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Species Distribution and Patterns in a Forest-savannah Ecotone: Environmental Change and Conservation Concerns

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ABSTRACT

Understanding the dynamics and patterns of biodiversity in transition forests is vital in promoting conservation and addressing environmental change issues. This work focused on elucidating the diversity, structure, and carbon potentials of a forest-savannah ecosystem. To achieve this, 8 forest plots that measured 50 m × 50 m each was set up in a forest-savannah landscape and used to identify and measure tree species ≥ 10 cm diameter at breast height (DBH measured at 130 cm). Species importance value was used to summarize the biodiversity patterns and the aboveground carbon estimates were elicited with the allometric equation. 43 species within 22 families were enumerated and the diversity was generally low (ranging from 1.82-2.5). Species such as *Daniellia oliveri* (Rolfe) Hutch. & Dalziel, *Pyrostria guinnensis* Comm. ex A. Juss, *Dialium guineense* Willd. and *Margariteria discoidea* (Baill.) G.L Webster were the dominant species, and had the highest importance values of 113.06, 55.13, 28.16 and 16.95, respectively, while *Allophlus africanus* P. Beauv., *Annona senegalensis* Pers., *Anthonatha macrophylla* P. Beauv., *Ficus capensis* Thumb. and *Lecaniodiscus cupanioides* Planch had the least importance values of 0.16 each. Carbon estimates ranged from 16.43172-42.9298 t/Ha. Most frequent species with higher basal areas no doubt contributed much to the carbon estimates, but did not have higher capacities in storing carbon. Managing the ecosystem with more carbon-dense species was seen as a suitable strategy for addressing environmental change in the ecosystem and region.

Keywords: Biodiversity; Carbon potentials; Climate change; Ecosystem conservation; Land use change

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1. Introduction

Tropical forest ecosystems play vital roles in addressing environmental change issues and are repositories of biodiversity. Though they occupy less than 10% of terrestrial surface land, they host much of global biodiversity, store 40-50 percent of terrestrial vegetation carbon and contribute more than one-third of primary productivity [1,2]. Traversing different latitudinal gradients, tropical ecosystems are found across different continents: America, Africa and Asia, and have varied biogeography, disturbance history and extents. The ecosystem is characterized by species-rich and diverse plant communities with its distributional patterns remaining a central question in ecology [3]. Efforts to unravel such patterns abound and have spanned a long period of time; with testimonials of such seen in the development of theories, models and hypotheses surrounding tropical ecology, biogeography and more recently its biogeochemical cycles. Distribution patterns across the ecosystem are inherently varied according to niche processes (more evidently on larger scales) and neutral processes on smaller scales [4]. Hence, the ecosystem is seen to be substantially varied in species richness, density and primary productivity across biomes and geographical delimitations.

Rainforests are particularly high in biodiversity; compared with other tropical ecosystems and known to occur in large proportions in regions such as the Amazon, Congo basin, and the Indo-Malayan Archipelago. Features of the rainforest are much known since the works of Richards [5], however, specific details on its surrounding zones are less known and much generalized. Notably among these are the transition forests that border the rainforest ecosystem; being where ecological communities of the rainforest and the adjoining ecosystem coincide. Such landscapes are found across the whole of the tropics where rainforests occur and notably along ecological gradients. With such gradients being created due to shifts in environmental factors, ecotones thus have the potentials of being hosts to populations that are adapted to both ecosystems on each side and species that accommodate changing environments.

Understanding biodiversity patterns across ecosystems is vital for ecological management and conservation and provides insights as key indicators to inherent environmental factors that define regions and ecosystems. Across Nigeria, baselines on the biodiversity of ecosystems are much documented by earlier inventories [6]. However, there is yet much dearth of knowledge regarding its transition to the savannah ecosystem particularly in South East Nigeria. Rainforest transition with savannah in south east Nigeria covers about a quarter of the eastern states. It is found in the north of the rainforest zone and is the transitional zone between grassland of northern Nigeria and the rainforest south [7]. Land use change is growing in magnitude across the region and is affecting the ecosystem greatly. In a bid to provide baseline insights on the ecotone and document the inherent botanical features of the ecosystem, this study was conducted. This work specifically focused on the diversity, structure, and carbon potentials of the ecosystem and thus, its conservation and climate change mitigation prospects.

2. Materials and methods

2.1 Study area

The area for the research is a part of South East Nigeria (**Figure 1**). The climate is characterized by a humid tropical, tropical wet and dry, and marked with rainy and dry seasons. It has a high annual rainfall which ranges from 1,400 mm in the North to 2,500 mm in the South, and a mean monthly temperature of 27.6 °C. The geology of the region comprises the ancient Cretaceous delta, with the Nkporo shale, the Mamu formation, the Ajali sandstone and the Nsukka formation as its main deposits [8]. The natural vegetations in this region are mainly the rainforest—savannah ecotone ecosystem. The zone experiences about 3 dry months in its northern zone and 1-2 dry months in the south, making it much more humid and with sufficient rainfall. Forest inventory was done in Awlaw in Oji River local government area of Enugu State. This location is characterized by an undulating and rugged terrain with an extensive and relatively undisturbed ecosystem.

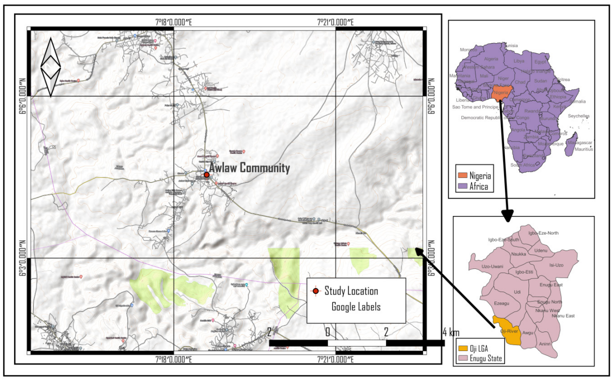

Figure 1. Map of the study area with the local government, Nigeria and Africa inset.

2.2 Data collection and analysis

To be able to determine the biodiversity and its patterns across the ecosystem, 8 forest plots were set up randomly across the forest locations. Each of the plots measured 50 m × 50 m and had intervals of not less than a hectare between the plots in each location. Tree species ≥ 10 cm diameter at breast height (DBH measured at 130 cm) were identified. DBH or girth tape was used to measure the tree stems while a rangefinder was used to measure the heights. Species found within all the plots were identified, measured and documented. Species identification followed the taxonomy of Nigerian plants [9] and The Plant List [10].

The species importance index was used to characterize the forest locations and verify the patterns of abundance of the species. This was calculated as follows:

Species importance values (SIV) = Relative density + Relative frequency + Relative dominance [11], where:

$$\text{Relative Density} = 100 \times \frac{\text{Number of stems of a species}}{\text{Total number of stems}} \tag{1}$$

$$\text{Relative frequency} = 100 \times \frac{\text{Frequency of a species}}{\text{Sum of all species}} \tag{2}$$

$$\text{Relative dominance} = 100 \times \frac{\text{Total basal area of a species}}{\text{Total basal area of all}} \tag{3}$$

The basal area was calculated as follows:

$$\text{BA} = \left(\frac{dbh}{2}\right)^2 \times \pi \tag{4}$$

where BA is the basal area (m^2); dbh is the diameter at breast height (cm) and π as pie (3.142).

The diversity of the ecosystem was ascertained following Kent and Coker [12]:

Shannon-Wiener index:

$$H' = -\sum_{i=1}^{s} pi \ln pi \tag{5}$$

where H^1 is the Shannon-Weiner index, s is the total number of species, pi is the proportion of individuals in the ith species, and ln is the natural logarithm.

Above ground carbon (AGC) was estimated with a pan-tropical equation [13]:

$$AGB = 0.0673 \times (pD^2H)^{0.976} \tag{6}$$

where AGB is the above ground biomass; ρ is the wood specific gravity (WSG; $g \cdot cm^{-3}$); D is the diameter at breast height (DBH; cm) and H is the height (m). Forest structural classes were categorized as small (< 20 cm dbh), medium (21-40 cm dbh), large (41-60 cm dbh) and largest (> 60 cm dbh). Pearson correlation was used to verify the correlation between the amount of carbon, basal area and number of stems.

3. Results

The ecosystem is composed of 43 species within 22 families. Distinct species ranged from 11-22 and the number of stems within each of the plots ranged from 46-110 individual stems (**Table 1**). Diversity was generally low (ranging from 1.82-2.5) and was not determined by the number of stems (**Table 1**).

As expected in a forest ecosystem, the structural patterns varied between the small (< 20 cm dbh), medium (21-40 cm dbh), large (41-60 cm dbh) and largest (> 60 cm dbh) stem sizes (**Figure 2**). Medium stem sizes (21-40 cm dbh) had the highest number of tree stems and were followed by the large stem, largest stem and small stems, respectively (**Figure 2**). The highest total basal area of 51452994.56 was from *Daniellia oliveri* (Rolfe) Hutch. & Dalziel and were followed by *Pyrostria guinnensis* Comm. ex A. Juss (with 20090882.585 total basal areas) and *Dialium guineense* Willd. (with a total basal area of 8876584.76265).

The dominant species within the ecosystem were

Daniellia oliveri (Rolfe) Hutch. & Dalziel, *Pyrostria guinnensis* Comm. ex A.Juss, *Dialium guineense* Willd. and *Margariteria discoidea* (Baill.) G.L Webster, with 50.06%, 19.67%, 8.69% and 4.22% dominance, respectively (**Table 2**). Similarly, the same species were seen to record in the same order, the highest important values of 112.76, 55.28, 28.22 and 16.98 values, respectively, while *Allophlus africanus* P.Beauv., *Annona senegalensis* Pers., *Anthonatha macrophylla* P. Beauv., and *Ficus capensis* Thumb., had the least importance values of 0.0008, 0.0012, 0.0012 and 0.0020, respectively (**Table 2**). *Pyrostria guinnensis* Comm. ex A. Juss was the species with the highest frequency of occurrence (15.92%), while 12 different species had the least frequency of occurrence (0.164204%; **Table 2**).

Table 1. Species diversity, richness and stem distribution.

Plot number	No. of species	Shannon diversity	No of stems
1	22	2.5892	79
2	14	2.01666	64
3	12	2.17817	46
4	14	1.99636	72
5	17	2.35784	75
6	18	2.32089	90
7	11	1.97324	72
8	12	1.82118	110

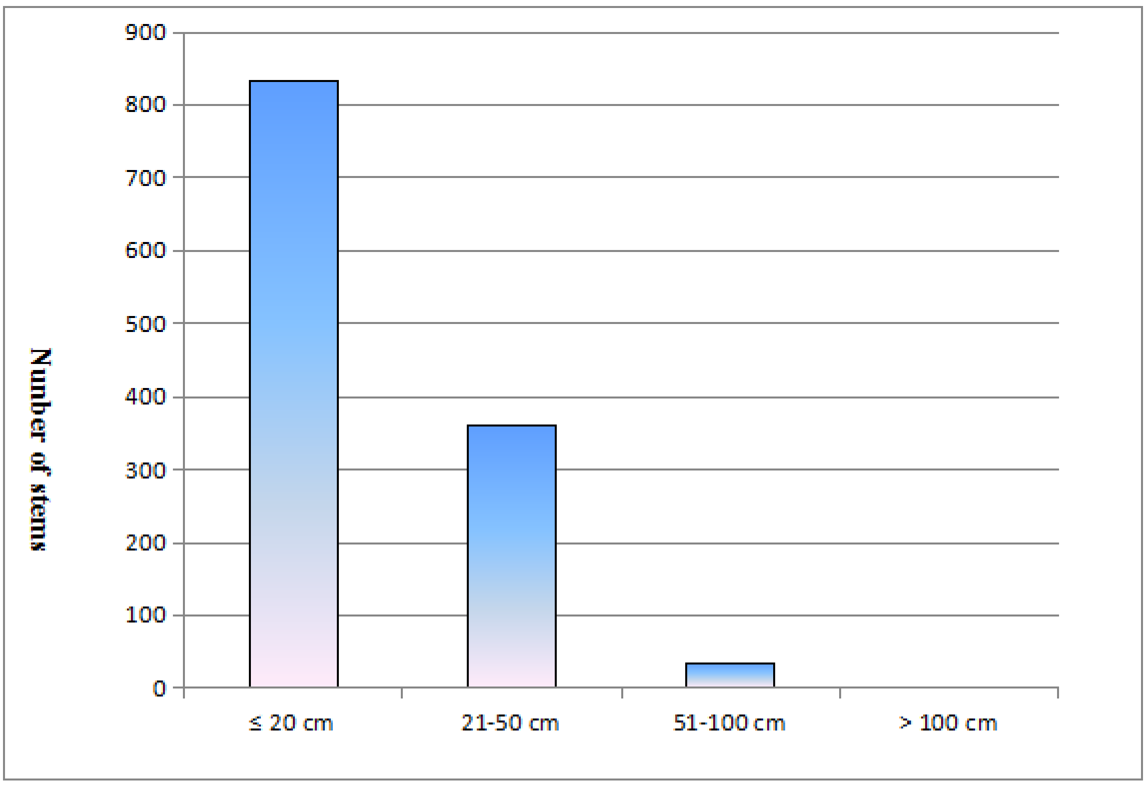

Figure 2. Stem sizes of the different individual stems in the ecosystem.

Table 2. Species importance values (SIV).

Species	Relative frequency	Relative density	Relative dominance	SIV
Afzelia africana (Sm. Ex pers.)	1.149425	0.187622	0.187622	1.524668
Albezia zygia (DC.)	0.492611	0.046715	0.046715	0.58604
AlbIzia adianthifolia (Shumach.) W.Wight	0.328407	0.015724	0.015724	0.359855
Allophlus africanus P.Beauv.	0.164204	0.000888	0.000888	0.16598
Annona senegalensis Pers.	0.164204	0.00123	0.00123	0.166663
Anthocleista djalonensis A. Chev.	1.970443	0.732412	0.732412	3.435267
Anthocleista vogelii (Planch.)	0.328407	0.014432	0.014432	0.357271
Anthonatha macrophylla P. Beauv.	0.164204	0.00123	0.00123	0.166663
Bridelia ferruginea Benth	0.328407	0.003876	0.003876	0.336159
Ceiba pentandra L.	0.164204	0.005297	0.005297	0.174797
Cola millenii (K. Schum.)	0.492611	0.009644	0.009644	0.5119
Daniellia oliveri (Rolfe) Hutch. & Dalziel	12.64368	50.06055	50.06055	112.7648
Dialium guineense Willd.	10.83744	8.694261	8.694261	28.22596
Ekerberga senegalensis A. Juss	0.985222	0.192207	0.192207	1.369636
Entandrophragma angolense (Welw.)	0.328407	0.012994	0.012994	0.354395
Ficus capensis Thumb.	0.164204	0.002079	0.002079	0.168361
Funtumia elastica (P. preuss)	1.642036	0.209512	0.209512	2.061061
Gmelina arborea Roxb.	0.164204	0.012008	0.012008	0.18822
Hymenocardia acida Tul.	1.642036	0.159175	0.159175	1.960385
Khaya senegalensis (Desr.) A. Juss	0.164204	0.039964	0.039964	0.244132
Lannea welwitsschii (Hien) Engl.	6.568144	2.764013	2.764013	12.09617
Lecaniodiscus cupanioides Planch.	0.164204	0.002497	0.002497	0.169198
Lophira lanceolata Tiegh. Ex Keay	6.075534	3.958401	3.958401	13.99234
Margariteria discoidea (Baill.) G.L Webster	8.538588	4.224488	4.224488	16.98756
Milicia excelsa Welw.	0.164204	0.00609	0.00609	0.176385
Milletttia thonngii (Shumach & Thonn.) Baker	0.492611	0.002586	0.002586	0.497783
Musanga cecropoides R.Br.	0.164204	0.007382	0.007382	0.178968
Napoleona imperialis P.Beauv.	3.284072	0.54899	0.54899	4.382052
Nauclea latifolia Smith	0.492611	0.010344	0.010344	0.513298
Parkia biglobosa (Jacq.) G.Don	3.284072	1.598756	1.598756	6.481584
Pentaclethra macrophylla Benth.	1.477833	0.31004	0.31004	2.097913
Periscopsis elata (Harms) van Meeuwen	0.492611	0.002079	0.002079	0.496768
Pseudocedrela kotschyi (Schweinf) Harms	5.090312	2.938613	2.938613	10.96754
Pterocarpus osun Craib	0.985222	0.051574	0.051574	1.08837
Pyrostria guinnensis Comm. ex A.Juss	15.92775	19.67825	19.67825	55.28425
Rauvolfia vomitoria Afzel.	0.164204	0.003051	0.003051	0.170305
Spathodea campanulata (P. Beauv.)	0.821018	0.039262	0.039262	0.899543
Spondias mombin (L.)	0.656814	0.052378	0.052378	0.761571
Sterculia tragacantha Lindl.	2.627258	0.552916	0.552916	3.733089
Terminalia avicennoides Guill. & Perr.	5.91133	2.496663	2.496663	10.90466
Terminalia glaucescens Planch.	0.985222	0.091521	0.091521	1.168263
Treculia africana Decene	0.164204	0.030753	0.030753	0.22571
Vitex doniana	1.149425	0.227537	0.227537	1.604499
	100	100	100	300

The carbon storage in the biomass across the plots ranged from 16.43172-42.9298 t/Ha (**Figure 3**).

Species within the ecosystem were dominated by three families: Fabaceae, Euphorbiaceae and Moraceae which had 9, 3 and 3 species, respectively (**Table 3**).

Carbon estimates across the plots correlated with the total basal area and a number of stems across the ecosystem.

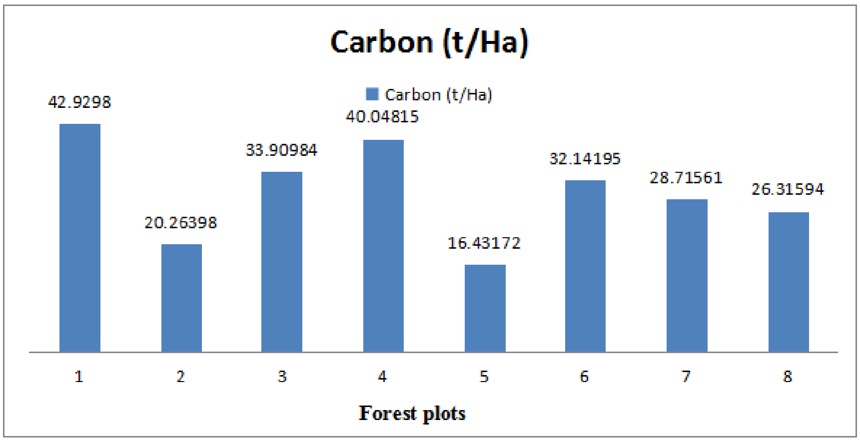

Figure 3. Distribution of aboveground carbon across the plots.

Table 3. Distribution of families and their species.

Family	Number of species
Anacardiaceae	2
Annonaceae	1
Apocynaceae	2
Bignoniaceae	1
Combretaceae	2
Euphorbiaceae	3
Fabaceae	9
Gentianaceae	1
Lamiaceae	1
Lecythidaceae	1
Leguminosae	2
Loganiaceae	1
Maliaceae	2
Malvaceae	1
Meliaceae	2
Moraceae	3
Ochinaceae	1
Rubiaceae	2
Sapindaceae	2
Streculiaceae	2
Urticaceae	1
Verbenaceae	1

4. Discussion

Tree species composition of the ecosystem was made up of 43 species (**Table 2**) that differed in occurrence/presence across the ecosystem (**Table 1**). This is however lower than what is recorded for other tropical forests in Africa [14]. This is equally much lower than the records from the Neotropics [15]. Such low occurrence was mainly because the region is within forest-savannah ecotone and not exclusively a rainforest, which will expectedly record a higher number of tree species as is characteristic of tropical forests. The abundance of trees in such ecotones is equally dependent on how far the ecosystem entered into the savannah (grassland). The extent or the depth of edge a vegetation type extends into the other ecosystem has much influence on the vegetation [16,17]. Such is due to inherent features such as microclimate conditions and fire vulnerabilities of (the major zone that dominates) the transition zone. Tree dominance was concentrated on *Daniellia oliveri* (Rolfe) Hutch. & Dalziel, *Pyrostria guinnensis* Comm. ex A.Juss, and *Dialium guineense* Willd.; which had more than half (78.42%) of the dominance in the region. Such dominance is however not characteristic of such transition zone alone, but are also patterns of dominance and monodominance that are similar to rainforest ecosystems [18]. The dominance of species in ecosystem borders directly on the successes species achieves in an environment [19]. Such is mainly characterized by the frequency/abundance of such species in a community. On the other hand, few families were seen to have many of the species in the ecosystem (**Table 3**); with Fabaceae being the most dominant (with the highest number of species). Fabaceae family is among the families with the largest number of species in the world [20,21]. It is equally reported to be very diverse and dominant in other ecosystems and regions, including the dry forests in the Neotropics [22,23].

The forest structure showed tree stems for each of the categories (**Figure 2**), with a greater number of tree stems concentrated in the lowest stem category than others. Ample number of stems was found within the middle class/juvenile stems and sufficient for good recruitment and replacement. Fewer tree stems were large and showed that the ecosystem though mature, is not however a climax vegetation; being greatly affected by disturbance regimes. Ecosystems undergo natural disturbances periodically and in most situations, recover from them within short time scales; depending on their intensity. Disturbances are equally important natural phenomenon of forest ecosystem dynamics and largely modulate the structure and functioning of forest ecosystems [24]. While such patterns are inherent in ecosystems and benefit them, landscapes (such as the ecotones with savannah) that may not have much resilience that exists in some others (such as the rainforest) are however more adversely affected by such occurrences. On the other hand, it may equally affect their biological diversity and other roles such as their capacity to provide ecosystem services; such as adequate timber supply and carbon storage. Ensuring that disturbances in ecosystems, especially anthropogenic associated disturbances are greatly minimized in the rainforest-savannah ecotones as well as other forest landscapes are much needed to inhibit the debilitating impacts on the forest structure and the ecosystem function and service provision in totality.

The aboveground carbon of the ecosystem ranged from 16.43172-42.9298 t/Ha across the ecosystem (**Figure 3**). Species composition is much varied across and within ecosystems, and largely influences their ability to provide varied functions. Carbon estimates correlated with basal area and a number of stems in the ecosystem. With R values of 0.71 and 0.55 (**Table 4**), it showed that there were other variables that contributed to the estimate. Plots that had higher basal areas and a number of stems did not consistently record higher estimates of carbon (**Table 5**) either. Such variations in carbon estimate of the plots were mainly due to differences in tree structure, density and composition across the plots. While these biodiversity variables are expected to vary at the plot level due to inherent local factors and disturbance ranges, the role the (plots) ecosystem plays in carbon storage is worthy of note. Species with higher frequencies of occurrence and dominance (**Table 2**) had cumulative higher basal areas, and densities, and hence, contributed to much of the carbon stores. However, many of such species did not necessarily have higher (WSG) capacities to store carbon as distinct species and showed how weak the landscape could be as regards climate change mitigation. *Daniellia oliveri* (Rolfe) Hutch. & Dalziel recorded the highest dominance of 50.06% and a low WSG (0.493 g/cm^3) while *Anthonatha macrophylla* P. Beauv. had the highest WSG (0.842 g/cm^3) and the second least dominance of 0.0012%; occurring only once alongside other 12 species (**Table 2**). This meant that the main species in the ecosystem do not necessarily have much capacity to store carbon, and could only store some ample amount due to its structural features (which could be prone to disturbance like any other landscape). Managing the ecosystem adequately to ensure higher carbon storage is a necessity for mitigating environmental change concerns. Such strategies would be best actualized by utilizing target species such as *Anthonatha macrophylla* P. Beauv. which can thrive in the ecosystem and possesses higher carbon capture potentials in reforestation and ecosystem restoration.

Table 4. Correlation between carbon estimates, basal area and number of stems.

		Total basal area	Total amount of carbon	Number of stems
TBA	Pearson Correlation	1	0.155	0.250
	Sig. (2-tailed)		0.714	0.551
	N	8	8	8
CARBON	Pearson Correlation	0.155	1	–0.066
	Sig. (2-tailed)	0.714		0.877
	N	8	8	8
STEMS	Pearson Correlation	0.250	–0.066	1
	Sig. (2-tailed)	0.551	0.877	
	N	8	8	8

TBA = Total basal area, STEMS = Number of stems.

Table 5. Distribution of basal area, carbon and number of stems across the plots.

Plot number	Total basal area	Carbon (t/Ha)	No of stems
1	1649359	42.9298	79
2	2833696	20.26398	64
3	3512737	33.90984	46
4	3494514	40.04815	72
5	1551143	16.43172	75
6	4213784	32.14195	90
7	2976830	28.71561	72
8	3977356	26.31594	110

5. Conclusions

Forest-savannah ecotone is not as diverse as tropical rainforests due to its transition to the savannah. They recorded ample carbon estimates but were characterized by many species that were not as carbon dense as the few ones. Managing the ecosystem with the more carbon-dense species was advocated as measure that could help the ecosystem ensure better climate change mitigation.

Conflict of Interest

There is no conflict of interest.

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