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Plant Diversity and Carbon Stock Assessment in an Informal Settlement of the City of Yaounde, Cameroon: The Case of Elig-Effa West

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Abstract

Due to rapid demographic growth, economic and technological changes, urban environments are highly exposed to the impacts of climate change and environmental catastrophes. Despite the pressure to which urban forests are exposed, they still play important roles through the service they provide: air quality, shade, and reduction of dioxide of carbon. The present study was carried out in the city of Yaoundé, Cameroon, especially in one of its suburb areas, Elig-Effa West, a neighborhood with spontaneous settlements. The study aimed at assessing the plant species diversity, and carbon sequestration potentials of diverse trees recorded using indirect methods. Six sampling plots of 100 × 100 m were established in the study area. Our results recorded a total of 16 species grouped into 12 families. Apocynaceae, Mimosaceae and Moraceae were the most represented families. The most represented species throughout the sampling plots were *Mangifera indica*, *Persea americana*, *Annona muricata* and *Psidium gaujava,* which are all fruiting trees. Carbon stock for the study area was estimated at 16.08 ± 5.60 tC with an average of 0.23 ± 0.08 tC/ha. The results also showed the species to be considered in a potential restoration program should be first fruiting trees, followed by non-fruiting trees useful to population, especially those that have their trunk peeled, a sign that they are used by the population. Nevertheless, informal settlements contribute to carbon sequestration, that well targeted urban reforestation will substantially improve.

Keywords

Carbon Sequestration, Carbon Stocks, Floristic Inventory, Indirect Methods, Elig-Ffa West

1. Introduction

Urban environments are complex systems that are constantly changing and are particularly exposed to a variety of anthropogenic pressures, including rapid demographic growth, cultural, social, economic and technological changes (Tedone, 2017). These urban environments are also highly exposed to the impacts of climate change and environmental risks. Nowadays, they are home to a relatively high number of plant formations that are either planted or natural and which can be considered as urban forests (Kouadio et al., 2016). In fact, green spaces or urban forests are considered as suburban forests and are represented by urban parks, public or private gardens, vacant land space, street trees in urban districts, etc. (Polorigni et al., 2015, Gomgnimbou et al., 2019, Liu et al., 2021). They fulfill multiple ecosystem functions for townspeople that can be subdivided into 4 categories: climate regulation, engineering, architectural, and aesthetic benefits (Kao, 1989; McPherson et al., 2017). For the above reasons, urban environments through urban trees appear to be undoubtedly an essential factor that contributes to the development and implementation of climate policies, and should therefore be taken into consideration. Indeed, as stated by Zapfack et al. (2013), in agro-ecosystems, changes in land occupation or in agricultural practices can also promote soil carbon sequestration.

According to the United Nations data, 3% of the planet's surface is occupied by cities, and they consume about 75% of the Natural resources (FAO, 2020). Currently, more than 50% of the world's population lives in that urban environment and this proportion is expected to reach 70% by 2050 (United Nations, 2014). This leads to intense urbanization which will therefore induce negative effects on the functioning and quality of these ecosystems through the landscape alteration and the loss of a multitude of ecosystem services (support, provisioning and regulation) (Clergeau, 2012). Although environmental pressures are mainly associated with urbanized environments, solutions can also be found there. For example, carbon sequestration in urban areas is a factor that can better connect the urban population with nature and thus benefit from the adoption of eco-responsible societal behavior (Meas, 2016). Indeed, urban environmental conditions are influenced by urban forest which provides ecosystem services reflected in improved air quality, shade, microclimate, and reduced atmospheric pollutants, which contribute to human well-being and increased property values in urban environments (Escobedo & Chacala, 2008; Solomou et al., 2019). Therefore, urban planning processes should focus on cities' sustainability and present future needs of services, infrastructure, communication, and green spaces (Velasquez & Barroso, 2008; Anguluri & Narayanan, 2017).

For the last two decades, the area of the city of Yaoundé, the capital of Cameroon, has doubled (Minhdu, 2020), and this high level of urbanization has extended even to unbuildable areas such as flood plains, valley bottoms and slopes of over 15% (UN-Habitat, 2009). Urbanization has taken place at the expense of natural vegetation cover, leading to a high rate of deforestation, alteration of local and regional climate, loss of natural habitats and biodiversity, as well as degradation of water and air quality. To balance the urban deforestation, many of the world's major cities have implemented local, regional and global initiatives that promote tree-planting programs based on assumed environmental and social benefits of urban forests (McDonald et al., 2016). Unfortunately, most of these planting programs have failed because of a poor understanding of the urban forest and soil dynamics, choice of species to be planted and opinion of urban population, just to name a few.

In Yaoundé, as in most of Cameroon's urban areas, 67% of the population lives in informal settlements due to extreme poverty, and massive rural exodus, just to name a few. In these informal settlements where the land is completely or partially destroyed, priority is given to temporary or permanent housing and infrastructure to the detriment of areas used for green recreational spaces (Deronzier, 2017). Despite the expansion of urban areas, the observation is that there are town trees which are planted or not destroyed by urban population for decades.

Though relatively well documented with regard to its social benefits (Kiran & Kinnary, 2011; Liu et al., 2021; Bonilla-Duarte et al., 2021), the physical benefits of urban vegetation are still poorly supported by scientific evidence, especially in Africa. As a matter of fact, very little is known concerning the effectiveness of urban vegetation to store carbon and thus reduce greenhouse gas emissions or concentration of other pollutants in the atmosphere. Indeed, most of the studies carried out around the same topics were in the US, Europe and Asia (Gratani et al., 2016; Kiran & Kinnary, 2011; Liu et al., 2021; Bonilla-Duarte et al., 2021). The above observations led us to conduct this research in Yaoundé, in Elig-Effa quarter, which displays the morphology of most of the suburb areas in Africa. Besides, it was selected for this preliminary study, in order to gather results on the compensatory role of urban trees in the mitigation process of climate change in the city of Yaoundé, a study which could be reproduced in other cities. Thus, the present work aims to identify the trees that form the urban forest of Yaoundé in general and of Elig-Effa in particular, and to determine what is the carbon sequestration potential of this urban forest. Moreover, through their categorization (are they planted or are they natural trees voluntarily preserved by the populations?), it aims to identify priority species for a potential reforestation program.

2. Material and Methods

2.1. Study Area

Yaoundé, the political and administrative capital of Cameroon is located between latitudes 3˚ and 5˚ North and longitudes 11˚ and 12˚ East. It is made off by 7 districts. Elig-Effa West, the study area, is located in Yaoundé VI, bounded to the north by the Cité Verte quarter, to the south by Obili, to the east by Melen and the west by Mvog-Betsi (**Figure 1**). Its area is 68.9 ha. The climate of Elig-Effa is similar to that of the southern part of Cameroon in general and Yaoundé

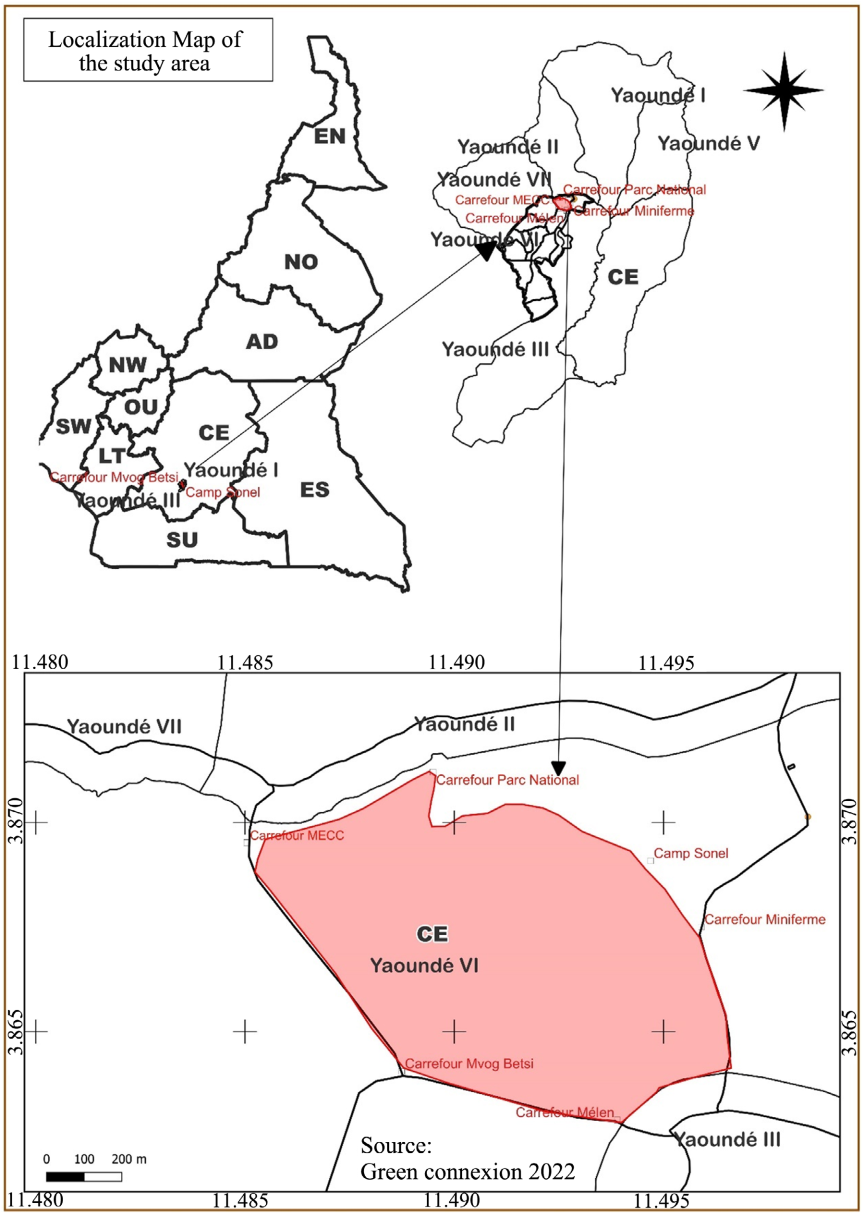

Figure 1. Location map of Elig-Effa district.

in particular. It is typically equatorial with four-seasons. The average annual rainfall is 1600 mm/year, with an average daily temperature of 24˚C and an evapotranspiration of 800 mm/year (Fouepe et al., 2011). Elig-Effa district lies on an ancient bedrock (Gneiss) with mostly hydromorphic and ferralitic soils. The hydrographic network is dense in this area and consists essentially of a small river called Ntougou which separates the Mvog-Ekoussou inhabitants of Mokolo from the Elig-Effa district. The population of Elig-Effa district is approximately estimated at 13,000 inhabitants of different tribes. The accelerated development of the city of Yaoundé has had an impact on the development of the flora, and this is shown by the total disappearance of the natural forest which opened the way to artificial forests made up essentially of few fruit trees such as mango trees, avocado trees, guava trees, papaya trees, etc.

2.2. Data Collection

2.2.1. Floristic Inventories

Floristic inventories were conducted using the quadrat method (plot) (Whittaker et al., 2001). Plots were chosen in such a way that there were evenly distributed over the entire study area. It has advantage to cross the majority of biotopes that might exist in the ecosystem. Data were collected in six sample plots of 10,000 m^2 each inside the surface area (**Figure 2**).

Along each plot, for each tree, was recorded, species name, height and diameter at breast height (DBH, 1.3 m above the ground). With regard to species which could not be identified in the field, a sample with a leaf, flower and fruit if possible was collected and pressed for further identification at the national herbarium, Yaoundé.

According to the following formula, we calculated the frequency ($F_{(x)}$) of each species expressed in percentage (%).

$$F_{(x)} = n/N \times 100 \quad (1)$$

where n = number of plots containing the species x, N is the number total of plot of the study area.

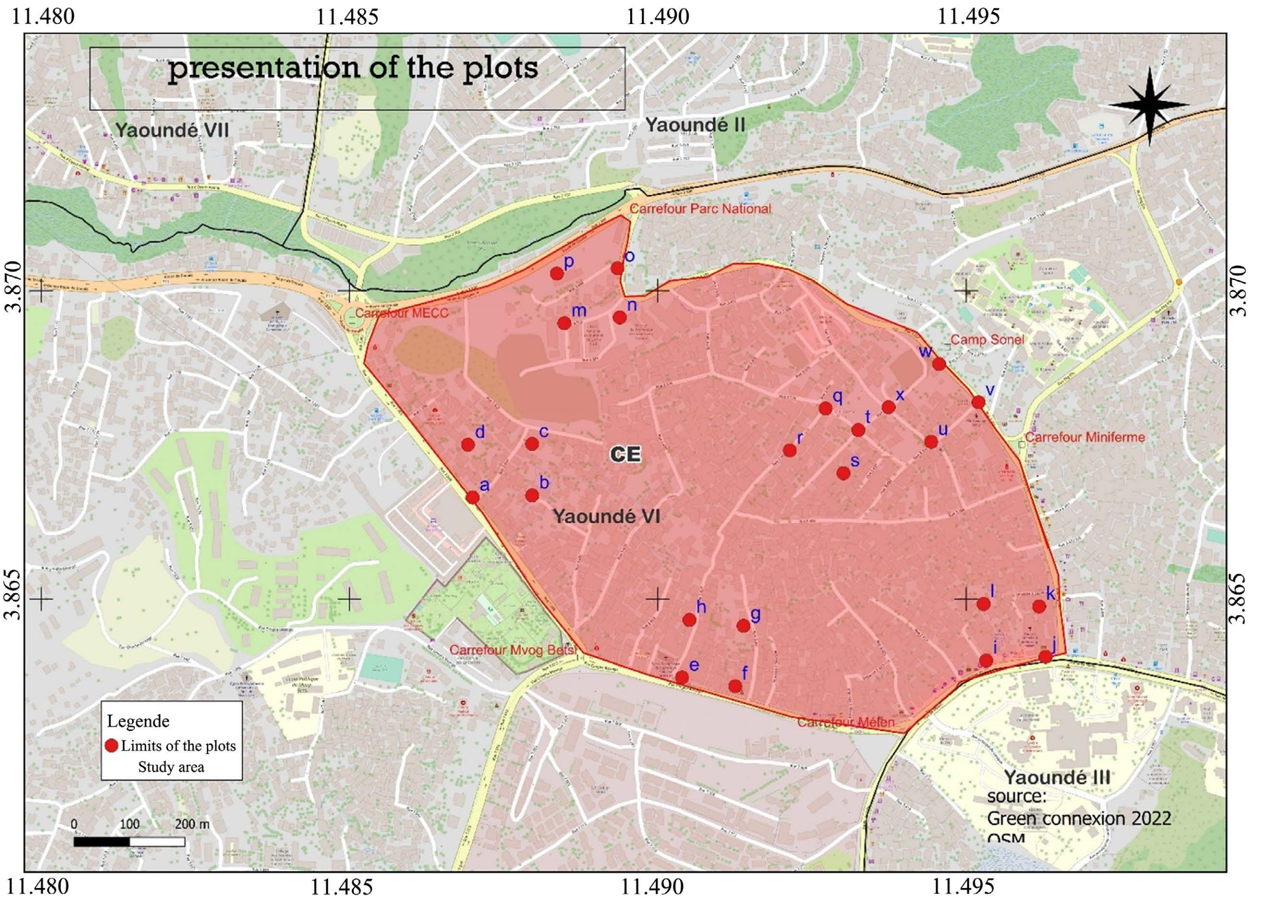

Figure 2. Location of each quadrat (plot) inside the study area.

2.2.2. Estimation of Carbon Storage per Species

The estimation of carbon stocks for each tree species per plot was based on the indirect method (Winrock International, 2005; Zapfack et al., 2013) as followed:

$$\text{Carbons stock}\left(\text{t C/ha}\right) = \text{Total Biomass}\left(\text{t}\right) \times 0.47 \tag{2}$$

The Total Biomass is the sum of above ground biomass and below ground biomass. All the values were converted into tons.

Above ground biomass (AGB) and below ground biomass (BGB) were estimated given the following formula:

$$\text{AGB}\left(\text{t}\right) = 0.0673 \times \left(\rho D^2 H\right)^{0.976} \tag{3}$$

With AGB in tons, ρ the tree specific density in g/cm^3, D the tree diameter at breast height (DBH) in cm and H the tree height in m (Chave et al., 2014). The species-specific densities (Zanne et al., 2009; Vivien & Faure, 2012) were used.

As for the BGB, the calculation of root biomass of standing trees was done according to the guidelines established by IPCC (2006). According to these guidelines, the root biomass equivalence of standing trees was obtained by multiplying the value of above ground-biomass (AGB) by a coefficient R whose value is estimated to be 0.24. R is the root/stem ratio.

$$\text{BGB}\left(\text{t}\right) = \text{AGB} \times R \tag{4}$$

2.2.3. Mean Carbon Stock of the Study Area

The mean carbon stock of the study area was calculated by multiplying the mean carbon stock of a plot (1 ha) by the surface area (69.8 ha) of the study site.

3. Results

3.1. Floristic Inventory

A total of 104 individuals' trees planted or maintained by the population were recorded in the study area, belonging to 12 families, 15 genera and 16 species with a diameter equal or greater than 10 cm (**Table 1**). *Mangifera indica* was recorded in all the six parcels, while *Persea americana* and *Psidium guayava* were recorded in 4. *Annona muricata*, *Dacryodes edulis* and *Terminalia mantaly* were recorded in three parcels. As for the other species, they were only recorded in one parcel. *Mangifera indica* was the species with the highest number of individuals (34), followed by *Persea americana* (16), *Anona muricata* (13) and *Psidium guayava* (11). Only one individual was recorded for the species *Albizia zygia*, *Distemonanthus benthamianus*, *Dracaena arborea*, *Ficus* sp. and *Thevetia neriifolia*. The most represented families were the Apocynaceae with three species followed by the Mimosaceae, and the Moraceae with respectively two species, the other families having only one species (**Figure 3**).

These results showed the presence of 6 species of fruits trees (37.5% of all species), 2 species of forest trees ((12.25%), one species of ornamental tree (6.25%), and others (43.75%).

Concerning the frequency of each species, *Mangifera indica* displayed the higher frequency (100%), followed by *Persea americana*, *Psidium gaujava* with each 66.67%, and *Annonia muricata*, *Dacryodes edulis* and *Terminalia mantaly* which displayed each a frequency of 50%. With exception of *Vocanaga Africana* which had a frequency of 33.33%, the rest of species had a frequency of 16.67% (Table 2).

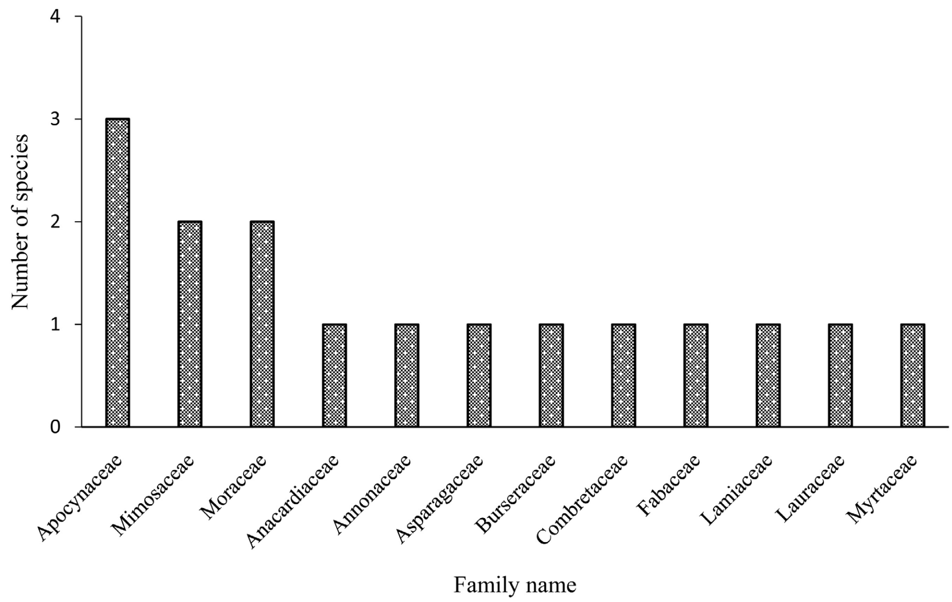

Figure 3. Plant families representativity of the study area.

Table 1. Summary table of the floristic inventory.

Genera and Species	Family	Total number of individuals	Parcels	Common name	Language
Albizia zygia	Mimosaceae	1	1	Saliémo	Ewondo
Alstonia boonei	Apocynaceae	3	3	Ekuk	Ewondo
Annona muricata	Annonaceae	13	3, 4, 5	ebom	Ewondo
Dacryodes edulis	Burseraceae	8	1, 3, 5	assa	Bassa, *Ewond*, Eton
Distemonanthus benthamianus	Fabaceae	1	1	atui	Ewondo
Dracaena arborea	Asparagaceae	1	5	Leloup	Yemba
Ficus exasperata	Moraceae	2	3	Akol	Ewondo
Ficus sp.	Moraceae	1	1	ndong	Baya
Mangifera indica	Anacardiaceae	34	1, 2, 3, 4, 5, 6	Afele	Ewondo
Mimosa sp.	Mimosaceae	3	2		
Persea americana	Lauraceae	16	1, 2, 4, 5	Mfio	Ewondo
Psidium guajava	Myrtaceae	11	1, 2, 4, 5	Afele	Ewondo
Terminalia mantaly	Combretaceae	5	1, 2, 4	Arbres à étages	Française
Thevetia neriifolia	Apocynaceae	1	1	Laurier jaune	Française
Vitex doniana	Lamiaceae	2	1	galbiki	foulfouldé
Voacanga africana	Apocynaceae	2	1, 3	obatoan	Ewondo

Table 2. Summary table of the frequency of each specie recorded at Elig-Effa.

Species	Frequency (%)
Mangifera indica	100
Persea americana	66.67
Psidium guajava	66.67
Annona muricata	50
Dacryodes edulis	50
Terminalia mantaly	50
Voacanga Africana	33.33
Albizia zygia	16.67
Alstonia boonei	16.67
Distemonanthus benthamianus	16.67
Dracaena arborea	16.67
Ficus exasperate	16.67
Ficus sp.	16.67
Mimosa sp.	16.67
Thevetia nerifolia	16.67
Vitex doniana	16.67

3.2. Carbon Stocks Per Species and Per Plot

The most important biomass was recorded for *Distemonanthus bentamianus*, *Vitex doniana*, *Mangifera indica*, *Ficus exasperate* and *Dracaena arborea* (**Table 3**). Therefore, the most important carbon stock was recorded in the same species, with *Thevetia nerifolia* having the lower carbon stock (0.0092 tC/ha). The lower biomass was still recorded for *Thevetia nerifolia* (0.019 t).

3.3. Overall Amount of Carbon in Elig-Effa

Based on the calculation of the carbon stock per plot, the overall amount of carbon stock in Elig-Effa which has a surface area of 68.9 ha, was recorded to be 16.0811 ± 5.5992 tC for an average of 0.2334 ± 0.0813 tC/ha.

3.4. Choice of Species to Consider in Restoration Planning

Regarding the results gathered during the study, the choices of species to be used in the restoration programme were made upon 2 criteria. First, the species with the higher frequency of apparition, and second, species with higher carbon stock. Therefore, based on these criteria, three categories of plants species were determined: Fruiting trees with *Mangifera indica*, *Persea americana*, *Psidium guajava* and *Dacryodes edulis*. Forest species which include *Distemonanthus benthamianus* and *Alstonia boonei* and the last category which are neither forest

Table 3. Amount of total biomass (t/ha) and Carbon stock (tC/ha) per species.

Species	Total Biomass (t/ha)	Carbon stocks (C/ha)
Distemonanthus benthamianus	1.5621	0.7341
Vitex doniana	0.9994 ± 0.7140	0.4697 ± 0.3356
Mangifera indica	0.7672 ± 0.1466	0.3606 ± 0.0689
Ficus sp.	0.6442	0.3028
Dracaena arborea	0.5123	0.2408
Terminalia mantaly	0.4857 ± 0.1966	0.2283 ± 0.0924
Albizia zygia	0.3078	0.1447
Persea americana	0.2429 ± 0.0719	0.1142 ± 0.03379
Dacryodes edulis	0.1983 ± 0.0851	0.0932 ± 0.040016
Psidium guajava	0.0884 ± 0.0213	0.0416 ± 0.0101
Alstonia boonei	0.0808 ± 0.0010	0.0380 ± 0.0047
Annona muricata	0.0686 ± 0.0167	0.0322 ± 0.0078
Voacanga africana	0.0488 ± 0.0006	0.0231 ± 0.0005
Ficus exasperata	0.0337 ± 0.0137	0.0158 ± 0.0064
Mimosa sp.	0.0329 ± 0.0113	0.0155 ± 0.0053
Thevetia neriifolia	0.0197	0.0092

nor fruiting trees which include *Vitex doniana*, *Dracaena arborea* and *Terminalia mantaly* among others.

4. Discussion

4.1. Floristic Inventory

This research aimed to inventory and assess the carbon storage of urban trees in Elig-Effa West, Yaoundé-Cameroon. Investigation of the floristic inventory of the study area revealed 104 individuals divided into 12 families, 15 genera and 16 species. These species belong to fruits trees, forest-trees, ornamental and other trees. These results showed that the study area is sparsely wooded compared to the results obtained by Um (2020) who obtained 236 individuals divided into 23 families, 35 genera and 35 species on a 1.5 km stretch in the Mefou river banks. This low number of individuals can be explained by man-made and natural stresses urban environments trees faced that may lead to degradation of urban forest and therefore reduce their life spans compared to trees in rural areas or natural stands (Schneiders et al., 2012; Kiran & Kinnary, 2011). Moreover, among the most important factors of stress that can be listed, air pollution occupies the first rank and has a negative impact on tree health. The impact on health is noticed by the reduction of plant growth which depends on the plant species, but also on the concentration and distribution of pollutants coupled to a number of environmental factors (Kiran & Kinnary, 2011). The small number of family recorded during this study can be explained by the poor species diversity. This study is somehow similar to the study carried out by Nguekeng et al. (2018) who worked in cocoa agroforestry plantations and discovered despite the high number of individuals recorded, that the species belong only to 16 families. The most abundant species found in the study area were: *Mangifera indica* (34 individuals), *Persea americana* (16 individuals), *Annona muricata* (13 individuals), *Psidium gaujava* (12 individuals) and *Dacryodes edulis* (8 individuals) which are all non-forest species. These observations leaded to the conclusion that the presence or absence of a forest species in Elig-Effa west depends on the will of the urban resident, who chooses which trees to plant or to keep according to their direct interest. It was found that almost all the trunk of trees species recorded were peeled, proof that these plants have socio-economic impacts. Indeed, according to the literature explored and the says of residents we encountered during fieldworks; these species are useful in the traditional pharmacopeia. This was the case for most of the fruit trees recorded (*Mangifera indica*, *Dacryodes edulis*, *Persea americana*, *Annona muricata*, *Psidium gaujava*) and shade trees (*Terminalia mantaly*, etc.). The high number of fruits trees was also observed by Nguekeng et al. (2018) who recorded with exception to cocoa trees, 53 fruiting species during their study which represented 23% of the total number of individuals. This observation can be justified by the choice of species which are introduced by the riparian population at the moment of selection.

The species richness of each plot varied from 1 to 11 species and the number of plants counted varied from 5 to 28 per hectare. Low species richness is noted in plot 6, where only one plant species was recorded. The high species richness of some plots can be explained by the ecological conditions which favor the regeneration of the species present, whereas the low species richness is explained by the fact that the dead trees encountered inside the plot were not counted.

4.2. Calculation of the Specific and Global Carbon Potential of the Inventoried Trees

According to the results obtained from the calculation using the method by Chave et al. (2014), the most represented diameter classes in terms of number of individuals were those that sequester the maximum carbon stock. However, it is important to note that when looking at the carbon stock per species, species with the highest diameter classes stored the most abundant carbon (case of *Distemonanthus benthamianus* which has a diameter of 57.33 Cm, had 0.7341 tC/ha). Based on the diameter classes, the values obtained during this study were similar from those of Bossiomo (2018) in the Mbalmayo forest Reserve who observed that the trees of diameter of [50]-[60] were those which sequester the most important carbon.

The average carbon stock assessed in Elig Effa was 0.23 tC/ha. This value was far below that of Bossiomo (2018) who worked in the Mbalmayo forest Reserve and Gomgnimbou et al. (2019) who worked in Burkina Faso especially in the

Ka-Ya-Wooto scrubland. The carbon stock recorded in these two studies were respectively 64.74 teqCO_2/ha (equivalent to 17.64 tC/ha) and 356.98 tC/ha. These differences in carbon stocks are probably due to the different equation used for estimating biomass, to the type of climate encountered in the different areas, but also to the health and quantity of trees recorded in each of the studied area. Indeed, according to Amougou et al. (2016), carbon stocks depend on several parameters, including the quality and quantity of trees. Similarly, the high contribution of large-diameter trees to total biomass stocks was demonstrated by other studies (Joosten et al., 2004; Mbow, 2009).

Compared to the estimated value of carbon stocks sequestered by a tropical forest, which, according to the FAO is 163.1 tC/ha, and of 50 to 175 tC/ha according to Nasi et al. (2008), the value recorded during our study is from far much lower. This can be explained by the abundance of trees of large diameter and height in a forest, which is not the case for city trees that are subject to many constraints such as the cutting of trees for urbanization purposes, the exploitation of bark for medicinal purposes, but also pruning to reduce roof destruction, and accidents. The high carbon stock in forest trees can also be explained by humid climate which slow down the mineralization rate of organic matter constituting the important carbon stock of soil (FAO, 2012). Meanwhile, urban environments are characterized by high temperatures, and according to Arrouays et al. (2002), the increase in temperature leads to a destocking of soil carbon. Similarly, Fissore et al. (2008) stated that high temperature induced a high activity of microorganisms, leading to an oxidation of organic matter which affects the CO_2 in the atmosphere.

The low total carbon stock of 16.08 tC recorded in the overall surface area covered by Elig-Effa (68.9 ha) can also be explained by the human occupation of urban spaces. However, despite being a small quantity, this value is still of major importance for the balance of the urban ecosystem. Indeed, this quantity of sequestered carbon contributes significantly to the decrease of greenhouse effect.

5. Conclusion

Cities are the major source of CO_2 emissions, and urban forests can play a significant role in helping to reduce atmospheric carbon levels. Therefore, existing urban trees should be maintained, conserve and promote, although they have been consciously planted by public agents or private citizens. Because no concrete method currently exists that can directly evaluate the CO_2 uptake by urban greenery, all approaches described herein rely on indirect estimates and are prone to uncertainties. However, as demonstrated by this study, urban trees found in Elig-Effa contribute to sequestering CO_2 and mitigating the effects of carbon emitted from automobiles and surrounding industries. The values given in this paper are based on limited field data, so, more field data are needed in urban areas to help improve carbon calculation. Therefore, the results of this study constitute a basis for carbon sequestration studies in an informal settlement and contribute to the development of reference emission scenarios for ecosystems similar to those in the Elig-Effa west informal settlement.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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