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Floral Species Diversity and Carbon Stocks of Protected Forest Ecosystem at UENR's Bat Sanctuary, Sunyani, Ghana

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Abstract

The study assessed the functional status of the University of Energy and Natural Resources' (UENR) bat sanctuary by examining its floral species diversity and carbon stocks. Twenty-nine sampling points (plots) were randomly generated by using the ArcGIS random sampling algorithm. Using a three-nest sampling plot of 100 m^2, 25 m^2, and 1 m^2 quadrat, the enumeration of trees (DBH > 10 cm), saplings (>2 cm DBH < 10 cm) and seedlings (girth < 2 cm) was undertaken, respectively. Additionally, the diversity of each floral species was computed using the Shannon Wiener diversity index whilst the carbon stocks were estimated using allometric equations. The total carbon stock per plot was derived from the summation of the aboveground carbon (AGC), belowground carbon (BGC) and deadwood carbon (DWC). In sum, 485 floral individuals belonging to 58 species and 25 families were enumerated with Bignoniaceae (16.4%), Apocynaceae (10.0%), Caesalpiniaceae (9.2%) and Rubiaceae (8.8%) being the most common families within the protected area (PA) based on their Importance Values (IV). The average carbon sequestered per hectare of the PA was 2789.3 tons. However, there was no significant difference ($p > 0.05$) between the 10 m buffer created and the core area with respect to floral species diversity and carbon stocks. The study had provided valuable information on the functional status of the bat sanctuary, which will help promote its conservation for sustained provision of ecosystem services.

Keywords

Carbon Stocks, Floral Species Diversity, Protected Area (PA), Edge Effects, Geostatistics, Ghana

1. Introduction

Forests and climate change have an intricate connection. Whilst forests lessen climate change by absorbing atmospheric carbon, they can contribute to climate change if they are degraded or destroyed (Mansourian et al., 2009). On the other hand, climate change worsens when the changes in climatic variables lead to a further degradation or loss of forests. Tropical forests sequester approximately 37% of the atmospheric carbon in the aboveground tree biomass and soil (Martin et al., 2015). The Amazon forest, for example, stores an estimated 150 to 200 Gt of carbon in biomass and soil (Feldspausch et al., 2012). Likewise, the forests in Ghana assist in the regulation of climate change by storing considerable volumes of atmospheric carbon in the form of carbon dioxide (CO_2). Although detailed information about carbon stocks of forests for the entire country is scanty (Donkor et al., 2016), their protection is of importance for the conservation of global species diversity and atmospheric carbon sequestration.

Protected areas (PAs) are elements of complex landscapes (Crooks & Sanjayan, 2006). According to Dudley (2008), a PA is "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values". They are managed mainly for biodiversity conservation, yet an important sink for atmospheric CO_2 (Crooks & Sanjayan, 2006). Since their degradation affects global carbon cycle and biodiversity conservation, reliable and timely information on the abundance of species, their distribution and information about their habitats as well as threats are requisites for proper management after establishing protected areas (De Leeum et al., 2002). Such information will serve as reference for identification and monitoring of areas within the landscape that will need specific attention. It will also enable ecosystem managers to be able to identify location specific factors that affect the distribution of biodiversity and landscape. However, even when this information is established, changes resulting from processes of natural selection, resource use, and changes in environmental conditions make further studies necessary (De Leeum et al., 2002).

The study focused on the University of Energy and Natural Resources Bat Sanctuary (UENRBS). There has been an increase in land use conversions in recent times in the study site due to increasing infrastructural development thereby raising concerns as regards the sustainability of the remnant forests at the bat sanctuary. Information on species distribution and carbon stocks in biomass is an important consideration in evaluating not only the responsiveness of the PA to current developments but also its ecological values. Thus, an assessment and mapping of the ecosystem's values and health will require reliable information on floral species distribution and stocks of carbon stored in biomass.

In Ghana, various studies have documented the kinds, distribution and abundance of plant and animal species for conservation purposes (Burgess et al., 2007; Hall and Swaine, 1981). Yet, the stocks of carbon, diversity, abundance, richness and spatial distribution of species within the sanctuary have been given limited attention. Again, limited effort has been made towards assessment of edge effects at the sanctuary. This is important because subtle changes in the microhabitat along the edges of the sanctuary, could affect the distribution, abundance and diversity of plant species (Boakye et al., 2017). Thus, effects of edges on the sanctuary need to be assessed in order to make informed decisions on the conservation status of the protected forest ecosystem.

As a result, this study aims at mapping carbon stocks and spatial distribution in the sanctuary by mapping the distribution of the floral biodiversity and assessing the effects of edges on the sanctuary. Specifically, the study 1) undertakes a total enumeration of floral species of the PA; 2) to examine the diversity of functional groups of species in the sanctuary; and 3) explores the relationship between species composition and carbon stocks at both the edge (buffer) and core areas of the sanctuary.

2. Methods

2.1. Description of the Study Area

The study was undertaken at the bat sanctuary of the University of Energy and Natural Resources (UENR), Sunyani. The sanctuary is located at latitude 7˚20' 50''N and longitude 2˚20'30''W. It has a total area of 3.6 hectares and occupies about 7.3% of the UENR campus area. It was established to provide a natural habitat for animals (mainly wildlife) which would be used for research purposes. The dominant tree species is *Newbouldia laevis* and the least abundant is *Triplochiton scleroxylon*. The dominant undergrowth is the *Psychotria spp*., which can support duikers. According to MoFA (2010) the mean monthly temperature of Sunyani is between 23˚C and 33˚C whilst the relative humidity is generally high; averaging between 75 and 80 percent during the rainy seasons and 70 and 80 percent during the dry seasons of the year. The average annual rainfall for Sunyani is about 1100 mm. The area experiences a double maxima rainfall pattern which offers farmers the opportunity to farm twice in a year; the main season and the minor season (MoFA, 2010) although the rainfall pattern appears to be changing in recent times due in part to deforestation and forest degradation. The main rocks underlying the area are the Precambrian Birimian formations which have high mineral deposits and widespread masses of granite. The soils, mainly Ochrosols, are generally fertile with high water holding capacity and support a wide range of agricultural crops (MoFA, 2010).

2.2. Floral Survey Procedures

The study commenced by mapping the boundaries of the protected area (PA) using the Garmin Global Positioning System (GPS) 64 sc. The points were plotted to ascertain the actual boundaries of the PA. To find out the effects of edges on carbon stocks and floral species diversity, a 10 m width of the edges from the boundaries of the protected area was created using the Buffer Wizard of the ArcGIS (v10.4) and designated as a buffer zone whilst the interior beyond the 10 m buffer was designated as core zone. In all, twenty-nine (29) sampling points (plots) were randomly generated for species enumeration with 10 plots located within the buffer and 19 plots located within the core zone (**Figure 1**). The coordinates were transferred to the GPS to help in plots location on the field for survey. At the field, a three-nest square sampling plots comprising a 10 m × 10 m quadrat (main plot), 5 m × 5 m and 1 m × 1 m subplots were constructed for vegetation assessment. Whilst enumeration of tree species was undertaken in the 100 m^2 plots, shrubs and seedlings enumeration was undertaken in the 25 m^2 and 1 m^2 subplots, respectively. The trees had diameter at breast height (DBH) greater than 10 cm, saplings had DBH greater than 2 cm but less than 10 cm and seedlings had girth less than 2 cm.

2.3. Statistical Analysis

We calculated plant species richness and diversity using the Shannon-Wiener indices. The Shannon-Weiner index (H') and Family Importance Value Index (FIVI) were calculated by using equations simplified in **Table 1**. The carbon stocks of the floral species of the PA were computed as summation of the aboveground carbon (AGC), the belowground carbon (BGC) and dead wood carbon (DWC) using the allometric equations described by Brown (1997) and Cairns et al. (1997) (**Table 1**). The data obtained from the field survey were analysed to extract salient information to assess the impacts of the explanatory variables on the dependent variables. A two-sample T-test was conducted to test the differences in the vegetation and carbon parameters. Beforehand, the data were cleaned and arranged under themes.

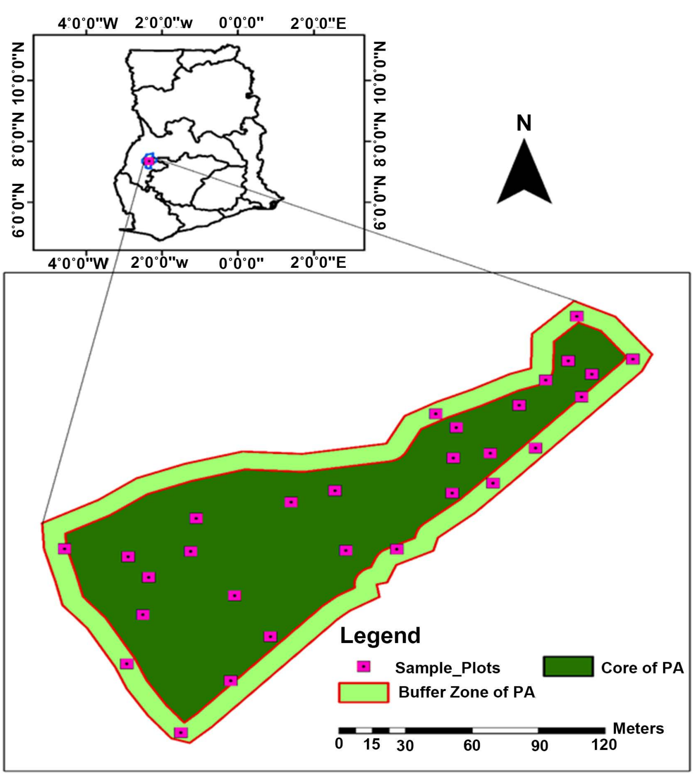

Figure 1. Location of plots within the protected area (PA) studied.

Table 1. Description of indices.

Index	Formula	Description
Shannon-Wiener Diversity (*H'*)	$-\sum Pi\ln(pi)$	Pi is the proportion of S made up of the i^{th} species, and ln is natural logarithm.
Density (*Di*)	$\frac{N_A}{TA_{sampled}}$	N_A is the number of species "*A*"; $TA_{sampled}$ is total area sampled.
Relative Density (*RD*)	$\frac{RD}{TD}\times 100$	*RD* is the relative density of species; *AD*: is the absolute density of species (per 100 m^2) and *TD* is the total density of flora species (per 100 m^2).
Frequency (*F*)	$\frac{NP_a}{TP_{sampled}}$	NP_a is the number of plots in which species "*A*" occurs; and $TP_{sampled}$ is total plots sampled.
Relative Frequency (*RF*)	$\frac{AF}{TF}\times 100$	*RF* is relative frequency of species; *AF*: is the absolute frequency of the species, and *TF* is the sum of absolute frequencies of all species.
Cover (*Ci)*	$\frac{\pi*(DBH)^2}{4000}$	*DBH* is diameter at breast height (1.3 m); π 3.14.
Relative Cover (*RCi*)	$\frac{ACi}{TCi}\times 100$	*RC* is the relative cover of species; *AC* is an absolute cover (or basal area) of species *i*, and *TDi* is a total cover (or basal area) of all species.
Family Importance Value Index (*FIVI*)	$\frac{RD+RF+RCi}{3}$	
Above-Ground Biomass (*AGB*)	$WD*\left(EXP\left(-1.4229+2.148\left(\ln[DBH]\right)+0.207\left(\ln[DBH]\right)^2-0.0281\left(\ln[DBH]\right)^3\right)\right)$ where: *WD* is the wood density (0.6)	
Below-Ground Biomass (*BGB*)	$EXP\left(-1.0587+0.8836*\left(\ln[AGB]\right)\right)$	
Total Biomass (*TB*)	$AGB+BGB+DWB$	*DWB* is deadwood biomass
Total Carbon (TC)	$0.5\times TB$	(IPCC, 2003)
CO_2e	$TC\times M_w(CO_2)$	*TC* is the total carbon; M_W is the molecular weight of Carbon (I *V*) oxide (44/12).

Such thematic representation of data allowed easier usage of the MS Excel T-test algorithm. The T-test was computed to test whether significant differences exist between the mean carbon of the edges and inner core of the PA at 5% level of significance. Again, the diversities of species of the respective zones of the PA were compared. All statistical analyses were done using Excel application of the Microsoft office suite, 2016 (Microsoft Corp.).

3. Results and Discussion

3.1. Species Diversity and Composition

Overall, 485 individuals belonging to 58 species and 25 families were enumerated at the study area. The most represented species are *Newbouldia laevis* (19.4%), *Griffonia simplicifolia* (9.3%), *Salacia elegans* (7.8%), *Senna siamea* (5.4%), *Holarrhena floribunda* (5.4%), *Psychotria ankasensis* (4.9%), and *Millettia thonningii* (4.5%). The most dominant families included Bignoniaceae (19.4%), Caesalpiniaceae (15.3%) Rubiaceae (9.1%), Clastraceae (7.8%), Apocynaceae (6.4%) Mimosaceae (6.4%) Sapindaceae (6.2%) and Papilionaceae (6.2%).

3.1.1. Classification by Growth Form

Table 2 shows the diversity of floral species in core area compared to the buffer zone. The tree species were less diverse (*H'* = 4.32 ± 0.09) in the core compared to the buffer zone (*H'* = 4.55 ± 0.09), though difference in mean diversities between the two zones where statistically insignificant at 95% confidence level. A similar situation was observed for the seedling life form, where diversity was higher in the buffer (*H'* = 5.11 ± 0.11) than the core zones (*H'* = 4.93 ± 0.09), yet statistically insignificant (*p*-value > 0.05). However, the sapling life forms were more diverse within the core zone of the protected area than the buffer zone. The higher diversity of seedlings at the buffer zone may be a result of the exposure to sunlight, which helps to promote germination. Kettenring et al. (2006) reports that light requirements for germination contribute to the formation of persistent seed banks in Carex species. Other factors accounting for the difference in diversity could be the uneven spatial distribution of soil nutrients and other growth requirements in the soil (Boakye et al., 2017).

3.1.2. The Family Importance Value Index (FIVI) of the Species

Importance Value is a measure of how dominant a species is in a given forest area. A high importance value indicates that members of a family are well represented in the stand. The family important value (FIV) summed the relative percentage values of density, frequency and dominance of all the families of the first five most documented floral species within the PA. Bignoniaceae (16.38%), Apocynaceae (10.02%), Caesalpiniaceae (9.21%), Rubiaceae (8.84%), Mimosaceae (7.06%), and Moraceae (6.71%) were the common families within the PA, whilst Boraginaceae (0.60%), Fabaceae (0.60%), Connaraceae (0.56%), Dilleniaceae (0.27%), and Araliaceae (0.27%) were the rarest families of the PA (Table 3). The Shannon Wiener diversity indices of the first five most common families were 4.39, 4.79, 4.33, 4.70, 4.77 and 4.99 respectively.

3.2. Carbon Stocks Estimation

Table 4 shows the total carbon storage of floral species per plot and their respective carbon dioxide (CO_2) equivalences. The total amount of CO_2 sequestered per hectare of the bat sanctuary ranges from 1992.5 to 31,781.2 t/ha, with a mean of 10,227.4 t/ha. Generally, the total terrestrial ecosystem carbon is estimated based on six carbon pools (Eggleston et al., 2006). However, for the purpose of this study, the total carbon of the PA was estimated by the summation of three major carbon pools of the AGC, BGC and DWC of the different life forms of

Table 2. Variation in floral species diversity in the bat sanctuary.

Life forms	Shannon Diversity		*P*-value
	Core	Buffer	
Trees	4.32 ± 0.09	4.55 ± 0.09	0.089
Saplings	4.32 ± 0.10	4.29 ± 0.06	0.823
Seedlings	4.93 ± 0.09	5.11 ± 0.11	0.217

(Mean ±std. error).

Table 3. Family importance value Index (*FIVI*) for the documented families.

Family	*RD*	*RF*	*RC*	*FIVI*	*H'*
Araliaceae	0.231	0.571	0.002	0.268	4.75
Dilleniaceae	0.231	0.571	0.000	0.268	5.49
Connaraceae	0.543	1.143	0.002	0.563	5.49
Fabaceae	0.298	0.571	0.928	0.599	5.14
Boraginaceae	1.215	0.571	0.018	0.602	3.20
Anacardiaceae	0.134	0.571	1.217	0.641	5.14
Menispermaceae	0.457	1.714	0.002	0.724	5.24
Annonaceae	0.782	1.714	0.056	0.851	4.86
Combretaceae	0.942	2.286	0.002	1.076	5.49
Meliaceae	0.804	2.286	0.767	1.285	5.04
Irvingiaceae	0.198	0.571	3.812	1.527	5.14
Asclepiadaceae	2.394	2.857	0.019	1.757	5.00
Bombacaceae	0.523	1.143	4.001	1.889	4.88
Sterculiaceae	1.354	2.286	5.316	2.985	4.70
Clastraceae	6.987	6.857	0.090	4.645	4.64
Euphorbiaceae	5.737	6.857	2.627	5.074	4.78
Papilionaceae	6.661	6.857	3.138	5.552	4.62
Sapindaceae	6.988	7.429	2.418	5.611	4.65
Verbenaceae	4.218	3.429	9.924	5.857	4.49
Moraceae	4.212	5.714	10.209	6.712	4.99
Mimosaceae	6.123	7.429	7.632	7.061	4.77
Rubiaceae	8.767	8.000	9.767	8.845	4.70
Caesalpiniaceae	12.193	8.571	6.858	9.207	4.33
Apocynaceae	7.179	8.000	14.893	10.024	4.79
Bignoniaceae	20.828	12.000	16.303	16.377	4.39

Table 4. Estimates of carbon pools of the sanctuary.

C pools	Description	Carbon (tons/ha)	
		Mean	Range
AGC	AGB*0.5	2491.9	478.9 - 7799.9
BGC	BGB*0.5	11.9	64.5 - 867.7
DWC	DWB*0.5	0	0
Total carbon	AGC + BGC + DWC	2511.3	543.4 - 8667.6
CO_2e	TC*(44/12)	10,227.4	1992.5 - 31,781.2

AGC = Aboveground carbon, BGC = Belowground carbon, TC = Total carbon, CO_2e = Carbon dioxide equivalent.

species enumerated. The AGC ranges from 478.9 tons/ha to 7799.9 tons/ha with an average of 2491.9 tons/ha. With an average carbon content of 297.4 tons/ha, the BGC range from 64.5 tons/ha to 867.7 tons/ha. This carbon stock per hectare obtained was relatively higher compared to that of Donkor et al. (2016) who performed a similar study in the Bosomkese forest reserve in the dry semi-deciduous forest zone (**Table 5**). The total carbon stocks per hectare within the floral species biomass and their respective carbon dioxide equivalent values have been appendiced (**Appendix I**).

We tested the management option of having a buffer zone around the PA. This may be required in addition to the laid down rules to help in the conservation of the protected area. Thus, we created a 10 m buffer zone as a management option from the edges of the forested ecosystem with the help of the buffer wizard of the ArcGIS application suite. The carbon stocks obtained from the sample plots found within the core of the PA were compared to those estimated for the buffer zone by means of the T-test. The mean carbon sequestration of the floral species in the core area was higher than that of the buffer area. Typically, most PAs are perceived to sequester varied amounts of carbon with respect to the buffer and core zones respectively due to the unequal distribution of soil nutrients and other growth requirements (Boakye et al., 2017). However, from **Figure 2**, our analysis indicated that the buffer zone of the protected area has no influence on the mean carbon stocks. Thus, the mean difference between the carbon stocks observed for the buffer and the core zones was statistically insignificant at 95% confidence level.

3.3. Geostatistical-Based Inference of Carbon Stocks

Figure 3 shows the spatial representation of total carbon drawn by using the Inverse Distance Weighing algorithm of the ArcGIS software. The carbon stocks ranged between 551.8 t/ha and about 8655.3 t/ha. The majority of the PA had estimated carbon stock values closer to the slightly overestimated mean of 2804.7 (±975.9) t/ha determined by the geostatistical modelling tool. This can be attributed to the fact that the species of the PA are of even age and the sampling technique helped to capture average values that are good representation of the protected area. The study area is averagely storing about 2804.7 t/ha of carbon. We found a relatively higher carbon per hectare of forest compared to Donkor et al. (2016) who found an average of 1748.4 tons/ha of carbon (**Table 5**). The higher carbon per hectare from our study is an indication that natural forest sequesters the greatest amount

Table 5. Comparison of estimates.

Carbon (t/ha)	Source	Area	Forest type	Method used
1748.4	Donkor et al. (2016)	Bosomkese Forest Reserve	Dry Semi-Deciduous	FS & GIS
2789.30	This study	Bat Sanctuary	Moist Semi-Deciduous	FS & GIS

FS is Field Survey; GIS is Geographic Information Science.

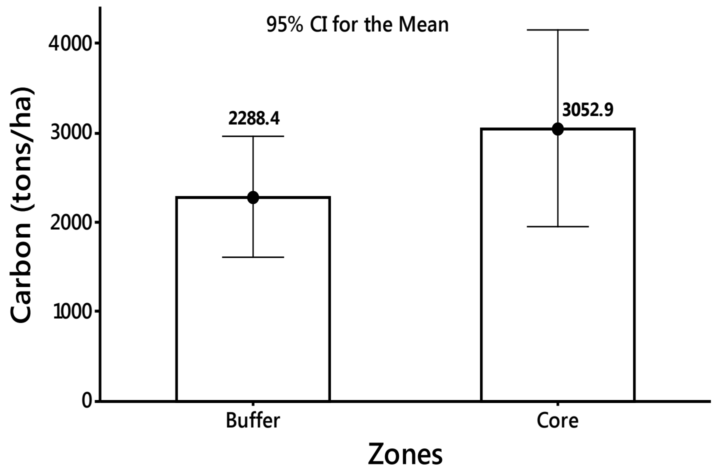

Figure 2. Carbon stocks dynamics of the PA.

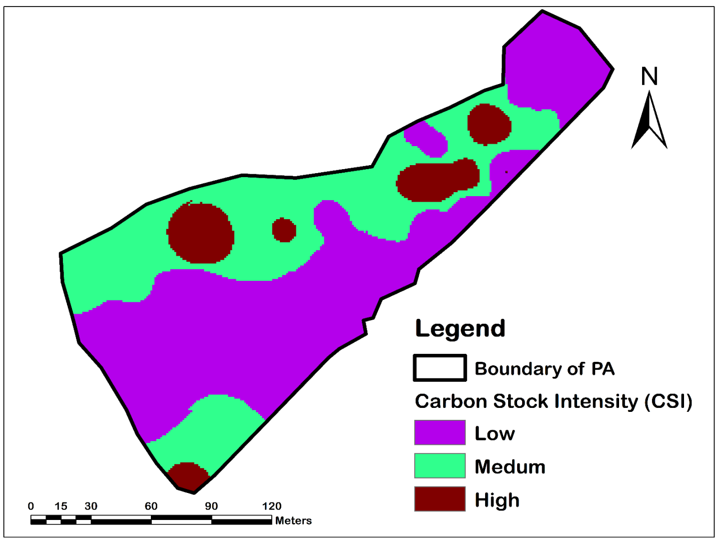

Figure 3. Carbon storage intensity (CSI) map of the PA produced by using the inverse distance weighting (IDW) interpolation approach.

of CO_2 and management regimes has an impact on the overall health of a protected forest area.

Additionally, the spatial extent and high carbon sequestration of the PA was computed. To assess fluctuation in relation to carbon dynamics, three categories of total carbon, with natural breaks, were identified. These were: the highest (TC ≥ 4111.0), middle (2681.0 ≤ S ≥ 4111.0), and lower (0.0 ≤ S ≥ 2681.0). About 130,434.2 sq. meters (53.7%) of the PA had a relatively low carbon stock, compared to medium carbon (9036.5 sq. meters; 41.9%) and high carbon storage areas (3587.4 sq. meters; 14.8%) (Table 6).

Figure 4 shows the carbon-diversity map obtained by superimposing the Shannon Wiener diversity image on the carbon image. Mostly, a larger proportion (8783.3 m^2; 36.2%) of the PA that stores low carbon has high diversity, which is represented in Table 7. The larger spatial coverage may be an evidence of the

Table 6. Estimate of the area occupied by intensity major carbon of the study area.

Categories	Area (m^2)	% of PA	Range
Low	13034.2	53.7%	<21,790.1
Moderate	9036.5	37.2%	21,790.1 - 32,105.1
High	2218.8	9.1%	>32,105.1

Table 7. Statistics obtained by superimposing floral diversity and carbon images.

Categories	Description	Areas (m^2)	Percent (%)
LC_LD	Low carbon and low diversity	252.9	1.0
LC_MD	Low carbon and moderate diversity	3997.2	16.5
LC_HD	Low carbon and high diversity	8783.3	36.2
MC_LD	Moderate carbon and low diversity	2401.1	9.9
MC_MD	Moderate carbon and moderate diversity	5771.1	23.8
MC_HD	Moderate carbon and high diversity	1179.4	4.9
HC_LD	High carbon and low diversity	1010.7	4.2
HC_MD	High carbon and moderate diversity	862.9	3.6
HC_HD	High carbon and high diversity	27.2	0.1

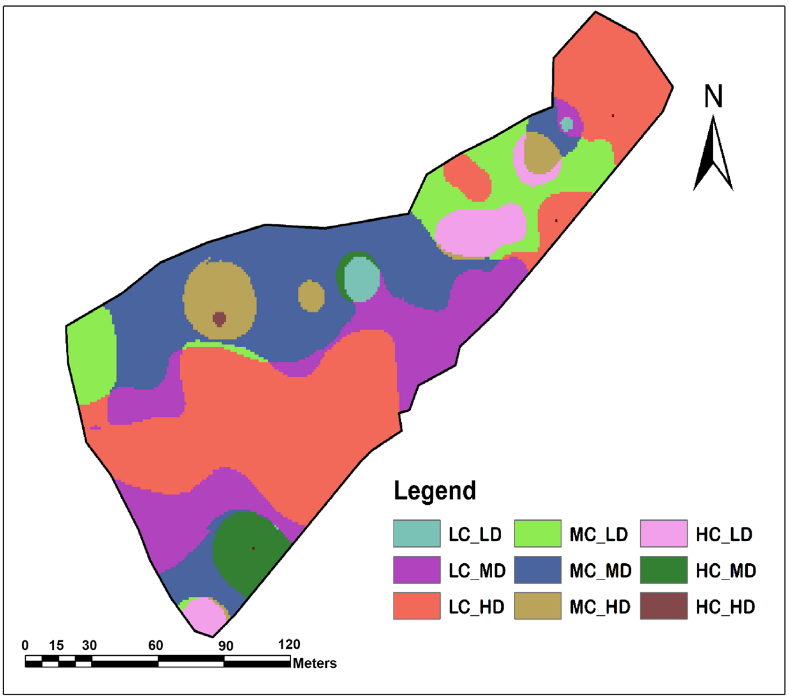

Figure 4. Spatial representation of the overlap of carbon and diversity.

poor correlation between carbon stock and floral diversity. Although negatively, Lange et al. (2015) found that legumes affect soil carbon concentration. Similarly, Mandal et al. (2013) also found a very weak relationship between carbon stock and species richness of collaborative forests.

4. Conclusion

The present study assessed the functional status of Protected Area (PA) by analysing the variations in carbon stocks and floral species diversity of both the buffer and core zones of the UENR's Bat sanctuary. Our results revealed that a total of 485 floral individuals belonging to 58 species and 25 families were enumerated at the sanctuary. Bignoniaceae (16.38%), Apocynaceae (10.02%), Caesalpiniaceae (9.21%), Rubiaceae (8.84%), Mimosaceae (7.06%), and Moraceae (6.71%) were the dominant families based on their Importance Value (IV). These functional groups were dominated by individual species such as *Newbouldia laevis*, *Griffonia simplicifolia*, *Salacia elegans*, and *Senna siamea*. The average carbon stock per hectare sequestered by the PA was 2789.30 tons. The buffer zone (edges) had no significant impact on the floral species diversity and carbon stocks of the sanctuary. The study has provided valuable information on the functional status of the bat sanctuary, a protected forest ecosystem, which will help promote its conservation for sustained provision of ecosystem services for posterity.

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Appendix

Appendix I. Total biomass and carbon per hectare per plot.

Plots	Biomass (tons/hectare)				CO_2e/hectare
	AGC	BGC	DWC	TC	
1	1684.1	218.6	0	1902.7	6976.5
2	1765.0	224.6	0	1989.7	7295.4
3	1602.3	205.9	0	1808.2	6630.1
4	2161.0	275.2	0	2436.1	8932.5
5	2450.1	306.2	0	2756.3	10106.3
6	5724.4	662.4	0	6386.8	23418.2
7	478.9	64.5	0	543.4	1992.5
8	1540.7	201.4	0	1742.1	6387.7
9	4885.5	572.5	0	5458.1	20012.9
10	7799.9	867.7	0	8667.6	31781.2
12	1555.3	200.6	0	1755.8	6438.1
12	2131.5	265.0	0	2396.5	8787.2
13	744.5	102.6	0	847.0	3105.8
14	2124.0	247.3	0	2371.3	8694.8
15	1725.0	201.3	0	1926.3	7063.0
16	3971.9	457.3	0	4429.2	16240.4
17	1019.3	135.0	0	1154.3	4232.4
18	6149.5	666.3	0	6815.8	24991.3
19	1259.4	161.2	0	1420.6	5208.7
20	538.1	74.0	0	612.1	2244.4
21	1283.6	154.1	0	1437.7	5271.7
22	2679.8	329.8	0	3009.7	11035.4
23	3262.4	378.6	0	3641.0	13350.4
24	1595.6	202.1	0	1797.7	6591.6
25	1932.5	246.1	0	2178.6	7988.2
26	4085.9	473.7	0	4559.6	16718.5
27	1656.0	203.3	0	1859.4	6817.8
28	2587.6	298.8	0	2886.4	10583.4
29	1871.9	227.7	0	2099.6	7698.7
GT	**72265.7**	**8623.8**	**0**	**80889.5**	**296594.9**