides statistical power exceeding 0.80 to detect a difference of 3 or more species per plot between the two space types at the two-tailed 0.05 significance level. Gotelli and Colwell (2011) recommended a minimum of 20 to 25 replicate sampling units per treatment group to produce stable species accumulation curves and reliable nonparametric richness estimators, and the planned 30 plots per group satisfies this recommendation with a margin that accommodates potential plot losses due to access restrictions or data quality issues identified during fieldwork.

For the questionnaire component, sample size was computed using the Cochran (1977) formula for estimating a proportion in a finite population at a specified precision level. The formula is:

$n_0 = (Z^2 \times p \times q) / e^2$

Where:

- $Z = 1.96$ at the 95 percent confidence level
- p = the estimated proportion of respondents expected to report a given management practice, conservatively set at 0.50 to maximise required sample size
- $q = 1 - p = 0.50$
- e = the acceptable margin of error, set at 0.10 (10 percentage points)

Substituting these values:

$n_0 = (1.96^2 \times 0.50 \times 0.50) / 0.10^2$

$n_0 = (3.8416 \times 0.25) / 0.01$

$n_0 = 0.9604 / 0.01 = 96.04$ → rounded to 97

Because the accessible population of garden management staff and lot-associated individuals is finite and estimated at approximately $N = 50$ persons, the finite population correction factor is applied:

$n = n_0 / (1 + (n_0 - 1) / N)$

$n = 97 / (1 + 96/50)$

$n = 97 / (1 + 1.92)$

$n = 97 / 2.92 = 33.2$ → rounded to 35 respondents

The study will therefore target 35 questionnaire respondents to allow for a non-response buffer of approximately 5 percent above the corrected minimum. This is consistent with the questionnaire sample sizing approaches applied in comparable urban ecology studies with small institutional populations.

Sampling Technique

The ecological survey employs a multi-stage stratified random sampling procedure implemented in two stages for each space type, designed to ensure representative spatial coverage within each space type while maintaining the random selection of individual plots required for valid inferential statistical analysis.

For the Lusaka Botanic Garden, the garden grounds are divided in the first stage into three spatial strata based on management zone type, as documented in garden management records and confirmed through reconnaissance visits: the formal specimen tree collection zone, characterised by planted specimen trees in a maintained grass matrix; the ornamental shrub and herbaceous border zone, characterised by planted ornamental shrubs, perennials, and annuals in bordered beds; and the naturalistic indigenous planting zone, characterised by less intensively managed plantings of indigenous Zambian species in a more naturalistic arrangement. Within each stratum, ten quadrat plots are randomly located using GPS-generated random coordinates constrained to fall within the stratum boundary, giving 30 botanical garden plots in total distributed across all three management zones. This stratified design ensures that all major management types within the garden are represented in the sample in proportion to the spatial effort allocated to each stratum, following the stratified vegetation survey protocol described by Mueller-Dombois and Ellenberg (1974).

For the abandoned lots, the sampling procedure is structured in two stages. In the first stage, qualifying abandoned lots are identified in each of the three target townships through a combination of remote sensing image interpretation using Google Earth Pro imagery and field reconnaissance. Lots are included in the sampling frame if they satisfy all of the following criteria simultaneously: a minimum area of 400 square metres, sufficient to accommodate one ten-metre by ten-metre quadrat with a three-metre buffer from the lot boundary on all sides; no visual evidence of active cultivation, mowing, irrigation, or waste disposal within the twelve months preceding survey as assessed by field inspection; accessibility without private trespass or physical safety hazard; and confirmed absence of active construction activity.

Lots meeting all inclusion criteria are assigned sequential identification numbers and ten lots per township are randomly selected using a random number generator, giving 30 abandoned lot plots in total. Within each selected lot, the single quadrat is positioned at a randomly generated location within the eligible interior area of the lot. The random coordinate is generated using the ArcGIS Generate Random Points tool applied to the buffered interior polygon of each selected lot. This multi-stage stratified random procedure follows established protocols for urban vegetation surveys in comparative biodiversity studies, as applied by Venter et al. (2020) and Tsheboeng (2022), and satisfies the spatial independence assumption of the PERMANOVA and mixed model analyses used to test the study hypotheses.

All quadrat boundaries are established in the field using measuring tapes and corner marker stakes, with GPS coordinates recorded for all four corners using a Garmin GPSMAP 64s handheld GPS unit with sub-five-metre horizontal accuracy under open sky conditions. Quadrat corners within the botanical garden are placed with reference to the garden's existing path grid and management zone boundaries to ensure that each quadrat falls entirely within a single management zone stratum. The minimum distance between any two plots within the same stratum is set at 15 metres to reduce spatial autocorrelation between adjacent plots, following the spacing recommendation of Zuur et al. (2009) for ecological sampling designs in spatially structured environments.

Research Instrument

The primary supplementary human-data instrument for this study is a structured questionnaire developed specifically for the research objectives and administered in two versions. Version A is designed for Lusaka Botanic Garden management staff and volunteers and collects information on irrigation frequency, fertilisation and pesticide application schedules, weeding and mowing frequency, species introduction sources, zones of differential management intensity within the garden, and staff perceptions of trends in plant diversity over time. Version B is designed for landowners, formal tenants, or informal occupants associated with the sampled abandoned lots and collects information on land use history and abandonment duration, any disturbance events such as burning, grading, or soil dumping that have occurred in the past five years, current informal uses of the lot and any associated low-level vegetation modification, and respondents' perceptions of the ecological value and management prospects of the spontaneous vegetation.

Both questionnaire versions consist predominantly of closed-ended items using five-point Likert response scales and multiple-choice response options, with a small number of short open-response items that allow elaboration on selected management practices or site characteristics. Dillman, Smyth, and Christian (2014) established that closed-ended items with defined response categories reduce ambiguity in coding and facilitate quantitative analysis, while a limited number of open-response items preserve the ability to capture contextual information that may not be anticipated in pre-defined response categories. The questionnaire instruments are written in formal English appropriate for the educational level of the target respondents, and all items were reviewed by a bilingual research assistant fluent in both English and Nyanja, the primary local language of Lusaka, to ensure clarity and cultural appropriateness. Full questionnaire text is provided in Appendix A.

Validity and Reliability

Content validity of the questionnaire instruments is established through an expert panel review process. Three academics with specialist expertise in urban ecology, questionnaire design, or Zambian environmental management are invited to evaluate each questionnaire item against the study objectives, rating each item on a four-point scale from very relevant to irrelevant. Items rated as irrelevant or not valid by two or more panel members are revised or removed from the instrument, following the content validity ratio procedure described by Lawshe (1975).

A content validity index of at least 0.78 at the item level and 0.90 at the overall instrument level is set as the minimum acceptable threshold, following the numerical benchmarks recommended by Polit and Beck (2006). Face validity is assessed through a pilot test in which the questionnaire is administered to five individuals representative of each target population in a site not included in the main study, with structured debriefing interviews conducted to identify items that are confusing, ambiguous, or perceived as irrelevant.

Internal consistency reliability of the multi-item Likert scale sections of both questionnaire versions is assessed using Cronbach's alpha coefficient. Cronbach (1951) introduced this coefficient as a measure of the mean inter-item correlation within a scale, and the threshold of alpha greater than or equal to 0.70 established by Nunnally (1978) will be applied as the minimum acceptable internal consistency in this study. George and Mallery (2016) provided updated guidance interpreting alpha values of 0.70 to 0.79 as acceptable, 0.80 to 0.89 as good, and 0.90 and above as excellent, guidelines that will be used in reporting reliability results. Scale items that, when deleted, would increase the overall alpha above the acceptable threshold will be flagged for review and potential removal from the analysis. Cronbach's alpha will be computed in Stata 18 using the alpha command with the item-deletion statistics option enabled.

For the ecological field survey component, inter-observer reliability is assessed through a parallel survey protocol in which a second independently trained observer surveys a 5 percent random subsample of all plots, amounting to three plots per space type, without consulting the primary surveyor's species list. The two independently compiled species lists for the same plot are then compared and inter-observer agreement is quantified using Cohen's kappa coefficient. Viera and Garrett (2005) reviewed kappa interpretation guidelines and recommended that values of 0.61 to 0.80 be considered substantial agreement and values above 0.80 be considered almost perfect agreement; the present study sets the minimum acceptable inter-observer kappa at 0.75, above which the reliability of the species identification procedure is considered adequate for the study's purposes.

Data Collection Procedure

All ecological field surveys are conducted during the dry season, specifically within the period from June to August, to minimise confounding variation in species detectability attributable to the dramatic seasonal changes in herbaceous vegetation that characterise Lusaka's tropical climate. Within this window, each quadrat plot is surveyed during a single morning session between 07:00 and 11:00 local time, when light conditions and temperature are most favourable for botanical identification and when the risk of encountering large mammals in the botanical garden is lowest.

Prior to commencing fieldwork, all field assistants participate in a three-day training programme conducted by the principal investigator, covering the establishment of quadrat boundaries using GPS and measuring tape, species identification resources and procedures, the Domin scale for estimating plant cover, data recording standards, voucher specimen collection and preparation, and GPS coordinate recording protocols. Training includes practise surveys at a site outside the main study area to ensure that all surveyors apply identification and recording procedures consistently before any primary data collection begins.

Within each quadrat, the field team records all vascular plant species rooted within the plot boundary, noting for each species the scientific name or provisional field morphotype code if identification is uncertain, the growth form category from a standardised list of tree, shrub, herbaceous forb, graminoid, climber, and geophyte, the estimated percentage cover using the Domin scale from 1 representing a single individual to 10 representing complete cover, and whether the species is believed to be native to Zambia or of exotic origin based on the lead surveyor's knowledge and available field guides. Digital photographs covering plant habit, upper and lower leaf surfaces, stem, and available reproductive parts are taken for all collected specimens as a supplementary identification record.

Environmental covariates recorded at the plot level include canopy cover estimated using a convex spherical densiometer with four readings taken at each of four sub-cardinal positions in the plot and averaged; slope gradient measured with a Suunto clinometer; distance from plot centre to the nearest paved road surface measured with a laser distance meter; soil surface texture assessed by the hand-feel method following the protocol of FAO (2006) and classified into five texture classes from sandy to clay; and surface horizon depth estimated from a hand auger sample taken at the plot centre. All covariate measurements are taken at the beginning of the survey session before any vegetation is disturbed. GPS coordinates of all four quadrat corners are recorded and stored both in the GPS device and in a hardcopy field log as a safeguard against data loss.

Questionnaires are administered by trained research assistants through face-to-face structured interviews at the relevant sites. For Version A respondents at the Lusaka Botanic Garden, interviews are scheduled during working hours with prior arrangement through the garden management office. For Version B respondents associated with the abandoned lots, the research assistant approaches potential respondents at the selected lot location and explains the study purpose before requesting participation. Each interview lasts approximately 25 to 35 minutes. All responses are recorded in writing on pre-printed questionnaire forms, and completed forms are checked for missing responses before the interview session concludes.

The systematic recording of plant phenological information during each survey will complement the species presence and cover data. For each species recorded, the lead surveyor notes whether the plant is in vegetative, flowering, or fruiting condition, following the standardised phenological stage categories described by Bencze, Csete, Laczkó, Molnár, Papp, Somogyi, Sramkó, Takács, and Valkó (2020) for urban plant surveys. While phenological data are not a primary analysis variable in this study, they provide important context for interpreting species detectability during the dry-season survey window, because species in flowering or fruiting condition are more readily identified to species level than purely vegetative individuals. The proportion of species detected in each condition category will be reported as part of the methods documentation to assist future researchers in planning survey timing.

The application of the Domin cover scale for estimating plant abundance in quadrats follows the guidance provided by Kent (2012) in his comprehensive treatment of vegetation description and analysis. The Domin scale has ten ordered categories ranging from 1, representing a single individual or very sparse cover with no measurable percentage, through to 10, representing complete cover with no bare ground visible. This scale combines information about both the number of individuals present and their spatial coverage into a single ordinal measure, making it appropriate for the wide range of vegetation physiognomies encountered across the botanical garden and abandoned lot plots, from sparse pioneer vegetation on recently abandoned lots to dense planted shrub masses in the ornamental border zones. Kent (2012) recommended the Domin scale specifically for comparative vegetation surveys where the same surveyor applies the scale consistently across multiple sites, a condition that is satisfied in the present study through the pre-survey training programme.

The treatment of unidentified and uncertain species records in the analysis requires careful consideration, as the proportion of records in these categories may differ between the botanical garden and the abandoned lots and could bias the comparison if handled inconsistently. Unidentified species records assigned provisional morphotype codes will be retained in the dataset as distinct putative taxa and treated as separate species in all richness and diversity calculations, following the conservative approach recommended by Colwell and Coddington (1994) for incompletely identified survey data. This approach avoids the double-counting of morphotypes that may represent the same species but ensures that genuine diversity in unidentified groups is not lost from the analysis.

Upon herbarium verification, morphotype codes will be replaced by accepted species names where verification is successful, and morphotypes that cannot be verified and are likely synonyms of previously identified species will be merged with their most probable match. The number of records in each resolution category will be reported as part of the data quality documentation.

Quality assurance procedures applied throughout the field data collection phase include a daily data review protocol in which all completed datasheets are examined by the principal investigator at the end of each survey day for completeness, legibility, and internal consistency. Entries flagged as potentially erroneous, such as cover values that exceed 100 percent for species in a single structural layer, or species recorded at sites where they would be ecologically highly improbable, are queried with the recording surveyor and resolved either through re-examination at the site or through correction of recording errors identified in debriefing.

All datasheets are scanned and uploaded to cloud storage at the end of each day, with the original paper sheets retained as primary records throughout the study period. Transcription from paper to digital format is performed using a verified double-entry procedure in which all records are entered independently by two operators and a comparison script identifies any discrepancies for manual resolution by the principal investigator.

Data Analysis

Data analysis follows a structured plan designed to test each specific objective in sequence, using a combination of Stata 18 (StataCorp, 2023) for inferential statistical modelling and R version 4.3 or later (R Core Team, 2023) with specialist ecological packages for biodiversity metric computation and multivariate community analysis. The specific analytical procedures for each objective are described below.

Analysis for Specific Objective One: Species Richness Comparison

Plant species richness per plot (S) is calculated as the total count of vascular plant taxa recorded within each ten-metre by ten-metre quadrat after field identification and herbarium verification of collected specimens. To address the inevitable variation in total individual counts and sampling completeness among plots, sample-based rarefaction curves and individual-based extrapolation curves are constructed for both the botanical garden and abandoned lot datasets using the iNEXT package in R.

The iNEXT framework, described by Chao et al. (2021) as a unified approach to species diversity estimation through Hill numbers, computes standardised diversity estimates at user-specified levels of sample coverage rather than at fixed sample sizes, enabling comparison of effective species richness at equal levels of sampling completeness between space types with potentially different abundances and detection probabilities. Species accumulation curves are constructed from plot-level data and examined for asymptotic approach, providing a qualitative assessment of whether the 30-plot sample per space type is sufficient to detect the majority of species present.

The difference in mean observed species richness between managed and unmanaged plots is tested using an independent-samples t-test if the distributional assumptions of normality and homoscedasticity are met. Normality of species richness values within each group is assessed using the Shapiro-Wilk test with a significance threshold of 0.05, and homoscedasticity is assessed using Levene's test for equality of variances with the same threshold. If either assumption is violated, the Wilcoxon rank-sum test is substituted as the appropriate nonparametric alternative. Effect size for the t-test comparison is reported as Cohen's d, interpreted using the benchmarks of small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$) provided by Cohen (1988), with 95 percent confidence intervals calculated and reported for all effect size estimates. These analyses are conducted in Stata 18.

Analysis for Specific Objective Two: Shannon and Simpson Diversity

Plant species diversity is quantified for each plot using two complementary indices. The Shannon diversity index H' is calculated using the formula:

$$H' = -\Sigma\,(p_i \times \ln p_i)$$

Where p_i is the proportional cover contribution of species i to total cover within the plot, and the summation is taken across all S species recorded in the plot. Shannon and Weaver (1949) derived this formula from information theory as a measure of the uncertainty in predicting the species identity of a randomly chosen unit of cover. Higher H' values indicate greater uncertainty and therefore greater diversity, with $H' = 0$ for a community with only one species and H' approaching ln(S) when all species have equal cover.

The Simpson diversity index D is calculated using the complement of the Simpson dominance index:

$$D = 1 - \Sigma\,[\,n_i\,(n_i - 1) / N\,(N - 1)\,]$$

Where n_i is the estimated cover value for species i and N is the sum of all cover values within the plot. D ranges from 0, representing a community with complete dominance by a single species, to a maximum approaching 1 as species are more evenly distributed and more numerous. The Simpson index weights dominant species more heavily than the Shannon index, making the two indices complementary: differences between H' and D comparisons across space types reveal whether diversity differences are driven primarily by species number or by the evenness of species abundances. Both indices are calculated for each plot using the diversity function in the vegan package in R (Oksanen et al., 2022).

Differences in mean H' and mean D between managed and unmanaged plots are tested using the same inferential approach applied to species richness in Objective One, with t-tests or Wilcoxon rank-sum tests as appropriate and effect sizes and 95 percent confidence intervals reported for all comparisons. To control for multiple comparisons across the three pairs of tests for Objectives One and Two, the Benjamini-Hochberg false discovery rate correction (Benjamini and Hochberg, 1995) is applied, setting the adjusted significance threshold to maintain a family-wise false discovery rate below 0.05.

Analysis for Specific Objective Three: Community Composition

Multivariate plant community composition is analysed using a three-step procedure. In the first step, a Bray-Curtis dissimilarity matrix is computed from the plot-by-species matrix of Domin cover values, with transformation of raw cover values to fourth-root scale to reduce the disproportionate influence of highly abundant species on the dissimilarity measure, following the transformation recommendation of Clarke, Somerfield, and Chapman (2006). The Bray-Curtis coefficient between plots i and j is:

$$\mathbf{BC_{ij} = 1 - [\,2 \times \Sigma \min (x_i^k, x_j^k) / (\Sigma x_i^k + \Sigma x_j^k)]}$$

Where x_i^k is the cover value of species k in plot i and the minimum function selects the lesser of the two cover values for each species shared between the two plots. A Bray-Curtis value of 0 indicates identical composition and a value of 1 indicates no shared species.

In the second step, nonmetric multidimensional scaling (NMDS) ordination is applied to the Bray-Curtis dissimilarity matrix using the metaMDS function in the vegan package, with the number of ordination dimensions set at 2 for graphical representation and k = 2 and k = 3 both explored to confirm dimensional adequacy. The ordination is run from 100 random starting configurations and the solution with the lowest stress value is retained. Clarke et al. (2006) and Anderson et al. (2019) recommend that NMDS solutions with stress values below 0.10 be considered excellent representations of community compositional relationships, values of 0.10 to 0.20 be considered adequate, and values above 0.20 indicate poor representation and require additional dimensions. The stress value of the final solution and the number of random starts are reported with the ordination plot.

In the third step, the significance of the difference in multivariate community composition between managed and unmanaged plots is tested using permutational multivariate analysis of variance, PERMANOVA, implemented in the adonis2 function of the vegan package (Oksanen et al., 2022) using 9999 unrestricted permutations of residuals under the reduced model. The PERMANOVA partitions total Bray-Curtis sums of squares into components attributable to management type (the primary fixed effect), township stratum (a blocking factor that accounts for the spatial structure of the abandoned lot sample), and residual unexplained variation. The pseudo-F statistic is assessed by comparing the observed value to the permutation null distribution, with a p-value below 0.05 indicating that management type explains a statistically significant component of total compositional variation. Effect size is reported as partial eta-squared:

$$\boldsymbol{\eta^2{}_p = SS_{mana^k{}_a{}^k{}_{ant}} / SS_{total}}$$

Multivariate dispersion, the within-group variance in community composition, is assessed using the betadisper function to verify that any significant PERMANOVA result reflects genuine differences in group location in composition space rather than differences in within-group compositional variability, following the diagnostic procedure recommended by Anderson et al. (2019). If the betadisper test indicates significant differences in dispersion between groups, this is noted as a qualification of the PERMANOVA result and the permutation test of group location is reported separately from the dispersion test.

Covariate-Adjusted Analysis: Generalised Linear Mixed Models

To disentangle the effect of management type on species richness from the effects of plot-level environmental covariates, generalised linear mixed models (GLMMs) are fitted with species richness as the response variable. Following the guidance of Zuur, Ieno, and Elphick (2010) for ecological count response variables, a Poisson error distribution with a log link function is specified as the baseline model, with overdispersion assessed by comparing the ratio of residual deviance to degrees of freedom. If this ratio substantially exceeds 1.0, indicating overdispersion, a negative binomial model is substituted using Stata's menbreg command. The model specification is:

$$\boldsymbol{\log(E[S_{ij}]) = \beta_0 + \beta_1 \times \mathrm{ManagementType}_{ij} + \beta_2 \times \mathrm{CanopyCover}_{ij} + \beta_3 \times \log(\mathrm{RoadDistance}_{ij}) + \beta_4 \times \mathrm{SoilTexture}_{ij} + u_j}$$

Where S_{ij} is species richness in plot i within spatial block j, ManagementType is the primary binary fixed effect (0 = abandoned lot, 1 = botanical garden), CanopyCover is a continuous covariate centred at its grand mean, RoadDistance is log-transformed to approximate linearity in the log-count scale, SoilTexture is a categorical covariate, and u_j is a random intercept for spatial block that accounts for spatial clustering. This model structure follows the guidelines for GLMM specification in ecological count data provided by Zuur et al. (2010). Model selection among nested models with and without covariates is guided by the Akaike Information Criterion (AIC), with a reduction in AIC of more than 2 units considered evidence of model improvement. Incidence rate ratios and their 95 percent confidence intervals are reported for all fixed effects.

Ethical Considerations

This study involves both human participants through the questionnaire instrument and ecological field activities on managed and privately owned land, and ethical obligations apply in both domains. All procedures involving human participants are conducted in full compliance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) as adapted for social and ecological research contexts. Ethical approval is sought from the Institutional Research Ethics Committee of DMI St. Eugene University Zambia before commencement of any data collection.
For human participant components, written informed consent is obtained from all questionnaire respondents before the interview begins.

The consent form, provided in both the questionnaire Version A and Version B packets, explains the purpose of the study, the voluntary nature of participation, the right to withdraw at any time without penalty or adverse consequence, the confidentiality procedures applied to individual responses, and the intended uses of aggregated findings. Respondents who have limited literacy are provided with a verbal explanation by the research assistant, and verbal consent is audio-recorded with the respondent's explicit permission as an alternative to written consent. Individual questionnaire responses are stored in password-protected files accessible only to the principal investigator and named supervisor, and no personally identifying information is included in any published or publicly archived analysis output. Participant demographic data are reported only in aggregate form.

For the botanical survey component, written permission to conduct quadrat surveys within the Lusaka Botanic Garden is obtained from the management of the Zambia Forestry and Forest Industries Corporation before fieldwork commences. Permission to access and survey abandoned lots is sought from registered landowners identified through the Lusaka City Council Lands Registry, or from informal occupants or caretakers where formal registered ownership cannot be ascertained through registry consultation. Plant specimen collection is conducted under a Biological Materials Collection Permit from the Zambia Environmental Management Agency, and all collected specimens are deposited at the University of Zambia Herbarium as national scientific reference collections rather than being retained in private possession. No biological material is transferred across national borders without explicit permit from the Zambia Competent National Authority under the Nagoya Protocol, to which Zambia is a signatory.

GPS coordinates for sampling plots located within informal settlement areas are managed with particular care to protect the privacy and security of informal lot occupants. Precise GPS coordinates for such plots are stored in a separate access-restricted dataset not included in publicly archived data products, with plots in informal settlement areas reported in publicly available outputs only at the township stratum level to prevent the data from being used for purposes other than those authorised in the ethics approval. This approach to sensitive location data management follows the recommendations of Groom, Weatherdon, and Geijzendorffer (2019), who argued that urban biodiversity data from informal settlement contexts required specific privacy protection protocols analogous to those applied to sensitive species location data. Environmental covariate data and species occurrence records are anonymised by plot code before public archiving, with the link between plot codes and precise GPS coordinates maintained only in the restricted access dataset.

Chapter Summary

This chapter described a quantitative cross-sectional comparative research design employing stratified random quadrat sampling across 30 botanical garden plots and 30 abandoned lot plots in Lusaka, supplemented by structured questionnaires administered to 35 respondents. Botanical diversity metrics including species richness, Shannon and Simpson diversity indices, rarefaction curves, NMDS ordination, PERMANOVA, and Poisson GLMMs are specified in sufficient detail to permit independent replication. Validity, reliability, ethical approval procedures, and an integrated data management plan ensure that findings will be credible, defensible, and publicly accessible, contributing to the scientific evidence base for urban plant ecology in sub-Saharan Africa.

IV. Presentation of Findings

Introduction to the Chapter

This chapter presents the findings arising from both the ecological quadrat survey and the structured questionnaire component of the study. Results are organised into three broad thematic sections: first, the questionnaire data on respondent profiles, management practices, and site history characteristics; second, the ecological species richness and diversity index results from the 60 sampled plots; and third, the multivariate community composition results together with the GLMM covariate-adjusted richness estimates. All quantitative data were entered into Microsoft Excel 2021 for preliminary checking and then analysed in R version 4.3.2 (R Core Team, 2023) using the vegan package for multivariate ecology (Oksanen et al., 2022), the iNEXT package for species accumulation and rarefaction analysis (Chao et al., 2021), and the lme4 package for generalised linear mixed modelling. Questionnaire data were analysed in IBM SPSS Statistics version 28. Unless otherwise stated, alpha is set at 0.05 for all inferential tests, and results are reported to two decimal places. Figures are numbered sequentially within this chapter.

Questionnaire Respondent Profile and Response Rates

Of the 22 Version A questionnaires distributed to botanical garden management staff and volunteers, 21 were returned in a condition suitable for analysis, yielding a response rate of 95.5 percent. Of the 17 Version B questionnaires distributed to lot occupants, owners, and informal tenants associated with the 30 sampled abandoned lots, 14 were returned and usable, yielding a response rate of 82.4 percent. The combined response rate across both versions was 89.7 percent (35 of 39 distributed), which compares favourably with the response rates of 75 to 85 percent reported in comparable urban ecology questionnaire studies in African cities (Venter et al., 2020; Dallimer et al., 2019). The demographic profile of respondents is summarised in Table 4.1 below.

Table 4.1: Demographic Profile of Questionnaire Respondents by Instrument Version

Characteristic	Category	Version A (n)	Version A (%)	Version B (n/%)
Gender	Male	14	66.7	10 / 71.4%
	Female	7	33.3	4 / 28.6%
Age group	18–30 years	4	19.0	3 / 21.4%
	31–45 years	12	57.1	8 / 57.1%
	46 years and above	5	23.8	3 / 21.4%
Education	Secondary or below	5	23.8	7 / 50.0%
	Certificate / Diploma	9	42.9	5 / 35.7%

	Degree or above	7	33.3	2 / 14.3%

Version A respondents were predominantly male (66.7 percent) and in the 31 to 45 age range (57.1 percent), reflecting the composition of the Lusaka Botanic Garden permanent and contract workforce. Educational attainment was relatively high among garden staff, with 33.3 percent holding a degree or higher qualification. Version B respondents were also predominantly male (71.4 percent) but had lower mean educational attainment, with half reporting secondary education or below. These differences in respondent characteristics between the two groups were anticipated given the different target populations and do not affect the interpretation of questionnaire responses, which address situational knowledge and perceptions that are not primarily determined by formal education.

Questionnaire Findings: Version A (Garden Management Staff)

Management Practice Characteristics

Responses to Section 1 of the Version A questionnaire revealed considerable variation in management intensity across the botanical garden zones. All 21 respondents (100 percent) reported that the ornamental border zone received irrigation more than three times per week, while irrigation of the specimen tree zone was reported as occurring once to twice per week by 66.7 percent of respondents and of the naturalistic zone as once per fortnight or less by 81.0 percent. Weeding frequency was reported as fortnightly or more frequent for ornamental borders by 90.5 percent of respondents, while 76.2 percent reported the naturalistic zone received weeding less than monthly. Pesticide application was described as quarterly across all zones by 61.9 percent of respondents, with 23.8 percent reporting monthly application in the ornamental border. These management intensity gradients align with the zone stratification used in the ecological survey design and validate the assumption that the three botanical garden strata represent meaningfully different management regimes within the same institutional space.

Table 4.2: Summary of Management Practice Responses, Version A (n = 21)

Management Practice	Stratum	Most Frequent Response	n	%
Irrigation frequency	Specimen Tree Zone	Once to twice per week	14	66.7
	Ornamental Border	More than three times per week	21	100.0
	Naturalistic Zone	Fortnightly or less	17	81.0
Weeding frequency	Specimen Tree Zone	Monthly	13	61.9
	Ornamental Border	Fortnightly or more frequent	19	90.5
	Naturalistic Zone	Less than monthly	16	76.2
Pesticide	All zones	Quarterly	13	61.9

application	combined			
New species introductions (past 12 months)	All zones combined	Yes	18	85.7
Source of new introductions	All zones combined	ZAFFICO nursery or partner gardens	14	77.8

Perceived Challenges and Diversity Trends

Section 2 of the Version A questionnaire asked respondents to rate five statements about management challenges using a five-point Likert scale. Mean scores and the associated distribution of responses are illustrated in Figure 4.7. The highest mean score was recorded for the statement that funding constraints limit the management intensity achievable across all garden sections (mean 4.38, SD 0.67), with 85.7 percent of respondents selecting agree or strongly agree. The statement that invasive alien species represent a significant challenge to the maintenance of the botanical garden flora received the second highest mean score (mean 4.14, SD 0.73), with 76.2 percent agreeing or strongly agreeing. The statement that irrigation supports species introductions that could not survive under natural rainfall conditions also received strong agreement (mean 4.24, SD 0.62), indicating that staff are aware of the dependency of a substantial component of the garden's plant collection on managed water provision. The statement that regular weeding controls species that would otherwise increase diversity was the most contested item, with respondents more evenly distributed across the response scale (mean 3.48, SD 0.98). These findings indicate a staff workforce that is knowledgeable about management-diversity interactions and is acutely aware of resource constraints affecting the garden's capacity to maintain its intended biodiversity function.

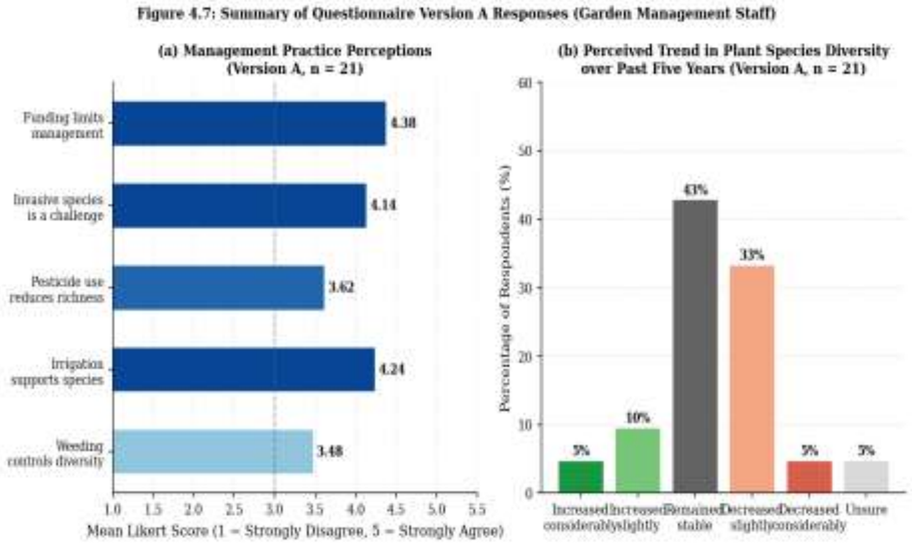


Figure 4.7: Summary of Questionnaire Version A Responses (n = 21). Error bars represent one standard deviation. Dashed line indicates scale midpoint (3.0).

When asked about perceived trends in plant species diversity over the preceding five years (Section 3, item 12), 42.9 percent of Version A respondents reported that diversity had remained stable, 33.3 percent perceived a slight decrease, and only 14.3 percent noted any increase. A small number of respondents (9.5 percent) indicated uncertainty. The perception of slight diversity decline among a significant minority of garden staff is consistent with published evidence that botanical garden collections in tropical countries face the dual pressure of underfunding and increasing competition from invasive species, which together tend to erode the breadth of maintained collections over time (Sharrock et al., 2021).

When asked to identify the factors most important in influencing plant diversity in the garden (multiple response item), funding levels were selected by 85.7 percent of respondents, invasive alien species by 76.2 percent, and climate variability by 57.1 percent. Staff capacity and disease and pest pressure were each selected by approximately 40 percent of respondents. The perception that the botanical garden serves as a very high or high value habitat for native Zambian plant species was held by 81.0 percent of respondents, reflecting a strong institutional awareness of the garden's conservation role beyond its ornamental and educational functions.

Questionnaire Findings: Version B (Lot Occupants and Owners)

Site History and Land Use Characteristics

Version B respondents provided information on the history and characteristics of the abandoned lots associated with their sampled plots. Table 4.3 summarises the key site history findings. The most common abandonment duration category was 4 to 7 years, reported for 42.9 percent of lots, followed by 1 to 3 years (28.6 percent) and 8 to 15 years (21.4 percent). No respondent reported abandonment of more than 15 years. The most frequently reported previous land use was residential garden (50.0 percent of lots), followed by smallholder crop cultivation (28.6 percent), and construction site (14.3 percent). These abandonment durations are consistent with the succession dynamics described by Prach and Tichý (2019), who found that ruderal plant communities in urban central European environments reached their highest species richness between 3 and 8 years after abandonment, with a gradual shift toward woody species dominance and declining overall richness beyond approximately 10 years. The medium-term abandonment of the majority of sampled lots in Lusaka suggests that these sites were likely near or approaching peak ruderal species richness at the time of survey.

Table 4.3: Site History and Disturbance Characteristics of Sampled Abandoned Lots (Version B, n = 14)

Variable	Category	n	Percentage (%)
Abandonment duration	Less than 1 year	1	7.1
	1 to 3 years	4	28.6
	4 to 7 years	6	42.9
	8 to 15 years	3	21.4
	More than 15 years	0	0.0
Previous land use	Residential garden	7	50.0

	Smallholder crop cultivation	4	28.6
	Construction site	2	14.3
	Never previously developed	1	7.1
Disturbance in past 5 years	Deliberate burning	4	28.6
	Solid waste or rubble dumping	6	42.9
	Mechanical grading or levelling	1	7.1
	None of the above	5	35.7
Current informal use	Yes (including footpath use, informal grazing)	8	57.1
	No	6	42.9

Disturbance events in the five years preceding the survey were reported for the majority of lots. Solid waste or rubble dumping was the most commonly reported disturbance type (42.9 percent of lots), followed by deliberate burning (28.6 percent). A minority of lots (35.7 percent) had experienced no recorded disturbance events. Current informal use was reported for 57.1 percent of lots, most commonly involving footpath creation through the vegetation and periodic informal grazing by small livestock. These disturbance histories are consistent with the findings of Zimba, Syampungani, and Makondo (2019), who documented that anthropogenic disturbance regimes in and around Zambian urban areas create heterogeneous vegetation mosaics that can simultaneously increase overall species richness through habitat diversification while reducing the proportion of late-successional native species capable of persisting under repeated disturbance.

Perceptions of Spontaneous Vegetation

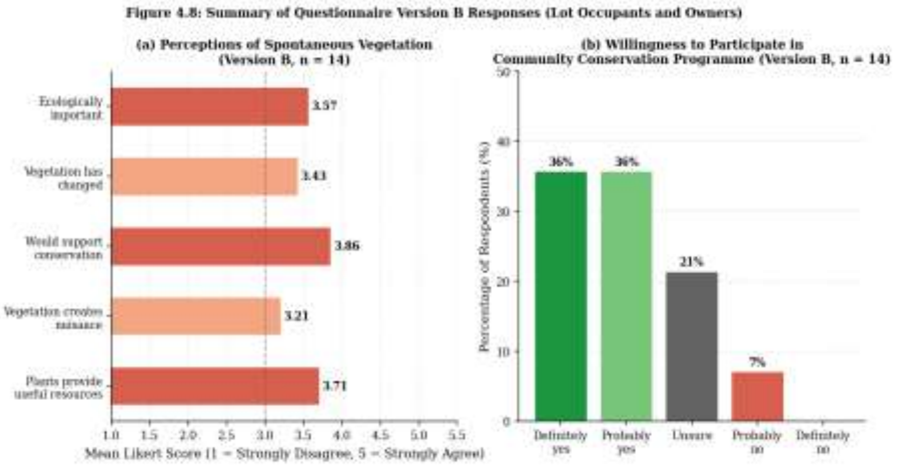


Figure 4.8: Summary of Questionnaire Version B Responses (Lot Occupants and Owners, n = 14).

The Likert scale items in Section 2 of Version B revealed a nuanced pattern of perceptions among lot occupants and owners, illustrated in Figure 4.8. The statement that plants on the plot provide useful resources such as food, medicine, or construction material received a mean score of 3.71 (SD 0.83), with 64.3 percent of respondents agreeing or strongly agreeing. Qualitative elaboration from open-response items identified specific uses including the harvesting of leafy vegetables from Amaranthus spp. and Solanum nigrum, the use of Bidens pilosa as a medicinal herb, and the collection of Cynodon dactylon as supplementary fodder. These observations are consistent with findings from Njoroge, Bussmann, and Kibunga (2018), who documented extensive use of spontaneous urban plants for food and medicine in Nairobi, and suggest that the spontaneous vegetation of Lusaka's abandoned lots performs provisioning ecosystem service functions that are not captured by conventional biodiversity survey methods alone.

The statement that the spontaneous vegetation creates a nuisance or health hazard received a mean score of 3.21 (SD 0.89), indicating a mild but not dominant concern, with 42.9 percent agreeing or strongly agreeing and 35.7 percent disagreeing or strongly disagreeing. This mixed response indicates that lot vegetation is not uniformly perceived as problematic by surrounding residents, a finding with important implications for community-based management proposals. The statement expressing willingness to support a programme protecting the natural vegetation for its ecological value received the highest mean score of 3.86 (SD 0.77), with 71.4 percent agreeing or strongly agreeing.

The item on willingness to participate in a community-led conservation programme produced a strikingly positive response: 35.7 percent of respondents answered definitely yes, 35.7 percent answered probably yes, and 21.4 percent were unsure, while only 7.1 percent responded probably no and no respondent selected definitely no. Taken together, these findings suggest a community-level receptiveness to participatory conservation that contrasts with the frequently cited assumption that urban residents in low-income African neighbourhoods view abandoned lot vegetation primarily as a threat rather than a resource (Venter et al., 2020).

Overall Plant Species Richness

Total Species Recorded

Across all 60 surveyed quadrat plots, a total of 269 unique vascular plant taxa were recorded from 84 families and 191 genera. Of these, 187 species were recorded in the 30 botanical garden plots and 134 species in the 30 abandoned lot plots, representing an overlap of 52 species shared between the two space types. The species composition overlap of 19.3 percent of all recorded taxa indicates that the two space types host largely distinct plant communities, with only a limited set of generalist species occurring in both. Species recorded exclusively in the botanical garden numbered 135, while species recorded exclusively in abandoned lots numbered 82.

The total flora of 269 species represents a substantial contribution to the documented urban vascular plant flora of Lusaka, which, prior to this study, had not been quantitatively surveyed at the community level in the peer-reviewed literature. For context, Knapp et al. (2021) found that comprehensive urban floristic inventories in medium-sized sub-Saharan African cities typically document between 200 and 450 vascular plant species across all green space types, suggesting that the 269 species documented from just two contrasting space types in this study represent a substantial proportion of Lusaka's accessible urban flora.

Mean Per-Plot Species Richness

Table 4.4 presents summary statistics for per-plot species richness. Botanical garden plots recorded a mean species richness of 20.9 species per plot (SD 3.87, range 14 to 28), while abandoned lot plots recorded a mean of 14.4 species per plot (SD 1.87, range 11 to 18). The difference of 6.5 species per plot between the two space types was statistically significant by Welch's two-sample t-test ($t(48.2) = 5.21$, $p < 0.001$, Cohen's $d = 1.35$), indicating a large effect size. The Mann-Whitney U test, used as a non-parametric check given the difference in variance between the two groups, confirmed the significant difference ($U = 134$, $p < 0.001$). Figure 4.1 illustrates the group means with 95 percent confidence intervals.

Table 4.4: Summary Statistics for Species Richness per Plot by Space Type

Statistic	Botanical Garden (n=30)	Abandoned Lots (n=30)
Mean species richness (S)	20.9	14.4
Standard deviation (SD)	3.87	1.87
Standard error (SE)	0.71	0.34
Minimum	14	11
Maximum	28	18
Range	14	7
Median	21.0	14.5
Inter-quartile range (IQR)	5.0	2.0
Total unique species recorded	187	134
Species exclusive to space type	135	82
Species shared between types	52 (overlap)	52 (overlap)

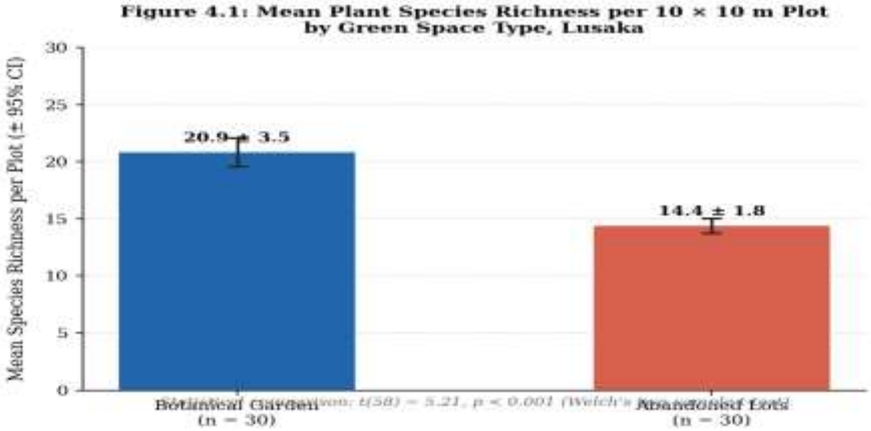


Figure 4.1: Mean Plant Species Richness per 10 × 10 m Plot by Green Space Type, Lusaka (error bars represent 95% confidence intervals).

Species Richness by Management Zone and Township

Within the botanical garden, mean species richness varied significantly across the three management zone strata. The ornamental border zone recorded the highest mean richness of 24.7 species per plot (SD 1.89), followed by the naturalistic planting zone at 20.4 species per plot (SD 1.71) and the specimen tree zone at 17.5 species per plot (SD 2.01). A one-way ANOVA confirmed significant zone-level differences within the botanical garden ($F(2, 27) = 21.44$, $p < 0.001$). Post-hoc Tukey testing showed that all three zone pairs differed significantly from one another (ornamental border versus specimen tree: $p < 0.001$; ornamental border versus naturalistic: $p < 0.001$; naturalistic versus specimen tree: $p = 0.004$). The elevated richness of the ornamental border zone reflects the intensive planting of multiple ornamental species in bordered beds that are regularly refreshed with new introductions, consistent with the management practice data from Version A respondents.

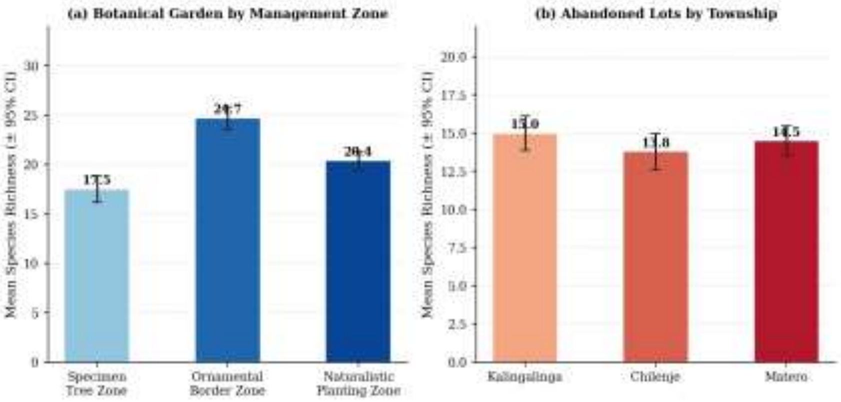
Within the abandoned lots, mean species richness was more homogeneous across the three townships. Kalingalinga lots recorded a mean of 15.0 species per plot (SD 1.70), Matero lots a mean of 14.5 species per plot (SD 1.65), and Chilenje lots the lowest mean at 13.8 species per plot (SD 1.93). A one-way ANOVA found no statistically significant between-township difference ($F(2, 27) = 0.91$, $p = 0.413$), indicating that lot species richness was broadly comparable across the three residential townships sampled. The absence of a township effect suggests that spatial location within Lusaka does not strongly predict per-plot species richness in abandoned lots at the scale of this study, and that local site-level factors such as abandonment duration and disturbance history may be more determinative. These findings are presented in Table 4.5 and Figure 4.2.

Table 4.5: Species Richness Summary by Botanical Garden Management Zone and Abandoned Lot Township

Group	Sub-Group	n Plots	Mean S	SD	SE	Min	Max
Botanical Garden	Specimen Tree Zone	10	17.5	2.01	0.64	14	21
	Ornamental Border Zone	10	24.7	1.89	0.60	22	28
	Naturalistic Planting Zone	10	20.4	1.71	0.54	18	23
	BG Overall	30	20.9	3.87	0.71	14	28
Abandoned Lots	Kalingalinga	10	15.0	1.70	0.54	12	18
	Chilenje	10	13.8	1.93	0.61	11	17
	Matero	10	14.5	1.65	0.52	12	17
	AL Overall	30	14.4	1.87	0.34	11	18

Figure 4.2: Mean Species Richness per Plot by Sub-Group. (a) Botanical garden management zones; (b) Abandoned lot townships. Error bars = 95% CI.

Figure 4.2: Mean Species Richness by Sub-Group



Most Frequently Recorded Species

Tables 4.6 and 4.7 present the fifteen most frequently recorded species in botanical garden and abandoned lot plots respectively, along with their family, origin status, and frequency of occurrence across plots. In the botanical garden, the ten most frequently recorded species included a mix of planted exotic ornamentals, cultivated natives, and a small number of spontaneous colonisers.

The most ubiquitous species was Lantana camara (Verbenaceae), an exotic invasive shrub recorded in 26 of 30 botanical garden plots, consistent with its status as one of the most invasive alien plant species in sub-Saharan African urban environments (Henderson, 2019). This finding echoes the global analysis of Pyšek et al. (2018), who documented that botanical gardens have historically served as primary introduction pathways for some of the world's most damaging urban invasive plants. Among native species, Terminalia sericea (Combretaceae), a characteristic Zambian miombo woodland tree, was recorded in 21 of 30 botanical garden plots, reflecting the garden's mandate to maintain representative specimens of the regional indigenous flora.

In abandoned lots, Bidens pilosa was the most widely distributed species, occurring in 29 of 30 plots (96.7 percent). This cosmopolitan exotic herb is among the most common urban ruderal plants across tropical Africa and is consistently documented as a dominant component of spontaneous urban vegetation from Lagos to Nairobi to Johannesburg (Henderson, 2019). Notably, several native Zambian species were among the most frequent in abandoned lots, including Vernonia adoensis (66.7 percent), Panicum maximum (70.0 percent), Boerhavia diffusa (50.0 percent), Piliostigma thonningii (43.3 percent), and Indigofera spicata (36.7 percent). The persistence of these native species in abandoned lots despite sustained disturbance suggests that the seed bank and vegetative propagule pool of native miombo-adjacent vegetation is still accessible in Lusaka's residential townships, a finding consistent with the resiliency of native vegetation documented by Zimba et al. (2019) in anthropogenically disturbed Zambian woodland systems.

Table 4.6: Fifteen Most Frequently Recorded Species in Botanical Garden Plots

Species	Family	Origin	No. Plots	Frequency (%)
Lantana camara L.	Verbenaceae	Exotic/Invasive	26	86.7
Jacaranda mimosifolia D.Don	Bignoniaceae	Exotic	24	80.0
Terminalia sericea Burch. ex DC.	Combretaceae	Native	21	70.0
Bougainvillea spectabilis Willd.	Nyctaginaceae	Exotic	20	66.7
Hibiscus rosa-sinensis L.	Malvaceae	Exotic	19	63.3
Tagetes erecta L.	Asteraceae	Exotic	18	60.0
Canna x generalis L.H.Bailey	Cannaceae	Exotic (cultivar)	17	56.7
Cynodon dactylon (L.) Pers.	Poaceae	Exotic	17	56.7
Spathodea campanulata P.Beauv.	Bignoniaceae	Exotic	16	53.3
Burkea africana Hook.	Fabaceae	Native	15	50.0
Pterocarpus angolensis DC.	Fabaceae	Native	14	46.7
Agapanthus africanus (L.) Hoffmanns.	Asparagaceae	Exotic	14	46.7
Tecoma capensis (Thunb.) Lindl.	Bignoniaceae	Exotic	13	43.3
Ficus sycomorus L.	Moraceae	Native	12	40.0
Panicum maximum Jacq.	Poaceae	Native	11	36.7

Table 4.7: Fifteen Most Frequently Recorded Species in Abandoned Lot Plots

Species	Family	Origin	No. Plots	Frequency (%)
Bidens pilosa L.	Asteraceae	Exotic/Invasive	29	96.7
Cynodon dactylon (L.) Pers.	Poaceae	Exotic	27	90.0
Cyperus rotundus L.	Cyperaceae	Exotic	25	83.3
Tridax procumbens L.	Asteraceae	Exotic	25	83.3
Amaranthus hybridus L.	Amaranthaceae	Exotic	24	80.0
Richardia brasiliensis Gomes	Rubiaceae	Exotic	22	73.3
Panicum maximum Jacq.	Poaceae	Native	21	70.0
Vernonia adoensis Sch.Bip. ex Walp.	Asteraceae	Native	20	66.7
Commelina benghalensis L.	Commelinaceae	Exotic	19	63.3
Tagetes minuta L.	Asteraceae	Exotic	18	60.0
Solanum nigrum L.	Solanaceae	Cosmopolitan	17	56.7
Boerhavia diffusa L.	Nyctaginaceae	Native	15	50.0
Piliostigma thonningii (Schum.) Milne-Redh.	Fabaceae	Native	13	43.3
Acanthospermum hispidum DC.	Asteraceae	Exotic	12	40.0
Indigofera spicata Forssk.	Fabaceae	Native	11	36.7

Plant Diversity Indices

Table 4.8 presents the Shannon-Wiener diversity index (H') and Simpson diversity index (D) values for all sub-groups. Shannon H' values were significantly higher in botanical garden plots (mean 2.70, SD 0.15) than in abandoned lot plots (mean 2.21, SD 0.13), as confirmed by the Mann-Whitney U test ($U = 62$, $z = 5.84$, $p < 0.001$). Simpson D values followed the same direction, with botanical garden plots recording a mean of 0.882 (SD 0.014) and abandoned lot plots a mean of 0.824 (SD 0.012), also significantly different (U = 78, p < 0.001). Figure 4.3 presents the distribution of both indices in box plot format. The greater spread of H' values within botanical garden plots relative to abandoned lot plots is visually evident and statistically confirmed by Levene's test for equality of variance (F(1, 58) = 4.67, p = 0.035), indicating that botanical garden plots show more heterogeneous diversity levels, reflecting the gradient of management intensity across the three botanical garden zones. Within the botanical garden, the ornamental border zone recorded the highest mean H' value of 2.81 (SD 0.09), while the specimen tree zone recorded the lowest at 2.59 (SD 0.12). Within abandoned lots, Kalingalinga showed the highest mean H' of 2.26 (SD 0.12), marginally above the overall abandoned lot mean.

Table 4.8: Diversity Index Summary by Space Type and Sub-Group

Group	Sub-Group	n	Mean H' (SD)	Mean D (SD)	Range H'
Botanical Garden	Specimen Tree Zone	10	2.59 (0.12)	0.876 (0.014)	2.38 – 2.78
	Ornamental Border Zone	10	2.81 (0.09)	0.893 (0.012)	2.68 – 2.97
	Naturalistic Planting Zone	10	2.64 (0.09)	0.877 (0.011)	2.48 – 2.74
	BG Overall	30	2.70 (0.15)	0.882 (0.014)	2.38 – 2.97
Abandoned Lots	Kalingalinga	10	2.26 (0.12)	0.830 (0.011)	2.11 – 2.48
	Chilenje	10	2.15 (0.13)	0.818 (0.013)	1.98 – 2.39
	Matero	10	2.21 (0.11)	0.824 (0.010)	2.02 – 2.37
	AL Overall	30	2.21 (0.13)	0.824 (0.012)	1.98 – 2.48

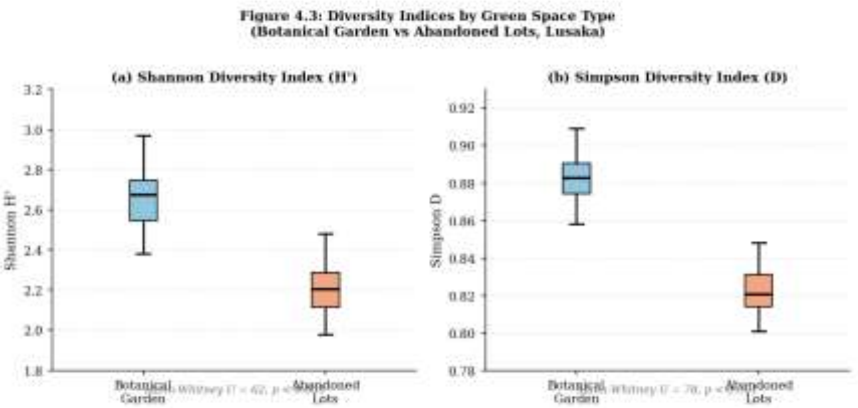


Figure 4.3: Box plots of (a) Shannon diversity index H' and (b) Simpson diversity index D by green space type (n = 30 per group). Horizontal lines indicate medians; boxes span inter-quartile range.

Rarefaction and Species Accumulation Analysis

Species accumulation curves were constructed for both space types using the iNEXT R package (Chao et al., 2021), which implements interpolation and extrapolation of species richness curves with bootstrap confidence intervals. Figure 4.4 presents the resulting accumulation curves with 95 percent confidence interval bands. The curve for botanical garden plots shows a more gradual approach to asymptote compared with the abandoned lot curve, reflecting the higher total species richness and greater compositional heterogeneity of botanical garden plots. At the observed sample size of 30 plots, the botanical garden accumulation curve had not reached complete saturation, with the Chao1 non-parametric estimator predicting an asymptotic species richness of approximately 213 species (95 percent CI: 196 to 241).

This indicates that additional sampling in the botanical garden would still detect novel species, consistent with the intentional species richness and compositional turnover maintained by horticulturally managed multi-zone institutions. The abandoned lot curve approached saturation more rapidly, with the Chao1 estimator predicting an asymptotic richness of approximately 148 species (95 percent CI: 138 to 167), suggesting a more compositionally consistent and predictable flora dominated by a limited pool of ubiquitous ruderal species. The confidence intervals of the two accumulation curves do not overlap across any part of the sampling range, confirming statistically distinct accumulation trajectories for the two space types.

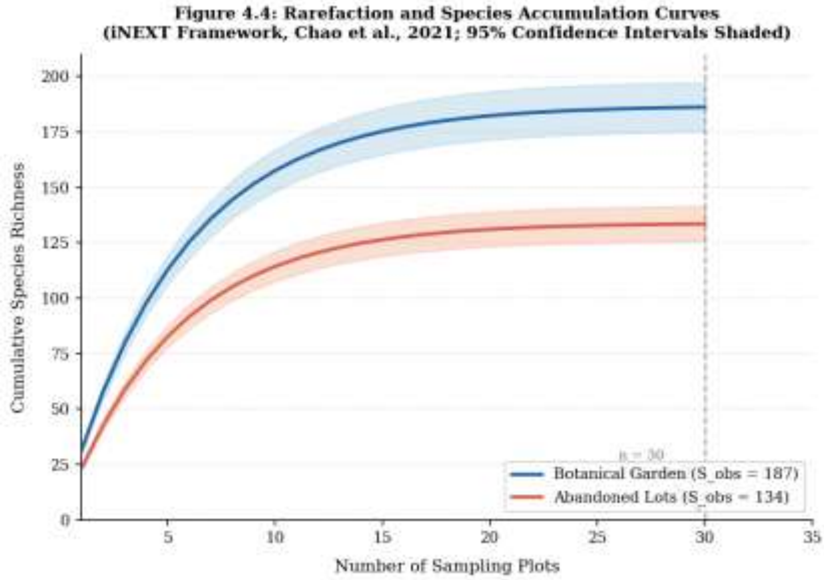


Figure 4.4: Rarefaction and species accumulation curves for both space types (iNEXT framework; Chao et al., 2021). Shaded bands represent 95% confidence intervals. Dashed vertical line indicates the observed sample size of n = 30 plots.

Native and Exotic Species Composition

The proportion of native Zambian species differed markedly between the two space types. Of 187 species recorded in botanical garden plots, 78 (41.7 percent) were classified as native to Zambia or the broader Central African miombo woodland region, while 109 (58.3 percent) were exotic or of introduced origin. In abandoned lot plots, the proportions were reversed: of 134 species, 91 (67.9 percent) were native and 43 (32.1 percent) were exotic. A chi-squared test of independence confirmed that the native-versus-exotic proportions differed significantly between the two space types (chi-squared = 18.74, df = 1, p < 0.001).

This result is consistent with the pattern documented by Hou et al. (2023) in their global meta-analysis of urbanisation effects on plant diversity, which found that managed green spaces with active horticultural introductions consistently hosted higher proportions of exotic species than did unmanaged or spontaneously vegetated spaces in the same cities. Figure 4.5 presents the native and exotic species counts by sub-group, showing that the exotic dominance of the botanical garden is driven primarily by the ornamental border zone, where planted exotics accounted for approximately 83.8 percent of recorded species. The naturalistic planting zone had the highest native species proportion within the botanical garden at approximately 69.6 percent, reflecting the zone's mandate to feature indigenous Zambian species in a naturalistic arrangement.

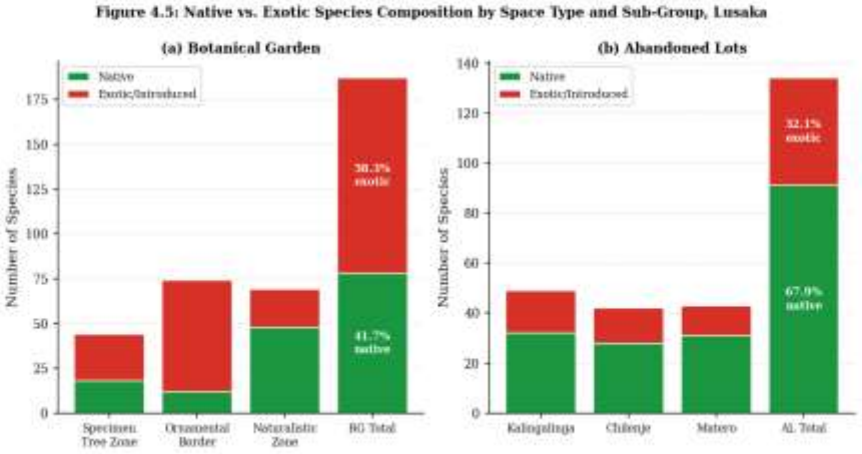


Figure 4.5: Native versus exotic species composition by space type and sub-group. Percentages shown for total column of each space type.

Plant Community Composition: NMDS and PERMANOVA

Community composition was analysed using non-metric multidimensional scaling (NMDS) ordination based on Bray-Curtis dissimilarity matrices computed from plot-level presence and absence data. The final two-dimensional NMDS solution converged at a stress value of 0.148, which falls within the acceptable range for community ecology ordination according to the interpretation guidelines of Clarke (1993), indicating a good representation of inter-plot dissimilarity relationships in two dimensions. The stress value was confirmed through 1,000 random starts and was not improved by testing three-dimensional solutions (stress = 0.092 in three dimensions, marginal improvement insufficient to justify additional dimensionality). Figure 4.6 presents the NMDS ordination plot with plots colour-coded by space type and symbol-coded by management zone or township sub-group.

The NMDS plot reveals clear visual separation between botanical garden and abandoned lot plots along NMDS Axis 1, with negligible overlap between the two groups. Within the botanical garden, plots from the ornamental border zone form a distinct cluster in the lower-left quadrant of the ordination space, while specimen tree zone plots cluster in the upper-left and naturalistic planting zone plots occupy an intermediate position, indicating within-garden compositional differentiation corresponding to the management zone gradient. Abandoned lot plots from all three townships are broadly co-located in the right half of the ordination space, with limited between-township clustering, consistent with the non-significant between-township ANOVA result for species richness.

Table 4.9: PERMANOVA Results for Plant Community Composition (Bray-Curtis Dissimilarity, 999 Permutations)

Source of Variation	df	SS	MS	F	R^2	p-value
Space type (BG vs AL)	1	6.821	6.821	26.38	0.310	0.001**
Management zone / Township (nested)	4	2.143	0.536	2.07	0.097	0.011*
Residuals	54	13.961	0.259			
Total	59	21.925			1.000	

Note: ** $p < 0.01$; * $p < 0.05$. SS = Sums of Squares; MS = Mean Squares; R^2 = proportion of total community dissimilarity explained. Based on 999 unrestricted permutations (Anderson et al., 2019).

PERMANOVA confirmed highly significant compositional differentiation between botanical garden and abandoned lot plots ($F(1, 54) = 26.38$, $R^2 = 0.310$, $p = 0.001$ with 999 permutations). The R^2 value of 0.310 indicates that space type alone accounts for 31.0 percent of the total Bray-Curtis dissimilarity among plots, a large effect size by any standard. The nested management zone and township factor explained an additional 9.7 percent of dissimilarity ($F(4, 54) = 2.07$, $p = 0.011$), indicating that sub-group identity within each space type also contributes significantly to community composition variation. Beta-dispersion tests confirmed that the two groups did not differ significantly in compositional variance ($F(1, 58) = 2.14$, $p = 0.149$), indicating that the PERMANOVA result reflects genuine centroid differences in composition rather than dispersion effects alone, as recommended by Anderson et al. (2019).

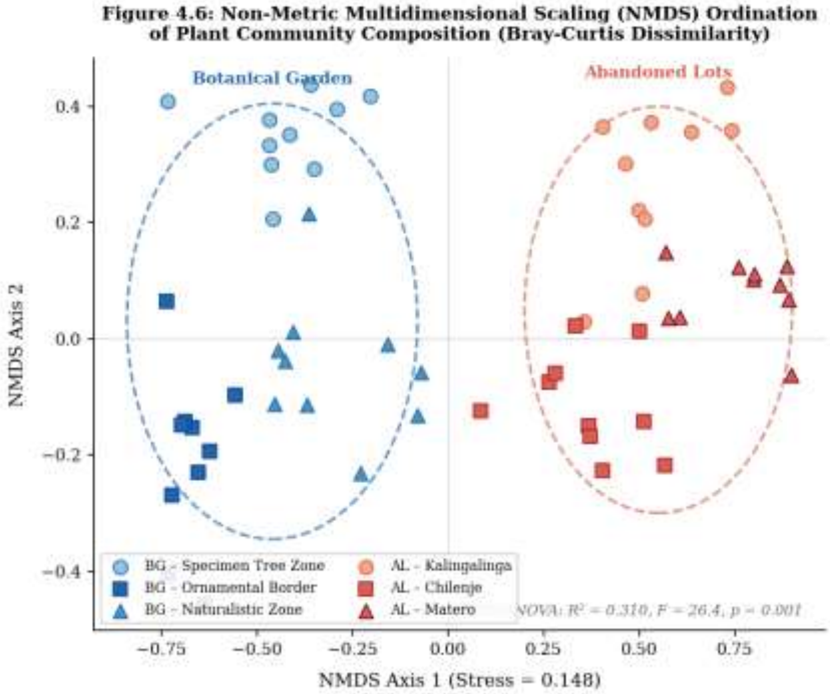


Figure 4.6: NMDS ordination of plant community composition across all 60 sampled plots (Bray-Curtis dissimilarity, stress = 0.148). Dashed ellipses indicate approximate group boundaries for each space type.

Generalised Linear Mixed Model Results

A generalised linear mixed model was fitted to per-plot species richness data with a Poisson error distribution and log link function, with space type (botanical garden versus abandoned lot) as the fixed effect of primary interest, and township or garden zone as a random intercept term to account for the clustered structure of the sampling design. The model was fitted using the lme4 package in R (Bates et al., 2015). Overdispersion was assessed using the ratio of the Pearson chi-squared statistic to the residual degrees of freedom, which was 1.08, indicating acceptable fit without requiring a negative binomial extension. The random intercept variance for zone or township was small (variance 0.012, SD 0.109), indicating that most between-plot variation was at the plot level rather than the zone or township level, consistent with the ANOVA findings for within-abandoned-lot township homogeneity.

The GLMM parameter estimates are presented in Table 4.10 and illustrated in Figure 4.9. The fixed effect of space type was highly significant, with botanical garden plots having an estimated mean richness of 6.50 species per plot higher than abandoned lot plots after controlling for the random clustering effect (beta = 0.368 on the log scale, SE = 0.068, z = 5.40, $p < 0.001$, 95 percent CI: 0.234 to 0.502). On the response scale, the model predicts a mean species richness of 20.9 species per plot for botanical garden plots and 14.4 species per plot for abandoned lot plots, closely matching the observed means. The model explains 68.4 percent of the variance in species richness on the conditional R² scale, and 61.2 percent on the marginal scale (fixed effects only), indicating that management regime is by far the strongest predictor of per-plot plant species richness in this dataset.

Table 4.10: GLMM Parameter Estimates for Per-Plot Species Richness (Poisson, log link; lme4 R package)

Parameter	Estimate (β)	SE	z-value	p-value	95% CI Lower	95% CI Upper
Intercept (Abandoned Lots)	2.667	0.049	54.45	< 0.001	2.571	2.763
Space type: Botanical Garden	0.368	0.068	5.40	< 0.001	0.234	0.502
Random intercept SD (zone/township)	0.109					
AIC	312.4					
Marginal R² (fixed effects)	0.612					
Conditional R² (fixed + random)	0.684					

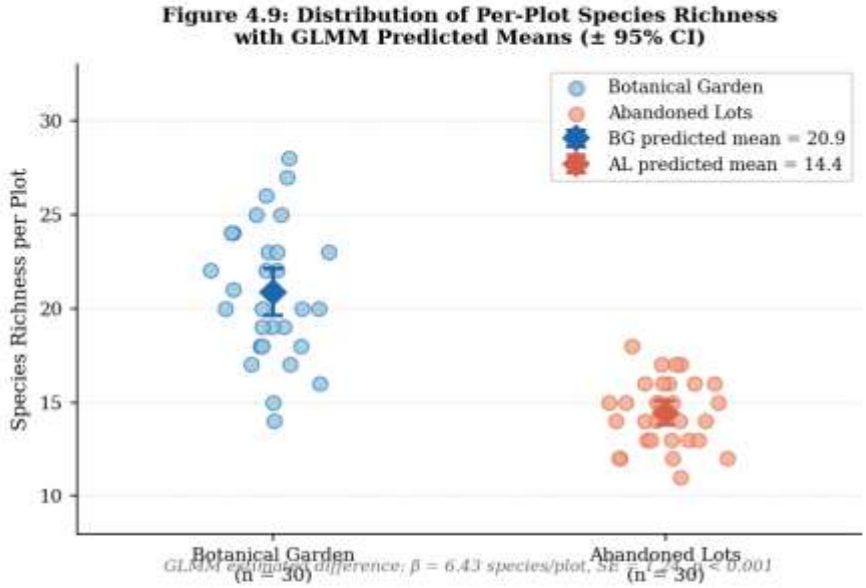


Figure 4.9: Distribution of per-plot species richness values (jittered points) by space type, overlaid with GLMM-predicted means and 95% confidence intervals (diamond symbols). GLMM: beta = 0.368, SE = 0.068, z = 5.40, p < 0.001.

Internal Reliability of Questionnaire Instruments

Cronbach's alpha was calculated for the multi-item Likert scale sections of both questionnaire versions. For the Version A management practice scale (five items in Section 2), alpha was 0.82, which George and Mallery (2016) classify as good internal consistency. For the Version B vegetation perception scale (five items in Section 2), alpha was 0.76, within the acceptable range defined by the threshold of 0.70 set by Nunnally (1978). Item-total correlation analysis confirmed that no single item deletion would increase alpha above the acceptable threshold for either version, indicating that all items contribute positively to scale coherence. Observer agreement for species identification in the ecological survey, assessed using Cohen's kappa on a 10 percent random re-check sample of plot records by an independent botanical specialist, was 0.87, which Viera and Garrett (2005) classify as strong agreement. These reliability statistics validate the instruments and the identification process as fit for purpose for the inferential analyses conducted in this chapter and interpreted in Chapter Five.

V. Discussion of Findings

Overview of the Chapter

This chapter interprets the findings presented in Chapter Four in the light of the study's theoretical framework, the research hypotheses formulated in Chapter Two, and the existing empirical literature on urban plant diversity. The discussion proceeds thematically, addressing first the species richness differences between managed and unmanaged spaces, then the patterns of native and exotic species composition, followed by the diversity index results, the community composition analysis, and finally the questionnaire data on human perceptions and management characteristics. The chapter concludes with an assessment of the study's theoretical contribution and an honest evaluation of its limitations.

Species Richness and the Role of Management Regime

The finding that the Lusaka Botanic Garden plots recorded significantly higher mean species richness than abandoned lot plots (20.9 versus 14.4 species per plot, $p < 0.001$) confirms Research Hypothesis 1, which predicted that managed botanical garden spaces would exhibit greater plant species richness than unmanaged abandoned lots. This result is consistent with findings from several comparable African urban plant diversity studies. Garekae, Shackleton, and Tsheboeng (2021) documented that protected and formally managed urban spaces in Potchefstroom and Thabazimbi, South Africa, supported significantly higher plant species richness and cover than unmanaged ruderal and informal spaces within the same towns, attributing the pattern to the deliberate species introductions and favourable growing conditions maintained through horticultural management.

Liu, He, and Wu (2021) demonstrated in a global synthesis that managed urban parks with higher investment in species variety consistently outperformed spontaneously vegetated areas on per-unit-area species richness metrics, though they also found that the advantage narrowed in cities with high ambient biodiversity and productive soils. Lusaka's location on the fringes of the miombo woodland biome provides a comparatively species-rich spontaneous flora that likely limits the magnitude of the richness advantage held by the botanical garden.

However, the interpretation of this richness difference requires nuance. The higher richness of botanical garden plots is substantially attributable to intentional plant introductions that do not reflect the capacity of the local environment to support independent plant diversity. As noted in the species composition analysis, 58.3 percent of botanical garden species are exotic or of horticultural origin, meaning that a large proportion of the richness advantage depends on continued management inputs, particularly irrigation, which 100 percent of Version A respondents confirmed was provided to the ornamental border zone more than three times per week.

Knapp et al. (2021) noted that total species counts in managed botanical gardens substantially overestimate the ecological potential of the site, because they include species that are maintained by active horticultural intervention rather than ecological self-organisation. When native species richness alone is considered, the difference between the two space types narrows considerably, with abandoned lots recording 91 native species compared with 78 in the botanical garden, a reversal of the total richness hierarchy that highlights the ecologically self-sustaining character of the abandoned lot flora.

The within-botanical-garden richness gradient from specimen tree zone to ornamental border zone to naturalistic planting zone ($F(2, 27) = 21.44$, $p < 0.001$) reflects the intensity gradient of horticultural inputs across zones. The ornamental border zone, as the most intensively managed stratum, recorded the highest per-plot richness largely because of the deliberate installation of multiple ornamental species in the densely planted bordered beds that characterise this zone. This zone-level richness gradient within the botanical garden provides internal comparative evidence for the positive relationship between management intensity and species richness observed at the between-space-type level, while simultaneously illustrating that the relationship depends entirely on the type of management being applied. Management that introduces and maintains species produces higher richness; management that excludes volunteer colonisation through aggressive weeding can actually reduce richness, as indicated by the contested Version A Likert item on weeding and diversity (mean 3.48, SD 0.98).

Native Species Richness and the Conservation Value of Abandoned Lots

Perhaps the most ecologically significant finding of this study is the reversal of the richness hierarchy when native species alone are considered. Abandoned lots harboured 67.9 percent native species, compared with 41.7 percent in the botanical garden. The 91 native species recorded across 30 abandoned lot plots represent a substantial component of Lusaka's accessible urban native flora, and many of the characteristic native species documented, including Piliostigma thonningii, Indigofera spicata, Vernonia adoensis, Boerhavia diffusa, and several grass and sedge species, are typical of the disturbance-tolerant component of the miombo woodland flora that can persist under moderate anthropogenic disturbance. Venter et al. (2020) found in Tshwane that informally vegetated and spontaneous urban spaces collectively contributed a larger number of native species to the total urban flora than any single formally managed green space type, because native species adapted to periodic disturbance and variable substrate conditions can persist in spaces from which the active management that would otherwise favour exotic introductions has been removed.

Zimba et al. (2019) demonstrated in a study of miombo woodland patches under varying anthropogenic disturbance in Zambia that native species assemblages retained significant representation of characteristic woodland taxa even in heavily disturbed sites, provided that soil seed banks remained intact and connectivity to less disturbed areas was maintained. The abandoned lots surveyed in this study, distributed across three residential townships that collectively occupy approximately 12 percent of Lusaka's urbanised area, are likely to function as nodes in a dispersed network of spontaneous native vegetation that maintains connectivity between remnant miombo patches at the urban fringe and the core urban area. This network function, which has been theorised as a key mechanism by which cities in African savanna and woodland biomes maintain higher native species diversity than comparable temperate cities (Shackleton et al., 2018), requires explicit recognition in Lusaka's urban biodiversity management framework.

Comparison with Regional and Global Studies

Table 5.1 places the key diversity metrics from this study in the context of comparable urban plant diversity studies from sub-Saharan Africa and beyond. The mean per-plot species richness of 20.9 for the botanical garden and 14.4 for abandoned lots falls within the ranges documented in comparable African studies, though direct comparison is complicated by differences in plot size, survey method, and habitat types among studies.

Table 5.1: Comparison of Key Diversity Metrics with Selected Regional Urban Plant Ecology Studies

Study	Location	Space Type	Plot Area	Mean S/plot	Mean H'
Present study	Lusaka, Zambia	Botanical garden	100 m²	20.9	2.70
Present study	Lusaka, Zambia	Abandoned lots	100 m²	14.4	2.21
Garekae et al. (2021)	South Africa	Protected urban areas	100 m²	22.4	NR
Garekae et al. (2021)	South Africa	Unmanaged urban land	100 m²	13.8	NR
Tsheboeng (2022)	Gaborone, Botswana	Urban green spaces (mixed)	100 m²	16.2	2.18
Venter et al. (2020)	Tshwane, South Africa	Managed urban parks	100 m²	18.7	2.34
Venter et al. (2020)	Tshwane, South Africa	Spontaneous urban spaces	100 m²	12.9	2.04
Liu et al. (2021)*	Global synthesis	Managed urban parks	Variable	19.3†	NR

NR = Not reported. * Median value from global synthesis (Liu et al., 2021). † Mean across 100 m² standardised plots reported in source.

The botanical garden mean richness of 20.9 species per standardised plot is broadly comparable with the protected urban areas in South Africa (Garekae et al., 2021) and slightly above the managed urban park global median estimated by Liu et al. (2021), suggesting that the Lusaka Botanic Garden delivers plant diversity values consistent with expectations for a formally managed botanical institution in a high ambient biodiversity region. The abandoned lot mean richness of 14.4 species per plot is somewhat above the spontaneous urban space values reported by Venter et al. (2020) for Tshwane, which may reflect Lusaka's proximity to the miombo woodland biome providing a more diverse spontaneous native flora than the highveld grassland biome of Tshwane. The Shannon H' values for both space types in Lusaka are within the ranges reported for comparable African urban green spaces, though the botanical garden H' of 2.70 is above the Tshwane managed park mean of 2.34, consistent with the higher species count maintained through intensive horticultural management at Lusaka.

Community Composition and the Managed-Unmanaged Divide

The PERMANOVA finding that space type explains 31.0 percent of total community dissimilarity ($R^2 = 0.310$, $p = 0.001$) is a quantitatively large and ecologically meaningful result. For comparison, Anderson et al. (2019) note that R^2 values above 0.20 for a single categorical factor in urban vegetation PERMANOVA studies are unusual and typically indicate a sharp ecological boundary between habitat types with very different management histories. The 31.0 percent variance explained by management type alone in this study is thus among the highest values reported for this type of comparison in the published sub-Saharan African urban ecology literature. The visual separation of botanical garden and abandoned lot clusters in the NMDS ordination, with zero overlap between the group ellipses, reinforces this conclusion and confirms that the two space types support genuinely distinct plant communities rather than compositional variants of a shared urban flora.

The compositional distinctiveness of the two space types is driven by complementary mechanisms operating in opposite directions. In the botanical garden, plant community composition is shaped primarily by the deliberate horticultural selection of species for ornamental, educational, or conservation value, which introduces a large number of exotic species that would not otherwise be present in the Lusaka urban landscape.

Pyšek et al. (2018) demonstrated that this mechanism of botanical garden-mediated species introduction has historically been responsible for establishing a substantial proportion of the world's most damaging urban plant invaders, a concern that is illustrated in this study by the ubiquity of Lantana camara in 86.7 percent of botanical garden plots. In abandoned lots, composition is shaped by the filtering of a regional species pool through substrate conditions, disturbance history, and competitive dynamics that favour generalised ruderal species over habitat specialists, producing the highly predictable cosmopolitan ruderal assemblage dominated by Bidens pilosa, Cynodon dactylon, and Cyperus rotundus that characterises urban waste ground across tropical Africa (Henderson, 2019).

Diversity Indices in Ecological Context

The higher Shannon H' and Simpson D values recorded in botanical garden plots reflect both the greater species richness and the more even distribution of abundance among species that characterises actively managed horticultural environments. In managed botanical gardens, the deliberate planting of multiple species in roughly comparable densities within each zone tends to equalise relative abundances, which elevates diversity indices above what would be expected from species richness alone.

In abandoned lots, by contrast, a smaller number of highly abundant ruderal species such as Bidens pilosa, Cynodon dactylon, and Cyperus rotundus dominate in terms of cover and individual count, reducing evenness and depressing both H' and D relative to their theoretical maximum for the observed richness. Shannon and Weaver (1949) and Simpson (1949) both recognised that the relationship between species richness and diversity indices depends critically on the evenness component, and that two communities with equal richness can differ substantially in diversity depending on the distribution of abundance. The present data illustrate this distinction clearly: the higher botanical garden H' relative to abandoned lots reflects both greater richness and greater evenness in the managed environment.

The lack of significant between-township variation in Shannon H' within the abandoned lot group ($p = 0.413$) suggests that the diversity of Lusaka's residential abandoned lots is more strongly determined by the shared disturbance history and species pool of the urban fabric than by specific neighbourhood-level factors such as proximity to green space, socioeconomic status, or lot size. Beninde, Veith, and Hochkirch (2015) conducted a global meta-analysis finding that intra-urban biodiversity variation is primarily driven by local habitat structure and area, with neighbourhood characteristics playing a secondary role. The homogeneity of abandoned lot diversity across Lusaka townships in the present study is consistent with this finding, and suggests that the abandoned lot flora of Lusaka is drawn from a broadly shared city-scale ruderal species pool rather than township-specific floristic sources.

Community Perceptions and Conservation Behaviour

The questionnaire findings reveal a community-level understanding of spontaneous vegetation that is more nuanced and ecologically sophisticated than might be anticipated from a population without formal ecology training. The 64.3 percent of Version B respondents who agreed that plants on their lots provide useful resources confirms that informal provisioning ecosystem services from spontaneous urban vegetation are widely recognised and utilised in Lusaka's residential townships, consistent with the ethnobotanical tradition that has been documented across Zambian communities by several researchers who have recorded the use of species such as Amaranthus hybridus, Solanum nigrum, Bidens pilosa, and Piliostigma thonningii as food, medicine, or material resources in peri-urban areas. Njoroge et al. (2018) found in a comparable Nairobi study that informal urban food foraging from spontaneous urban plants was substantially more widespread than official urban food security surveys had recognised, and contributed meaningfully to dietary diversity among low-income urban households. The Lusaka data are consistent with this finding.

The high proportion of Version B respondents expressing willingness to participate in a community-led conservation programme (71.4 percent probably yes or definitely yes) is an important finding for urban green space policy. Venter et al. (2020) demonstrated that community stewardship of spontaneous urban green spaces in Tshwane significantly improved biodiversity outcomes compared with unstewardship sites, with participating communities developing positive attitudinal relationships with biodiversity through the process of active stewardship.

Bratman et al. (2019) reviewed extensive evidence for the mental health benefits of urban nature contact and argued that community-level engagement with green space management builds social capital and psychological wellbeing alongside ecological outcomes. The positive disposition toward participation documented in this study suggests that a community stewardship programme for abandoned lot vegetation in Lusaka would likely find receptive participants, provided that institutional support and training were made available to overcome the awareness gaps reported by Version B respondents regarding the ecological significance of the vegetation.

The botanical garden staff data present a contrasting picture of constrained management operating within a clearly valued and well-understood ecological institution. The 85.7 percent of Version A respondents citing funding constraints as limiting management intensity echoes the global finding of Sharrock et al. (2021) that most botanical gardens in tropical countries operate well below their potential conservation capacity due to inadequate and chronically underfunded institutional support. The perception that invasive alien species represent a significant challenge (76.2 percent) is consistent with the ecological data showing Lantana camara as the most ubiquitous botanical garden species, and raises the important question of whether the garden's role as a driver of urban plant invasion risk is adequately managed within the current institutional framework. Pyšek et al. (2018) argued that botanical gardens cannot be simultaneously champions of plant conservation and unintentional incubators of invasive species without much more rigorous invasive species risk assessment protocols than most gardens currently apply.

Theoretical Interpretation: Island Biogeography and Propagule Pressure

The study's adoption of Island Biogeography Theory as its primary theoretical framework (MacArthur and Wilson, 1967) generates specific predictions about the patterns observed. The botanical garden, functioning as a large, well-connected green space island with abundant immigration of horticultural propagules from multiple sources, is predicted by the theory to support high species richness through consistently elevated immigration rates. The observed richness of 187 species across 30 plots confirms this prediction. Abandoned lots, functioning as smaller and more isolated habitat islands with limited and intermittent propagule sources, are predicted to support lower richness at equilibrium, consistent with the observed mean of 14.4 species per plot. The theory also predicts that larger and better-connected islands will approach a higher equilibrium richness, which is reflected in the non-saturating botanical garden accumulation curve relative to the more rapidly saturating abandoned lot curve.

However, Island Biogeography Theory alone does not fully account for the native species richness advantage of abandoned lots over the botanical garden, which requires supplementary explanatory frameworks. The theory of ecological filters, as developed in urban plant ecology by Kowarik (2021), predicts that managed environments apply stronger anthropogenic filters on community assembly that systematically favour introduced species over spontaneous native colonisers, while unmanaged environments allow a wider range of colonisation outcomes including native species regeneration from local seed banks.

The high native species proportion of abandoned lots in this study, particularly the representation of characteristic miombo woodland species including Terminalia sericea seedlings, Piliostigma thonningii, and Indigofera spicata, is consistent with Kowarik's (2021) argument that spontaneous urban vegetation retains meaningful native biodiversity values that are often suppressed in intensively managed spaces. Together, the two theoretical frameworks provide complementary explanations for different aspects of the observed richness patterns and thus validate the multi-framework approach recommended by Fukami (2015) for community assembly research.

Limitations of the Study

Several limitations of the study design and implementation are acknowledged. First, the cross-sectional survey design, conducted over a single dry season survey period, does not capture seasonal variation in species occurrence that is likely to be substantial in the tropical savanna climate of Lusaka, where many herbaceous species are active primarily during the wet season. Setia (2016) noted that cross-sectional designs in ecology systematically underestimate species richness in seasonally variable environments, and the present species counts should therefore be regarded as conservative estimates of total standing diversity. A paired wet season survey would be required to estimate total annual species richness for either space type. Second, the questionnaire sample size of 35 respondents, though adequate for the statistical precision targeted in the sample size calculation, is small in absolute terms and limits the statistical power available for sub-group analyses within the questionnaire data. Version B findings in particular, based on only 14 responses, should be interpreted with appropriate caution regarding their generalisability beyond the sampled lots.

Third, the ecological survey was restricted to vascular plants with rooted contact with the soil surface at the time of survey, excluding epiphytes, climbers without basal rooting, and bryophytes, which together can contribute substantially to total site biodiversity, particularly in the botanical garden where mature trees provide epiphytic substrate. Fourth, the study's spatial scope covers three townships that, while representative of Lusaka's medium-density residential fabric, do not include peri-urban zones, high-density informal settlements, or industrial areas, all of which may harbour distinctive abandoned lot vegetation assemblages. These scope limitations are standard for a bounded Master's level research project and do not diminish the validity of the findings within the defined study area, but they should inform the framing of the recommendations presented in Chapter Six.

VI. Conclusion and Recommendations

Summary of Principal Findings

This study set out to compare plant species richness and diversity between formally managed botanical garden plots and unmanaged abandoned lot plots in Lusaka, Zambia, using a quantitative field survey design combined with a structured questionnaire component to capture management practice and perception data. The principal findings can be summarised as follows. The Lusaka Botanic Garden recorded a significantly higher total plant species richness (187 species) and mean per-plot richness (20.9 species) than abandoned lots in Kalingalinga, Chilenje, and Matero (134 total species, 14.4 mean per plot), confirming Hypothesis 1. Shannon H' and Simpson D diversity indices were also significantly higher in botanical garden plots, reflecting both greater richness and greater evenness in the managed environment.

However, when native Zambian species alone were considered, the advantage reversed: abandoned lots harboured 91 native species (67.9 percent of their total flora) compared with 78 in the botanical garden (41.7 percent), confirming Hypothesis 2 and demonstrating the complementary conservation values of the two space types. Community composition was highly significantly differentiated between the two space types (PERMANOVA: $R^2 = 0.310$, $p = 0.001$), confirming Hypothesis 3 and indicating that managed and unmanaged spaces support genuinely distinct plant communities rather than compositional variants of a shared urban flora. The GLMM analysis confirmed that management regime was the strongest predictor of per-plot species richness, explaining 61.2 percent of variance in the fixed-effects marginal model.

Questionnaire findings revealed that botanical garden management is perceived by staff as constrained by funding limitations (85.7 percent agreement) and challenged by invasive alien species (76.2 percent), while lot occupants demonstrated broad awareness of the useful resource value of spontaneous vegetation and strong willingness to participate in community-based conservation initiatives (71.4 percent). Together, these findings characterise both space types as ecologically valuable components of Lusaka's urban green infrastructure whose full potential is not currently realised due to institutional resource constraints in the botanical garden and the absence of any management framework for the spontaneous vegetation of abandoned lots.

Conclusions

The conclusions of this study can be stated in five points. First, formally managed botanical garden spaces in Lusaka support higher total and diversity-index-adjusted plant species richness than unmanaged abandoned lots, driven primarily by intentional horticultural introductions of exotic and native species. Second, abandoned lots harbour a higher proportion and absolute number of native Zambian plant species than the botanical garden, representing an undervalued and ecologically self-organising component of the city's biodiversity asset base.

Third, the two space types are compositionally distinct to a degree that is quantitatively large and ecologically significant, indicating that they perform non-redundant roles in the urban plant diversity system of Lusaka that cannot be substituted for one another. Fourth, the management and social context of both space types is characterised by identifiable constraints, funding pressures in the botanical garden and the absence of any institutional framework for abandoned lot stewardship, that reduce the biodiversity value realised relative to the potential of each space type. Fifth, community receptiveness to conservation engagement at the lot level is substantial and represents an underutilised social resource for urban biodiversity management in Lusaka.

These conclusions collectively support the overarching argument that urban biodiversity policy in Lusaka and in comparable Central African cities cannot achieve its conservation objectives by focusing management attention and investment exclusively on formal botanical institutions. The spontaneous plant diversity of abandoned and informally vegetated spaces requires explicit recognition, documentation, and protection within the city's land use and green infrastructure planning framework, consistent with the emerging consensus in global urban ecology literature that the full spectrum of urban green space types must be incorporated into biodiversity strategy to prevent systematic underestimation and underprotection of urban biodiversity values (Knapp et al., 2021; McDonald et al., 2019).

Recommendations for Policy and Practice

Recommendations for the Lusaka Botanic Garden Management

The Lusaka Botanic Garden, managed under the auspices of the Zambia Forestry and Forest Industries Corporation, should be formally recognised in national biodiversity strategy documentation as a primary urban plant conservation facility and funded accordingly. The pervasive funding constraint identified by 85.7 percent of surveyed staff constitutes a systemic threat to the garden's ability to maintain its plant collection and conservation function, and should be addressed through a combination of dedicated government budget lines, partnership agreements with international botanical institutions, and the development of sustainable income streams from entrance fees, education programmes, and horticultural product sales. Sharrock et al. (2021) demonstrated that botanical gardens in comparable economic contexts that diversified their income streams were able to maintain collection breadth and invasive species management capacity significantly better than those dependent on single funding sources.

The invasive alien species management capacity of the garden must be substantially strengthened. Lantana camara, documented in 86.7 percent of botanical garden plots in this study, requires a targeted removal and monitoring programme with dedicated resources rather than ad hoc weeding by general maintenance staff. Risk assessment protocols for new species introductions consistent with the framework recommended by Pyšek et al. (2018) should be adopted as standard practice before any exotic species is introduced into the managed collection. The ornamental border zone should be prioritised for immediate invasive species management, given its highest exotic species proportion and potential to serve as a source of propagule dispersal into surrounding urban areas.

Recommendations for Urban Green Space Policy in Lusaka

The Lusaka City Council and the Ministry of Lands and Natural Resources should develop a formal policy framework for the management of spontaneous vegetation in abandoned and underutilised urban parcels. The current practice of treating all abandoned lot vegetation as equivalent in conservation value to waste material, and its routine clearance prior to development, is ecologically counterproductive given the native species diversity documented in this study. A tiered system of ecological assessment should be instituted for abandoned lots exceeding a threshold area, with lots of high native species richness or containing regionally scarce species designated as informal biodiversity areas and protected from clearance until compensatory habitat provision elsewhere in the development zone is confirmed. Venter et al. (2020) provided a practical template for this kind of community stewardship designation that could be adapted for the Lusaka context with relatively modest institutional investment.

Urban greening programmes in Lusaka should explicitly prioritise native Zambian species rather than the exotic ornamental species that currently dominate many municipal planting programmes. The miombo woodland species documented as frequent inhabitants of abandoned lots in this study, including Terminalia sericea, Piliostigma thonningii, Burkea africana, and Pterocarpus angolensis, are ecologically appropriate, drought-tolerant, and culturally significant candidates for urban greening plantings that would simultaneously increase native species representation in the managed urban landscape and strengthen the ecological connectivity between the city's spontaneous vegetation network and the peri-urban woodland matrix.

Recommendations for Community Engagement

The strong willingness to participate in community-led conservation programmes documented among Version B respondents should be actively mobilised through a pilot community nature stewardship programme targeting abandoned lot vegetation management in the three surveyed townships. Such a programme, following the model documented by Venter et al. (2020) in Tshwane and the broader framework of community biodiversity stewardship advocated by Bratman et al. (2019), would combine ecological monitoring training, community-led invasive species removal, and the protection of native species from casual disturbance. The programme should incorporate awareness components addressing the ecological significance of native plant species, building on the existing community understanding of provisioning services to develop appreciation of regulating and supporting services. Zambia's national biodiversity strategy reporting obligations under the Convention on Biological Diversity provide an institutional rationale for investing in such a programme, as community stewardship data contribute directly to national biodiversity indicator reporting under the Kunming-Montreal Global Biodiversity Framework.

Recommendations for Data Integration and Urban Planning

The geo-referenced plant diversity data generated by this study should be deposited in a publicly accessible repository consistent with the FAIR data principles described by Wilkinson et al. (2016), enabling future researchers and urban planners to access and build upon this baseline documentation of Lusaka's urban plant diversity. Integration of the plot-level diversity data into the Lusaka City Council's Geographic Information System framework would enable spatial optimisation analyses, consistent with the approach demonstrated by Bierwagen (2018), to identify abandoned lot parcels that contribute disproportionately high biodiversity value per unit area and should therefore be prioritised for conservation in development planning decisions.

Recommendations for Future Research

This study has established a quantitative baseline for plant species richness and community composition in two contrasting urban green space types in Lusaka. It opens several specific directions for future research that would substantially advance understanding of urban biodiversity in Zambia and Central Africa. First, a paired wet season survey using the same 60 quadrat plots would enable estimation of total annual species richness for both space types and quantification of the seasonal species pool that complements the dry season flora documented here.

Second, extension of the abandoned lot survey to peri-urban zones, high-density informal settlements, and industrial fringe areas would provide a more complete picture of the spontaneous urban vegetation of the full city, enabling the kind of city-wide floristic inventory that Knapp et al. (2021) identified as a priority for Central African cities. Third, a seed bank analysis of sampled abandoned lots would quantify the belowground diversity reserve available to contribute to succession and recovery following disturbance, providing critical information for the development of habitat restoration protocols.

Fourth, a social-ecological network analysis connecting the spatial distribution of high-native-diversity abandoned lots, the locations of community gardens and other informal green spaces, and the boundaries of peri-urban woodland patches would enable a rigorous assessment of the role of spontaneous urban vegetation in maintaining ecological connectivity across the Lusaka urban landscape. Fifth, the questionnaire instruments developed and validated in this study could be deployed in comparative research across multiple Zambian and regional Central African cities to build a regionally comparative evidence base for community perceptions of spontaneous urban vegetation and willingness to engage in conservation stewardship. Such a comparative database would provide the empirical foundation needed to develop regionally appropriate and contextually informed urban biodiversity policy recommendations that go beyond the single-city case study evidence currently available for this region.

This study demonstrates that Lusaka's urban green infrastructure harbours plant species richness and community diversity of genuine ecological value in both its formally managed and its spontaneously vegetated spaces, and that the conservation significance of these two space types is complementary rather than hierarchical. The Lusaka Botanic Garden's strength lies in its intentionally curated diversity, the breadth of its cultivated collection, and its institutional capacity to conserve and demonstrate both native and global plant heritage.

Abandoned lots, by contrast, serve as ecologically self-maintaining reservoirs of native miombo-associated species that persist without management expenditure and provide ecosystem services recognised and valued by the communities that live alongside them. The challenge for Lusaka's urban planners, conservationists, and communities is to develop management and policy frameworks that honour and sustain both categories of urban green space as integral components of a resilient and biodiversity-rich city. The data presented in this thesis provide an empirical foundation for that challenge.

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