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Investigating Addis Ababa's Urban Green Spaces: Analysis of Woody Species, Heritage Trees, and Tree-Infrastructure Conflict

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Corresponding Author: **Eyob Tenkir Abstract**

Abstract: Rapid urban expansion, economic growth, population pressures, and lack of recognition of the value of urban heritage trees by urbanites are endangering urban woody species and urban heritage trees. The research aimed to evaluate treespecies composition, heritage trees, and conflicts with infrastructure in Addis Ababa. To meet these goals, designed, sampled, and conducted data collection was carried out using a comprehensive approach that included the identification of woody species, criteria for identifying heritage trees, and visual observations of conflicts between trees and infrastructure in selected green spaces. The research found out 68 species from 65 genera and 36 families. The Fabaceae family exhibited the highest species count in green spaces. Parks displayed greater diversity, with over 50% of species being Native, whereas roadside areas had lower diversity, with over 85% consisting of exotic species. Olea europaea, Grevillea robusta, and Vachellia etbaica were high in parks at varying altitudes, while roadside areas were dominated by Grevillea robusta and Acacia melanoxylon. Conflict assessments between trees and infrastructure yielded mean values of 0.64 for aboveground conflicts and 0.7 for belowground conflicts. Grevillea robusta and Acacia melanoxylon showed many conflicts with above and belowground infrastructure.42 potential heritage trees were identified, including 39Native species (including three endemics) and 3 exotic species. These trees hold significant historical, environmental, ecological, and cultural value. In conclusion, urban green spaces provide services as reservoirs of diverse native woody species, possesses potential heritage trees that require registration, and protection, and need urban tree infrastructure conflict management.

Keywords: Addis Ababa, Conflict,Heritage trees, Woody species

Introduction

Urban green spaces play a vital role in enhancing the quality of life for residents, providing recreational opportunities, and contributing to the overall wellbeing of urban ecosystems. They serve as valuable habitats for a diverse array of plant and animal species, helping to conserve biodiversity even in highly urbanized areas. Additionally, these green spaces help to mitigate the effects of climate change by absorbing carbon dioxide and providing shade and cooling effects in urban environments. They also contribute to soil health, and water conservation, helping to maintain the ecological balance of the city(Irwin et al., 2019; Nero et al., 2018, Panyadee et al., 2016, Kayode 2010). Woody vegetation, such as trees and shrubs, contributes significantly to the ecological and aesthetic value of the urban ecosystem (Doick et al., 2016). This indicates investigating the assemblage and heterogeneity of trees in municipal parklands and roadside areas is essential for effective urban planning, landscape design, and sustainable management.

Furthermore, trees in urban green spaces often hold significant cultural, historical, and ecological value. Some trees, known as heritage trees, possess unique characteristics, exceptional size, historical significance, or cultural importance that set them apart from other trees.

Cities attracted to large trees with special characteristics, which often labelled as heritage trees (Jim, 2017). Heritage trees have a high preservation value and are valuable because of their unique and historic contributions to community well-being (Yaacob et al., 2016).

Several historic trees prized for varied reasons in different nations, but all regarded as essential for maintaining species variety in urban areas. In order to help the registration of heritage trees, data on the species variety of large trees in urban areas need to be collected (Asanok, 2021).

Size, form, shape, beauty, age, color, rarity, genetic constitution, or other distinctive features, are the non-material criteria relate to cultural and aesthetic aspects.

It could be that the tree has a historical or cultural association with either a person, an event, or a place, and is considered a prominent community landmark. It may be a specimen associated with a historic person, place, event, or period. The tree could also be a representative of a crop grown by ancestors and their successors, which is at risk of disappearing from cultivation. Additionally, the tree could be associated with local folklore, myths, legends, or traditions. Lastly, the tree may be a specimen identified by members of a community as deserving of heritage recognition (Aird, 2005).

Large, ancient, and historically significant trees can be found throughout districts/sub-cities in Addis Ababa city. While none of these trees have been

acknowledged and celebrated, many others remain unknown and unappreciated, despite their importance in shaping the landscape and the history of the city.
Over the past few years, there has been a growing focus on evaluating heritage trees in urban green areas worldwide. This assessment process enables the recognition, documentation, and protection of these important natural resources. By conducting these assessments, valuable information is obtained about the biodiversity and cultural benefits that heritage trees offer, leading to improved strategies for their preservation and sustainable care.
Urban parks contribute significantly to the habitat needed by urban flora and fauna in urban green spaces and considered as critical biodiversity hotspots Goddard et al., 2010; Jim and Chen 2009; Khera et al. 2009; and Oleyar et al. 2008).

In contrast, there are instances where urban trees can cause a societal annoyance, such as when their roots ruin buildings or pavement, or when fruit or leaves scatter across the ground. These annoyances are referred to as "disservices" [(Roy et al., 2012).
Woody species planted on urban landscape especially in hardscape like in roadside and park can have conflict with infrastructure like tree roots growing beneath sidewalks can cause cracks or uplifted sections in the pavement (Costello and Jones 2003).
The limited knowledge about woody species diversity, heritage trees, and conflicts of trees with infrastructure in the Metropolitan area of Ethiopia necessitated a study to address these gaps. By examining green spaces in the Addis Ababa region, the study provides crucial information for urban forest management and conservation. The findings can be used to guide conservation efforts, register significant species as heritage trees, and create a more sustainable and culturally rich urban environment.
Thus, objectives of this research are: (1) assess the diversity of woody species in various green spaces in Addis Ababa (2) to identify the city's potential heritage tree species and (3) Conflict of the trees with above and belowground utilities.

Materials and Methods

Study Site

Addis Ababa, the capital and commercial center of Ethiopia, the seat of African Union head quarter, and several international diplomatic missions is located in the heart of the country at 9^0 2'N latitude and 38^0 45'E longitude. It has an average elevation of 2,400 meters above sea level, with Entoto Hill to the north having the highest point at 3,200 meters (Figure 1).

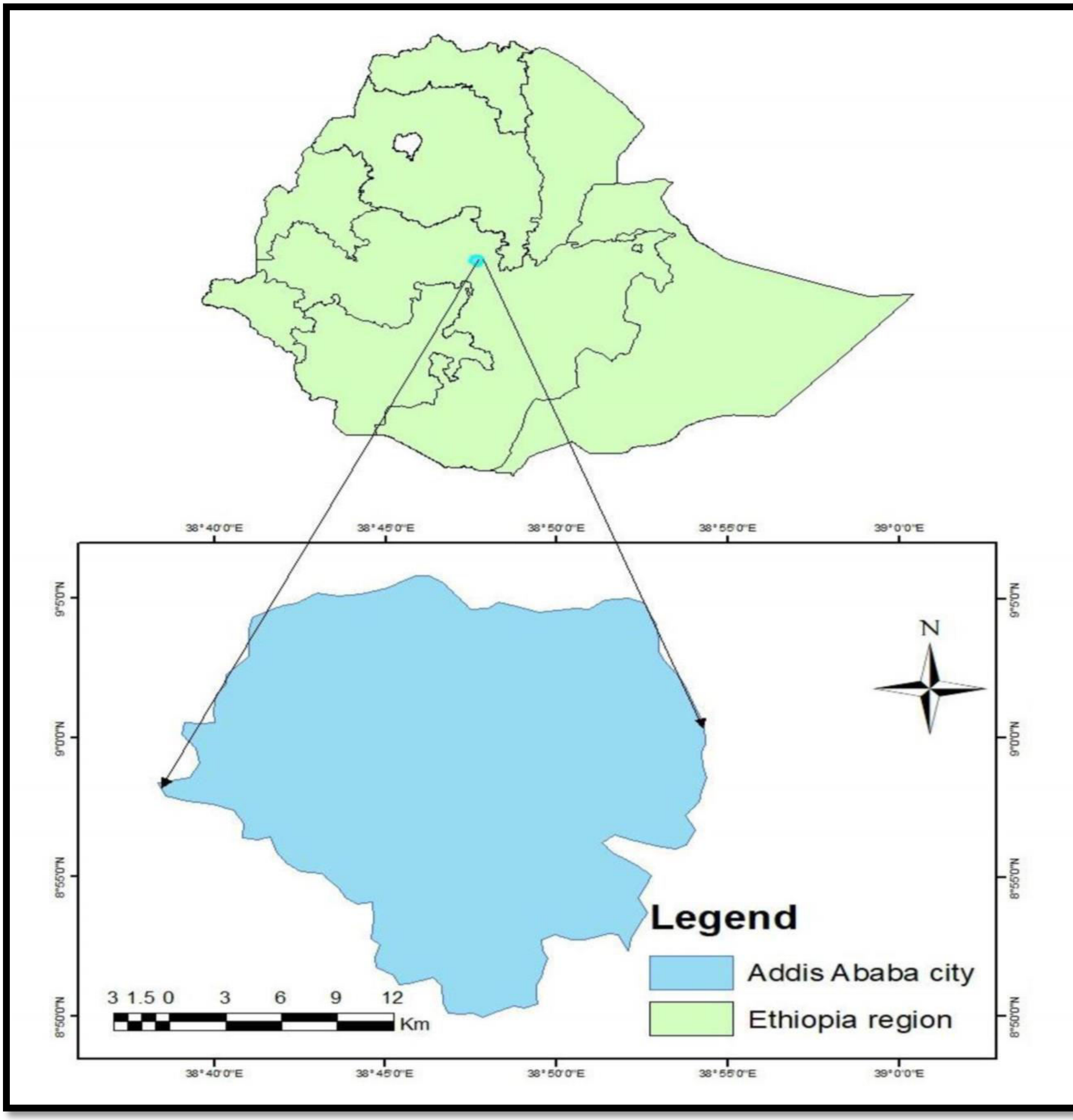

Figure 1: Map of Ethiopia showing Addis Ababa City

Data Collection Method

Reconnaissance survey was conducted to identify suitable data collection sites. In the survey then three altitudinal variations were identified that helped to capture the different woody species in the inner city of Addis Ababa.For the roadside woody species assessment, a total of 95 km of road were selected from the 316 km of Addis Ababa's primary arterial asphalt roads and ring road. These 95 km were distributed across three altitudinal categories, with 31.6 km sampled from each category (AACRA, 2019). Three Parksrepresenting of three altitudinal categories were also selected. The selected primary road and parks were older than ten years, holding of large, native, or remnant trees (Table 1).

Table 1: Green space Identified to collect Woody Species Data

No	**Category**	**Green Spaces**	
		Park	**Roadside**
1	Upper Altitude (2501-2700 m.a.s.l)	Sheger Park (40000m2)	31.6km
2	Middle Altitude (2301-2500 m.a.s.l)	Ambassador Park (17000m2)	31.6 km
3	Lower Altitude (2100-2300 m.a.s.l)	Akaki Park (77000m2)	31.6 km

Following Nowak et al., (2008), data collection plots (20m x 20m) were then established within selected parks, with the number of plots proportional to the park's size: 30 plots for Sheger, 13 for Ambassador, and 58 for Akaki.For roadside plantation, a complete survey was conducted (Nowak et al., 2008and Li et al.,2011).

Furthermore, following the methods outlined by Hasan, et al. (2008) and Raupp, et al. (2006), Visual Tree Assessment (VTA) method was used to identify potential conflicts between tree species and both aboveground and belowground infrastructure in both the parks and roadside areas.

To assess and identify heritage trees in urban green spaces, biological and cultural data collection methods were used. For the biological criteria, the following data were collected; location, species, and size, diameter at breast height (DBH), height, location data and photographs. For the cultural criteria key informant interviews and literature were reviewed and information related to stories associated with heritage trees, cultural traditions, events of importance, ecosystem function and geographical origin were collected ((Li, and Zhang, 2021; Jim, 2005). Following Li and Zhang, 2021; Liu et al. 2020; and Zhang et al. 2017 data on the growth status of heritage trees were collected and divided into four categories as “good”, “fair”, “poor”, and “dying” by the description of growth status (Table 1). Moreover, detailed heritage trees’ growing habit were recorded and categorized into five tree habitat types (Table 2) (Liand Zhang, , 2021; Li et al. 2018; Jim, ; Zhang, 2013).

Table 1: Gradients division of growth status of heritage trees in Addis Ababa, Ethiopia.

Type	Description
Good	The heritage tree is vigorous and without suffering disease
Fair	The identified heritage tree has minor damage with average growth performance
Poor	The identified heritage tree has weak growth performance, as well as slowly growing and serious damage
Dying	The identified heritage tree is moribund with mostly withered branches

Table 2: Five tree habitat types, which accommodate heritage trees, were identified in Addis Ababa City, Ethiopia.

Acronym	Habitat types	Paraphrased
PG	Parks Gardens	Including Botanic garden, public parks, and forest parks, environments, which are often protected well.
RC	Religious sites and cemeteries	Including Church, Monasteries, Mosques
GC	Government institutional units and community grounds	Including Government office compounds, schools that provide social and public services.
EC	Enterprises and comm ercial places	Including restaurants, and hotels which are usual ly places for commercial activities to generate revenue.
RS	Roadsides	Including expressways, isolation belts, and arteri al traffics where traffic is dense.

Each species' voucher specimens were collected and identified at the National Herbarium (ETH). Nomenclature follows that of the published volumes of the Flora of Ethiopia and Eritrea volume 3 (Hedberg and Edwards, 1989), Flora of Ethiopia and Eritrea: Volume 2, part 2 (Edwards et al., 1995), and Flora of Ethiopia and Eritrea: volume 2, part1 (Edwards, et al. 2000).

Data Analysis

The Shannon-Wiener Diversity Index (H') and Equitability/Evenness Index (J) were used to calculate the diversity of woody species (Kent & Coker 1992; Barnes et al. 1998). Because it includes species richness and species evenness (relative abundance), the Shannon-Wiener diversity index is the most commonly used indicator to quantify species diversity (Kent & Coker 1992). The following equation used to obtain the Shannon diversity index (H'):

$$H' = -\sum_{i=1}^{S} \text{Pi} \ln \text{Pi} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)$$

Where: H' = Shannon diversity index, S = the number of species, Pi = the proportion of individuals of the i^{th} species expressed as a proportion of total cover in the sample, and ln = the natural logarithm. The Shannon evenness index (J) was also calculated using the following

$$J = \frac{H'}{H'max} = \frac{H'}{\ln S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where J= Shannon equitability or evenness index, H' = Shannon-Wiener diversity index, H' max= the maximum level of diversity possible within a given population, which equals ln S, and S= the number of species, ln = the natural logarithm.

Woody Species similarity coefficient wasused to explore the similarity of woody species between different three categories of altitudinal gradients and three different green spaces of Addis Ababa, and was calculated using the similarity coefficient formula proposed below:

$$SJ= \frac{a}{a+b+c}$$

Where:

SJ = Jaccard similarity coefficient,

a = number of species common to (shared by) sites,

b = number of species unique to the first site, and

c = number of species unique to the second site

Heritage trees identified and their biological and any associated ecosystem services related to cultural values analyzed. Geographical information systems (GIS) and mapping technologies used to show distribution map of heritage trees within urban green spaces.

Conflict of each individual surveyed roadside and park green spaces woody species with aboveground and lower ground infrastructure analyzedusing PAST Paleontological Statistics software Version 3.0 (Hammer et al. 2001).The study utilized PAST application software to examine the conflict between different types of vegetation found along roadsides and in parks, specifically looking at how these green spaces interact with aboveground and belowground infrastructures.

Results

Diversity of Woody Species

In roadside and Park green spaces a total of 68 woody species, 58generaand 31 Families were recorded. In both roadside and Parks Fabaceae family hadlarger number of species than other families.

Upper Altitude Park had46 woody species and hadhigh proportion of Native species with a mean value of 0.8, Middle and lower Altitude Park had moderate proportion of Native species with a mean value of 0.54 and 0.52 respectively. UpperAltitude Parkhadrelatively higher evenness of species with a value of 0.48 and the middle and lower Altitude Park hadlower evenness of species with a value of 0.29. Roadside hadlow proportion of Native species with mean value of 0.14 and hadhigh evenness of species value of 0.33 (Table 3).

The sampled upper,middle and lower altitude parkshadhigh Shannon diversity index value of 3.04, 1.57, and 1.82 respectively. The roadside Shannon diversity index value for upper, middle and lower altitude were1.75, 1.65, and 1.83 respectively (Table 3).

Table 3: Composition and Diversity of Woody Species

	Diversity of Woody Species Upper altitude		**Diversity of Woody Species Middle Altitude**		**Diversity of Woody Species Lower Altitude**	
	Native	**Exotic**	**Native**	**Exotic**	**Native**	**Exotic**
Park Number of species	33	13	14	12	11	10
Park Mean	0.8	0.2	0.54	0.46	0.52	0.47
Shannon H	3.04		1.57		1.82	
Evenness_ e ^H/S	0.4785		0.1993		0.2933	
Road side Number of species	7	13	9	15	6	13
Roadside Mean	0.14	0.86	0.14	0.86	0.09	0.91
Shannon H	1.75		1.65		1.83	
Evenness_ e ^H/S	0.26		0.19		0.33	

The figure illustrates that lesser DBH categories have a higher frequency of woody plant individuals compared to upper DBH categories across all three-road types (Figure 2a). This patternwas consistent across all three-altitude parks (Figure 2b).

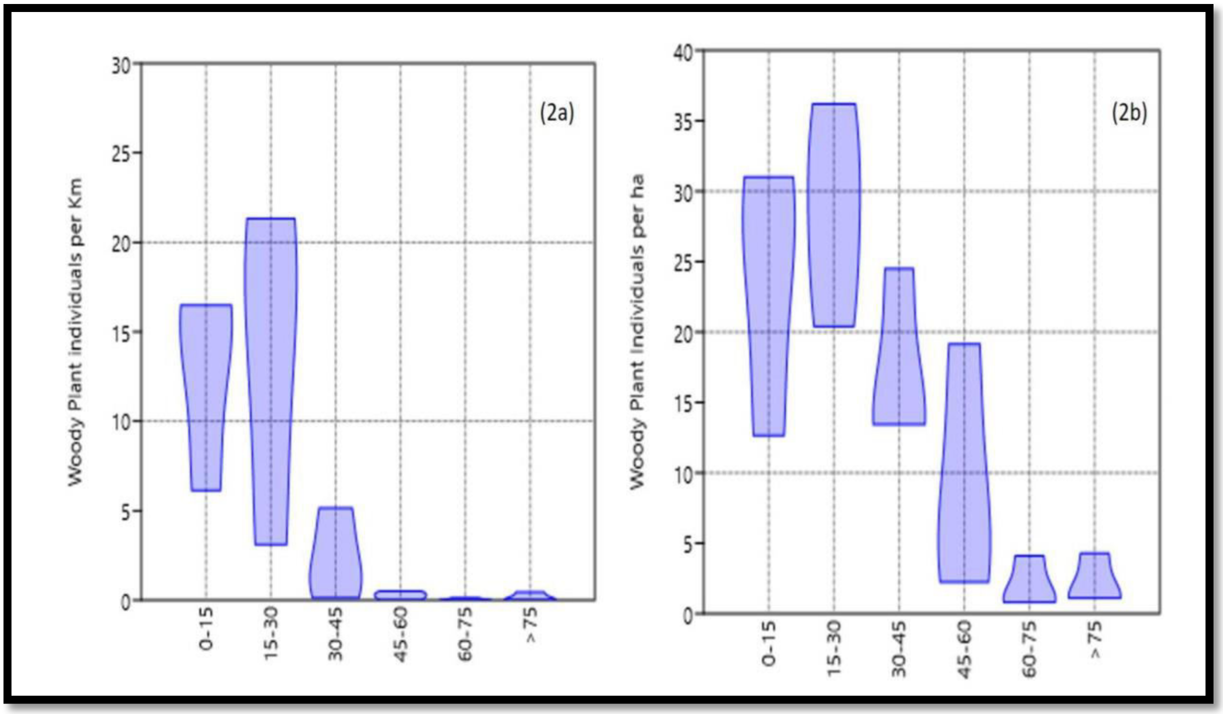

Figure 2: Distribution of Woody Species at Different DBH Classes of Roadsides (a) and Parks (b)

In roadside plantations along altitudinal gradients, both Acacia melanoxylon and Grevillea robusta exhibited higher population densities per kilometer. This trend observed across higher, middle, and lower altitudes. Five or more of the seven species wereexotic, which were with high proportions(Table 4).

At the highest altitudinal gradients, six of the seven plant species wereNative, with Olea europaea being the most densely recorded species. In the middle altitudinal gradients, five of the seven most populous species wereexotic and Graviellia robustahadhigh number of individuals. In the lower altitude park, four of the seven most populous species wereNative, with Vachellia etbaica being the most abundant species (Table 4).

Table 4: Seven most Densely Recorded Woody Species in upper, Middle & Lower Altitude Roadisde and Parks.

Species	Roadside Density per kilometer			Park Density per hectare		
	Upper	Middle	Lower	Upper	Middle	Lower
Acacia melanoxylon	17					
Acacia saligna			1			
Borassus aethiopium		1			5	
Callistemon citrinus		1	1		2	
Casuarina equisetifolia	1	2		1	5	
Cordia africana						1
Croton macrostachyus						1
Cupressus lusitanica						2
Cupressus sempervirens	2	1			5	
Dracaena steudneri	1			4		
Duranta erecta	1					
Eucalyptus camaldulensis						4
Grevillea robusta	11	16	10		59	1
Jacaranda mimosifolia		4	1		15	
Juniperus procera				5		
Melia azedarach			1		6	
Millettia ferruginea				3		
Olea europaea				6		
Olinia rochetiana				2		
Phoenix reclianata		2				
Prunus africana				2		
Psidium guajava			1			
Sesbania sesban	2					
Spathodea campanulata			2			
Vachellia abyssinica				2		
Vachellia etbaica						10

The coefficient between Upper Altitude Park and Middle Altitude Park was0.34, indicating a moderate similarity in the sets of taxa between the two parks of two different altitudinal gradient ranges. The coefficient between Upper Altitude Park and Lower Altitude Park was0.18, suggesting a low similarity in the sets of taxa between the two parks. The coefficient between Middle Altitude Park and Lower Altitude Park was0.18, indicating a relatively low similarity in the sets of taxa between the two parks (Table 5).

Table 5: Jaccard coefficientSimilarity of Species among the Upper, middle & Lower altitude
Parks

	Upper altitude Park	**Middle Altitude Park**	**Lower Altitude Park**
Upper altitude Park	1.00	0.34	0.18
Middle altitude Park	0.34	1.00	0.18
Lower altitude Park	0.18	0.18	1.00

The Jaccard similarity coefficient between Upper Altitude Roadside and Middle Altitude Roadside was 0.55, suggesting a relatively high similarity in the sets of taxa between the two roadside plantations. The coefficient between Upper Altitude Roadside and Lower Altitude Roadsidewas 0.45, indicating a moderate similarity in the sets of taxa between the two roadside plantations. The coefficient between Middle Altitude Roadside and Lower Altitude Roadside was0.43, suggesting a moderate similarity in the sets of taxa between the two roadside plantations (Table 6).

Table 6: Jaccard coefficient Similarity of Species among the Upper, middle and Lower altitude
Sampled Roadside Plantations

	Upper altitude Roadside	Middle altitude Roadside	Lower altitude Roadside
Upper altitude Roadside	1.00	0.55	0.45
Middle altitude Roadside	0.55	1.00	0.43
Lower altitude Roadside	0.45	0.43	1.00

Potential Heritage Trees of Addis baba

Thisstudy identified and proposed 42 potential heritage trees for Addis Ababa. These trees were located in six of the city's eleven sub-cities: Bole, Kirkos, Arada, Nefas Silkt Lafto, Gulele, and Kolfe Keranio.The distribution of heritage trees across the seven sub-cities of Addis Ababa was uneven, with Kolfe Keranio (16 trees) and Arada (13 trees) having the highest concentrations of heritage trees. Gulele, Bole, Kirkos, and Nefas Silk Lafto had fewer heritage trees, with three, one, one and eight trees respectively (Figure 3).

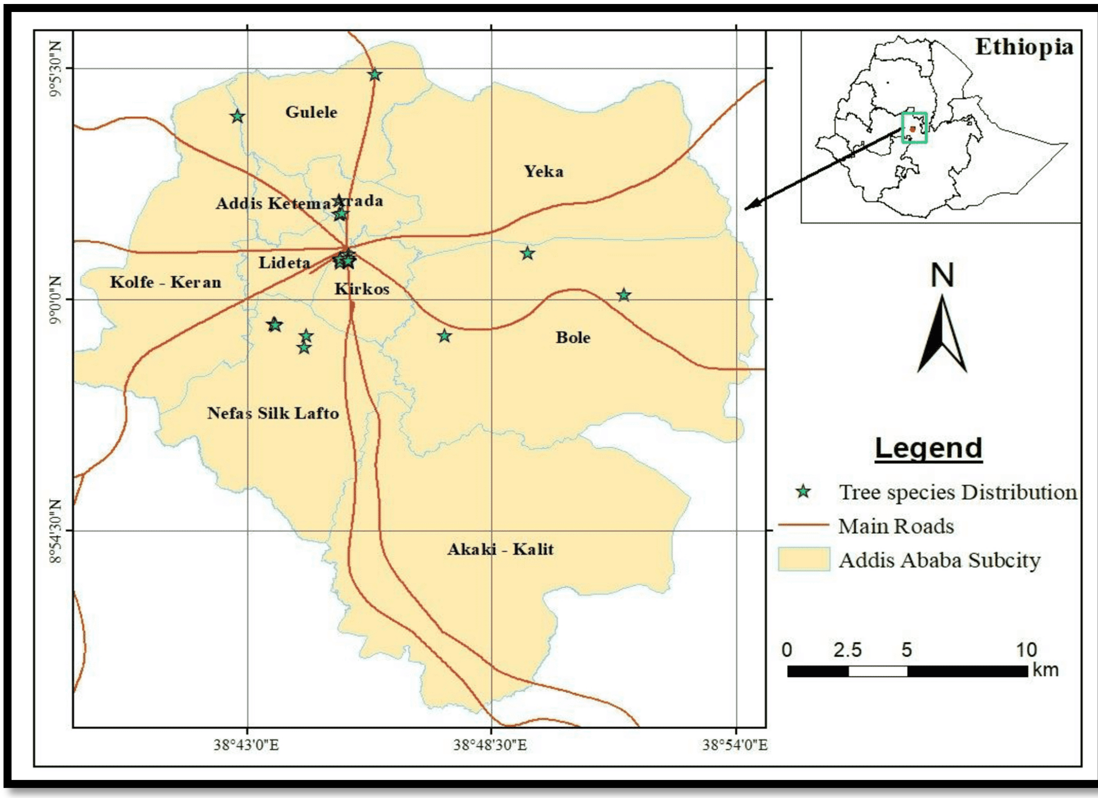

Figure 3: Spatial Distribution Map of the Identified Heritage Trees in Addis Ababa

In terms of their number and species, heritage trees were unevenly distributed in different tree habitats. In RC (39.5%) and PG (32.6%) had the first two highest tree counts, followed by EC (16.3%), GC (9.3%) and RS (2.3%). The number of species distributed in the PG habitat was eight (66.7%) (Figure 4).

The distribution of heritage trees varied significantly across different habitat types, with both the number of trees and the species composition showing unevenness. Religious sites and cemeteries (RC) and Parks Gardens (PG) held the highest number of heritage trees, accounting for 39.5% and 32.6% of the total, respectively. These were followed by ecological corridors (EC) with 16.3%, Government institutional units and community grounds (GC) with 9.3%, and Enterprises and commerce places Roadsides (RS) with a mere 2.3%.

Species diversity also differed among habitats. Parks Gardens (PG) boasted the highest number of heritage tree species, with eight species constituting 66.7% of the total (Figure 4).

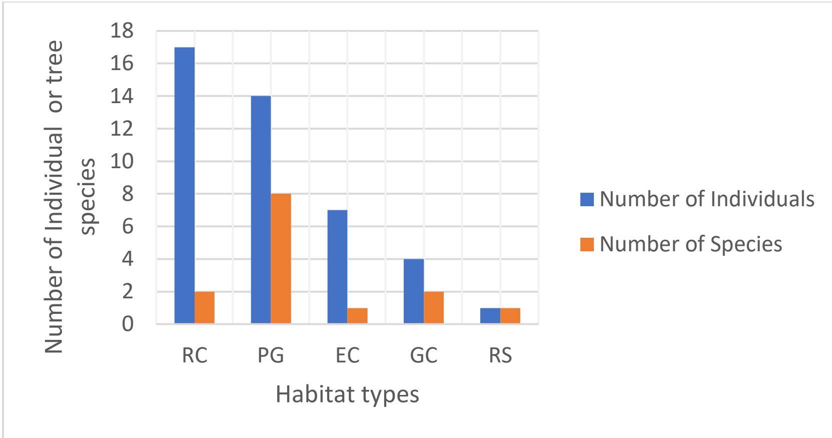

Figure 4: Number of Individuals and Number of Heritage Tree Species at different Habitat Types in Addis Ababa

The identified heritage trees comprise of 42 trees, representing 12 species, spanning across 11 genera and 9 families. Among these families, Oleaceae stoodout with 16 individual trees, followed closely by Fabaceae with 11 individual trees. Out of the 12 species identified, nine were native, accounting for 39 out of the 42 individuals, with the remaining three species being exotic (Table 7).

Figure 5: Photographs of Potential Heritage Trees with Significant Historical, Ecological and Cultural Ecosystem Services Connections to Specific Areas in Addis Ababa: (a) Ficus sur (Shola- Gurde Shola); (b) Vachillea abyssinica (Lafto- Nefasilk Lafto); and (c) Olea europaea sub sp. Cuspidata (Weyera- Weyera sefere)

Among the total species identified, with the exception of Grevillea robusta and Cupressus lusitanica, which used as habitats for eagles along with other Native trees, and Eucalyptus globulus, which was the first imported Eucalyptus tree to Ethiopia, the remaining species are Native to the Ethiopia (Table 7).

One of the identified heritage trees, Ficus sur, stands out with its impressive diameter, measuring 274 cm in DBH (diameter at breast height). The identified potential heritage trees play a vital role in providing a range of ecosystem services to urban dwellers. With their historical significance and attachment to the locality, they also contribute to supporting and cultural ecosystem services (cooling effects and car parking) (Table 7).

Among the potential heritage trees identified, Vachellia abyssinica species distributed in different sub cities of Addis Ababa and providing more ecosystem services. Three of the potentially identified trees, namely Erythrina brucei, Millettia ferruginea, and Vachellia negrii, are endemic to Ethiopia, further highlighting their ecological and cultural importance (Table 7).

Table 7: Potential Heritage Tree Species in Addis Ababa: Species Name, Size (DBH & Height), and Descriptions

No	Scientific Name	DBH	Ht.	Sub city	Individual Trees Ecosystem Functions
1	Ficus sur (Moraceae) (Native)	274	18	Bole	The proposed heritage tree has a historical attachment to the sites, which is named after this species. It provides shade and functions as a natural car park(Figure 5a).
2	Vachellia abyssinica (Fabaceae) (Native)	62	16	Nefas Silk Lafto	The sub city derives its name from the vernacular name of these trees. Notably, the renowned Lafto Mall, a prominent marketplace in the sub city, has preserved several of these significant trees, utilizing them as shaded parking lots (Figure 5b). The historical importance of this species, along with its valuable ecosystem services, presents a strong case for its inclusion as one of the proposed heritage trees.
3	Vachellia abyssinica (Fabaceae) (Native)	60	14		
4	Vachellia abyssinica (Fabaceae) (Native)	54	11		
5	Vachellia abyssinica (Fabaceae) (Native)	50	11		

6	Vachellia abyssinica (Fabaceae) (Native)	48	10		
7	Vachellia abyssinica (Fabaceae) (Native)	47	11		
8	Croton macrostachyus (Euphorbiaceae) (Native)	54	24	Nefasil k Lafto	The Mekenisa area in Addis Ababa named after the predominantCroton macrostachyus tree in the past, and this vernacular name continues to be associated with this part of the city today. The identified potential heritage trees are located within Mekanisa Abader School, and their conservation is crucial due to their historical significance.
9	Croton macrostachyus (Euphorbiaceae) (Native)	52	21		
10	Olea europaea subsp. cuspidata (Oleaceae) (Native)	156	23	Kolfe Kerany o	The neighborhood of Weyera Sefer in Addis Ababa derives its name from the local term "weyera," referring to the Olea europaea subsp. cuspidata (Wall.ex DC.)Cifferspecies. In the past, these Native trees were the dominant species in the area, leading to the naming of the locality as Weyera Sefer. Currently, these trees primarily found within the compounds of churches, especially in older churches located around Weyera Sefer.The Olea europaea trees listed in our inventory are predominantly
11	Olea europaea subsp. cuspidata (Oleaceae) (Native)	140	21		
12	Olea europaea subsp. cuspidata (Oleaceae)(Native)	104	22		
13	Olea europaea subsp. cuspidata (Oleaceae)	144	19		

	(Native)				mature and display a significant diameter at breast height(DBH) (Figure5c).These remarkable trees are located within the premises of the Keranyo Medehanelaem Church, whichwas established in 1823 EC (1830 GC). With their large size, age, and predominantly Olea europaea species, they have become an essential and captivating aspect of the church's landscape. The impressive stature of these trees, combined with their rich historical significance, and enhances the unique character and atmosphere of the church and its environs (Figure 5c). Therefore, it is of utmost importance to document and preserve these tree species as part of our heritage trees initiative.
14	Olea europaea subsp. cuspidata (Oleaceae) (Native)	120	15		
15	Olea europaea subsp. cuspidata (Oleaceae) (Native)	101	17		
16	Olea europaea subsp. Cuspidata (Oleaceae) (Native)	102	18		
17	Olea europaea subsp. cuspidata (Oleaceae) (Native)	100	21		
18	Olea europaea subsp. cuspidata (Oleaceae) (Native)	121	22		
19	Olea europaea subsp. cuspidata (Oleaceae) (Native)	110	20		
20	Olea europaea subsp. cuspidata (Oleaceae) (Native)	107	18		
21	Olea europaea subsp. cuspidata (Oleaceae) (Native)	102	17		
22	Olea europaea subsp. cuspidata	100	19		

	(Oleaceae) (Native)				
23	Olea europaea subsp. cuspidata (Oleaceae) (Native)	101	21		
24	Olea europaea subsp. cuspidata (Oleaceae) (Native)	112	22		
25	Olea europaea subsp. cuspidata (Oleaceae) (Native)	111	17		
26	Eucalyptus globulus (Myrtaceae) (Exotic)	208.9	24	Gullele	The identified Eucyapluts tree is the first introduced Eucalyptus globulus trees to Ethiopia from Australia in 1895 by EmperorMenilik who first established the capital city Addis Ababa.The tree is now has an age of more than 120 years. Currently, Eucalyptus plantations have expanded greatly in Ethiopia.
28	Afrocarpus falcatus (Podocarpaceae) (Native)	72	27	Arada	The Ambassador Park in Addis Ababa city is home to different tree species, which have the potential to consider as heritage trees. These trees are providing nesting grounds for over a thousand Eagles in the city.They are key ecological resources that enhance the city's biodiversity and in bird conservation. Given their
29	Afrocarpus falcatus (Podocarpaceae) (Native)	83.5	32		
30	Afrocarpus falcatus (Podocarpaceae) (Native)	57.5	34		
31	Afrocarpus falcatus (Podocarpaceae)	77.3	32		

	(Native)				importance, these trees are apply regarded as the city's heritage trees, symbolizing a precious natural legacy that fosters the flourishing avian population in the urban landscape.
32	Afrocarpus falcatus (Podocarpaceae) (Native)	97.2.3	28		
33	Ekebergia capensis (Meliaceae) (Native)	103.8	31		
34	Erythrina brucei (Fabaceae) (Native)	75	31		
35	Grevillea robusta (Proteaceae) (Exotic)	57.5	23		
36	Millettia ferruginea (Fabaceae) (Native)	59	27		
37	Cupressus lusitanica (Cupressaceae) (Exotic)	56.3	22		
38	Vachellia negrii (Fabaceae) (Native)	69	24	Gullele	In Gulele sub-city, the remarkable presence of Vachellia negrii becomes apparent.This specific tree species is an endemic tree. Moreover, it has garnered recognition as a vulnerable species according to the IUCN Red List for Ethiopian species, emphasizing the urgent necessity for conservation endeavors. As a woody species, Vachellia negrii holds considerable ecological importance, warranting a heightened level of focus and care. Thus, this species recruited as potential heritage tree,
39	Vachellia negrii (Fabaceae) (Native)	65	21		

					further emphasizing the imperative to safeguard its existence.
40	Vachellia abyssinica (Fabaceae) (Native)	130.6	25	Kirkos	The presence of the large tree with DBH of 130.6 cm of Vachellia abyssinicatree in the compound of National Theater contributes to the recreational value. The expansive canopy of these trees, covering about eighty-five percent of the area with a width of 12 meters and a length of 13 meters, has allowed for the establishment of an open-air restaurant and cafe beneath their shade. This unique amenity has become a cherished gathering place for visitors and locals, adding to the vibrancy and liveliness of the National Theater.
41	Vachellia abyssinica (Fabaceae)	67	24	Arada	The municipality office maintained the large with wide spread canopy Vachillea abyssinica trees in its compound. The office use those trees canopies occasionally as open area event celebration and gatherings. Thus, those Native, large and old age trees are heritage trees of Addis Ababa.
42	Vachellia abyssinica (Fabaceae)	72	26		

The assessment of the growth status of ancient trees in Addis Ababa resulted in the following categorization: 83.7% (36 trees) were classified as "Good," 11.6% (5 trees) as "Fair," and 4.6% (2 trees) as "Poor." Among the different species, the majority of trees (83.3%) exhibited a "Good" performance, comprising a total of 10 species (Figure 6).

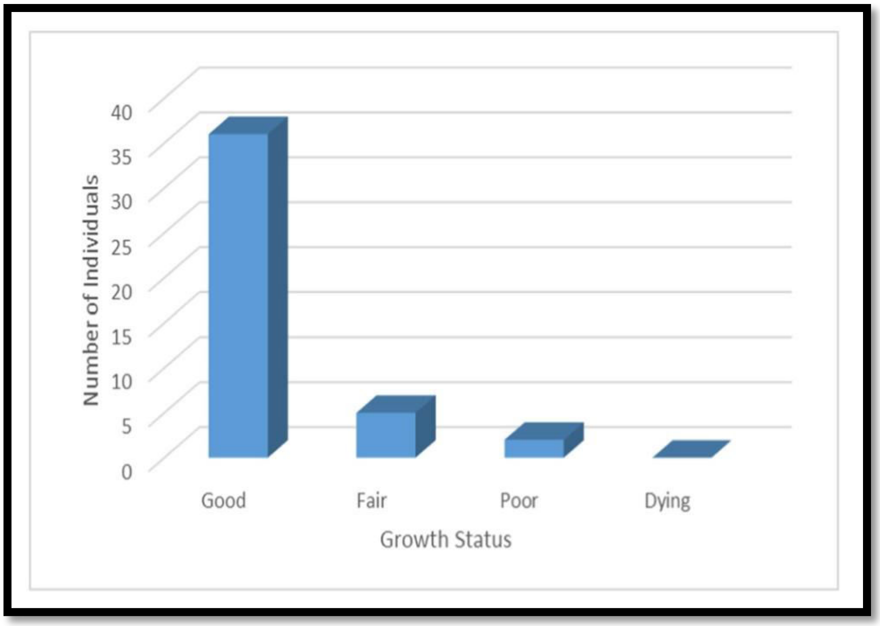

Figure 6. Growth status of identified Heritage Trees

Conflict of woody Species with Infrastructures

The park's woody species hadlower average conflicts with both aboveground and belowground utilities compared to roadside woody species. In the upper and middle altitudinal gradients, roadside woody species hadan average conflict index of 0.51 and 0.70 for aboveground and belowground utilities, respectively. However, in the lower altitudinal gradient, the conflict index wassignificantly lower, with average values of 0.14 and 0.17 for aboveground and belowground utilities, respectively (Table8).

Table 8: Roadside and Park Woody Species Conflict with Infrastructures

	Park			Road Side		
	Upper	Middle	Lower	Upper	Middle	Lower
Mean of AGC	0.14	0.14	0.019	0.51	0.7	0.14
Mean of BGC	0.19	0.10	0.022	0.44	0.64	0.17
Sum of AGC	63	24	7	232	678	46
Sumof BGC	86	17	8	199	615	56
Stand. Dev. of AGC	0.35	0.34	0.137	0.5	0.46	0.35
Stand. Dev. Of BGC	0.4	0.30	0.146	0.49	0.48	0.38

Grevillea robusta, is an exotic tree species that has been extensively planted and associated with a number of conflicts with both above-ground and below-ground infrastructure. Acacia melanoxylon, is another exotic tree species that has been widely planted in upper roadside greenspaces and exhibits similar conflicts with infrastructure. (Figure 7).

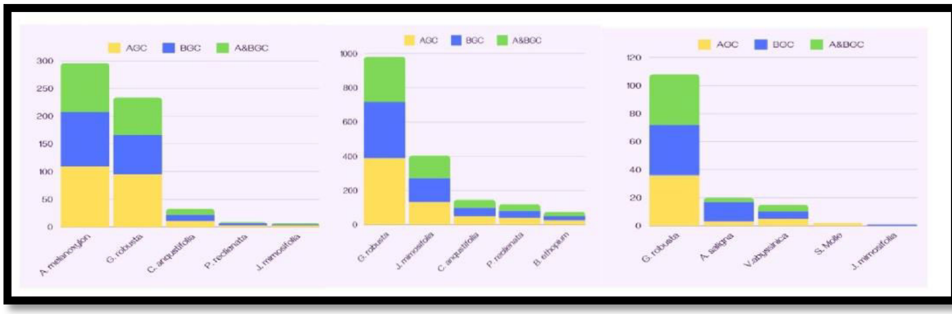

Figure 7: Distribution of Five Woody Species along the Altitudinal Gradient of Roadside Areas having High Above Ground Conflict (AGC); Below Ground Conflict (BGC), and Above and Below Ground Conflict with Infrastructures in the Higher (a), Middle (b), and Lower (c) Altitudinal Zones.

Below-ground conflicts arise primarily from the tree's extensive root system, penetrate sidewalks, pavements, and causing damage and disruption to these structures(Figure 8). Additionally, the tree's large canopy can interfere with overhead power lines and communication cables.

Figure 8: Roadside trees conflicting with sidewalk and electric power line

Discussion

Woody Species Composition

The valuationrecordeda total of 68 species, 65 genera, and 36 families in roadside and park green spaces, with the Fabaceae family having the largest number of species in roadsides and parksgreen spaces.This study's findings are similar to those of floral diversity studies in Accra, which found 70 woody species (Bertrand, 2018). In a study conducted in Pune metropolitan area of India, Kiran andVarcha (2022), recorded 69 woody species which also similar to the study, consisting of 43 Native species and 26 exotic species. However, the present study had lesser species diversity and abundance than the 176 species recorded in Kumasi (Nero et al., 2017); 297 tree species in Lome, Togo (Raoufou et al., 2011); 80 woody species in Bangalore’s Parks India(Harini and Divya , 2010), and 80 woody Species in Changchun City (Yufei , 2022).

Findings related to high number of species from few familiesand Fabaceae family is consistent with other studies of urban woody plant diversity, which have found that most trees in urban areas worldwide derive from only three families. In India in the composition of roadside tree, species at a metropolitan city of Indiafound Fabaceae family have secondhighest woody species(Arbeen et al., 2016).

There are a number of possible reasons for the dominance of the Fabaceae family in urban areas. One possibility reason couldbe the green space managers get large options to select, plant from Fabaceae family since the family is the third largest diverse family among flowering plants with 20,000 species of trees, shrubs, vines, and herbs distributed worldwide (Tucker, 2003).

The Upper Altitude Park had a greater diversity of woody plant species (46 species) than the Middle and Lower Altitude Parks (26 and 21 species, respectively). This may be because the Upper Altitude Park is less disturbed by human activities, which can promote higher woody plant species richness. Conversely, the lower species richness of the Lower Altitude Park is likely due to the dominant woody plant species, Vachellia trees, which reduce the richness of other woody plant species in two ways. First, Vachellia trees are dominantly the Native species that have a wide canopy cover that takes up space and prevents other woody plant species from growing freely underneath. Second, human use of the shade of these trees further inhibits the growth of woody species underneath.

The Upper Altitude Park also exhibited a higher proportion of Native species (mean value of 0.8). The Middle and Lower Altitude Parks showed a moderate proportion of Native species, with mean values of 0.54 and 0.52, respectively (Table 1). This suggests that while these parks still have a significant representation of native species, they also contain a proportion of non-Native or introduced species. Park green spaces in Nairobi, Kenya also exhibited high proportion (0.69) of Native species (David, 2016).

In this study, the middle and lower altitude parks have proportionally equal exotic and Native species. Other studies also showed urban parks have mixed exotic and Native species(McKinney, 2008; Garcillan et al., 2009).On the other hand, study conducted in Bangalore City Park found 0.65 of the recorded species are exotic species or 0.35 of Native species (Harini and Divya, 2010).

The high proportion of Native species in the Upper Altitude Park suggests that the park has a better-preserved native plant community than many other urban parks. This is a positive sign, as Native species are important for providing food and habitat for native birds in urban environment and for playing a role in ecosystem processes.

In a comparative analysis of three parks with different altitudinal gradient ranges, it was observed that Upper Middle and lower Altitude Parks have maximum 0.34 and minium 0.18 coefficnet of simliarity. This low similarity in their sets of taxa, implythat the species compositions in these three parks differ significantly. These findings provide valuable insights into the variations in species diversity across altitudinal gradients within the park system.Multiple studies have emphasized having diverse plant have critical role in urban parks for the sustainability of urban ecosystems (Anderson et al., 2021; Monalisa-Francisco and Ramos, 2019; Ming and Du, 2021).

The finding that urban recreational parks have a higher density of woody plant individuals in lower DBH categories (0 – 15& 15 - 30cm) than in higher DBH(>65 cm) categories. This finding is consistent with the results of other study the dominant DBH range is 5-15 cm(Xia-Lan et al., 2021). The analysis revealed an interesting DBH pattern characterized by an inverted 'J' shape, suggesting that the dominant urban trees in parks were relatively young. This is likely due to smaller woody plant individuals may be more likely to be planted in urban parks, as they are easier to transport and transplant than larger individuals.

Out of the seven identified species with a high number of individuals, Olea europaea, Graviellia robusta, and Vachellia etbaica demonstrate a greater abundance across the upper, middle, and lower altitudinal parks (Table 2). This result indicates the importance of preserving and managing these parks as valuable habitats for Native species, contributing to the overall resilience and sustainability of urban ecosystems. By protecting and enhancing the populations of these species, we can ensure the continued provision of ecosystem services, promote biodiversity conservation, and foster a sense of connection between nature and human communities(Arbeen et al., 2016).

In terms of roadside green spaces, they showed a lower proportion of Native species, with a mean value of 0.14, indicating a prevalence of non-native or introduced species in these areas (Table 1). This is consistent with other studies of urban roadside green spaces, which have found that these areas tend to have a lower proportion of Native species than urban parks (e.g. McKibbey, 2002; Nielsen et al., 2014). The reason may be roadside green spaces are often planted with non-Native woody plant species that urban green mangers consider non-Native species are more tolerant of pollution and other stressors.

Other studies also indicated that although cities seem able to support a wide variety of tree species, many cities have low and declining tree diversity, and even though there are many different tree species in urban areas, a few species typically dominate the tree population (Sjoman et al., 2012). The result showed due to high proportion of exotic species which outcompete Native species in urban landscapes, reduce their ability to provide ecosystem services, even if they are diverse (Nielsen et al., 2014; Pysek et al., 2009; Chyrtry et al., 2008).

Conversely, the study in India indicated that among the tree species found in the selected roads, a significant majority are Native and very low exotic species.The presence of Native species in urban area suggests that they are likely well adapted to the local environment(Arbeen et al., 2016). Therefore, it is crucial to prioritize the integration of more Native species in roadside plantations within urban landscape.

The roadside plantations along altitudinal gradients exhibit higher population densities per kilometer for the exotic species Acacia melanoxylon and Grevillea robusta, which dominate these plantations. It is worth highlighting that out of the seven species recorded, five of them are exotic, as shown in Table 2. This result is consistent with other studies that a higher number of exotic species compared to native species in streets and urban parks across various cities worldwide. For example, this trend has been observed in Brazil, Santiago Chile; and ten Nordic cities (Moro and Castro, 2015; Figueroa et al., 2016 and Sjöman et al., 2012).

The result indicate that urban landscapes dominated by non-native plant species. The reasons for this occurrence can vary and may include factors such as the intentional introduction of exotic species for aesthetic purposes, their adaptability to urban conditions, and the potential displacement of native species due to urbanization and habitat fragmentation. Understanding the prevalence and implications of exotic species in urban ecosystems is crucial for effective urban planning, conservation, and the preservation of biodiversity.

Potential Heritage Trees of Addis Ababa

In thiscomprehensive study conducted in Addis Ababa, 42 heritage trees are identified and recommended for preservation.These selected potential heritage trees found across six of the city's eleven sub-cities, namely Bole, Kirkos, Arada, Nefas Silk Lafto, Gulele, and Kolfe Keranio (Figure 3).The proposed heritage trees fulfill two or more of the selection criteria including size, species rarity, ecological significance, landscape contribution, association with sites and notable ecosystem services.

Similarly, Heritage Trees for Conservation and Management in Guangzhou City (China), identified 348 heritage trees (HTs) representing 25 different species having old age, historical significance and commemorative trees signifying their special recognition for their association with significant events or people (Jim, 2004).

Other studies also identified potential heritage trees using labels include terms such as ancient, beautiful, big, champion, elite, exceptional, famous, historic, landmark, old, outstanding, remarkable, specimen, veteran trees, ancient, and old-valuable (Read, 2000; Jim, 2005; Jim & Zhang, 2013).

In Addis Ababa, RC and PG collectively contain a significant portion of the city's heritage trees. These two habitats collectively contain 72% of the total number of heritage trees and 83.4% of all heritage tree species (Figure 4). This dominance is likely due to the fact that RC and PG offer more open, spacious, and natural environments compared to other habitats. These open conditions provide ample room for growth and reduce stress factors on the trees, allowing them to be conserved for long period of time and potentially reach heritage status.

Habitats like RC and PG exhibit higher species richness of urban trees. This is likely because these areas receive greater protection from urbanization compared to other habitats. This finding highlights the importance of safeguarding not just the heritage trees themselves, but also their surrounding microhabitats, which in turn support a wider variety of urban tree species.

It is important to note, however, that religious areas in Ethiopia also serve as vital conservation sites and biodiversity hotspots, primarily for Native trees and shrubs(Amare, et al. 2019). Ethiopian Orthodox Tewahido Churches where the identified heritage trees found are renowned for being sanctuaries for a variety of plant and animal species (Walter and Gillett, 1998).

The collection of heritage trees identified in the study consists of 43 individual trees, representing 12 diverse species. These species span across 11 different genera and 9 diverse families. Notably, the family Oleaceae stands out prominently, containing 16 individual trees, closely followed by the Fabaceae family with 12 individual trees (Table 5).

Among the identified species, the majority of them (9 out of 12) 75% are native, comprising 39 out of the 42 or 93% individual trees. The remaining 3 species or 25% areclassified as exotic. These heritage trees play a vital role in providing a range of ecosystem services and hold significant historical value for the city according to Table 5. The finding is inconsistent with the study made in Guangzhou that the native species had a dominant presence in the Heritage Tree, accounting for 68.0% of the total species and 94.0% of the trees. The majority of the major species identified in the heritage trees were native species(Jim, 2004).

Ten individual trees of four different species located in Ambassador Park have the potential to consider as heritage trees due to their crucial role in providing nesting habitats for over 1,000 birds residing in Addis Ababa city (Table 5&Figure 4e). These trees have become essential ecological assets, contributing to the city's biodiversity and avian conservation efforts. Recognizing their significance, these trees are rightfully need to be considered as heritage trees of Addis Ababa city, representing a valuable natural heritage that supports the thriving bird populations within the urban environment.

The presence of these heritage trees creates ecological corridors and connectivity within the urban landscape. They serve as steppingstones and refuges for birds, allowing them to move between fragmented habitats and maintain gene flow between populations. This connectivity promotes resilience and genetic diversity among bird communities in the city.

Studies also indicated that urban green spaces including parks, squares, and public road trees, promote the presence and diversity of bird species in urban environments (Barth et al., 2015; Castro Pena et al., 2017).

The identified potential heritage trees, namely Ficus sur (Shola), Vachillea abyssinica (Lafto), Croton macrostachyus (Mekenisa), and Olea europaea (Weyera), hold significant historical value in their respective locations (Table 5). By prioritizing the protection and promotion of these heritage trees, we can enrich the sense of place, cultivate community pride, and encourage sustainable urban greening practices in Addis Ababa.

Urban heritage trees possess unique natural or cultural characteristics that make them essential elements of the cultural landscape and society. Due to their significance, these trees require an effective protection policy to ensure their preservation and continued contribution to the urban environment(Mid, 2012).

The survey conducted identified 42 individual potential heritage trees, with 39 of them being Native species and five classified as endemic species. Within the group of endemic species aretwo individuals of Vachillea negrii classified as vulnerable according to the IUCN (International Union for Conservation of Nature) Red List species (Table 5). Recognizing the importance of preserving these exceptional heritage trees is crucial in safeguarding their distinct genetic traits and conserving the valuable biodiversity they possess. These trees serve as a fundamental element of the area's natural heritage, playing a vital role in maintaining a healthy and balanced ecosystem. It is essential to prioritize serious conservation efforts to prevent the extinction of such species.Various studies also indicated that urban forests play significant roles as valuable natural assets within cities serving as both biodiversity hotspots and reservoirs of native endemic species (Foo, 2016 & Paix et al., 2012).

The good growth performance exhibited by 83.7% of the heritage trees is likely due to their high presence in RC and PG habitat types, which offer more open space and experience less disturbance in urban environments. These conditions create a favorable environment for healthy growth in heritage trees. Another contributing factor is that most of the identified heritage trees are native and well-adapted to the ecological conditions of their habitat, resulting in good growth performance for these plant species.

Conflict of woody Species with Infrastructures

The analysis of roadside green spaces revealed a relatively high number of trees that are in conflict with both above ground and below ground infrastructure. Mean values used to quantify these conflicts, with the maximum values reaching 0.64 for above ground conflicts and 0.7 for below ground conflicts (Table 6). This suggests that significant portions of the trees in these areas are in close proximity to the surrounding infrastructure and could potentially have an impact on it.

The prevalence of Grevillea robusta and Acacia melanoxylon in roadside green spaces in Addis Ababa, along with their tendency to conflict with infrastructure, raise concerns about the sustainability and ecological value of these green spaces (Figure 5). Relying too heavily on these non-native species can result in increased maintenance costs, reduced biodiversity, and potential risks to infrastructure. Research conducted in California has also shown that trees conflicting with hardscape not only impede the growth of healthy and productive trees, but also require significant financial resources for repair and damage mitigation, which otherwise be used to improve tree health (McPherson, 2000).

Conclusion

The composition of woody species in both parks and roadside green spaces in Addis Ababa displays significant variations. Parks exhibit a higher level of diversity, with more than 50% of the species being Native. In contrast, roadside green spaces have a lower diversity, with over 85% of the species being exotic. Moreover, urban parks commonly feature Olea europaea and Vachellia etbaica (Native), whereas Grevillea robusta and Acacia melanoxylon (exotic) dominate the roadside green spaces. These findings emphasize the importance of incorporating a considerable proportion of Native species in roadside green spaces to enhance the conservation of biodiversity in urban environments.

In urban recreational parks and roadside green spaces, there is a greater abundance of woody plants in the lower diameter at breast height (DBH) class, whereas the number of individuals in the higher DBH class is relatively low. While the presence of numerous individuals in the lower DBH class is beneficial for sustainable management, it is equally important to prioritize the conservation and upkeep of larger diameter class individuals.

The forty-twopotential heritage trees identified, consist 39Native species (which includes three endemic species) and 2 exotic species. These trees hold immense historical, environmental, ecological, and cultural importance. It is imperative to initiate the registration, documentation, and protection of these trees to mitigate the potential impacts of urban development.

Roadside plantations exhibit conflicts with both aboveground and belowground infrastructure, with mean values of 0.64 and 0.7, respectively. Among the trees planted along the roadside, G. robusta and A. melanoxylon showed the highest conflict with infrastructure. These findings underscore the significance of managing and mitigating conflicts between trees and infrastructure in roadside green spaces.

Effective urban planning and tree management strategies are essential to minimize these conflicts, ensuring the safety and functionality of both the trees and the surrounding infrastructure. Measures such as selecting appropriate tree species, conducting regular monitoring, and implementing proactive maintenance can help reduce the likelihood of conflicts and promote harmonious coexistence between urban trees and infrastructure.

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