

Influence of Human Activity on Woody Plant Floristic Diversity and Carbon Stock of the Peripheral Areas of Lakes Bini, Transcam and Tison (Adamawa, Cameroon)

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Abstract

Lakes are highly productive ecosystems of significant ecological and economical value, locally and globally. They sequester an exceptionally large amount of carbon. In a bid to mitigate greenhouse gas emissions, research was conducted in Lakes Tison, Bini and Transcam in the Adamaoua region of Cameroon to contribute in safeguarding these ecosystems through conservation and rehabilitation efforts. The objective of this study was to examine the impact of human activities on woody plant diversity and carbon stocks around these three lakes. A split-plot experimental design was set up for this study. The lakes were considered as primary factors and their cardinal points as secondary factors. Three 20 × 60 m transects were formed on each side of the lakes, spaced 5 m apart. The findings revealed that the main indicators of anthropogenic activities around these lakes were traces of burning (60.28%) in Lake Tison and woodcutting (44.21%) in Lake Bini. The practice of bush fires for weeding and firewood collection around Lake Transcam contributed to the conversion of land for agricultural use, affecting plant diversity. The Shannon index of the three lakes ranged from 1.83 to 3.86. Carbon sequestration was five times higher in Lake Bini on the western side (90.75 tC/ha) of the total stock (91.75 tC/ha) than Lake Tison (17.77 tC/ha). The presence of an orchard to the west of Lake Bini reinforced the results obtained. Given their significance and value, aquatic environments are under enormous pressure from riparian populations and the exploitation of lake peripheries must be regulated.

Keywords

Anthropogenic, Lake, Carbon Stock, Adamaoua, Cameroon

1. Introduction

It's now obvious that the increase in greenhouse gases (GHGs) in the atmosphere and the resultant climate change have a major impact on the environment. Nature conservation is currently globally imperative. Action must be taken to reduce GHG emissions into the atmosphere. Since the United Nations (UN) conference on climate change held in Poznań in 2008, international discussions on a mechanism for reducing emissions from forests in developing countries have led to a consensus on what is now known as REDD+ (Reducing Emissions from Deforestation and Forest Degradation and promoting conservation and sustainable forest management). The idea is to reward individuals, communities, projects and countries that reduce greenhouse gas (GHG) emissions from forests. Countries willing and able to reduce their GHG emissions from deforestation were to be compensated financially [1]. Amongst the resolutions on the reduction of greenhouse gas emissions during the Kyoto Summit [2], one was to fine countries that emitted more carbon into the atmosphere and reward countries that produced less. This initiative encouraged non-industrialized countries to keep their forests intact, which constitute carbon sinks to facilitate the sustainable management of resources.

In Cameroon, environmental issues are intertwined with national politics. The destruction of biodiversity and increased greenhouse gas emissions into the atmosphere is clearly linked to anthropogenic activities. Despite their large size and rich biodiversity, deforestation rates of Cameroon's forests are estimated at 0.14%, with net degradation rates of 0.01% [3], most likely from pressure exerted by the indigenous population. Deforestation in countries such as Cameroon directly results in the emission of CO₂ into the atmosphere and consequent climate change, which remains one of the main concerns of the international community [1]. According to the FAO [4] [5], agriculture and land use change, such as deforestation, account for approximately 13% and 17% respectively, of total GHG emissions from human activity. The pressure exerted in the Sudano-Guinean zone is high, given that the main anthropogenic activity practiced on the land is agriculture. The Guinean high savannahs of Cameroon are diverse and rich in species of socio-economic interest. These species are under increasing pressure from human activities and climate change [6] [7]. As agriculture is the main activity, the need for fertile land is increasingly driving people to deforest aquatic environments, for their fertile soils and proximity to water sources, needed for irrigating off-season crops. The cutting of firewood is also a major factor in the degradation of these areas. These activities lead to eutrophication and pollution of aquatic environments. As a result, the lakes in the Ngaoundéré district have been heavily anthro-

pised, with the sharp reduction in plant diversity leading to a decline in carbon stocks. Several studies have been conducted on carbon sequestration in the Guinean high savannahs of Cameroon [8] [9], but to the best of our knowledge, no study has been conducted to assess the phytodiversity and carbon sequestration capacity of flora in the aquatic environments of the outskirts of Ngaoundéré subjected to anthropogenic activities. Indeed, work in this field has been limited to terrestrial environments, hence the unique nature of this study. Therefore, the objective of this study was to examine the influence of anthropogenic activities on plant diversity and carbon stocks in three lakes located in the city of Ngaoundéré.

2. Methodology

2.1. Presentation of the Study Area

The Sudano-Guinean zone is located in the far north of Cameroon, Adamaoua region, and its capital is Ngaoundéré. The Adamaoua region is located between latitudes 6° and 8° north and longitudes 11° and 15° east. It covers an area of 63,701 km². This region consists mainly of highlands stretching from west to east between the Federal Republic of Nigeria and the Central African Republic. It occupies a central location between the southern and northern parts of Cameroon as it is bordered to the south by the Centre, North-West and West regions and to the north by the North region (**Figure 1**).

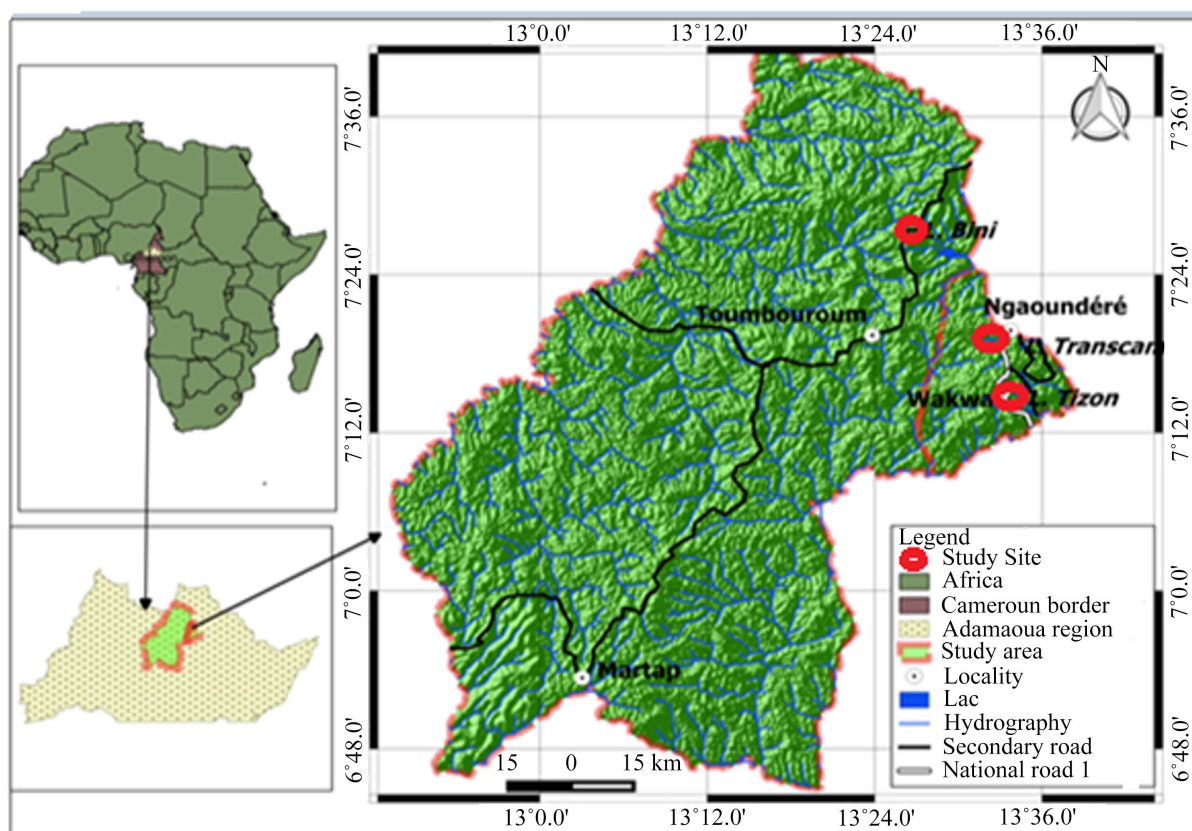


Figure 1. Study sites surrounded in red color.

2.2. Population Demographics

The population of the Adamaoua region is composed of 11 ethnic groups. Some are considered heterogeneous, such as the Fulani, M'bororo and Hausa, while others are indigenous (Gbaya, Kaka, Koutine or Péré, Tikar, Konja, Vouté or Babouté, Mboum, Nyem-Nyem and Dourou or Dii). The Fulani occupy large towns and are scattered throughout smaller villages in the Divisions of Mayo Banyo, Vina and Djérem. The Gbaya, Mboum and Bororo are also widely dispersed.

2.3. Physical and Human Environments

The Adamaoua region is located on a large plateau with an average altitude of 1100 metres, separating the southern Cameroon plateau from the northern lowlands. The landscapes are very diverse, as described below: 1) Mountainous landscapes in the west with the Tchabal Mountains; 2) Swampy valleys and volcanic cones in the centre; 3) Sloping tables cut through by the Mbéré collapse trench.

This region has a tropical climate tempered by altitude. Temperatures are cool and rainfall is abundant, accompanied by heavy storms during the rainy season. The dry season, which lasts from December to July, is very harsh year after year. The soils are ferruginous and ferralitic. They are covered with herbaceous flora, but in the mountains, there are shrubby and wooded savannahs, although now degraded by human activity. The subsoil contains highly sought-after minerals such as bauxite. The rivers that flow down the four slopes of the Congo, Atlantic, Niger and Chad (Djerem, Kadéï, Vina and Bénoué) have their source on the plateau. The majority of the region's population belongs to an African ethnic group known as the Sudanese. First colonised by the Fulani, the peoples speak Fulfulde and Arabic, while the official language is French. In terms of customs and traditions, the populations are largely rural and Islamised, and polygamy is still practised. The peoples are organised into chiefdoms called lamidats, headed by a lamido.

2.4. Tourism and Ecology

The Adamaoua region is considered as Cameroon's natural water tower. It is also renowned for its crater lakes, ranches, thermal mineral springs, wildlife reserves and caves. Considering the region's topography, it is prone to flooding while its location in the Sudano-Sahelian zone consisting of the far North and North of regions of Cameroon, it is also prone to desertification. The other main problem in this region is poaching. Culture also plays an important role, with the presence of Lamidats and feudal ethnic groups.

2.5. Experimental Design

The experimental design used was a split-plot with three replicates. The lakes represented the main treatments sites or environments, while the cardinal points represented the secondary treatments points and the number of transects the replicates. The different study sites were chosen according to the apparent degree of

anthropisation of the environment: the Tison site is the least anthropised environment, considered natural, followed by the Bini site, which is heavily affected by anthropogenic actions, and the Transcam site, which is the most anthropised site.

In the various study areas, orientation and geographical positioning were carried out using a Global Positioning System (GPS) device. After locating the cardinal points using a compass, three transects (L) measuring 20×60 m and spaced 5 m apart, were formed using a measuring tape, then repeated on all four sides of the lake.

Vegetation surveys (R1, R2 and R3) were carried out on each transect (L1, L2, L3) at each cardinal point and repeated (M1, M2 and M3) every 20 m away from the lake shore. Each observation at the sites is considered to be independent of the others (**Figure 2**).

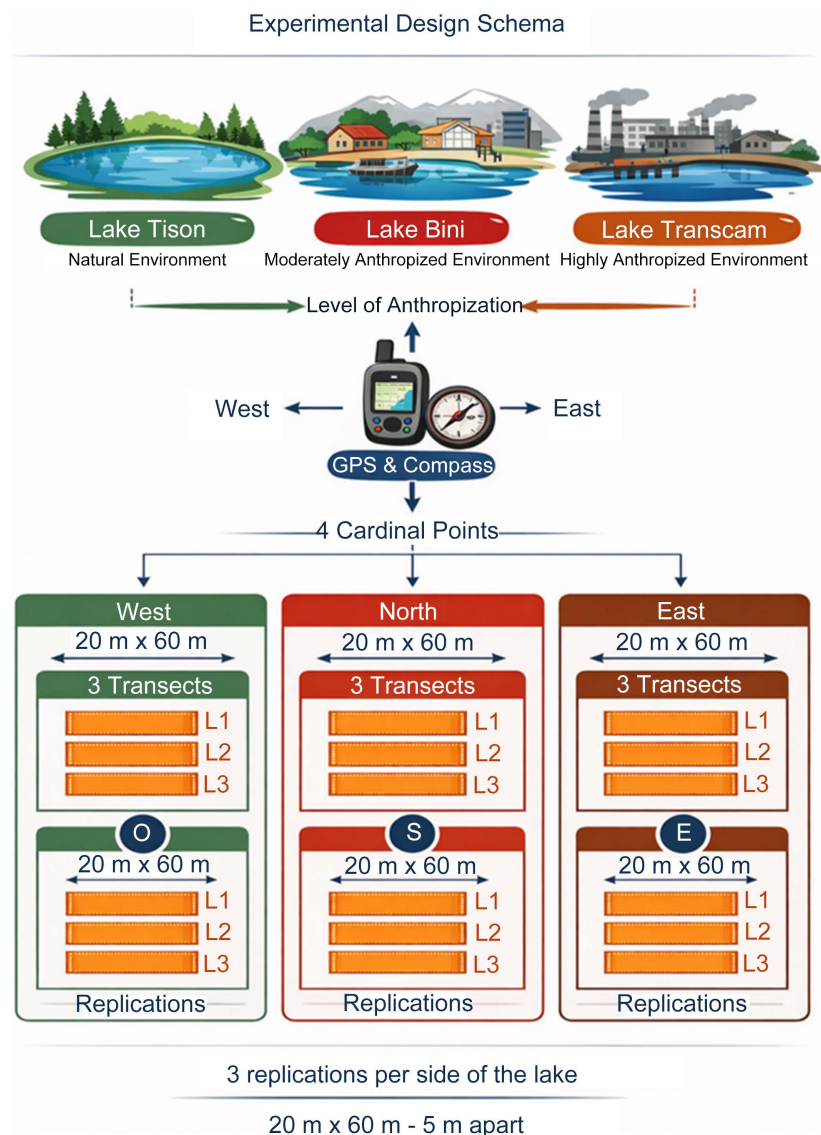


Figure 2. Experimental design schema.

2.6. Determination of Anthropisation Indices

The assessment of signs of human impact is carried out within the transects. For each plant, signs of human impact resulting from human activities—such as felling, burning, pruning, trimming, debarking, stump removal and trampling—are recorded on pre-designed forms. The name of the plant, followed by the traces of the observed human activity, is noted. A single individual may also be assigned several impact codes. These individuals bearing signs of human impact on woody plants were counted one by one and grouped by area within 20 m × 20 m plots along the transects surveyed.

2.7. Floristic Inventories of Species

For floristic inventories, the sampling technique used was based on that used by Tchobsala *et al.* [10] in the Guinean high savannahs of Adamaoua in Cameroon. It consisted of delimiting 20 × 20 m² plots to record all woody species along the transect.

Inventories and dendrometric parameters such as Diameter at Breast Height (DBH) were measured using a graduated measuring tape. The diameter of the crown was measured using a decameter. Height was measured using a clinometer. Pre-designed survey forms were used to record the various parameters with a pen. All woody species present within transects were counted. Species measuring less than 1.30 m were counted and considered as shoots. Plants taller than 1.30 m and with a DBH greater than 10 cm were considered adult individuals.

2.8. Ecological Characterizations

2.8.1. Ecological Profile

The ecological profile was created using species quantification parameters. The concepts used relate to the assessment of frequency, abundance and dominance. The frequency of a taxon is the number of individuals of a taxon out of the total number of individuals of all taxa at a given site.

$$F = N_i / N$$

where N_i is the number of individuals of a species; N is the total number of individuals of all species at a given site.

The absolute frequency of a taxon is the total number of individuals in surveys where the taxon is present, divided by the total number of individuals in all surveys.

The relative frequency is the absolute frequency multiplied by 100.

$$FR(\%) = \frac{N_i}{N} \times 100 \quad \text{with } FR(\%) = \text{Relative frequency,}$$

N_i = number of individuals of a taxon in surveys where the taxon is present; N = number of individuals in all surveys.

This proportion or frequency makes it possible to determine which individuals in a taxon are accidental, incidental, fairly common, common, and very common (Table 1).

Table 1. Frequency index (Braun-Blanquet [11]).

Index	Frequency	Species type
I	$F < 20$	Accidental taxon
II	$20 < F < 40$	Accessory taxon
III	$40 < F < 60$	Fairly common taxon
IV	$60 < F < 80$	Frequent taxon
V	$80 < F < 100$	Very common taxon

Dominance refers to the coverage of individuals of each species and expressed in percentage. Absolute dominance is the ratio of the total basal area of the species (STTe) to the total basal area (STTE).

$$DA = \frac{STTe}{STTE}$$

Relative dominance or relative coverage, is the ratio of the total basal area of the species (STTe) to the total basal area of the community (STTC) multiplied by 100.

$$DR = \frac{STTe}{STTE} \times 100$$

Curtis' relative importance value is the sum of relative density, relative frequency and relative overlap.

$$IVCR(\%) = FR + DR + DeR$$

With IVCR: Curtis's Importance Value; RF: Relative Frequency; RD: Relative Dominance; RD: Relative Density.

Basal area is given by the formula:

$$G_i = \pi D_H^2 / 4$$

where G_i is the basal area of species i , D_H is the diameter of the crown of the species.

2.8.2. Diversity and Equity

Specific diversity was analyzed using diversity indices [12] [13].

2.8.3. Shannon Index

The Shannon-Weaver or Shannon-Wiener Index is an index for measuring biodiversity. This index is an indicator of species richness. It is calculated using the following formula:

$$H' = -\sum_{i=1}^S P_i \ln P_i$$

H' : Shannon biodiversity index.

i : a given species in the environment.

$p(i)$: proportion of species i relative to the total number of species (S) in the study environment (or specific diversity of the environment), calculated as fol-

lows: $p(i) = n_i/N$, where n_i is the number of individuals of the species and N is the total number of individuals, all species combined.

The Shannon index makes it possible to quantify the specific richness of biodiversity in a study environment and thus to observe changes over time. It must be used in conjunction with the Simpson index.

2.8.4. Simpson's Index

Simpson's index is a formula used to calculate the probability that two individuals selected at random from a given environment are of the same species.

$$D = \sum N_i (N_i - 1) / N (N - 1)$$

D : Simpson's index.

N_i : number of individuals of a given species.

N : total number of individuals.

Alongside these two indices, we can calculate Pielou's evenness (E), which is the inverse of Shannon's index.

2.8.5. Jaccard Similarity Coefficient

The Jaccard similarity coefficient [14] allows different plots to be compared.

It is given by the formula:

$$PJ = \frac{c}{a + b - c} \times 100$$

where a = number of species in list a (Environment 1); b = number of species in list b (Environment 2), c = number of species common to both environments. The similarity between environments is expressed by the high value of this index.

The Hamming distance proposed by Daget *et al.* [15], cited by Le Floch [14], is added to this index to compare floristic surveys according to the formula:

$$H = 100 - PJ$$

where PJ is the Jaccard index. The thresholds used are shown in **Table 2**.

Table 2. Threshold for comparing floristic records based on Hamming distance.

Seuil	Comparison
$H < 20$	Very slight difference in flora
$20 < H < 40$	Low floristic difference
$40 < H < 60$	Average floristic difference
$60 < H < 80$	Significant floristic difference
$80 < H$	Very strong floristic difference

2.8.6. Estimating Carbon Stocks

The biomass of a tree refers to the mass of the plant's living tissue. It is generally expressed in metric tonnes (t). It includes the above-ground part (leaves, branches and stems) and the below-ground part (roots). The existing methods for calculating forest carbon are the allometric (non-destructive) method and the destructive

method. The non-destructive method chosen is more environmentally friendly.

2.8.7. Estimation of Above-Ground Biomass

Above-ground biomass is obtained by determining tree biomass. Tree biomass was estimated indirectly on the same plots using an allometric model that takes into account tree parameters such as DBH and height. Among the equations used to estimate this biomass, the one by Jérôme Chave and *et al.* [16] was selected because it was developed under climatic conditions with average rainfall ranging from 1500 to 4000 mm, including that of Adamaoua (1200 - 2000 mm), and the coefficient of determination between tree biomass and its two parameters (DBH) is highly significant ($R^2 = 0.987$), since it accurately captures the biological and physical structure of trees through their fundamental characteristics. It is given by the formula:

$$Ba = \exp(-3.114 + 0.9719 \ln(DBH^2 * H))$$

where, Ba is the above-ground biomass of the tree in kg, DBH is the diameter at breast height in metres, and *H* is the height of the tree in metres.

2.8.8. Estimation of Underground Biomass

The biomass of the root system was estimated using the relationship developed by Cairns *et al.* [17]:

$$Br = \exp(-1.0587 + 0.8836 \times \ln(Ba)),$$

where Br = root biomass, ln = natural logarithm and Ba = above-ground biomass.

2.8.9. Estimation of Total Biomass

Total biomass consists of above-ground and below-ground biomass. To determine the final biomass values, above-ground biomass was added to below-ground root biomass:

$$Bt = Ba + Br$$

where Bt = total biomass, Br = root biomass and Ba = above-ground biomass [18].

2.8.10. Estimation of Carbon Stock and Credit

The carbon stock is assessed by measuring the calculated biomass. The carbon stock in total biomass was assessed using the following equation [19]:

$$CS = B \times CF$$

where CS = carbon stored in total biomass (t C/ha), B = biomass (Tc/ha) and CF = Carbon Fraction (%). CF = 50%.

The amount of CO₂ emitted = CE × 44/12.

The ecological service was evaluated in monetary terms using the estimated value of the ecological service at 10 USD/tCO₂ [20]. The carbon credit is obtained by multiplying the amount of CO₂ by 10 dollars.

3. Method of Analyzing Results

Analysis of variance was used to compare the environments (Lake Tison, Lake

Bini and Lake Transcam), cardinal points and their interactions (environment-cardinal point). Duncan's test was used for comparisons of significant means. Principal component analysis (PCA) was performed to determine the dispersion of species at each site. These analyses were performed using XL-stat software (PCA), the Excel spreadsheet from the Office 2010 package (histograms) and Stat-graphic plus 5.0 (ANOVA and Duncan's test, etc.).

4. Results and Discussion

4.1. Study of Anthropogenic Indices at the Sites

The seven most frequent anthropogenic indices (cutting, burning, pruning, trimming, bark stripping, stump removal and trampling) were identified at the different sites. The Bini site was severely impacted by cutting (455 individuals/ha), especially in the east of the site with 139 individuals/ha (**Table 3**), in connection with the agricultural practices observed in the environment. Meanwhile, individuals in the Tison site were mostly affected by burn marks (867 individuals/ha), particularly in the west with 245 individuals/ha, in connection with the use of fire for weeding. Similar results were found by Danboya [21] in the Mayo Binou forest gallery in Adamaoua, where 40% of the plots sampled show signs of wood cutting.

Table 3. Representations of anthropisation indices according to sites and cardinal points.

LAKES	I A	NORTH	SOUTH	EAST	WEST	TOTAL
TRANSCAM	CO	61	78	58	11	208
	BR	11	11	44	5	71
	EL/EM	8	6	58	8	80
	EC	8	6	53	6	73
	ES	0	0	14	3	17
	PI	42	6	39	0	87
TISON	CO	28	31	108	81	248
	BR	222	186	214	245	867
	EL/EM	36	0	0	14	50
	EC	106	6	108	33	253
	ES	6	0	0	0	6
	PI	0	14	0	0	14
BINI	CO	96	120	139	100	455
	BR	64	75	56	0	195
	EL/EM	22	29	6	97	154
	EC	17	19	11	61	108
	ES	0	6	19	0	25
	PI	6	22	0	64	92

AI = Anthropisation Index, Co = Cutting, BR = Burning, El = Pruning, EM = Trimming, EC = Debarking, ES = Stump removal, PI = Trampling.

4.2. Specific and Family Abundance of Woody Plants in the Three Environments

The number of species and families in the different environments were strongly influenced by human activity. **Figure 3** shows the number of species and families in the three study environments according to the cardinal points. The Lake Tison site had the highest number of species, particularly in the east with 29 species divided into 29 families, and in the north of Bini with 26 species divided into 18 families. The Transcam site had the least number of species, especially in the west with 4 species divided into 4 families. This might be due to deforestation of the Transcam area. These results differ from those of Danboya [21] and Tchobsala [9], who obtained different results in the Gada Bidou forest gallery (33 species divided into 17 families) in Adamaoua, Cameroon.

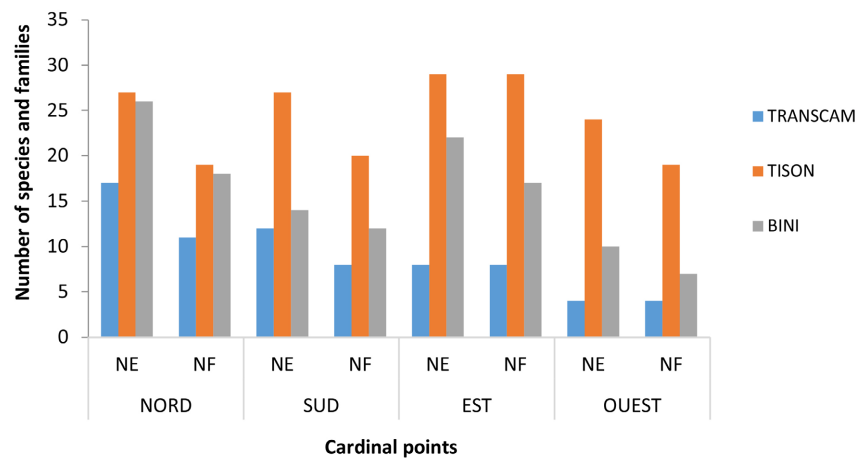


Figure 3. Number of species and families according to location and cardinal points. NE = number of species, NF = number of families.

4.3. IVCR of Woody Plants in the Three Environments

The specific diversity of vegetation in the environments was assessed with the use of Curtis (IVCR) ecological values in their study environments. **Table 4** presents an inventory of the species and their Curtis importance values. The highest values were found in *Acacia polyacantha*, West of Transcam (149.9%), followed by *Mangifera indica* with a Curtis importance value of 142%, West of Lake Bini, *Terminalia glaucescens* in the North (125.05%), West (125.91%) and South (104.27%) of Lake Tison. The least ecological value was found South of Tison with *Antidesma venosum* (1.18%). The importance of these species in different environments is justified by their abundance in the study environments.

4.4. Dispersion of Woody Plants across Different Sites

The principal component analysis was used in the survey to identify the species of woody plants in the different sites (**Figure 4**) while their presentation on the factorial plane of axes 1 and 2 grouped the distribution of woody species with similar characteristics.

Table 4. IVCR of woody plants in three environments.

Species names	Transcam				Tison				Bini			
	North	South	East	West	North	South	East	West	North	South	East	West
	Ivcr	Ivcr	Ivcr	Ivcr	Ivcr	Ivcr	Ivcr	Ivcr	Ivcr	Ivcr	Ivcr	Ivcr
<i>Acacia nilotica</i>	0	0	0	0	0	3.36	0	0	0	0	0	0
<i>Acacia polyacantha</i>	0	12.16	0	149.86	0	0	0	0	0	0	0	0
<i>Acacia seyal</i>	8.71	0	0	0	0	3.76	2.27	0	0	0	0	0
<i>Acacia sieberiana</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Albizia zygia</i>	0	8.94	0	0	0	0	0	0	0	0	0	0
<i>Alchornea cordifolia</i>	0	78.43	0	0	0	0	0	0	0	0	0	0
<i>Allophylus africanus</i>	0	0	0	0	7.46	3.93	3.72	6.73	3.35	0	4.50	0
<i>Anacardium occidentale</i>	8.14	8.65	100.39	0	0	0	0	0	0	0	0	0
<i>Annona senegalensis</i>	11.33	0	14.18	61.87	7.01	11.56	0	9.99	20.30	19.60	10.94	0
<i>Antidesma venosum</i>	0	0	0	0	0	1.18	3.72	0	4.34	0	2.89	0
<i>Cinera glomeratum</i>	0	0	0	0	0	0	0	0	2.32	0	0	0
<i>Citrus limon</i>	12.72	0	0	0	0	0	0	0	0	0	0	0
<i>Combretum nigricans</i>	0	0	0	0	10.84	3.04	3.42	0	2.67	0	0	0
<i>Croton macrostachyus</i>	47.63	0	0	0	0	5.01	2.31	4.16	2.82	25.57	6.52	11.76
<i>Cussonia arborea</i>	0	0	0	0	8.69	11.59	13.55	10.84	0	0	0	0
<i>Dacryodes edulis</i>	0	0	0	0	0	0	0	0	0	0	2.86	6.93
<i>Daniellia oliveri</i>	0	0	0	0	3.32	0	2.27	0	0	0	0	0
<i>Elaeis guineensis</i>	0	0	0	0	0	0	2.25	0	0	0	0	0
<i>Entada africana</i>	0	0	0	0	12.46	14.17	16.48	12.68	0	16.08	0	0
<i>Erythrina sigmoidea</i>	9.05	0	0	0	0	0	4.92	5.51	4.67	0	6.29	0
<i>Fagarra senegalensis</i>	0	0	0	0	0	0	0	0	9.43	12.39	12.33	0
<i>Ficus glumosa</i>	9.53	0	0	0	6.81	25.41	21.79	19.29	7.39	20.92	21.77	5.57
<i>Ficus sycomorus</i>	0	0	7.47	0	0	0	0	2.37	0	0	0	0
<i>Ficus thonningii</i>	44.43	0	0	0	5.76	0	6.63	0.01	0	15.95	3.22	21.91
<i>Flacourtia indica</i>	0	0	0	0	0	0	0	0	5.80	0	0	0
<i>Gardenia aqualla</i>	0	0	0	0	0	0	0	0	0	0	2.89	0
<i>Harungana madagascariensis</i>	8.28	0	0	0	0	0	0	0	41.92	15.36	90.42	0
<i>Hymenocardia acida</i>	0	0	0	0	2.91	9.97	0	11.75	12.80	0	3.31	0
<i>Jacaranda ovalifolia</i>	0	8.47	0	0	0	0	0	0	0	0	0	0

Continued

<i>Kigelia africana</i>	0	0	0	0	5.49	0	2.25	0	0	0	0	0
<i>Lannea acida</i>	0	0	0	0	15.78	7.80	16.85	8.56	2.35	0	0	0
<i>Maerua angolensis</i>	0	0	0	0	0	0	2.30	0	0	0	0	0
<i>Maesa lanceolata</i>	0	0	0	0	6.47	0	8.82	4.80	18.98	22.87	22.06	0
<i>Mangifera indica</i>	39.30	90.13	82.49	0	3.62	4.45	5.32	0	0	0	0	142.06
<i>Margaritaria discoidea</i>	0	0	0	0	6.47	24.00	9.38	7.32	12.13	0	0	0
<i>Maytenus senegalensis</i>	0	0	0	0	5.78	8.13	5.37	5.42	0	0	0	0
<i>Ochna schweinfurthiana</i>	0	0	0	0	0	0	0	0	4.67	0	0	0
<i>Ormocarpum bibracteatum</i>	0	0	0	0	8.43	5.42	2.30	7.52	0	0	0	0
<i>Persea americana</i>	8.82	0	26.83	0	0	0	0	0	0	0	4.83	51.55
<i>Phoenix reclinata</i>	0	0	0	0	0	3.04	2.75	3.31	0	0	0	0
<i>Phyllanthus muellerianus</i>	11.19	8.56	0	0	10.78	0	6.07	7.61	3.29	13.47	0	0
<i>Piliostigma thonningii</i>	0	8.47	0	54.35	8.30	10.30	4.89	4.90	42.72	39.89	15.81	0
<i>Protea madiensis</i>	0	0	0	0	0	10.49	0	4.35	0	0	3.54	0
<i>Psidium guajava</i>	11.60	8.50	57.49	0	0	0	0	0	0	16.75	29.57	37.21
<i>Psorospermum senegalense</i>	8.33	0	0	0	0	0	0	0	0	0	4.38	0
<i>Sarcocephalus lactifolius</i>	0	0	0	0	4.10	0	0	0	0	0	0	0
<i>Senna siamea</i>	0	0	0	0	0	0	0	0	6.29	0	0	0
<i>Steganotaenia araliacea</i>	0	0	0	0	4.46	2.53	0	0	2.78	0	0	0
<i>Stereospermum kunthianum</i>	0	0	0	0	6.27	0	2.61	0	2.32	0	0	0
<i>Strychnos spinosa</i>	0	0	0	0	0	2.55	0	0	5.13	0	0	0
<i>Syzygium guineense</i> var <i>guineense</i>	26.89	19.70	0	0	6.11	2.97	26.64	7.33	25.79	0	19.78	5.57
<i>Syzygium guineense</i> var <i>macrocarpum</i>	0	0	0	0	4.54	3.51	0	3.84	3.71	0	3.36	0
<i>Tamarindus indica</i>	0	0	7.54	0	0	0	0	0	0	0	0	11.83
<i>Tectonia grandis</i>	16.50	32.15	0	0	0	0	0	0	0	0	0	0
<i>Terminalia glaucescens</i>	0	0	0	0	125.05	104.26	98.50	125.90	39.35	72.88	19.88	0
<i>Terminalia macroptera</i>	0	0	10.24	0	0	0	0	0	0	0	0	0
<i>Terminalia mentalis</i>	0	22.45	0	0	0	0	0	0	0	0	0	0
<i>Uapaca togoensis</i>	17.45	0	0	0	5.43	0	0	0	12.57	0	0	5.56
<i>Vernonia colorata</i>	0	0	0	0	0	0	0	0	0	4.10	0	0
<i>Vitellaria paradoxa</i>	0	0	0	0	11.46	3.23	10.77	5.16	0	0	0	0
<i>Vitex doniana</i>	0	0	0	33.91	0	6.74	5.40	7.50	0	4.10	6.26	0
<i>Ximenia americana</i>	0	0	0	0	5.32	7.47	6.34	4.43	0	0	0	0
	300	300	300	300	300	300	300	300	300	300	300	300



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4.5. Floristic Indices and Equitability

Table 5 shows the values of various indices calculated. The Shannon-Weaver diversity index ranges from 1.83 to 3.86 in the different environments. It is higher north of Transcam (3.86) and Bini (3.74) due to the existence of a nursery in northern Transcam, which promotes the dissemination of diaspores in the environment. North of Bini, the Shannon index is high due to the lack of access roads to the environment. This index is lower west of Transcam (1.83), which can be explained by the scarcity of individuals in the site. Pielou's equity index confirms Shannon's results by presenting the highest index in northern Transcam (0.76), which reflects the heterogeneity of northern Transcam compared to western Transcam. The Simpson index shows that the probability of finding two different species in the environment is very low compared to other cardinal points. These results differ from those obtained by Danboya [21] in the Mayo binou forest gallery in Ngaoundéré, where Shannon indices vary between 1.3 and 2.58 and Pielou's equitability between 0.2 and 0.4.

Table 5. Indices of floristic diversity of vegetation according to cardinal points.

Environmental index	Transcam				Tison				Bini			
	North	South	East	West	North	South	East	West	North	South	East	West
ISH	3.86	2.74	2.02	1.84	3.67	3.84	3.69	3.48	3.74	3.42	3.61	2.19
EQ	0.76	0.47	0.29	0.48	0.45	0.48	0.45	0.42	0.43	0.40	0.44	0.29
D	0.05	0.20	0.29	0.24	0.17	0.12	0.15	0.18	0.11	0.11	0.11	0.27
1-D	0.95	0.80	0.71	0.76	0.83	0.88	0.85	0.82	0.89	0.89	0.89	0.73

ISH = Shannon Weaver diversity indices; EQ = Pielou's equitability; D = Simpson's index; 1 - D = inverse of Simpson's index.

4.6. Similarity between Sites

The Jaccard index indicates the degree of homogeneity within and between the different sites (**Table 6**). There is a high degree of floristic dissimilarity between Tison and Transcam (73.52) on the one hand, and between Transcam and Bini (77.40) on the other. The similarity between Lake Tison and Lake Bini is very high (13.64). This indicates heterogeneity between the two sites, but the difference is very marked between Tison and Bini, resulting in a high Hamming distance (86.36).

Table 6. Jaccard test values (Jaccard index).

	Transcam		Tison		Bini	
	PJ	H	PJ	H	PJ	H
Transcam	100	0				
Tison	26.48	73.52	100	0		
Bini	22.59	77.40	13.64	86.36	100	0

H = Hamming distance, PJ = Jaccard index.

4.7. Carbon Sequestration in the Different Study Environments

4.7.1. Above-Ground Biomass

Lake Bini recorded the highest phytomass (**Table 7**), with almost 90.87 t/ha of the 91.75 t/ha registered on the western side. The biomass of Lake Tison was 17.77 t/ha; five times less than was documented in Lake Bini. This result could be explained to the practice of agroforestry in Lake Tison. This part of the lake features an orchard dominated by species such as *Mangifera indica*, *Persea americana* and *Psidium guajava*, as well as crops like *Ipomea patatae* and *Solanum tuberosum*. These results are similar to those of Tchobsala *et al.* [9] in Adamaoua, where the highest above-ground phytomass was 90.01 t/ha. Significant differences were observed between biomasses depending on the cardinal points, as well as between the different sites, at the 5% threshold.

Table 7. Above-ground biomass of different lakes according to cardinal points (t/ha).

Site	North	South	East	West	Total	Average
Transcam	0.02	0.37	1.21	0.01	1.60	0.64 ± 0.49C
Tison	1.54	2.58	6.74	6.90	17.77	7.10 ± 2.78B
Bini	0.37	0.37	0.14	90.87	91.75	36.70 ± 25.28A
Average	0.64 ± 0.45d	1.10 ± 0.34c	2.69 ± 1.89b	32.59 ± 11.30a	37.03 ± 13.98	

The figures followed by different lowercase letters (a, b, c, d) in rows, and uppercase letters (A, B, and C) in columns are significantly different at $P < 0.05$, according to the LSD test.

4.7.2. Underground Biomass

The significant difference of underground phytomass based on the cardinal points and sites at the biological threshold was obtained through Analysis of variance. Lake Bini has the highest root biomass (9.28 t/ha), with 9.05 t/ha to the west of Bini (**Table 8**). This could be linked to the importance of its above-ground biomass, attributed to the presence of very large trees in the area. These results are higher than those reported by Abib [22] in the humid savannah of Ngaoundéré, where the amount of carbon in root phytomass was 3.94 tC/ha.

Table 8. Underground phytomass by lake and cardinal point (t/ha).

Site	North	South	East	West	Total	Average
Transcam	0.004	0.069	0.199	0.001	0.276	0.110 ± 0.02C
Tison	0.247	0.412	0.965	0.922	2.547	1.019 ± 0.36B
Bini	0.084	0.077	0.071	9.054	9.288	3.715 ± 1.48A
Average	0.112 ± 0.04c	0.186 ± 0.09c	0.412 ± 0.18b	3.326 ± 2.98a	4.037 ± 3.29	

The figures followed by different lowercase letters (a, b, c) in rows, and uppercase letters (A, B, and C) in columns are significantly different at $P < 0.05$, according to the LSD test.

4.7.3. Total Carbon Quantity at the Sites

Above-ground and below-ground biomass enabled us to determine the total

quantity of carbon at the different sites (Table 9). Analysis of variance revealed a significant difference between total carbon based on the cardinal points and sites at the biological threshold. Lake Bini sequestered more carbon, particularly in the west with 99.92 t/ha, while in the north, south and east, the Tison area sequestered the most carbon with 1.79 t/ha, 2.99 t/ha and 7.70 t/ha. However, the amount of carbon on the western side of Bini exceeded that of the Tison site (20.31 t/ha). This could be ascribed to the importance of orchards in the western zone. These results were lower than those of Tchobsala [23], who showed that wooded savannahs (169.91 t/ha) sequester much more carbon than shrubby savannahs (49.18 t/ha) and cleared plots (36.53 t/ha).

Table 9. Amount of carbon in different lakes (t/ha).

SITES	NORTH	SOUTH	EAST	WEST	TOTAL	AVERAGE
TRANSCAM	0.02	0.43	1.41	0.007	1.87	3.75 ± 0.65C
TISON	1.79	2.99	7.70	7.82	20.31	40.62 ± 3.14B
BINI	0.45	0.44	0.21	99.92	101.04	202.08 ± 49.77A
AVERAGE	0.75 ± 0.32c	1.29 ± 0.47bc	3.11 ± 2.02b	35.91 ± 15.56a	41.07 ± 18.37	

The figures followed by different lowercase letters (a, b, c) in rows, and uppercase letters (A, B, and C) in columns are significantly different at P < 0.05, according to the LSD test.

4.7.4. Carbon Stocks in Different Cardinal Points

Lake Bini recorded the highest carbon stock (370.48 tC/ha) with 366.37 tC/ha sequestered on the western side, which was more than the carbon stock in Lake Tison (74.48 tC/ha) (Table 10). Lake Tison however stored more carbon in the North, South and East (Table 10). This result once again highlighted the importance of agroforestry systems in combating global warming. The presence of an orchard on the site elucidated the very high carbon stock in this environment. These results differ from those of Ibrahim and Abib [19] in the peri-urban vegetation of Ngaoundéré, who showed that shrubby and wooded savannahs store 81.48 tC/ha/year and 118.36 tC/ha/year, respectively. This difference is likely due to the study environments. The low production of carbon sequestered in the fields showed that intensive logging of vegetation on the northern, southern and eastern fronts of Bini greatly reduced carbon sequestration in this environment. Similar results were obtained by Zapfack [24] in the forest region of Yaoundé, where cultivated fields showed low carbon production (1.91 tC/ha/year). Data obtained revealed significant differences between carbon stocks and the amount of phytomass at different sites and cardinal points, at the 5% threshold (P < 0.05).

Table 10. Carbon stock of different lakes according to cardinal points in tC/ha.

Site	North	South	East	West	Total	Average
Transcam	0.07	1.60	5.17	0.02	6.88	1.72 ± 2.41C
Tison	6.56	10.96	28.25	28.69	74.48	18.62 ± 11.51B

Continued

Bini	1.67	1.64	0.78	366.37	370.48	92.62 ± 82.50A
Average	2.77 ± 1.38c	4.73 ± 2.39c	11.40 ± 9.75b	131.69 ± 93.74a	150.61 ± 107.26	

The figures followed by different lowercase letters (a, b, c) in rows, and uppercase letters (A, B, and C) in columns are significantly different at $P < 0.05$, according to the LSD test.

4.7.5. Carbon Credits from Lakes

The carbon credit at each site was proportional to the carbon sequestered. The Bini site had the highest carbon credit (\$3704.82), while Lake Transcam had the lowest (\$68.82) (**Table 11**). The highest carbon credit (\$3663.75) was obtained on the western side of Bini compared to Lake Tison which presented the highest values in the North (\$65.69), South (\$109.68) and East (\$286.92). The dollars values in each of these points exceeded that of Lake Transcam (**Table 11**).

Table 11. Carbon credits by lake and cardinal point (dollars).

Sites	North	South	East	West	Total
Transcam	0.764	16.059	51.715	0.289	68.827
Tison	65.691	109.681	282.562	286.922	744.858
Bini	16.773	16.438	7.861	3663.750	3704.824

5. Conclusion

The study of phytodiversity and carbon sequestration in woody plants around the shores of Lakes Tison, Bini and Transcam in the Ngaoundéré district showed that aquatic environments underwent rapid degradation. The pressure exerted by local populations on the vegetation in these environments in search of fertile land and energy sources, led to the deforestation of aquatic environments. The cutting of firewood (455 individuals/ha) at Lake Bini and traces of burning (867 individuals/ha) at Lake Tison were the most commonly observed indicators. Bush fires and land conversion for agricultural purposes were the main causes of deforestation in these environments. Floristic diversity in aquatic environments was high (29 species and 29 families) east of Tison and (26 species and 18 families) north of Bini, but differed with the cardinal points of the sites due to different anthropogenic activities on either side of the cardinal points. This accounted for the variation in the different diversity indices (ISH from 1.83 to 3.86) and carbon sequestration capacities within the same site. At the Bini site, population pressure in the environment significantly reduced carbon sequestration capacity in the north, south and east (1.67 tC/ha; 1.64 tC/ha; 0.78 tC/ha) compared to the Tison lakes (6.56 tC/ha; 10.96 tC/ha; 28.69 tC/ha). Agricultural practices around this lake led to deforestation, which resulted in significant variations in carbon storage capacity. Contrarily, the practice of agroforestry west of Lake Bini (366.37 tC/ha), greatly boosted the carbon sequestration capacity in this environment, which exceeded the amount of carbon stored in the four sides of Lake Tison (74.48 tC/ha). Lake

Transcam was the most anthropised environment, with the least carbon stock and species diversity values. Similar parameters might be observed around Lake Bini if nothing is done, within a few years. Urgent conservation of these three lakes is needed to safeguard the increasingly threatened phytodiversity.

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Conflicts of Interest

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

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