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Vegetation Structure and Carbon Stocks of Two Protected Areas Within the South-Sudanian Savannas of Burkina Faso, West Africa

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Highlights:

- Carbon stock assessment of rarely sampled South-Sudanian savanna vegetation and adjacent gallery forests of two protected areas in Burkina Faso, West Africa
- Vegetation analysis of four savanna types
- Provision of baseline for further carbon offset schemes

ABSTRACT

Savannas and adjacent vegetation types like gallery forests are highly valuable ecosystems contributing to several ecosystem services including carbon budgeting. Financial mechanisms such as REDD+ have provided an opportunity for developing countries to alleviate poverty through conservation of its forestry resources. For availing this opportunity carbon stock assessments are essential. Therefore, a research study at two protected areas i.e. Nazinga

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Game Ranch and Bontioli Nature Reserve, in Burkina Faso was conducted with the objective of assessing carbon Mg C ha^{-1} in aboveground biomass $(AGB)_{dry}$ of trees in different formations of the south-sudanian savanna in Burkina Faso, West Africa. Similarly analysis of various vegetation parameters was also conducted to understand the overall vegetation structure of these two protected areas. For estimating AGB_{dry}, existing allometric equation for dry tropical woody vegetation types was used. The Importance Value Index (IVI) and Family Importance Value (FIV) were estimated through standard procedures. Various linear and non-linear regression analyses were conducted to test the relationships between carbon and other parameters such as DBH, height and basal area (BA). The results showed that both sites collectively contain mean carbon of 3.41 ± 4.98 Mg C ha^{-1}. Amongst different vegetation types, gallery forests recorded the highest mean carbon of 9.38 ± 6.90 Mg C ha^{-1}. The highest IVI of 115.56 at Nazinga Game Ranch was recorded for *Anogeissus leiocarpa*. Similarly, highest IVI of 98.59 was recorded for *Mitragyna inermis* at Bontioli Nature Reserve. The highest FIV was recorded for Combretaceae for both of the sites. To our knowledge, this was the first study conducted to assess the carbon stocks at the two protected areas in southern Burkina Faso. The study therefore was an attempt for addressing the knowledge gap particularly on carbon stocks of protected savannas. It could serve as a baseline for carbon stocks for future initiatives such as payment for environmental services and REDD+ at these areas.

Keywords: carbon stock assessment; protected areas; savannas; degradation; woody vegetation; West Africa

1. Introduction

The population of Burkina Faso was recorded as 15.7 million in 2009, it is spread over an area of 274,000 km^2 and almost 80% of the population lives in rural areas and depends on agriculture as main source of mainstay [1]. The population depends heavily on natural resources [2]. About 91% of the energy needs are met by fuelwood [3]. Moreover, livestock production and increase in population have put undue pressures on plant resources [4]. As a

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consequence, the vegetation structure and composition of the savanna habitats have been severely affected [5].

Burkina Faso has a forest area of 19.6%, with additional 17.5% categorized as “other woodlands” [6]. The increasing pressure on forestry resources has resulted in a significant annual deforestation rate of 1.0% for the period 2010-2015 [6]. In addition climate change constitutes a serious challenge, which is undermining efforts towards sustainable development. Carbon sequestration can therefore serve as an essential strategy for the mitigation of climate change [7]. Reduced Emissions from Deforestation and Forest Degradation (REDD+) is a financial scheme focusing towards reducing carbon emissions, which involves reducing emissions from deforestation and forest degradation, aiming towards the conservation and enhancement of forest carbon stocks, and a sustainable forest management including ecological and social targets [8]. Hence, REDD+ not just only provides developing countries the opportunity to tackle climate change by alleviating poverty but also conserving their forest resources [9]. Moreover, it has also been identified as one of the economically most feasible mitigation options in tackling climate change [10]. The most important issue for REDD+ schemes, however, is the estimation and the monitoring of the carbon stocks and their success therefore largely depends on the availability of scientific information on forest carbon stocks [11]. Unfortunately, there does not exist sufficient work on the quantification of carbon stocks in savannas [12]. Additionally, savannas have also been a major uncertainty in carbon accounting of Africa [13] . The study therefore focused on assessing the carbon [Mg C ha^{-1}] in aboveground biomass $(AGB)_{dry}$ of trees of typical vegetation types in two protected areas of Burkina Faso: Nazinga Game Ranch and Bontioli Nature Reserve. The study also investigated the structural composition of the vegetation at these two protected areas.

2. Materials and Methods

2.1 Study Area

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Nazinga Game Ranch was created in 1979 (Fig. 1) and is spread over an area of 97,536 ha at an altitude of 280m asl [14]. According to Burkina Faso's legislation, it has been classified as a protected area, listed as "Wildlife Reserve" and it is very well known as a tourist destination [15]. There is a single dry season running from October to May and a single rainy season, from June to September. It has a mean annual rainfall of 900 mm [14]. The average annual temperature is 27.1 °C. The Nazinga Game Ranch is traversed by Sessile River and its two tributaries i.e. Dawevele and Nazinga Rivers; the rivers have characteristic seasonal flows. The vegetation has the characteristics of Southern Sudanian savanna. Typical species of the area include; Shea Tree (*Vitellaria paradoxa* C.F. Gaertn.), Kodayoru Tree (*Terminalia laxiflora* Engl. & Diels), Female Gardenia (*Gardenia erubescens* Stapf & Hutch.), Lingahi Tree (*Afzelia africana* Sm.), African Birch (*Anogeissus leiocarpa* (DC.) Guill. & Perr.) among others [16]. For better management purposes, the Nazinga Game Ranch has been divided into four zones: (i) conservation zone, (ii) buffer zone, (iii) commercial hunting zone, and (iv) village hunting zone. The conservation zone consists of 9% and the buffer zone consists of 5% of the total area. The commercial hunting zone and the village hunting zone make 86% combined of the total area [17]. A few settlements are also located in the commercial hunting zone and village hunting zone. The area has been once known to be one of the least populated areas in Burkina Faso, but has been subjected to increasing migrations after the Sahelian drought in the 1970s [14] . The agriculture is the mainstay for the local people and the major agricultural crops are Corn (*Zea mays* L.), Sorghum (*Sorghum bicolor* (L.) Moench), Pearl millet (*Pennisetum glaucum* (L.) R. Br.) and Peanut (*Arachis hypogaea* L.).

Bontioli Nature Reserve is also called ''Forêt Classée de Bontioli'' and is located in the Sudanian zone of southwestern Burkina Faso in the province of Bougouriba (Fig. 2). It is a Category IV protected area, managed mainly for conservation through active management, according to IUCN Protected Areas Categorie. It consists of the *Total Reserve* and the *Partial Reserve*. These areas were established by the territorial government during the colonial period based on two ministerial orders; (i) Order n° 3147/SE/EF of 23 March, 1957, which was related to the demarcation of the area (29,500 ha) and the establishment of the *Partial Reserve* (ii) Order 3417/SE/EF of 29 March, 1957, which was related to the demarcation of the area and

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classification of the *Total Reserve* (12,700 ha). Our research activities were confined to the *Total Reserve* only, as the *Partial Reserve* of Bontioli does not has consistent savanna cover because of being subjected to high pressure from human activities [18].

The vegetation of the Bontioli Nature Reserve also has the characteristics of the Southern Sudanian savanna. The rainfall varies between 900-1000 mm per year [18]. The rainy season ranges from May to October and the dry season spans from November to April [19]. The mean temperature has been recorded as 27.1 °C for the period of 2004-2006. The main river is the Bougouriba, which is pivotal for the hydrographical network within the Bontioli Nature Reserve [18] . The highest altitude for the Bontioli Nature Reserve has been recorded as 350 m asl and the lowest altitude as 250 m asl. The tree species include Wild Syringe (*Burkea africana* Hook.), Barwood (*Pterocarpus erinaceus* Poir.), Ordeal Tree (*Crossopteryx febrifuga* (Afzel. ex G. Don) Benth.) and Cangara Tree (*Combretum glutinosum* Perr. ex DC).

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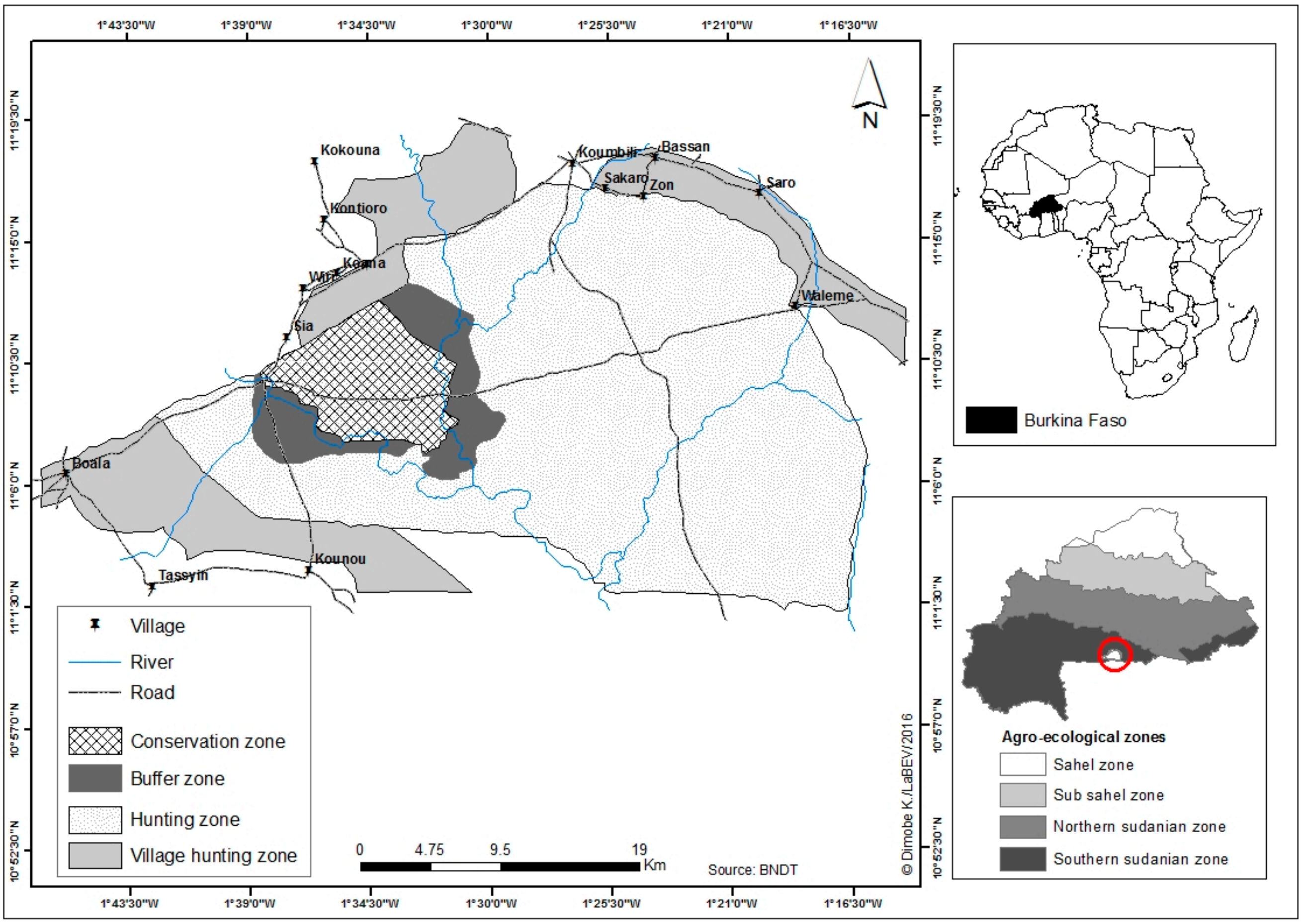

Figure 1: Nazinga Game Ranch, Burkina Faso

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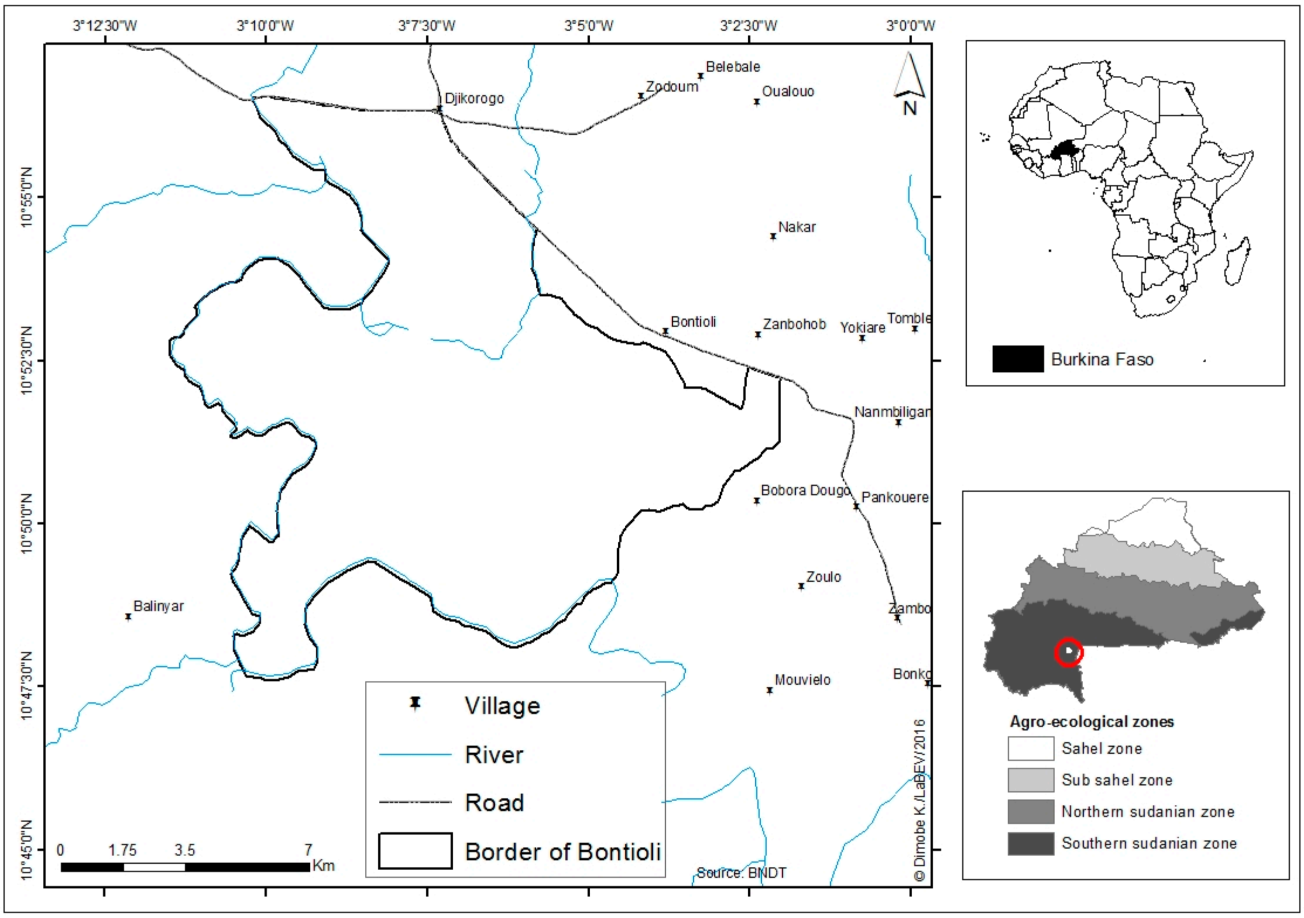

Figure 2: Bontioli Nature Reserve, Burkina Faso

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2.2 Sampling Design

A random sampling design was adopted for this study following Gibbs et al. [20]. The vegetation at both sites is classified as Southern Sudanian savanna [21]. The vegetation was further segregated into different types, according to their physiognomy; (i) woodland savanna, (ii) tree savanna, (iii) shrub savanna, and (iv) gallery forest [22]. The tree and shrub savannas were categorized according to the *Yangambi* classification in 1956 [23]. Gallery forests were categorized as the narrow patches found along the fringes of semi-permanent water courses [24]. Woodland savannas were categorized on basis of their close canopies and discontinuous grasses [25]. 20 plots were established at either site, with 5 plots each per vegetation type. The plots were square-shaped and had a size of 20 m × 20 m as suggested by Holdaway et al. [26].

2.3 Data Collection and Analysis

2.3.1 AGB$_{dry}$ and carbon stock estimation

The diameter at breast height (DBH) over bark for each tree, ≥ 5 cm, in every plot was measured with the help of the diameter tape at 1.3 m above ground level. In case of multi-stemmed trees, all stems with DBH above 5 cm were measured and the following formula was used for calculation of the respective total DBH [27];

$$DBH_{total}\ [cm] = 2 \times \sqrt{(DBH_1)^2/2 + \ldots + (DBH_n)^2/2} \qquad (1)$$

The heights of the trees were estimated using Blume Leiss Hypsometer. The heights of trees less than two meters were measured with the help of a measuring tape. For multi-stemmed trees such as *Mitragyna inermis* (Willd.) Kuntze, the tip of the tallest stem was measured.

For tree AGB$_{dry}$ estimation, the allometric equation suggested by Chave et al. [28] for dry forest stands was used, which is valid for DBH within the range of 5-156 cm;

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$$AGB_{dry(Kg)} = 0.112 \times (\rho D^2 H)^{0.916} \quad (2)$$

Where, D = DBH (cm), H = height (m), ρ = Wood Density (g cm^{-3})

The published wood densities were used for the AGB_{dry} estimation (Table 2). The wood densities at species or generic level were used subject to their availability [29]. The AGB_{dry} per plot was scaled up to Mg ha^{-1}. The AGB_{dry} (in Mg ha^{-1}) was converted to carbon stocks by multiplying with a carbon conversion factor of 0.5 [30].

2.3.2 Quadratic Mean Diameter and Density

The quadratic mean diameter for every plot was calculated as $\sqrt{(\sum d_i^2)/n}$ (d_i was DBH in cm for every tree and n the total number of trees) [31]. The quadratic mean diameter is referred to as mean DBH throughout the document hereafter. The density was the total number of trees per plot per ha.

2.3.3 Basal Area (BA), Importance Value Index (IVI) and Family Importance Value (FIV)

The BA for each sampled tree was calculated as the following;

$$BA = (DBH/2)^2 \times \pi \times \text{expansion factor for ha} \quad (3)$$

IVIs were calculated from the species relative frequency (Rf), relative density (RDe) and relative dominance (RDo) [32];

$$Rf\ (\%) = \frac{\text{Number of plots present with the species}}{\text{Total number of plots}} \times 100 \quad (4)$$

$$RDe\ (\%) = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} \times 100 \quad (5)$$

$$RDo\ (\%) = \underline{\text{Total BA of a species}} \times 100 \quad (6)$$

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Total BA for all species

IVI for each species was calculated as the sum of Rf, RDe and RDo. The FIVs were calculated from relative diversity (RDi), relative density (RDe) and relative dominance (RDo) according to [33];

$$\text{RDi (\%)} = \frac{\text{Number of species in family}}{\text{Total number of species}} \times 100 \tag{7}$$

$$\text{RDe (\%)} = \frac{\text{Number of trees in family}}{\text{Total number of trees}} \times 100 \tag{8}$$

$$\text{RDo (\%)} = \frac{\text{BA of family}}{\text{Total BA}} \times 100 \tag{9}$$

FIV for each family was eventually calculated as the sum of RDi, RDe and RDo.

2.4 Statistical Analysis

To assess the normal distribution of different variables, the Shapiro-Wilk-Test was used. The means ± Standard Deviations (SD) for averages of different variables per plot were calculated. As some data was not normally distributed, Wilcoxon Rank Sum Test was used for probing the statistical differences between two variables and Kruskal Wallis Rank Sum Test was used for more than two variables. The post-hoc analysis for significant differences in means was done using Tukey's test. A significance level of 0.05 was used for all statistical tests. The statistical analysis was performed and graphs were produced using the version 3.1.0 of R [34] .

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3. Results

3.1 DBH and height

No significant difference was recorded between mean DBHs of two sites ($p > 0.05$). The mean DBH although differed significantly amongst the vegetation types for both sites collectively ($p < 0.05$). The mean DBH of gallery forests showed significant variation from the other vegetation types for both sites collectively ($p < 0.05$; Table 1). The gallery forests recorded the highest mean DBH of 48.80 ± 16.45 cm for both sites collectively. The DBH classes for both sites collectively showed a reverse J-shape. The highest number of the trees was recorded in DBH class of 5 cm forming 39.37% of the total. Together, 5 cm and 10 cm DBH classes formed 71.16% of the total stems (Fig. 3).

Similarly, no significant difference was recorded between mean heights of the two sites ($p > 0.05$). Significant difference was recorded amongst the vegetation types for both sites collectively ($p < 0.05$; Table 1). The mean heights of gallery forests and woodland savannas differed significantly from the tree and shrub savannas ($p < 0.05$; Table 1). The largest value of 9.47 ± 1.38 m for mean height was recorded for the gallery forests for both sites collectively (Table 1).

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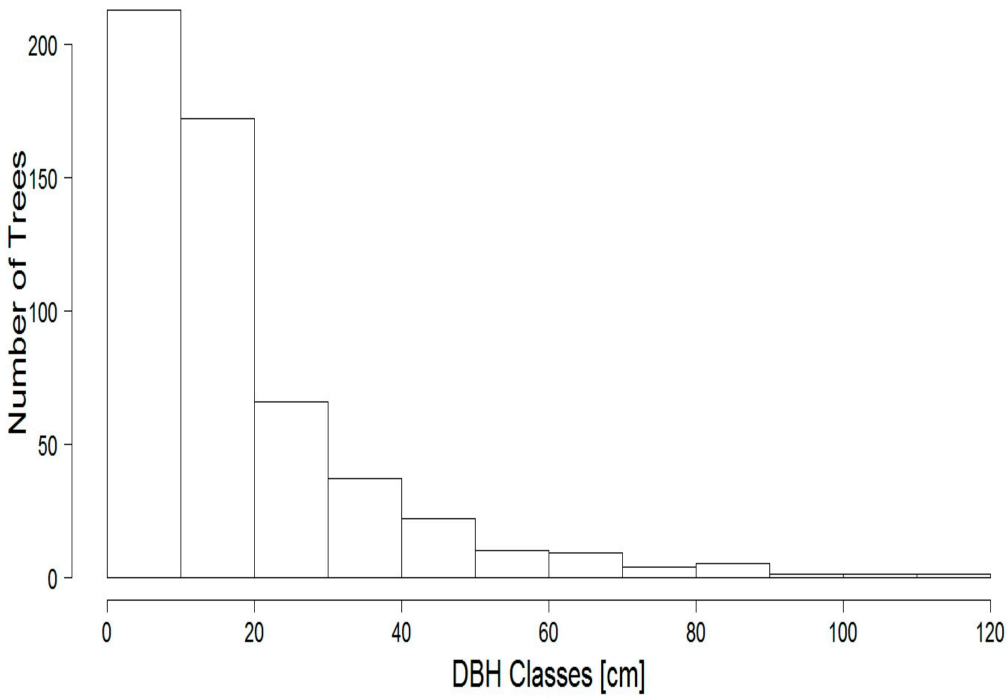

Figure 3: The number of trees in different DBH classes, n=40, for both sites of Nazinga Game Ranch and Bontioli Nature Reserve collectively. Number of trees for both sites (n=541).

3.2 Density and BA

No significant difference was recorded between mean densities of two sites (p > 0.05). Variation in mean densities of all vegetation types for both sites collectively was however recorded (p < 0.05). The highest mean density of 305 ± 10.70 trees ha^{-1} was recorded for the woodland savannas for both sites collectively (Table 1). Shrub savannas with mean density of 27.5 ± 2.48 trees ha^{-1} were significantly different from other vegetation types (p < 0.05; Table 1). The mean densities of woodland savannas and gallery forests were also significantly different from each other (p < 0.05; Table 1).

There was no significant difference between the mean BA for the two sites either (p > 0.05). Significant difference was recorded between vegetation types for both sites collectively (p < 0.05; Table 1). The mean BA for gallery forests was significantly different from other vegetation

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types for both sites collectively ($p < 0.05$; Table 1). The highest mean BA of 4.67 ± 3.73 m^2 ha^{-1} was recorded for the gallery forests for both sites collectively (Table 1).

3.3 AGB_{dry}

No significant difference was recorded for the mean AGB_{dry}, for both sites collectively ($p > 0.05$). Significant difference in mean AGB_{dry} was recorded for the vegetation types for both sites collectively ($p < 0.05$; Table 1). The mean AGB_{dry} for gallery forests was significantly different from other vegetation types collectively for both sites ($p < 0.05$; Table 1). The overall mean AGB_{dry} for both sites collectively was 6.70 ± 10.02 Mg ha^{-1} (Table 1). Amongst vegetation types for both sites collectively, the highest mean AGB_{dry} was recorded for gallery forests, 18.77 ± 13.80 Mg ha^{-1} (Table 1).

3.4 Carbon stocks

There was no significant difference between the mean carbons of the two sites ($p > 0.05$). Significant difference, however, was recorded among the vegetation types collectively for both sites ($p < 0.05$; Table 1). The mean carbon for gallery forests was significantly different from other vegetation types for both sites collectively ($p < 0.05$; Table 1). The overall mean carbon for both sites collectively was recorded as 3.41 ± 4.98 Mg C ha^{-1} (Table 1). Gallery forests also showed the highest mean carbon, 9.38 ± 6.90 Mg C ha^{-1} (Table 1).

3.5 IVI, FIV and relative abundance of trees

At Nazinga Game Ranch, the highest IVI of 115.56 was recorded for *Anogeissus leiocarpa* (Table A.2). *Mitragyna inermis* and *Cassia sieberiana* followed with IVIs of 65.43 and 52.43 respectively (Table A.2). At Bontioli Nature Reserve, the highest IVI was recorded for *Mitragyna inermis*, which was 98.59 (Table A.2). *Vitellaria paradoxa* and *Combretum fragrans* followed with 43.55 and 35.75 respectively (Table A.2).

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The highest FIV in Nazinga Game Ranch was recorded for Combretaceae, 109.25 (Table A.3). It was followed by Fabaceae-Caesalpiniaceae, 56.50, and Rubiaceae, 48.12, respectively (Table A.3). For Bontioli Nature Reserve, the highest FIV was also recorded for Combretaceae, 99.91 (Table A.3). Rubiaceae and Fabaceae-Mimosoideae followed with 78.84 and 27.68 respectively (Table A.3). Amongst the tree species for both sites collectively, *Anogeissus leiocarpa* was dominant with 22.58% (Table A.1). *Mitragyna inermis* and *Vitellaria paradoxa* followed with 12.91% and 12.36% respectively (Table A.1).

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Table 1.

Structural characteristics of the four vegetation types at the study sites of Nazinga Game Ranch and Bontioli Nature Reserve.

Sites	Vegetation Types				Total
Nazinga Game Ranch					
	Woodland Savanna	**Tree Savanna**	**Gallery Forest**	**Shrub Savanna**	
Mean DBH [cm]	22.12±6.47	12.02±2.25	45.67±10.51	9.36±1.09	26.49±15.44
Mean tree height [m]	9.38±2.55	5.26±0.50	9.41±1.00	4.37±1.27	7.11±2.75
Mean Density [trees ha^{-1}]	160±8.31	80.5±7.52	73.75±8.98	11.25±1.62	325±60.99
Mean BA [m^2 ha^{-1}]	0.96±0.49	0.28±0.10	4.09±1.70	0.17±0.04	1.37±1.84
Mean Carbon [Mg C ha^{-1}]	3.01±1.82	0.50±0.25	9.32±3.71	0.24±0.09	3.27±4.22
Mean AGB_{dry} [Mg ha^{-1}]	6.03±3.64	1.00±0.50	18.64±7.42	0.49±0.19	6.54±8.41
Bontioli Nature Reserve					
Mean DBH [cm]	19.72±4.24	12.94±2.90	49.61±23.00	13.66±6.98	30.15±18.19
Mean tree height [m]	9.17±1.45	6.49±0.40	9.52±1.81	4.62±1.99	7.45±2.50
Mean Density [trees ha^{-1}]	145±13.53	130±10.98	61.25±8.98	16.25±3.25	352.5±60.21
Mean BA [m^2 ha^{-1}]	1.05±0.41	0.45±0.27	5.25±5.26	0.36±0.41	1.78±2.33
Mean Carbon [Mg C ha^{-1}]	3.13±1.14	0.98±0.66	9.45±9.66	0.67±0.76	3.56±3.41
Mean AGB_{dry} [Mg ha^{-1}]	5.92±2.74	1.42±0.42	18.91±19.33	1.24±1.61	6.87±11.63
Both Sites Collectively*					
Mean DBH [cm]	22.66±5.43a	13.73±3.59a	48.80±16.45b	11.74±4.95a	28.38±16.70
Mean tree height [m]	9.28±1.96a	5.88±0.77b	9.47±1.38a	4.50±1.58b	7.28±2.60
Mean Density [trees ha^{-1}]	305±10.70ac	210±10.32a	135±8.57ad	27.5±2.48b	677.5±117.40
Mean BA [m^2 ha^{-1}]	1.00±0.43a	0.37±0.21a	4.67±3.73b	0.27±0.29a	1.58±2.08
Mean Carbon [Mg C ha^{-1}]	3.07±1.43a	0.74±0.53a	9.38±6.90b	0.45±0.56a	3.41±4.98
Mean AGB_{dry} [Mg ha^{-1}]	5.97±3.04a	1.21±0.49a	18.77±13.80b	0.86±1.15a	6.70±10.02

*Within rows (excluding 'Total' column) of 'Both Sites Collectively', means (± SD) not sharing a common lower case, differ significantly (p< 0.05) based on Tukey's test for comparison of means.

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4. Discussion

4.1 DBH and DBH class distribution

Our results for mean DBH for gallery forests were not consistent with Savadogo et al. [25] who reported mean DBH of 15 ± 3.84 cm. This difference could be attributed to their low sampling intensity. Similarly, our result were also higher than what was reported by Paré et al. [35], DBH of 15.3 ± 3.9 cm for the unprotected site *Yale*, southern Burkina Faso. The difference could be due to higher DBHs for gallery forests in our study. Our DBH classes distribution, representing a horizontal structure, showed a reverse J-shape for both sites collectively. The reverse J-shape is typical for tropical and sub-tropical forests [36]. The reverse J-shape is also an indication of good regeneration of the woody vegetation community [37]. The highest number of trees (39.37%) was recorded in the DBH class of 5 cm in our study for both sites collectively. The density decreased with increasing DBH classes. Tia [18] also emphasized that with increasing DBH the density decreases.

4.2 Stem densities, tree heights and BA

Savadogo et al. [25] reported gallery forests with highest mean stem density, which is contrary to our result. Tia [18[reported mean density of 331 tree ha^{-1} for the Bontioli Nature Reserve, which is close to our mean density for Bontioli Nature Reserve. Our result for overall mean density is close to Paré et al. [35] for their mean density of 703 ± 49 trees ha^{-1}.

The height measurements were consistent with other studies [18, 25,37], However, Tia [18] emphasized that trees heights are leveled down by anthropogenic pressures such as bushfires and wood cuttings. High values for mean BA for gallery forests were also confirmed [25, 37].

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4.3 AGB_{dry} and carbon stocks

Our study revealed that mean AGB_{dry} and carbon stocks for Nazinga Game Ranch and Bontioli Nature Reserve were not significantly different. This can be attributed to the mean DBHs and mean heights which were also not significantly different between the two sites. Overall, the similarity between the two sites, as shown statistically, could be attributed to the similar environmental conditions. To our knowledge, there are no AGB_{dry} and carbon stock estimates available for these two sites. Previous estimates would have helped in comparison of our results. Lewis et al. [39] also emphasized that only very few carbon stock estimates based on field inventories are available for West Africa. We came across estimates provided by Fischer et al. [40] for entire Burkina Faso, but this data was not comparable with our study because of the national level focus on different land uses categorized according to FAO [41].

In our study, the highest overall mean carbon was recorded for gallery forests. The mean carbon of gallery forests was also significantly different from other vegetation types. This significant difference could be attributed to their mean DBH, which was also the highest amongst the vegetation types. The gallery forests were mainly comprised of *Mitragyna inermis*. This species was the second most abundant species amongst all the species collectively from both sites. *Mitragyna inermis* was mainly found in clumps and was mostly comprised of multi-stems. We assume that the calculation of the DBH of *Mitragyna inermis*, through the equation which was used in this study, may have resulted in an overestimation for DBHs for gallery forests and hence in the overall mean carbon estimation. There is no statistical difference among the remaining vegetation types: the mean DBH of woodland savannas was not significantly different from the tree and shrub savannas either. However, the density of woodland savannas was higher than the other two.

Sawadogo et al. [42] reported AGB_{dry}, through destructive sampling, for *Anogeissus leiocarpa, Combretum glutinosum, Detarium microcarpum, Entada africana* and *Piliostigma thonningii* as 320.95 kg, 42.26 kg, 61.74 kg, 32.16 kg and 29.42 kg respectively, for the sites of Laba and Tiogo State Forests, located in transition from north to south Sudanian zone in Burkina Faso. Our estimates for AGB_{dry} were only consistent with Sawadogo et al. [42] for *Entada africana* (30.94 kg) in the Bontioli Nature Reserve. Estimates were not consistent in case of

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Anogeissus leiocarpa (168.34 kg) and (508.64 kg) for Nazinga Game Ranch and Bontioli Nature Reserve respectively; for *Combretum glutinosum* (19.03 kg) for Bontioli Nature Reserve; for *Detarium microcarpum* (37.87 kg) for Nazinga Game Ranch; and for *Piliostigma thonningii* (14.21 kg) and (11.61 kg) for Nazinga Game Ranch and Bontioli Nature Reserve respectively. Inconsistencies between estimates of AGB_{dry} between two studies could be because of the variability of basic wood density in the individuals of the same species for different geographical locations and ages [43]. Karlson et al. [44] reported AGB_{dry} of 15.96 Mg ha^{-1} for Saponé, central Burkina Faso. They included open woodlands, agroforestry parklands, small scale tree plantations and dense forest patches in their study. These stands are often characterized by trees of bigger sizes, which could be the reason why higher AGB_{dry} estimates for them in comparison to our study have been recorded. Our result for carbon stock for both sites collectively was higher than Dayamba et al., [45] who reported 1.10 ± 0.32 Mg C ha^{-1} for natural vegetation with high degradation for Bale province, south Sudanian zone, western Burkina Faso – whereas they used the same generalized allometric equation for estimation of AGB_{dry} given by Chave et al. [28] we used for this study.

4.4 Floristics

Our result for Combretaceae and Rubiaceae as most abundant families for both sites collectively is consistent with other authors. [18, 25, 35, 38]. Our most common families were Combretaceae, Rubiaceae and Fabaceae-Caesalpiniaceae, which portrays a typical taxonomic pattern of savanna-woodland mosaics in Africa and for the northern Sudanian Zone in Burkina Faso [46].

Savadogo et al. [25] reported highest IVI of 214.50 for *Mitragyna inermis*, which is also consistent with our result for Nazinga Game Ranch. The high IVI for *Mitragyna inermis* in our study for Nazinga Game Ranch may also suggest that gallery forests are less affected by human disturbances [38, 47]. Karlson et al. [44] reported 37 species for their study site at Saponé, central Burkina Faso, which is close to 29 species collectively for both sites by our study. Species such as *Detarium microcarpum* and *Lannea microcarpa* were amongst the

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rarest recorded for our both sites collectively. This could be attributed to the preferences of local inhabitants at both sites for these two species for the associated multiple benefits which can be derived from them [18]. The highest number of 140 individuals was recorded for *Anogeissus leiocarpa* for Nazinga Game Ranch against contrasting 12 trees for Bontioli Nature Reserve. This drastic difference could be due to the proximity of this species to the settlements in Bontioli Nature Reserve. *Anogeissus leiocarpa* is known for its medicinal qualities and hence could be the subject of prodigious cutting in Bontioli Nature Reserve [48].

5. Conclusion

The highest mean AGB_{dry} and highest mean carbon were recorded for Bontioli Nature Reserve, however statistically there was no significant difference recorded between the two investgigated sites for these two variables. Significant difference was recorded between the vegetations collectively for both sites where the highest mean AGB_{dry} and highest mean carbon were recorded for gallery forests. Combretaceae was recorded as a major family for both sites collectively. The highest IVIs were recorded for *Anogeissus leiocarpa* and *Mitragyna inermis* for the sites of Nazinga Game Ranch and Bontioli Nature Reserve respectively.

To our knowledge, it was a first attempt to estimate the AGB_{dry} and carbon stocks of different vegetation types at the two protected areas of Nazinga Game Ranch and Bontioli Nature Reserve. Our results can therefore serve as a benchmark for future studies and baselines for future possible payment for environmental schemes and REDD+ programmes, if initiated for these areas. This study also provides insights, that can be useful for areas with similar environmental settings.

We suggest that future AGB_{dry} and carbon stock studies should be conducted in wet seasons at these two protected areas. As our study was conducted in dry season, estimates in the wet season would be helpful in underscoring any potential inter-seasonal differences for the two protected areas. Furthermore, land use and land cover change analysis and carbon inventories over different time periods can also give a better picture of the deforestation and degradation. Dimobe et al. [22] for instance have reported loss of vegetation cover over the past 29 years as a result of agriculture expansion at Bontioli Nature Reserve through land use and land cover

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change analysis using remote sensing and questionnaire surveys combined. Similar study for Nazinga Game Ranch, where there are also reports of high dependency of local communities on the vegetation [15], will also be helpful for identificaton of drivers responsible for deforestation and degradation.

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Appendix. Supplementary Material

Table A.1. Species represents the tree species at both sites of Nazinga Game Ranch and Bontioli Nature Reserve collectively. n = number of trees for each species. Relative abundance (%) (percentage of tree species individuals relative to the total number of trees). Wood density represents the published values of wood densities at species and generic levels for all the trees at both sites.

Species	*N*	Relative Abundance (%)	Wood Density ($g\ cm^{-3}$) Species level	Generic level	References
Acacia sieberiana DC. var. villosa A. Chev.	2	0.36	0.65		(UNFCCC, 1992)
Afzelia africana Sm.	1	0.18	0.71		(Ogunwusi et al., 2013)
Anogeissus leiocarpa (DC.) Guill. & Perr.	152	28.04	0.73		(Ogunwusi et al., 2013)
Bridelia scleroneura Müll. Arg.	3	0.55		0.81	(Agbontalor, 2008)
Cassia sieberiana DC.	16	2.95	0.72		(Nyg and Elfving, 2000)
Combretum adenogonium Steud. ex A. Rich.	13	2.39	0.64		(Brazier et al., 1983)
Combretum collinum Fresen.	8	1.47	0.79		(UNFCCC, 1992)
Combretum fragrans F.Hoffm.	37	6.82	0.64		(Brazier et al., 1983)
Combretum glutinosum Perr. ex DC.	2	0.36	0.90		(von Maydell, 1983)
Daniellia oliveri (Rolfe) Hutch. & Dalz.	13	2.39	0.40		(Rijsdijk and Laming, 1994)
Detarium microcarpum Guill. & Perr.	4	0.73	0.78		(Fontodji et al., 2013)

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Diospyros mespiliformis Hochst. ex A. DC.	1	0.18		0.72	(Nyg and Elfving, 2000)
Entada africana Guill. & Perr.	7	1.29	0.53		(Nyg and Elfving, 2000)
Gardenia erubescens Stapf & Hutch.	1	0.18	0.64		(UNFCCC, 1992)
Gardenia ternifolia Schum. & Thonn.	3	0.55	0.81		(Agbontalor, 2008)
Lannea microcarpa Engl. & K. Krause	1	0.18	0.51		(Nyg and Elfving, 2000)
Maytenus senegalensis (Lam.) Exell	2	0.36		0.71	(Brown, 1997)
Mitragyna inermis (Willd.) O. Ktze.	70	12.91		0.56	(Brown, 1997)
Parkia biglobosa (Jacq.) R. Br. ex G. Don f.	17	3.13	0.61		(Bolza and Keating, 1972)
Pericopsis laxiflora (Benth. ex Bak.) van Meeuwen	1	0.18		0.93	(Louppe et al., 2008)
Piliostigma thonningii (Schum.) Milne-Redhead	9	1.66	0.61		(Nyg and Elfving, 2000)
Pseudocedrela kotschyi (Schweinf.) Harms	7	1.29	0.62		(Takahashi, 1978)
Pterocarpus erinaceus Poir.	4	0.73	0.62		(Nyg and Elfving, 2000)
Saba senegalensis (A. DC.) Pichon	6	1.10		0.62	(Nyg and Elfving, 2000)
Stereospermum kunthianum Cham.	3	0.55	0.60		(Brazier et al., 1983)
Terminalia laxiflora Engl. & Diels	65	11.99		0.71	(Brown, 1997)
Terminalia macroptera Guill. & Perr.	23	4.24		0.71	(Brown, 1997)
Vitellaria paradoxa C.F. Gaertn.	67	12.36	0.72		(Van der Vossen and Mkamilo, 2007)
Ximenia americana L.	4	0.73	0.95		(von Maydell, 1983)

UNFCCC = United Nations Framework Convention on Climate Change

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Table A.2. IVI of tree species at Nazinga Game Ranch and Bontioli Nature Reserve. Rf (%) is the relative frequency of tree species, RDe (%) is the relative density of trees species and RDo (%) is the relative basal area of the tree species.

Nazinga Game Ranch				
Species	**Rf (%)**	**RDe (%)**	**RDo (%)**	**IVI**
Afzelia africana Sm.	5	0.38	0.67	6.06
Anogeissus leiocarpa (DC.) Guill. & Perr.	35	53.84	26.72	115.56
Cassia sieberiana DC.	30	6.15	16.28	52.43
Detarium microcarpum Guill. & Perr.	10	1.53	0.25	11.79
Diospyros mespiliformis Hochst. ex A. DC.	5	0.38	0.04	5.43
Maytenus senegalensis (Lam.) Exell	10	0.76	0.08	10.85
Mitragyna inermis (Willd.) O. Ktze.	25	8.84	31.58	65.43
Parkia biglobosa (Jacq.) R. Br. ex G. Don f.	5	0.38	5.13	10.51
Piliostigma thonningii (Schum.) Milne-Redhead	5	0.38	0.06	5.44
Saba senegalensis (A. DC.) Pichon	15	2.30	14.17	31.48
Stereospermum kunthianum Cham.	5	0.38	0.03	5.42
Terminalia laxiflora Engl. & Diels	25	11.15	2.14	38.29
Vitellaria paradoxa C.F. Gaertn.	25	13.46	2.78	41.25
Bontioli Nature Reserve				
Species	**Rf (%)**	**RDe (%)**	**RDo (%)**	**IVI**
Acacia sieberiana DC. var. villosa A. Chev.	5	0.70	0.16	5.87
Anogeissus leiocarpa (DC.) Guill. & Perr.	15	4.25	6.12	25.38
Bridelia scleroneura Müll. Arg.	5	1.06	0.51	6.57
Combretum adenogonium Steud. ex A. Rich.	15	4.60	2.00	21.61
Combretum collinum Fresen.	5	2.83	0.50	8.33
Combretum fragrans F.Hoffm.	15	13.12	7.62	35.75
Combretum glutinosum Perr. ex DC.	10	0.70	0.10	10.81
Daniellia oliveri (Rolfe) Hutch. & Dalz.	15	4.60	9.63	29.24
Entada africana Guill. & Perr.	10	2.48	0.51	12.99
Gardenia erubescens Stapf & Hutch.	5	0.35	0.06	5.41
Gardenia ternifolia Schum. & Thonn.	10	1.06	0.72	11.78
Lannea microcarpa Engl. & K. Krause	5	0.35	0.26	5.61
Mitragyna inermis (Willd.) O. Ktze.	35	16.66	46.93	98.59
Parkia biglobosa (Jacq.) R. Br. ex G. Don f.	10	5.67	5.09	20.77
Pericopsis laxiflora (Benth. ex Bak.) van Meeuwen	5	0.35	0.18	5.53

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Piliostigma thonningii (Schum.) Milne-Redhead	20	2.83	0.31	23.15
Pseudocedrela kotschyi (Schweinf.) Harms	10	2.48	1.59	14.07
Pterocarpus erinaceus Poir.	5	1.41	3.39	9.81
Stereospermum kunthianum Cham.	5	0.70	0.05	5.76
Terminalia laxiflora Engl. & Diels	20	12.76	2.92	35.69
Terminalia macroptera Guill. & Perr.	5	8.15	3.73	16.89
Vitellaria paradoxa C.F. Gaertn.	25	11.34	7.20	43.55
Ximenia americana L.	15	1.41	0.30	16.72

Table A.3. FIV of Nazinga Game Ranch and Bontioli Nature Reserve. RDi (%) is the relative diversity of the plant family, RDe (%) is the relative density of the plant family and RDo (%) is the relative basal area of the plant family.

Nazinga Game Ranch				
Family	**RDi (%)**	**RDe (%)**	**RDo (%)**	**FIV**
Apocynaceae	7.69	2.30	14.17	24.17
Bignoniaceae	7.69	0.38	0.03	8.11
Fabaceae-Caesalpiniaceae	30.76	8.46	17.27	56.50
Celastraceae	7.69	0.76	0.08	8.54
Combretaceae	15.38	65	28.86	109.25
Ebenaceae	7.69	0.38	0.04	8.12
Fabaceae-Mimosoideae	7.69	0.38	5.13	13.21
Rubiaceae	7.69	8.84	31.58	48.12
Sapotaceae	7.69	13.46	2.78	23.94
Bontioli Nature Reserve				
Family	**RDi (%)**	**RDe (%)**	**RDo (%)**	**FIV**
Anacardiaceae	4.34	0.35	0.26	4.96
Bignoniaceae	4.34	0.70	0.05	5.11
Fabaceae-Caesalpiniaceae	8.69	7.44	9.95	26.09
Combretaceae	30.43	46.45	23.02	99.91
Euphorbiaceae	4.34	1.06	0.51	5.92
Fabaceae-Papilionioideae	8.69	1.77	3.58	14.04
Meliaceae	4.34	2.48	1.59	8.42
Fabaceae-Mimosoideae	13.04	8.86	5.77	27.68
Olacaceae	4.34	1.41	0.30	6.07
Rubiaceae	13.04	18.08	47.72	78.84
Sapotaceae	4.34	11.34	7.20	22.89