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Potential of biological invasion for carbon sequestration in a protected area: the case of the *Limbe Botanic Garden* (LBG) forest, Cameroon

Abstract

The Limbe Botanical Garden (LBG) is a relict urban forest located in the heart of the city of Limbe. This forest has many ecological, economic, social and tourist functions and is the green lung of the city of Limbé. Unfortunately, this forest has always been threatened by various anthropic pressures and more recently by invasive exotic species. These threats make us fear the progressive disappearance of this massif, which would be a threat to the plant and animal populations, the riparian communities and the ecosystem services such as carbon regulation. The general objective of our study is to assess the validity of the hypothesis of increased carbon sequestration of invasive species compared to native species. For the floristic inventory, twenty 100 m^2 (10 m x 10 m) plots were set up in this LBG urban forest. We recorded information such as the number of adult and juvenile individuals and the diameter of trees greater than or equal to 10 cm. The inventory recorded 349 plant species. The most frequent species is *Cyathea camerooniana* with 92.3% presence. *Cedrela odorata* has a frequency of occurrence of 76.9% in this urban forest and a frequency of 60% in the LBG. This taxon has a very high above-ground biomass (187.4 tC/ha) and therefore the highest carbon storage capacity (93.7 tC/ha). It is followed by *Diospyros crassifolia* and *Dialium pachyphyllum*, both native species. *Cedrela odorata* has a positive impact on carbon sequestration and therefore contributes to the well-being of the people. However, the conclusion needs to be qualified because invasive species can influence the functioning of forests in the long term.

Keywords: invasive tree, above-ground biomass, floristic diversity, invasive species, urban forest, *Cedrela odorata*

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Tchinmegni Felenou I,[1] Djeukam Pougoum Stelle Vartant[1,2]

[1]Higher Institute of Environmental Sciences (HIES), Yaoundé P.O Box: 16 317, Cameroon
[2]FOKABS, Yaoundé P.O. Box: 181, Cameroon

Correspondence: Tchinmegni Felenou I, Higher Institute of Environmental Sciences (HIES), Yaoundé P.O Box: 16 317, Cameroon, Tel +224 627407580, Email felenou@gmail.com

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Introduction

The problem of biodiversity management in Africa can be summed up as reconciling, on the one hand, the socio-economic development needs of societies and, on the other, the need to preserve biological diversity. Cameroon, by aligning itself with the international community, has adopted, among other solutions, the creation of protected areas which, according to Wolf et al.,[1] must subscribe to the primary objective of protecting biodiversity against the extinction of species or threats to ecosystems. The creation of national parks and reserves, classified forests, but also herbariums and botanical gardens are among the priorities for the protection of Cameroon's forests. Despite these current policies for the conservation of flora in Cameroon, weaknesses still exist, when it is estimated that the current loss of these ecosystems is caused by their abusive exploitation.[2] Ex-situ conservation, although not an alternative, can be a plus for this policy of sustainable biodiversity management. This refers to techniques for conserving plants or animals outside their original habitat, generally through the collection and storage of genetic material in a seed bank, herbaria or in zoological or botanical gardens. In botanical gardens, plants are cultivated and studied generally to meet four main objectives: conservation, scientific research, education, teaching and tourism.[3] These gardens are also another solution advocated as carbon sinks, through afforestation or reforestation projects.[4] They can thus be considered as one of the main strategies to stabilise the concentration of the main greenhouse gases in the atmosphere.[5] Several botanical gardens were created in Cameroon, among which the best known and oldest is the Limbe Botanical Garden (LBG). This botanical garden is a relict urban forest located in the heart of the city of Limbé. Today it has become a dense humid forest on poor clay soil of the terminal continental. This forest has many ecological, economic and social functions. In particular, it shelters a good part of the water table that supplies the city with drinking water. Unfortunately, this forest has always been threatened by various anthropic pressures and more recently by invasive exotic species. Invasive species such as *Chromoleana odorata, Tithonia diversifolia, Cecropia peltata, Lantana camara, Cedrela odorata* are currently present.[6]

Introductions of invasive alien species are, to date, considered to be an important component of human-induced global change.[7] In some cases, this leads to species extinctions.[8] In Cameroon, to date, around fifty exotic species are listed as invasive. These threats raise fears of the gradual disappearance of forest massifs, which would threaten plant and animal populations, riparian communities and ecosystem services. Recent studies have shown that invasive alien plants can alter ecosystem processes such as photosynthesis, respiration and carbon sequestration.[9,10] Invasive plants often have a higher aboveground biomass and therefore sequester more carbon than native species.[11] They can also be effective competitors of native species for water, nutrients, light and living space. It is generally recognised that these plants are fast growing and more productive than native species.[12] It must be acknowledged that until now, most studies have focused on the distribution and life history traits of invasive species, very few studies have looked at the effects of biological invasions for ecological functions such as biomass production and carbon sequestration in forest ecosystems.

The overall objective of our study is to assess the validity of the hypothesis that invasive plants have a higher aboveground biomass and sequester more carbon than native species. We chose *Cedrela odorata* (Meliaceae) as our study model. This species, which originates from tropical America, was introduced into Cameroon in the 1950s in various reforestation programmes, particularly in the forest attached to the Limbé Botanical Garden. It is a tree much appreciated for its straight bole which makes it an excellent timber. However, in recent years, further studies have shown that *Cedrela odorata* regenerates abundantly in the understorey and therefore constitutes a danger for the biological diversity and survival of native species in this forest ecosystem.[13–15] Specifically, the aim was to estimate the plant diversity present in the introduction area, to assess the above-ground biomass of the trees encountered and to calculate their carbon storage capacity

Methodology

Study site

The Limbe Botanical Garden (LBG) is the first botanical garden in Cameroon and the oldest in Africa. It was created in 1892, during the German colonial era, in Victoria (former name of Limbé), between the ocean and Mount Cameroon at 4°0'49.46″N and 9°12'3.13″E. Initially intended for agricultural purposes, it has become one of the main curiosities of the South West Cameroon Region. The Limbe Botanical Garden has also served as a training centre for Cameroonians in the fields of agriculture, horticulture and forestry. It is also an international centre for biodiversity research (Figure 1).

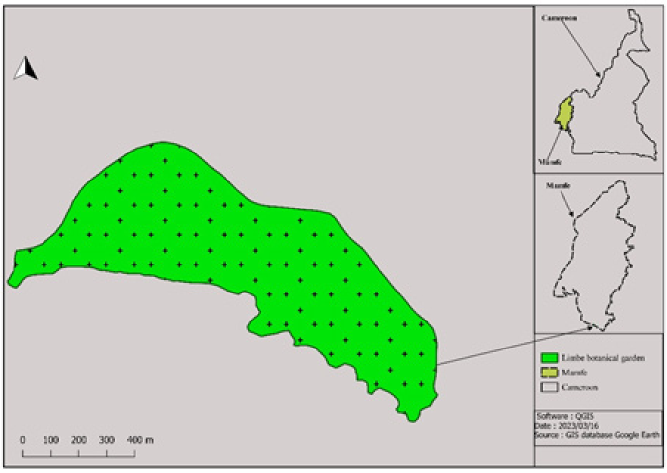

Figure 1 Limbe botanical garden.

Today, the garden, which originally covered 250 hectares, has only 48 hectares, the rest (202 hectares) being the forestry part which is the subject of this study. The garden has about 1,500 taxa (1,000 herbaceous and 500 woody plants). There are rare or endangered plants: 150 endemics, 100 from the south-west, including *Calamus sp*, *Prunus africana*, *Gnetum spp*. Some plants are the object of particular attention, notably the African palms, the endemic plants of Mount Cameroon, the *Musa spp*. Others are cultivated for conservation purposes: *Irvingia gabonensis, Garcinia kola, Afrostyrax kamerunensis, Cola spp, Prunus africana, Gnetum spp, Pterocarpus soyauxii, Diospyros, Rauvolfia vomitoria, Nauclea diderrichii, Terminalia spp, Enantia chlorantha, Eremomastax speciosa, Bryophyllum spp* and *Physostigma venenosum*. The botanical garden also houses a herbarium, which in 2001 had about 21,000 specimens and more recently 30,000. Its acronym in the Index Herbariorum is SCA.

Data collection

For the flora inventory, we used plots of 100m^2 (10mx10m). Twenty (20) surveys were set up in the forest of the Limbé botanical garden and the area of influence. Thus, on each plot, tree species were identified and their diameters (DBH≥10cm) were measured at 1.30m above the ground. We noted information such as the number of adult and juvenile individuals. The species nomenclature is consistent with the different floras of Africa and Cameroon.[16–18] The Shannon-Weaver diversity index was used to measure the average amount of information given by the species indication of an individual in the collection. This average was calculated from the proportions of species found. This index represents the total information given by the frequency of the various species along the inventory area. This index is calculated as follows:

$$H' = -\Sigma_{(i=1)}^{s} \text{Pi log Pi} \quad \text{with} \quad \boldsymbol{P}(\boldsymbol{i}) = \frac{\boldsymbol{n_i}}{\boldsymbol{N}}$$

Where

H' = Shannon Biodiversity Index,

i = A species in the study area,

Pi = Proportional abundance or percentage importance of the species,

S = Total number of species,

n_i = Number of individuals of a species in the sample,

N = Total number of individuals of all species in the sample.

Thus, the value of H' depends on the number of species present, their relative proportions, the sample size and the log base. The Shannon index ranges from 0 to log S.

Structural parameters and estimation of above-ground plant biomass

Structural parameters (density, basal area) were calculated to account for the structure of the garden vegetation. The above-ground plant biomass was estimated. In order to do this, faced with the limitations of the direct method,[19] namely, the execution time, the cost of operations and the destruction of tree stems, we opted for allometric methods. The equation of Chave et al.,[20] was used. It is given by the following mathematical equation:

$$AGB = \rho \exp(-1,499 + 2,148 \ln(DBH) + 0,207(\ln(DBH))^3$$

In this formula,

AGB is the aboveground biomass determined in kg;

DBH, the diameter at breast height or 1.30 m above ground level (in cm);

ρ, the anhydrous specific gravity of wood (in g/cm^3);

ln, the natural logarithm and

exp, the exponential function.

For specific densities (ρ), we used the reference list of Reyes et al. When a species had several values, we used the mean value. For species for which we do not have the specific density, the default value (default ρ=0.58 g/cm^3) for African tropical forests was used as recommended by Djomo et al.,[21] The sequestered carbon rate is estimated at 50% of the biomass.[22] Finally, the mass of carbon dioxide (CO_2) is obtained by multiplying that of carbon by 0.27.

Data analysis

The data collected from the floristic inventory were analysed qualitatively and quantitatively to assess floristic richness, composition and diversity, Sorensen's similarity coefficient[23] and Shannon's diversity index.[24]

For the comparison of the means of the structural parameters between the park forest and the LBG, we used the parametric Student's t test. To test the existence of possible relationships between some structural parameters of Cedrela odorata and those of other species, we used Pearson's r correlation. These tests were carried out using the R software version 2020 for Windows

Results

The inventory resulted in the identification of 349 plants species. Dicotyledons are the most represented (90.86% of species) with 43 families. Monocotyledons are represented by 10 families. The best represented families are Euphorbiaceae and Apocynaceae with proportions varying from 7 to 9% of species. The flora is mainly composed of Microphanerophytes (51 and 34%), Mesophanerophytes (24 to 25%), Nanophanerophytes (11 to 21%) and Megaphanerophytes (9 to 13%). Species from African forest regions (A GB) are the most numerous (97%). They are followed by species endemic to the forest blocks in Western Nigeria (A GCN) (11.83%) and species that occur naturally in the savannah-forest transition zone (AGB-ST) (2%).

The most frequent species in the forest is *Cyathea camerooniana* with 92.3% presence. It is followed by 4 other species with a frequency of 76.9% respectively, *Lophira alata, Craterispermum angustifolium, Cynometra hankei* and *Cedrela odorata*. In the contiguous periphery, 6 species have a frequency of 100%. These are *Hymenostegia brachyura, Schefflera abyssinica, Saccoglotis gabonensis, Lovoa trichilioides, Mansonia altissima, Berlinia bracteosa and Cedrela odorata* has a frequency of 60%.

Sorensen's coefficients of similarity calculated for the forest plots vary from 6.45 to 52.05%. For the plots in the zone of influence, these range from 32.87 to 46% with an average of 38%. The calculated coefficient of similarity between the forest and the zone of influence is 48.8%. The Shannon indices calculated for the two zones are quite low. They range from 1.03 to 2.72 for the forest and from 1.99 to 3.06 for the zone of influence.

The average density of all species is 33515.3±8131.3 individuals/ha for the forest and 44420.0±23342.8 individuals/ha for the zone of influence. The difference between these two densities is not significant (Student's t-test, $t=2.12$; $p=0.305$). There is also no significant difference between the mean densities of species with a DBH ≥ 10cm (Student's t-test, $t=2.12$; $p=0.085$). In the forest, on the other hand, there was a significant correlation at the $\alpha=0.05$ threshold between the density of individuals (DBH ≥ 10cm) of *Cedrela odorata* and the density of the other species (Peason's test, $r= - 0.6$; $p=0.029$). *Cedrela odorata* has the highest density with 12,292.31 individuals/ha. It is followed by *Cyathea camerooniana* and *Macaranga hurifolia* with 2130.77 and 1992.31 individuals/ha, respectively. In the area of influence, *Cedrela odorata* has a density of 1480 individuals/ha all in the juvenile stage. The mean densities of *Cedrela odorata* individuals between the two study areas were not significant (Student's t-test, $t=2.12$; $p=0.466$).

The total above-ground biomass for the two areas together is estimated at 295.9tC/ha; this corresponds to a sequestered carbon stock of 147.9tC/ha. The CO_2 equivalent is 39.9tC/ha. This above-ground biomass per tree varies from 0.2tC/ha for the species *Pausinystalia johimbe* to 187.4tC/ha for *Cedrela odorata*. This corresponds to an individual carbon stock that varies from 0.1 to 93.7 tC/ha (Table 1). Native species such as *Diospyros crassifolia* and *Dialium pachyphyllum* have lower biomasses than *Cedrela odorata* (43.9 and 38.2tC/ha, respectively). Another exotic species, *Musanga cecropioides*, sequesters a very small amount of carbon (3.7tC/ha). There was a significant negative correlation between the above-ground biomass of *Cedrela odorata* and that of the other plant species present in the plots (Pearson test, $r= -0.81$; $p<0.0001$).

Table 1 Plant above-ground biomass, sequestered carbon and mass of CO_2 equivalent calculated in tonnes of carbon per hectare

Plant species	Aboveground biomass (tC/ha)	Carbon stock (tC/ha)	CO_2 equivalent (tC/ha)
Musanga cecropioides	7,5	3,7	1,0
Pycnanthus angolensis	0,5	0,2	0,1
Distemonanthus benthamianus	2,0	1,0	0,3
Coelocaryon preussii	0,4	0,2	0,1
Myrianthus arboreus	1,1	0,5	0,1
Pausinystalia johimbe	0,2	0,1	0,0
Sterculia tragacantha	1,4	0,7	0,2
Strombosia pustulata	0,7	0,4	0,1
Cedrela odorata	187,4	93,7	25,3
Cordia platythyrsa	1,2	0,6	0,2
Annickia chlorantha	1,1	0,5	0,1
Dialium pachyphyllum	38,2	19,1	5,2
Pterygota macrocarpa	1,8	0,9	0,2
Petersianthus macrocarpus	0,4	0,2	0,1
Diospyros-crassifolia	43,9	21,9	5,9
Prunus africana	6,3	3,1	0,8
Acacia crassicarpa	1,6	0,8	0,2
Total	295,9	147,9	39,9

Discussion

Biological invasions are nowadays a major concern for biologists and nature managers. They are increasingly recognised as altering agents of ecosystem processes.[25] Due to its nature as a mixed, semi-natural planted forest, the Limbe Botanical Garden forest provides an excellent model for understanding the consequences of invasive species introduction on carbon storage in forest stands. The study recorded 349 plant species in contrast to the recent study conducted in the Mvog-Bets Zoo-Botanical Garden, Nkwemoh et al.,[26] recorded 276 plant species instead. The high floristic diversity observed in our study could be explained by the fact that the forest is old and planted with indigenous and exotic species with a fairly high floristic diversity. The results are in agreement with those authors who pointed out that the best represented families are Euphorbiaceae and Apocynaceae. The study showed that *Cedrela odorata* is present in high density compared to other planted and native species. In a study on the invasion strategy and potential of *Cedrela odorata* in forest stands, Galindo et al.,[27] demonstrated that this species has a high potential for land occupation with an average basal area of 28.139m^2/ha. *Cedrela odorata* exerts a strong competitive pressure. This taxon regenerates enormously in the undergrowth compared to other plants. Besides adult individuals, there are numerous juvenile individuals of various sizes and ages.

This study found that *Cedrela odorata* has the highest above-ground biomass and therefore the highest carbon storage capacity. It is followed by *Diospyros crassifolia* and *Dialium pachyphyllum*, both native species. These results support the hypothesis that invasive plants have a high above-ground biomass and sequester more carbon than native species. These results also raise the thorny question of the short and long term impact of invasive species on carbon sequestration. In this case, they show that this taxon has a positive impact on carbon sequestration and therefore indirectly contributes to the well-being of the Limbe populations. However, this conclusion must be qualified because it should not make us forget that invasive species influence biomass production and thus indirectly the functioning of forests.[28] Their invasive power alters the dominance of indicator species, thus changing the structure of communities, biomass and therefore the carbon stock.[29] The work of Hernández-Máximo et al.,[30] has shown that *Cedrela odorata* has a very high reproductive capacity. It is a very abundant species with low production and a depressive and aggressive effect on other plants. With the advent of global change, the effects of *Cedrela odorata* on the structure of plant communities may become more pronounced. In the context of our study, we can conclude that any management activity including *Cedrela odorata* will require a clear analysis of short- and long-term carbon gains and losses. This management may not necessarily result in a carbon gain as it has been shown that while an invasive species is a source of carbon gain, these gains may be lost when the species is managed.

Conclusion

This study showed that the floristic diversity in the forest attached to the Limbe Botanical Garden is estimated at 349 plants species. The above-ground plant biomass is 295.9tC/ha. The carbon stock for the whole is estimated at 147.9tC/ha. The CO_2 equivalent is 39.9tC/ha. The invasive alien species *Cedrela odorata* has a high aboveground biomass (187.4tC/ha) and the highest carbon storage capacity (93.7tC/ha). This invasive species therefore contributes effectively to carbon sequestration in the Limbé botanical garden compared to other species present. Further studies in the short and long term, taking into account other forest ecosystems, will allow a better understanding of the consequences of biological invasions for carbon sequestration and, above all, to demonstrate the effectiveness of invasive species management in tropical forests in terms of carbon gain and loss.

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Conflicts of interest

The authors declared that there is no conflict of interest.

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