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Conservation value and carbon sequestration potential of urban green spaces in a growing city: Case of the city of Bouaflé

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Abstract

Faced with the effects of climate change, green spaces are very determining in the provision of ecosystem services, particularly in carbon sequestration. This is why, from a perspective of sustainable management of these high-value spaces, this study was carried out. Surface and itinerant survey methods were combined to collect floristic data. At the end of the inventories, 99 species distributed between 33 families and 75 genera including 24 species with special status were recorded in eight (08) types of development. The total biomass of all the species inventoried at Bouaflé is 4385.78 t, corresponding to a carbon rate of 2192.91 t for a CO_2 equivalent of 8047.99 t. The economic value of the rate of CO_2 sequestered by all types of development varies from 24143.97 Euros, or 15814274 FCFA according to the CDM carbon price to 112671.86 Euros, or 73800068 FCFA according to the REDD+ carbon price. Social and educational establishments recorded the highest biomass (1841.88 t) while the lowest biomass (5.53 t) was estimated in sports equipment. The average biomass estimated in all types of development is of the order of 232.02±185.64 t/ha, which corresponds to a carbon rate of 116.01±92.82 t/ha and an equivalent CO_2 of 425.76±340.65 t/ha. Considering each type of development, the average value of biomass varies between 24.83 t/ha in sports facilities and 468.79 t/ha in cemeteries.

Keywords: Carbon Sequestration; Urban Green Space; Bouaflé; Côte d'Ivoire

1. Introduction

Urban vegetation as a whole offers many benefits that are as varied as they are useful, called ecosystem services (Millenium Ecosystem Assessment, 2005). These ecosystem services include the reduction of atmospheric pollutants (Nowak et al., 2006), the reduction of heat islands (Akbari et al., 2001), the supply of resources, the reduction of carbon dioxide levels by the phenomenon of carbon sequestration (Vroh et al., 2014). These different ecosystem services thus guarantee a viable and sustainable living environment in the city. Unfortunately, urban vegetation is subject to various pressures due to galloping demographics, high demand for land, the extension or construction of infrastructures and poor knowledge of the ecosystem services they offer. This situation, which is detrimental to the well-being of city dwellers, is observed in Ivory Coast and particularly in the town of Bouaflé. Indeed, the integrity of the green spaces of the town of Bouaflé is threatened by pressures due to numerous human activities. Furthermore, environmental issues do not occupy a priority place in the political and strategic decisions of the municipality. This situation, which only accentuates the phenomenon of atmospheric pollution, deserves to be addressed diligently through mitigation means and strategies that can contribute to the sequestration of greenhouse gases by developed green spaces. It is for this purpose that the present study was carried out in order to reduce anthropogenic pressures on urban green spaces and to resolve air pollution problems through environmental awareness. More specifically, on the one hand it was a question

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of evaluating the diversity of woody tree species of the types of development in the town of Bouaflé, and on the other hand of estimating the total biomass in order to deduce the quantity of carbon sequestered by these trees.

2. Materials and methods

2.1. Study site

The study was conducted in the town of Bouaflé located between longitudes 5°45-5°47 West and latitudes 6°57-7°00 North (Figure 1). The capital of the Marahoué region, the town of Bouaflé extends over an area of 605 ha and has around twenty neighborhoods with housing typologies varying from residential to precarious, including evolving (Kouassi et al., 2019). The climate of the Bouaflé region corresponds to the attenuated equatorial transition regime (Baoulean climate). The average monthly rainfall amounts vary between 4.27 mm for the month of January and 157.36 mm for the month of April with an average monthly temperature of 28.34. The commune of Bouaflé has a very dense hydrography, mainly made up of the Marahoué river which favors the presence of numerous rivers, natural lakes and marshy areas. Transition zone, the vegetation of the Bouaflé zone essentially belongs to the mesophilic forest zone overall, with natural formations consisting of dense semi-deciduous humid forests, dry forests; forest/savannah contact zone, interspersed with gallery forests, and open savannahs (Yedmel et al., 2010). Its geographical location as a meeting point between the peoples of the savannah and the forest and its enormous economic, social and cultural potential have strongly contributed to a densification of the city's buildings and its rapid expansion.

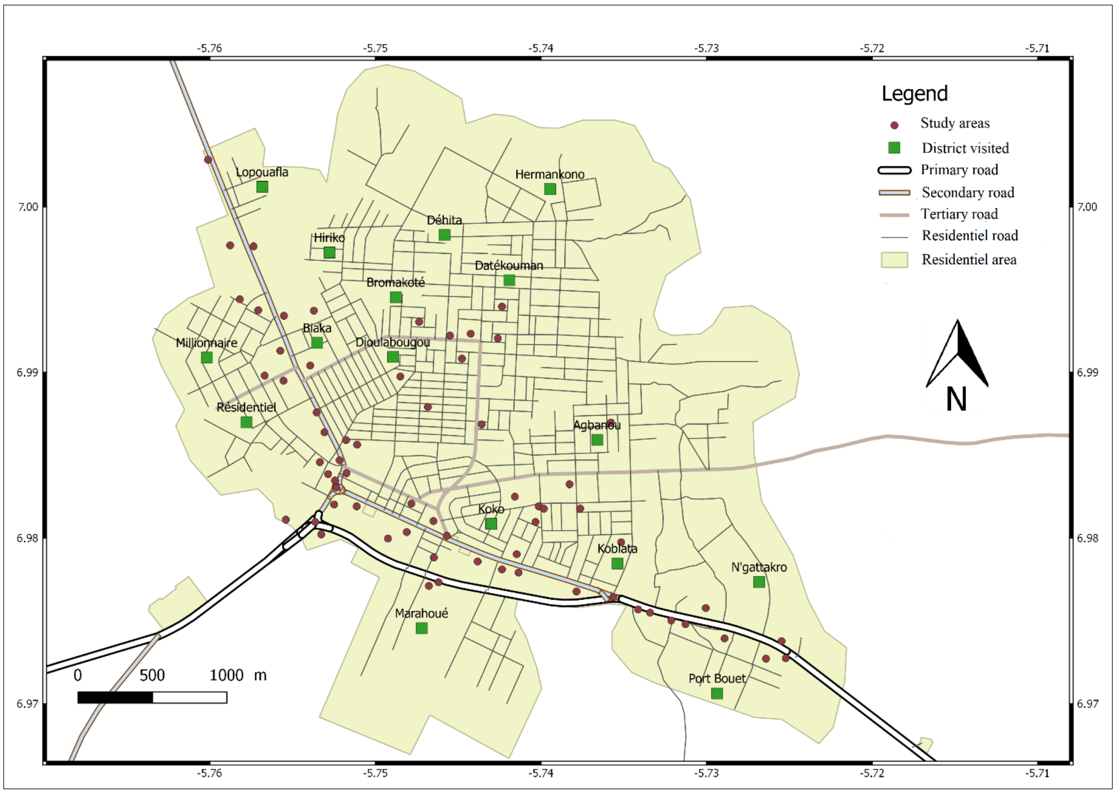

Figure 1 Location of study sites in the town of Bouaflé

2.2. Collection of floristic data

The evaluation of the ecosystem services provided by the types of forest development in the town of Bouaflé was first based on floristic inventories in all types of development. To this end, two complementary survey techniques, namely the surface survey and the roving survey, were combined in order to compensate for the limitations of each method applied individually. Regarding the surface survey method, plots of 400 m^2 (20 m x 20 m) were demarcated in all types of forest development in the city. Inside each plot, individuals of woody species more than 10 cm in diameter and at least 2 m in height were measured. For homes, floristic inventories were carried out within 30 consecutive lots located on either side of the street. The surface area of each lot visited varied between 450 and 600 m^2. As for the itinerant survey method, it was carried out between the plots and only concerned species not encountered in the plots (Aké-Assi, 1984). Newly observed species were noted and samples collected to complete the final floristic list. Palm trees, coconut trees and palm trees have also been recorded. The identification of the inventoried species was made on site. However, samples of species not identified in the field were taken, made into a herbarium and identified thanks to the support of the National Floristic Center (CNF) of Côte d'Ivoire. The dichotomous key proposed by Hawthorne (1996) served as a guide to taxa identification.

2.3. Analysis and processing of floristic data

2.3.1. Floristic wealth

The work of Aké-Assi (2002) and Raunkaier (1934) served as a basis for establishing the number of species, genera and families, as well as the morphological and chorological types for each type of development.

2.3.2. Species with special status

Several elements are taken into account in determining the conservation value. In the present study, the value for the conservation of urban green spaces was determined through the presence of species with special status: endemic, rare and endangered species of flora (Aké-Assi, 2002; UICN, 2020).

2.3.3. Estimation of total biomass

The estimation of total biomass was based on above-ground and below-ground components. Aboveground biomass was estimated from general allometric equations for urban trees (Aguaron & McPherson, 2012) according to the following mathematical formulas :

$$\mathbf{AGB\ (trees) = 0{,}16155 \times DBH^{2{,}310647}}$$

$$\mathbf{AGB\ (oil\ palm, coconut) = 1{,}282 \times (7{,}7\ H + 4{,}5)}$$

The underground or root biomass (BGB: Below Ground Biomass) was estimated by multiplying the value of the aboveground biomass (AGB) by an R coefficient whose value is estimated at 0.24 (GIEC, 2006). Thus, the total biomass is obtained by adding the aboveground and root biomasses.

2.3.4. Determination of average biomass

The average biomass is obtained by dividing the total biomass by the total surface area occupied by the plots inventoried in each type of forest management according to the mathematical formula :

$$\mathbf{Biom\ (moy) = Biom\ (t) / S}$$

2.3.5. Estimation of sequestered carbon stock and CO_2 rate (t C/ha)

The carbon stock sequestered by plant species is estimated from the total biomass and is obtained by applying a conversion factor noted CF to the total biomass (Brown & Lugo, 1992). The CF conversion factor is 0.5. Formula is :

$$\mathbf{C\ (t/ha) = Biom\ (t) \times CF}$$

The mass of carbon dioxide (CO_2) sequestered is obtained by multiplying the mass of carbon by the ratio of the molar masses of carbon denoted M (C) and those of CO_2 denoted M (CO_2) whose value is 44/ 12 or 3.67 according to the following formula :

$$\mathbf{m\ (CO_2) = C\ (t/ha) \times 3{,}67}$$

In this formula, m (CO_2) is the mass of carbon dioxide (CO_2) and C (t C/ha) is the carbon equivalent in tonnes per hectare.

2.3.6. Economic value in carbon stock of types of forest management

The financial cost of the carbon content of each type of development in the town of Bouaflé was estimated from the Clean Development Mechanism (CDM) markets, voluntary markets and the Reduction of Emissions due to Deforestation and Forest Degradation (REDD+). The average sale price of forest credit is €3/tonne of CO_2 for the CDM, €4.7/tonne of CO_2 for voluntary markets (Chenost et al., 2010) and €14/tonne of carbon (value low) or 100 €/tonne of carbon (high value) for REDD+ (Boulier & Simon, 2010).

3. Results

The woody flora of the types of development in the town of Bouaflé is rich in 99 species divided into 33 families and 75 genera. In the green spaces accompanying pathways, there is no species more than 10 cm in diameter and more than 2 m in height. At the end of the inventories, 24 species have a special status including two endemic to the Ivorian flora, four endemic to the West African forest block and five endemic to Upper Guinea were recorded (Table 1). Fourteen (14) species listed on the IUCN red list (2020) and two species are present on the list of rare species according to Aké-Assi (Table 1).

Table 1 Species with special status encountered in the types of forest management in the town of Bouaflé

Especies	Level of endmism	UICN status (2020)	Aké Assi (2001, 2002)	HG
Acroceras zizanioides	-	LC	-	-
Albizia adianthifolia	-	LC	-	-
Anthocleista nobilis	-	-	-	1
Baphia bancoensis	GCi	-	-	-
Baphia nitida	-	LC	-	-
Cnestis racemosa	-	-	-	1
Commelina benghalensis	-	LC	-	-
Cyperus rotundus	-	LC	-	-
Desmodium adscendens	-	LC	-	-
Desmodium salicifolium	-	LC	-	-
Ficus platyphylla	-	-	-	1
Leptoderris miegei	GCi	-	-	-
Leptoderris miegei	-	-	-	1
Mariscus flabelliformis	GCW	-	-	-
Milicia excelsa	-	LR/nt	R	-
Milicia regia	GCW	VU	R	1
Nauclea diderrichii	-	VU	-	-
Panicum repens	-	LC	-	-
Paspalum scrobiculatum	-	LC	-	-
Solenostemon monostachyus	GCW	-	-	-
Terminalia ivorensis	-	VU	-	-
Tetracera affinis	GCW	-	-	1
Vitellaria paradoxa	-	VU	-	-

GCI: endemic to the Ivorian flora; GCW: West African forest block; HG: endemic to Upper Guinea, LR/nt: Low risk of extinction; LC: minor concern; VU = vulnerable; IUCN = International Union for Conservation of Nature; A: rare species or species that have become rare and threatened with extinction of the Ivorian flora according to Aké Assi (2001, 2002).

Total biomass of all the species inventoried at Bouaflé is 4385.78 t, corresponding to a carbon rate of 2192.91 t for a CO_2 equivalent of 8047.99 t. The economic value of the rate of CO_2 sequestered by all types of development varies from 24143.97 Euros, or 15814274 FCFA according to the CDM carbon price to 112671.86 Euros, or 73800068 FCFA according to the REDD+ carbon price (Table 2). Social and educational establishments recorded the highest biomass (1841.88 t) while the lowest biomass (5.53 t) was estimated in sports equipment. The highest values of sequestered carbon rate and CO_2 equivalent were also recorded in social and educational establishments (Table 2). The average biomass estimated in all types of development is of the order of 232.02±185.64 t/ha, which corresponds to a carbon rate of 116.01±92.82 t/ha and an equivalent CO_2 of 425.76±340.65 t/ha. Considering each type of development, the average value of biomass varies between 24.83 t/ha in sports facilities and 468.79 t/ha in cemeteries (Table 3). The comparison of the average biomasses using the Kruskal-Wallis test showed that the compared means are not statistically different (x^2 = 71; p = 0.48).

Table 2 Values of total biomass, carbon rate and economic value of carbon stock sequestered by types of development in the town of Bouaflé

Types of development	Biomass (t)	C (t)	CO_2 (t)	Carbon price MDP (€)	Carbon price of voluntary market (€)	Carbon price of REDD+ (€)
PUB BUL	1164,1	582,05	2136,12	6408,36	10039,76	29905,68
SOC & EDU	1841,88	920,94	3379,85	10139,55	15885,30	47317,90
IND & COM	139,05	69,53	255,18	765,54	1199,35	3572,52
CEM	427,24	213,62	783,99	2351,97	3684,75	10975,86
SPO EQU	5,53	2,77	10,17	30,51	47,80	142,38
PUB GAR	53,11	26,56	97,48	292,44	458,16	1364,72
DWE	754,87	377,44	1385,2	4155,60	6510,44	19392,80
TOTAL	4385,78	2192,91	8047,99	24143,97	37825,55	112671,86

PUB BUL : Public buildings accompaniment ; SOC & EDU : green spaces of social and educational establishments ; IND & COM : industrial and commercial establishments accompaniment ; CEM : Cemeteries; SPO EQU : Sports equipment ; PUB GAR : Public garden ; DWE : Accompaniment for dwellings;

Table 3 Average biomass values estimated in each type of development in the town of Bouaflé

Types of development	Average biomass (t/ha)	Average sequestred carbone (t/ha)	Average CO_2 equivalent (t/ha)	Kruskal-Wallis test statistic
PUB BUL	226,62±214,61 [a]	113,31±107,31 [a]	415,85±393,81 [a]	
SOC & EDU	297,79±208,64 [a]	148,9±104,32 [a]	546,46±382,87 [a]	
IND & COM	125,69±96,44 [a]	62,85±48,22 [a]	230,66±176,98 [a]	x^2 = 71 ;
CEM	468,79±274,98 [a]	234,4±137,49 [a]	860,25±504,60 [a]	p = 0,48
SPO EQU	24,83±10,36 [a]	12,42±5,18 [a]	45,58±19,02 [a]	
PUB GAR	454,64±309,76 [a]	227,32±154,88 [a]	834,26±568,41 [a]	
DWE	25,71±11,9 [a]	12,86±5,95 [a]	47,20±21,85 [a]	
TOTAL MOYENNE	232,02±185,64	116,01±92,82	425,76±340,65	

Numbers with the same superscript letter in the same column are not statistically different at the 5% threshold; PUB BUL : Public buildings accompaniment ; SOC & EDU : green spaces of social and educational establishments ; IND & COM : industrial and commercial establishments accompaniment ; CEM : Cemeteries; SPO EQU : Sports equipment ; PUB GAR : Public garden ; DWE : Accompaniment for dwellings;

4. Discussion

The presence of species with special status in the urban flora of Bouaflé clearly confirms the role of conservation of plant diversity that urban green spaces can play, if they benefit from special protection. Unfortunately, the numerous anthropogenic activities that take place in cities do not favor the survival of these species which seek a particular microclimate for their development (Sangne et al., 2008). This is why, according to Myers et al. (2000), this type of species deserves special attention for conservation.

The rate of CO_2 sequestered by all types of development is 8047.99 tonnes for a financial value varying from 24143.97 Euros (15814274 FCFA) to 112671.86 Euros (73800068 FCFA). The carbon storage potential of trees in different types of development reflects the role of these trees in reducing heat islands and, in turn, in climate regulation. One of the main functions of forests being the fixation and sequestration of atmospheric carbon through photosynthesis, forests represent important carbon sinks on a global scale (Mangion, 2010). Compared to other mechanisms for mitigating the harmful effects of climate change, the mitigation potential of the forest is the best opportunity to exploit at a lower cost. For Côte d'Ivoire, according to 2010 data reported by the World Bank on greenhouse gas emissions, each inhabitant emits around 300 kg of CO_2, hence the importance of diversifying, enriching or to reforest green spaces (Vroh et al., 2014). Today, with the numerous problems of health, food security and climate change, caused by pollution and technological disasters, the environment and biodiversity constitute the only known environment, necessary for the existence of men, to provide for to their natural needs (Dupouey et al., 2004). The importance of the types of development is also revealed by their impressive economic values. The economic value of green spaces is a crucial factor that could encourage populations to protect green spaces in urban areas. The benefits linked to the presence of plants in the urban environment far exceed the costs incurred for their creation. Thus, the services provided by the forest ecosystem in urban areas can contribute to economic development and the well-being of populations.

The differences in biomass and carbon stock recorded in the types of development in each city could be explained by the distribution of the basal area and density of trees in each type of development. Indeed, the parameters determining the quantity of biomass are DBH and height (Laporte et al., 2010). The larger and taller a tree is, the higher its biomass. The highest average biomass values recorded in the cemeteries therefore demonstrate the presence of a high number of individuals with large diameters and large sizes. These results confirm the theory of Thompson et al. (2004) according to which: the more the tree grows, the more it sequesters carbon and it is therefore considered a carbon sink. This could also be due to good diversity and, above all, to the presence of fast-growing species with high carbon storage capacity (Bakayoko et al., 2012). The quantity of carbon sequestered can also be due to the density of trees which is another determining parameter of the biomass and the rate of carbon sequestered. These results corroborate those of McPherson (1998) and Nowak & Crane (2001) who maintain that the parameters which determine carbon capture are the density of the tree and its diameter at maturity.

5. Conclusion

The study carried out on the green spaces of the town of Bouaflé indicates that the tree heritage includes 99 species. It is a heritage that shelters a large number of species, including species with special status. Despite the low number of species recorded, it is clear that there is a strong potential for carbon storage. Through this carbon storage potential, the study highlighted the role played by these green spaces in improving the quality of the urban environment. This is why maintaining and strengthening these green spaces must be a priority in the urban development plan.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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