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Importance Value Index and Species Relative Contribution to Carbon Stocks in Savanna Ecosystems : Implications for Climate Change Mitigation and Forest Management in Patako Forest (Senegal)

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Abstract:- Understanding species Importance Value Index (IVI) and contribution to carbon storage is key to improving knowledge on climate change mitigation and forest management models. The present study conducted in Patako Forest aims to investigate how species harvested for fuelwood and timber contributed to carbon sequestration. Data was collected using a stratified random sampling in 251 plots from different vegetation types. The results showed a good species richness of 102 species with significant variation of IVIs among vegetation types. Indeed, more than 90% of the IVIs was dominated by 21 species. It was dominated by fuelwood species in the savanna types and woodland, whereas timber species dominated in the gallery forest. This relative importance influenced species carbon storage contribution. In the shrub savanna 88.57% of carbon was stored by four species among which *Combretum glutinosum* (56.95%), with an IVI of 160.62 recorded an average of 7.67±1.30 t.C/ha. An inequitable carbon distribution was also recorded in tree savanna where five species counted about 80% of the carbon stock. *Combretum glutinosum*, *Terminalia macroptera* and *Cordyla pinnata* were the most frequent species and contributed about 72% of carbon stock in the woodland. In gallery forest, *Khaya senegalensis* stored the largest carbon stock (40.36±2.31 t.C/ha) with an IVI estimated at 38.52. The relations between IVI and species contribution to carbon storage should be taken into consideration for sustainable forest management in the context of climate change.

Keywords:- *Importance Value Index, Carbon stocks, Forest management, Patako Forest, Savanna ecosystems.*

I. INTRODUCTION

Carbon is globally held in a variety of carbon sinks forming a biogeochemical cycle with permanent carbon fluxes exchanges between sinks that play an important role in the global climate. As part of the biosphere, forests store about 862 Gt carbon in live and dead vegetation and soil, with 42% of it stored in live above and belowground biomass (Pan et al., 2011). Carbon sequestration involves the capture, transformation or energy conversion and storage of the carbon from the atmosphere which would otherwise increase global warming through cumulative effect. Among approaches being proposed to mitigate climate change, the need to enhance forest ecosystems through carbon sequestration has gained momentum these last decades (Anthony et al., 2011).

Forests play a significant role in climate change mitigation as they emit as well as sequester CO_2. Tree cover loss due to deforestation and forest degradation contribute to about 10-20% of global CO_2 annual emissions (van der Werf et al., 2009). The importance of forest carbon storage is more and more amplified by a warming climate that needs to be urgently addressed with reduction in greenhouse gases (GHG) and natural-based solutions initiatives (Ripple et al., 2020). Hence, estimating the carbon content in the woody vegetation becomes relevant to improve the knowledge of carbon sequestration potential of the most important and preferred species for communities. Restoring degraded forest ecosystems or planning and implementing a sustainable forest management strategy can support long term carbon sequestration and has a combined co-benefit of controlling wood collection and conserving of biodiversity while reducing GHG emissions from uncontrolled deforestation rates.

Savannas are known as dynamic ecosystems with many direct and indirect drivers that influence biomass (Sambou et al. 2015) but have a huge potential of carbon sequestration (Mbow et al., 2014). Sudanian savannas are spatially large and sensitive due to various human activities they cover but are key option to mitigate global warming and global climate change.

Human activities on forests ecosystems can affect CO_2 source/sink dynamics through factors such as fuelwood collection and timber harvesting. These activities often imply an exportation of biomass outside the ecosystem. This result in a loss of carbon as biomass combustion (fuelwood and charcoal) or either conserved for medium or long-term in a various type of furniture.

The potential of carbon sequestration is an increasingly important management objective for national GHG emissions inventory. As such, savannas' ecosystems inventory data and biomass have been used to develop baseline of forest carbon in the Agriculture, Forestry and Other Land Use sector, including assessment of the main drivers of disturbance. Despite human pressure on species used for fuelwood and timber, tree specific contribution to carbon storage, especially those of high interest for local livelihood has not been studied in non-managed forests of Senegal to assess the link between the Importance Value Index(IVI) and biomass. Species richness and various ecosystem services provided by sudanian protected areas in the western centre of Senegal reveal the importance of forest ecosystem's conservation with regard to the quality of goods and services they provide to local communities and beyond (Sambou et al. 2021, Dieng et al. 2016). This supports the sustainable forest management strategy which aims to maintain or increase forest carbon stocks, while producing an annual yield of timber, fiber, and energy as well as generating sustainable mitigation and long-term adaptation co-benefits.

The present study deals with the estimation of tree biomass and carbon stocks in Patako Forest. It highlights the influence of IVI on species contribution to carbon storage and emphasizes the need for greater attention for biodiversity conservation and environmental sustainability.

II. MATERIALS AND METHODS

➢ *Study Area Description*

The study was conducted in the Patako Forest located in the Saloum Delta region of Senegal (West Africa). Patako Forest is a protected area that has been classified in 1934 with 5638 ha and located between two rural municipalities (Keur Saloum Diane and Keur Samba Gueye) (Figure 1). The status of protection is governed by law which provisionally prohibit the exploitation excepted some uses like dead wood and non-timber forest products collection. A short rainy season from June to October with a monomodal pattern and a dry season from November to May characterize the climate of the study area. The mean annual rainfall ranges between 600 and 800 mm with high temperatures throughout the year which average 27°C. The area is dominated by ferruginous tropical soils, poorly evolved soils, hydromorphic soils on alluvial plains and gley-salted soils along valleys. These pedoclimatic conditions influence the distribution of vegetation. The latter is dominated by sudanian savannas generally with short cycle grasses due to fire frequencies. The vegetation types consist of shrub and tree savanna. The savanna vegetation types consisted of at least 73% of species exploited for fuelwood, 14% for timber and 4% for non-timber forest products (Sambou, 2004). A gallery forest grows along two principal valleys.

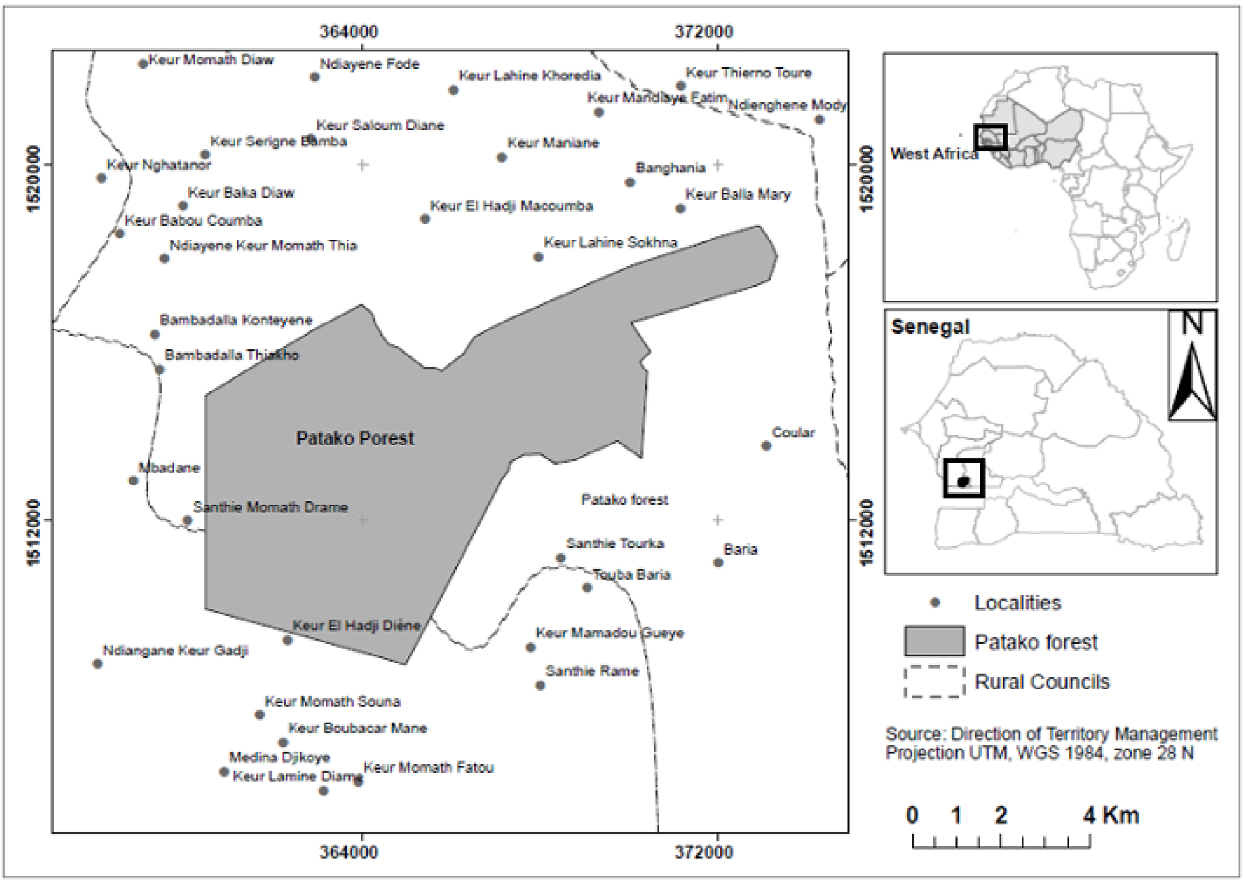

Fig 1:- Study area

➢ *Sampling Design and Data Collection*

Data was collected in a forest ecosystem of four vegetation types (shrub savanna, tree savanna, woodland and gallery forest), identified based on stratification using Landsat images (Sambou et al. 2015). The sampling design consisted of dividing each type into grids of 250 m x 250 m. The total number of eligible (homogeneous) grids represented the population of survey and depended on the coverage of each vegetation type. Then, the homogeneous grids were identified and selected based on a simple random sampling without replacement (Sambou et al. 2007). Furthermore, within each selected grid, 8 plots of 0.04 ha (20 m x 20 m) each one was randomly installed along the medians and the diagonals (Sambou et al. 2007; Sambou et al. 2021). Data collection using this sampling design was conducted in a total of 216 plots with 56 in woodland, 144 in tree savanna and 16 in shrub savanna. Concerning the gallery forest, 35 rectangular plots (10 m × 40 m) were also randomly surveyed. Within each plot, trees with a circumference ≥ 15.7 cm at 1.3 m above the ground level were systematically identified and measured. The circumference was preferred during data collection to reduce the impact of irregular shape of trees because in most case they are not quit round shaped (Sambou et al. 2021). Then the circumference was converted to diameter at breast height (dbh).

The minimum sample size (N) required was computed with a margin error (d) of 5% using Dagnelie (1998) as follow :

$$N = \left(\frac{t^2_{1-\frac{\alpha}{2}} \times CV^2}{d^2} \right) \quad (1)$$

Where N is the size of the sample, $_{1-\frac{\alpha}{2}}$ the value of t distribution (1.96) with a probability of 0.975 (α = 0.05) and *CV*, the coefficient of variation of the basal area of each vegetation type.

➢ *Data Analysis*

The Importance Value Indices (IVI) was determined as the sum of relative density (RD_i), relative dominance (RDo_i) and relative frequency (RF_i). The IVI of a species is the percentage value that determines species representativity with in a vegetation type.

$$IVI_i = RD_i + RDo_i + RF_i \quad (2)$$

RD_i was determined by dividing the number of individual trees belonging to $species_i$ by the total number of individuals x 100; RDo_i was derived from the division of the $species_i$ basal area by the total basal area of all species x 100; and RF_i is the frequency of a given species divided by the total frequency of all species x 100. The basal area of a vegetation type (G), i.e. the sum of the cross-sectional area at 1.3 m above the ground level of all trees on a plot, expressed in m^2/ha was calculated as follow:

$$G = \frac{\pi}{4s} \sum_{i=1}^{n} 0.0001\, d_i^2 \quad (3)$$

d_i is the diameter (in cm) of the $i^{\text{-th}}$ tree of the plot; s = 0.04 ha

➢ *Estimation of Carbon in the Aboveground Biomass:*

The assessment of biomass carbon stocks required the collection of a series of dendrometric data from an inventory of woody vegetation. This inventory was carried out using a stratified randomised second-order sampling method (Sambou et al. 2021). As inventory processes are subject to a certain type of measurement errors (Rondeux, 1999), it is therefore necessary to correct them to minimise potential error propagation. The first level considered was to convert the values of circumference into diameter. The dbh is one of the main parameter used for estimating carbon stocks. For multi-stemmed trees or shrubs individuals, the circumference of each stem was measured separately, but in order to have a conservative estimation of the aboveground biomass it was necessary to consolidate the diameters of the various stems into a single index. This step required to calculate the quadratic sum as follow: the square root of the sum of all squared stem dbh (NCPN, 2006; Thiombiano et al. 2016).

$$DBH = \sqrt{\sum dbh^2} \quad (4)$$

Tree biomass carbon stocks were estimated using appropriate allometric equations. The equation used for the present study were two models which fit almost the vegetation types or ecological conditions. Mbow et al. (2014) was used to estimate the biomass of species in the savanna vegetation types, whereas Chave et al. (2005) served for the gallery forest species. Based on the relation of tree biomass and carbon content the value of estimated biomass was converted to carbon stock by multiplying it by the conversion factor 0.5 (IPCC, 2006 ; Kumar and Sharma 2014).

III. RESULTS

➢ *Species Importance Value Index Distribution*

A total of 102 tree species distributed into 81 genera and 35 families were recorded. *Combretum glutinosum* was the most abundant species in the savanna vegetation types whereas *Terminalia macroptera* was observed to be having the second most abundant species and most frequent species in the study area. The highest dominance among trees species was recorded for *Combretum glutinosum* with highest share of relative density (35%-71%) followed by relative dominance (29%-58%) and relative frequency (14%-31%) in the savanna types. The relative share was dominated by a cohort of large diameter tree species.

More than 90% of the IVIs was dominated by 21 species. Table 1 summarizes for each vegetation type species with IVI higher than 5, indicative of certain representativity within the Patako Forest. *Combretum glutinosum* is by far the most abundant species. Similar floristic composition can be found in some vegetation types with a real dominance of

Combretaceae. This dominance largely explains the high IVIs estimated in the tree savanna (160.62) and shrub savanna (109.57). *Terminalia macroptera* and *Acacia macrostachya* recorded IVIs of 40.02 and 28.72, i.e. 13.34 and 9.57 respectively of all species recorded in the tree savanna. In the woodland *Terminalia macroptera* (IVI= 77.92), *Combretum glutinosum* (IVI= 76.01) and *Cordyla pinnata* (IVI= 22.91) were, by order of magnitude, the most important species. The gallery forest standed out from the other types of vegetation as species with highest IVIs were respectively *Elaeis guineensis* (IVI= 47.05) and *Khaya senegalensis* (IVI= 38.52) (Table 1).

Families	**Species**	**IVI**			
		Shrub savanna	**Tree savanna**	**Woodland**	**Gallery forest**
Combretaceae	*Combretum glutinosum* Perr. ex DC.	160.62	109.57	76.01	10.22
Combretaceae	*Combretum nigricans* Lepr. ex Guill. and Perr.	32.91	12.03	-	-
Fabaceae	*Cordyla pinnata* (Lepr. ex A. Rich) Milne-Redhead	30.97	20.13	22.91	-
Commeliaceae	*Terminalia avicennioides* Guill. and Perr.	25.05	-	-	-
Combretaceae	*Terminalia macroptera* Guill. and Perr.	12.82	40.02	77.92	-
Anacardiaceae	*Lannea acida* A. Rich.	9.12	14.71	5.80	-
Fabaceae	*Prosopis Africana* (Guill. and Perr.) Taub.	6.36	5.00	10.72	-
Bombacaceae	*Bombax costatum* Pellegr. and Vuillet	5.80	-	7.46	-
Fabaceae	*Acacia macrostachya* Reichenb. ex DC.	5.21	28.72	17.72	-
Loganiaceae	Strychnos spinosa Lam.	-	8.62	-	-
Fabaceae	*Pterocarpus erinaceus* Poir.	-	7.79	13.53	10.23
Fabaceae	*Daniellia oliveri* (Rolfe) Hutch. and Dalz.	-	5.82	13.55	-
Fabaceae	*Xeroderris stühlmannii* (Taub.) Mendoça et Sousa	-	-	8.43	-
Olacaceae	*Ximenia Americana* L.	-	-	8.24	-
Arecaceae	*Elaeis guineensis* Jacq.	-	-	-	47.05
Meliaceae	*Khaya senegalensis* (Desr.) A. Juss.	-	-	-	38.52
Bombacaceae	*Ceiba pentandra* (L.) Gaertn.	-	-	-	19.26
Fabaceae	*Detarium senegalense* J.F.Gmel.	-	-	-	16.88
Sterculiaceae	*Cola cordifolia* (Cav.) R. Br.	-	-	-	12.87
Arecaceae	*Phoenix reclinata* Jacq.	-	-	-	12.33
Fabaceae	*Erythrophleum suaveolens* (Guill. and Perr.) Brenan	-	-	-	10.73
Sapindaceae	*Aphania senegalensis* (Juss. ex Poir.) Radlk.	-	-	-	9.36
Apocynaceae	*Saba senegalensis* (A. DC.) Pichon	-	-	-	7.33
Myrtaceae	*Syzysium guineense* (Willd.) DC. *var guineense*	-	-	-	6.36
Bombacaceae	*Adansonia digitate* L.	-	-	-	5.77
Combretaceae	*Combretum micranthum* G. Don	-	-	-	5.58
Fabaceae	*Dichrostachys cinereal* (L.) Wight and Arn.	-	-	-	5.06
	Others	11.15	47.22	37.06	82.44

Table 1:- Species with an IVI greater than 5

➤ *Species Contribution to Carbon Stocks*

Woody species contributed differently to carbon storage in Patako Forest. Among the categories of tree sizes two were of high interest in terms of contribution. Table 2 highlights fuelwood species contribution to carbon storage whereas Table 3 provides an overview of the average share of timber species.

In the shrub savanna the contribution to carbon stock was dominated by four species (88.57%) among which *Combretum glutinosum* represented 56.95%, i.e. 7.67±1.30 t.C/ha. *Cordyla pinnata* contributed about 18.77% to carbon stock while *Combretum nigricans* (1.07±1 t.C/ha) and *Terminalia avicennioides* (0.65±0.05 t.C/ha) counted respectively for 7.97% and 4.88% of the total stock.

Inequitable carbon distribution was also recorded in the tree savanna where five species recorded about 80% of the carbon stock. Indeed, the carbon storage contibution is significantly dominated by *Combretum glutinosum* (43.79%) which represented an average of 8.50±0.01 t.C/ha (Table 2). The high tree densities recorded explains its large contribution to carbon stocks despite the predominance of small sizes diameter. The carbon stored by *Cordyla pinnata* was estimated at 12.43%. A slightly low proportion was estimated for *Terminalia macroptera* (11.81%). *Lannea acida* contributed for 6.42% to carbon stocks (1.24±0.03 t.C/ha, against 5.36%. for *Acacia macrostachya*.

Species harvested for fuelwood	Shrub savanna		Tree savanna		Woodland		Gallery forest		*P-value*
	n	t.C/ha	n	t.C/ha	n	t.C/ha	n	t.C/ha	
Acacia macrostachya	2	0,02 ± 0,00	38	1,04 ± 0,02	26	1,04 ± 0,01	4	0,06 ± 0,01	0,035
Combretum glutinosum	136	7,67 ± 1,30	135	8,50 ± 0,01	125	8,43 ± 0,04	16	1,85 ± 0,17	0,019
Combretum nigricans	14	1,07 ± 1	9	0,32 ± 0,01	2	0,09 ± 0,02	3	0,31 ± 0,09	0,163
T. avicennioides	17	0,65 ± 0,05	3	0,10 ± 0,03	-	-	-	-	0,028
Terminalia macroptera	5	0,23 ± 0,10	43	2,29 ± 0,04	136	7,83 ± 0,03	8	1,73 ± 0,22	0,237

Table 2 :- Contribution to carbon storage of species harvested for fuelwood

Tree species contribution to carbon storage was more equitable in the woodland compared to the other vegetation types mentioned above. *Combretum glutinosum* (8.43±0.04 t.C/ha), *Terminalia macroptera* (7.83±0.03 t.C/ha) and *Cordyla pinnata* (4.28±0.05 t.C/ha) represented respectively 29.57%, 27.47% and 15.04% of the carbon stock. These species are among the most abundant and contributed for about 72% to carbon stock of the woodland as shown in table 2.

In the gallery forest, the most important contribution was provided by *Khaya senegalensis* (40.36±2.31 t.C/ha) mainly due to the accumulation of biomass in large diameter trees. This stock represented 29.25% of carbon stored in this vegetation type. *Detarium senegalense* stored about 14.99±0.60 t.C/ha (9.68%) of the gallery forest carbon stock (Table 3). In general, large diameter species contributed for about more than 70% of the estimated carbon despite the high tree diversity recorded in the gallery forest. Some non-timber wood species like *Elaeis guineensis, Cola cordifolia, Erytrophleum suaveolens, Ficus spp*. etc. have a substantial contribution to gallery forest's carbon stock even they were not very abundant.

Species harvested for timber	Shrub savanna		Tree savanna		Woodland		Gallery forest		*P-value*
	n	t.C/ha	n	t.C/ha	N	t.C/ha	n	t.C/ha	
Cordyla pinnata	8	2,52 ± 0,31	7	4,70 ± 0,03	12	4,28 ± 0,05	1	0,02 ± 0,00	0,465
Daniellia oliveri	-	-	5	2,68 ± 0,03	14	2,07 ± 0,05	6	0,18 ± 0,02	0,250
Detarium senegalense	-	-	-	-	-	-	17	14,99 ± 0,60	0,001
Khaya senegalensis	-	-	-	-	-	-	30	40,36 ± 2,31	0,001
Lannea acida	3	0,41 ± 0,16	7	1,24 ± 0,03	4	0,49 ± 0,06	1	0,02 ± 0,01	0,596
Pterocarpus erinaceus	-	-	5	0,19 ± 0,01	36	1,15 ± 0,01	27	0,65 ± 0,03	0,715

Table 3:- Contribution to carbon storage of species harvested for timber

IV. DISCUSSION

➢ *Species Importance Value Index Distribution*

Species used for fuelwood are mainly dominated by shrubs with small or medium size diameters and height. Their IVIs varied between vegetation types and from one species to another. This variation depends on the interaction of various factors linked with the site quality, edaphic and climatic conditions, nature of the land use and species functional types (Koul and Panwar, 2008). In the savanna types *Combretum glutinosum* and *Terminalia macroptera* were the most important species in terms of IVI due to their high density, frequency and basal area (Sambou et al., 2021). These species are among the dominant and most harvested by local communities for daily cooking uses. Regarding gallery forest, IVIs were dominated by large diameter tree species. However, the important tree diversity recorded in this vegetation type justify the fact that several species have been grouped into "other category" (Table 1) with a total IVI equivalent to 82.44. Better ecological conditions, especially soil quality and humid environment have created a good microclimate that influences species growth and adaptability. Alexandrov, (2007) identified stands' age and productivity as a major factor influencing plant species characteristics in forest ecosystems, one of these being the potential of carbon sequestration.

➢ *Species Contribution to Carbon Stocks*

The category of species mainly used by local communities for fuelwood (*Acacia macrostachya, Combretum glutinosum, Combretum nigricans, Terminalia avicennioides, Terminalia macroptera*) have a high wood density (i.e ranging from 0.5 g/cm^3 to 0.90 g/cm^3) according to global wood density database (Zanne et al., 2009). These are small size diameter species generally multi-stemmed at the base and substantially contributed to carbon storage in the savanna vegetation types. Carbon contribution was also subject to the growth characteristics of the tree species (Chi et al 2020), the ecological conditions for growth and historical logging damages (Sambou et al. 2021). Therefore, the cumulative impacts of stems cutting have led to fuelwood species regenerative strategies as a response of multiple human induced stresses. Such adaptive potential could be recognized as an effective and low-cost method of offsetting carbon emissions.

In Patako Forest tree species used for timber are characterised by a single trunk at the bottom, the large size of their diameter, height, and the scope of their crowns. Sambou (2004) identified the following species as mostly used by the populations for timber: *Cordyla pinnata, Daniellia oliveri, Detarium senegalense, Khaya senegalensis, Lannea acida, Pterocarpus erinaceus.* Among those, *Pterocarpus erinaceus, Cordyla pinnata and Khaya senegalensis* were the most preferred by fraudulent logging operators due to the quality of their wood for furniture. Their wood density ranged from 0.5 g/cm^3 to 0.90 g/cm^3 (Zanne et al., 2009). Cannell, (1999) stated that longer-lived, high-density trees store more carbon than short-lived, low density, fast-growing trees or other types of vegetation. Thus, combined with large-diameter sizes and high IVIs these species were key to the ability of Patako's gallery forest and woodland to accumulate substantial amounts of carbon needed to mitigate climate change (Luyssaert et al., 2008; Lutz et al., 2018). Timber species counted for a small percentage of the average tree density but have a substantial percentage of the IVIs and a high contribution to total aboveground carbon.

Human activities such as tree logging for fuelwood or timber are key drivers that affect Patako forest biomass and carbon stocks. These drivers enable stand disturbance and land cover modifications and more severely to land cover conversion (Sambou et al. 2015). But the rate of forest biomass renewal sems to be influenced by the intensity and type of forest exploitation (Medjibe et al., 2013; Neba et al., 2014). In generally, there is a negative relationship between harvest intensity and forest carbon stocks whereby as harvest intensity increases, forest carbon stocks decrease (Simard et al., 2020).

A single large tree can add the same amount of carbon to the Patako Forest carbon sink as many other small sized species generally used for fuelwood. This fact is due to the influence of dendrometric parameters such as diameter on tree biomass. According to Lutz et al., (2018), the relationship between large-diameter trees and overall forest biomass suggests that forests cannot accumulate important amounts of aboveground carbon without large trees. This category of tree individuals stores a substantial portion of the overall carbon in living trees (Stephenson et al., 2014). Recognition of the contribution and importance on large-diameter trees carbon budget has led to recommendations for sustainable forest management and long-term ecosystem stability (Moomaw et al., 2019).

Hence, the sharp increase in carbon storage with increasing tree diameter highlight the importance of preserving mature and old large trees to keep this carbon stored in Patako Forest where it may remain for centuries. Forest management strategy in the context of Patako Forest should be carefully assessed prior to adoption of new forest management rules given that species contribution to carbon stocks is critically important in a warming climate, and that large trees disproportionately store more carbon and constitute important seed producers that ensure the renewal of stocks and biodiversity conservation.

V. CONCLUSION

Trees and shrubs contributed differently to carbon storage due to a variety of factors guided by species survival strategies and external environmental stressors as well as human activities. Species generally used by local communities for fuelwood (*Combretum glutinosum, Terminalia macroptera, Acacia macrostachya*, etc.) have respectively the largest IVIs in the savanna vegetation types of Patako Forest. This dominance and relative abundance, despite the small size of diameters, influenced their carbon storage contribution due to the cumulative effect of stems as single equivalent diameter for biomass estimation. Whereas for timber species (*Cordyla pinnata, Khaya senegalensis, Detarium senegalensis, Pterocarpus erinaceus, Lannea acida*, etc.) even with few individuals contributed significantly to IVIs and aboveground carbon stock in woodland as well as in gallery forest. Therefore, the argument of species to be chosen for sequestering maximum amount of carbon in the context of climate change compensation mechanisms, should include properties such as better climate adaptability, high specific density, fast growing, and communities' preference or interest for biodiversity restoration and conservation.

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