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RESEARCH ARTICLE

ECOLOGICAL CHARACTERISTICS OF HYPARHHENIA DIPLANDRA (HACK) STAPF SAVANNAH IN IGNIE AREA, NORTH OF BRAZZAVILLE, CONGO

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ABSTRACT

The knowledge of the Congo savannahs requires studies on the floristics and the production of herbaceous aerial phytomass, in relation to the soils. The general objective of this study was to characterise *Hyparrhenia diplandra*(Hack) Stapf savannah in Ignié zone in terms of floristics and herbaceous above-ground production in relation to soils. Four plots of 50 m each were delimited. The floristic inventory was carried out by the method of aligned quadrat points. Shrub density was determined by counting individuals per species in an area of 100 m2 with 5 replicates. Floristic diversity was estimated by calculating diversity indices. Herbaceous above-ground phytomass was measured by the integral harvesting method. Soil samples were collected and air-dried and analysed for grain size and chemical composition. The results showed that the flora i was less diverse (Shannon index ranging from 1.39 to 3.02) and the distribution of species was not equitable (equitability index ranging from 0.42 to 0.67). Herbaceous above-ground phytomass and shrub density ranged from 4.75 to 6.85 t DM/ha and from 4.8 to 9.8 shrubs/100 m2 respectively. The soils are sandy, acidic, with average levels of organic matter (2.16 to 2.77%). These results indicate that the savannah studied could be used for agricultural and pastoral activities.

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INTRODUCTION

Savannas are ecosystems located in the intertropical zone in Asia, Africa, South America and Australia (Atanga *et al*., 2014). They occupy an important place among the ecosystems of warm regions. Savannas are of ecological and economic interest as they support a large proportion of the world's human population and wild and domestic herbivores, and sustain both small and large pastoral economies on a global scale (Scholes *et al*. 1997). This makes them of major ecological interest. The management of savannah ecosystems is emerging as a way forward for many tropical countries, particularly in Africa (Fournier, 1991). In Africa, as elsewhere in the tropics, savannahs are extensively used for cattle breeding, and improving production should be based on the sustainable management of savannahs, which constitute potential pastures (Yoka *et al*., 2010).

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In Congo, the savannahs occupy 35% of the territory, however its flora remains little known (CCD, 2006). The best surveyed savannas are those of the Niari Valley in the southern part (Diamouangana, 2000). The savannahs of the Mbé Plateau, where the present study area is located, are made up of vast grassy and shrubby areas. The herbaceous carpet appears dense and is essentially composed of grasses that can reach heights of two to three) meters. The shrubby tract of low density, is formed of individuals, reaching a height of 3 to 4 meters. These savannahs develop on very sandy soils of the Batéké formations (Makany, 1976). The dominant grasses are *Hyparrhenia diplandra* (Hack.) Staf, *Andropogon schirensis* Hochst. ex A. Rich, *Trachypogon spicatus*, *Ctenium newtoii*. These savannahs are not sufficiently studied. The last studies conducted there date back to the work of Apani (1990). Since that date, anthropic activities in the area have caused disturbances to the vegetation and soils. Knowledge of the savannahs of the zone from a phytoecological point of view is necessary for their sustainable management in the context of climate change. This study is part of this theme and its general objective is to characterise the *Hyparrhenia diplandra* (Hack.)

Stapf savannah of the Ignié zone in terms of flora and herbaceous production. The three objectives set were : (i) to evaluate the floristic diversity of the savannah; (ii) to estimate the herbaceous above-ground phytomass; (iii) to assess the granulometric and chemical composition of the soil. Three research hypotheses are as follows: (i) floristic diversity is higher in plots less disturbed by human activities; (ii) herbaceous above-ground phytomass is higher in plots less disturbed by human activities; (iii) the granulometric and chemical composition of the soil does not seem to vary from one plot to another within the same savannah.

MATERIALS AND METHODS

*Study area.*The study was carried out in Ignié, located in the Plateau de Mbé, a sub-area of the Plateaux Batéké, north of Brazzaville, Congo. Geographically, it is located between 3°53'20" and 4°1'40" South latitude and between 15°16'40" and 15°25'0" East longitude (Mayima *et al*., 2019). The climate is humid tropical (Ongagna *et al*., 2009) with an annual rainfall of about 1400 mm. The rainy season lasts nine months, from September to May, with a period of reduced rainfall in January and February. The dry season occurs from June to August. The average temperature is between 23°C and 27°C. The relative humidity in the area varies between 60% and 93%. Evaporation varies in the opposite direction to the relative humidity during the year and also increases atmospheric humidity and reduces plant transpiration (Apani, 1990). The soils in the study area, like those in most of Congo, are highly desaturated ferrallitic soils. They are sandy, acidic and poor in fine elements (Apani, 1990). The vegetation is dominated by savannahs with two facies: grassy savannahs and shrubby savannahs (Makany, 1973,Apani, 1990).

Methods

Experimental set-up .Two sites were selected for the delimitation of the experimental plots. In each site, two plots of 50 m each (i.e. an area of 2500 m^2) were delimited. Each plot, representing a homogeneous area, was subdivided into four (04) plots of 25 m each. The distance between two sites is 500 m and the distance between two plots on the same site is 300 m. Sampling was carried out over an area of one hectare (10 000 m^2). *Floristic inventory*. The floristic inventory was performed by using the linear analysis method or the method of aligned quadrat points (Diamouangana, 2002, Yoka, 2009). This method makes it possible to determine the botanical composition and specific contributions of savannah species, with a view to their valorisation in the pastoral domain, despite the fact that it does not provide an exhaustive inventory of the floristic composition of a plant grouping (César, 1990). Observations were made on lines 10 m long and read every 10 cm using a metal rod that was moved perpendicular to the ground (Boudet, 1997). These lines were marked by two stakes between which a decameter is stretched above the vegetation canopy. At each measurement pointed , any species in contact with the stem is recorded. The species i were recorded noted only once per point observed. Four lines of 10 m are randomly placed in each plot. A species was to be the main one when it had a specific contribution of more than 5% (Apani, 1990) and a producer when its specific contribution reaches 1% (Diamouangana, 2002).

Measurement of above-ground herbaceous phytomass: Herbaceous above-ground phytomass was measured by the harvest method (Fournier, 1994). Measurements were made in randomly selected 1m2 plots. The above-ground parts of the plants were cut off flush with the ground using secateurs. The resulting samples were packed in plastic bags and then oven dried at 85 °C for 24 hours. After drying, the samples were weighed with an electric balance to obtain a dry weight. An average biomass (in t DM/ha) was calculated for all plots.

***Assessment of shrub density*:** Shrub density was assessed by counting shrubs that were at least 1 m high in each study plot (Yoka, 2006 and 2009). This count was done in five (05) contiguous plots of 100 m2 each, by species. Shrub density was estimated first in terms of the number of shrubs per 100 m^2 and then in terms of hectare.

Soil characterisation: Soil samples were removed with an auger at a depth of 0-20 cm. In each plot, one soil sample was taken per plot. A total of four (04) samples were taken to form a composite sample per plot. The samples thus obtained were air-dried and placed in plastic bags for granulometric and chemical analysis at the analysis laboratory of the Institut National de Recherche en Sciences Exactes et Naturelles (IRSEN, formerly ORSTOM) in Pointe-Noire, Republic of Congo. The granulometry was carried out using the Robinson pipette method. The organic matter rate was calculated by the destruction and weighing method. The water pH was measured in a suspension with a soil/water ratio of 1/2.5. Total carbon was determined by the Walkey and Black method. Total nitrogen was determined by the Kjeldahl method. Total phosphorus was determined by the cold colorimetric method (ORSTOM, 1997).

Data processing and statistic analysis

Accuracy of measurements. The accuracy of the data on the linear analysis was estimated by calculating the confidence interval of the grass cover (Boudet, 1991and Diamouangana,2002) according to the following formula:

$$CI : \pm 2\sqrt{\frac{n\,(N-n)}{N^3}}$$

IC: confidence interval;
n: number of the dominant species;
N: cumulative number of all species.

According to Boudet (1991) and Diamouangana (2002), the effect of chance can be considered eliminated when the precision obtained reaches 5%. With lines of 100 points, no confidence interval of 5% was obtained, it is with lines of 200 points that confidence intervals of 5% were obtained. Therefore, in the present work only lines of 200 points were used. At the level of each study plot, the line of 200 points most representative in terms of number of species was selected to characterise the floristic composition.

***Specific frequency and specific contribution*:** The frequency of species recorded was the percentage (%) of occurrences of a species in relation to the number of occurrences of all species.

It is given by the following formula:

$$Fsi\ (\%) = \left(\frac{ni}{Ni}\right) x\ 100$$

With:

Fsi: specific frequency of species i ;
ni: number of sample units where species i is present;
Ni: is the total number of sample units of all species.

The species specific contribution (Csi) is the ratio of the species specific frequency to the sum of the specific frequencies of all species and is given by the following formula :

$$Csi = \frac{fsi}{\Sigma Fsi} = 100x\ \frac{ni}{\Sigma Ni}$$

With:
Ni: the number of sample units where species i was found ;
Σni: the number of specific observations made.

***Floristic diversity indices*:** Diversity and regularity indices are assessed and defined as follows (Barbault, 1997):

Maximum diversity : $H_{max} = Log_2 S$
S = total number of species ;
$H' = -\sum Csi$ x $log_2 Csi$ avec O < Csi < 1
Csi = Species-specific contribution i.

The Shannon-Weaver index generally ranged from 0 to 5. According to Orth *et al*. (1996), the Shannon-Weaver index has high values for species with equal overlaps and takes low values when some species have high overlaps.

Equitability index or regularity: The equitability of Pielou, 1966, (Frontier and Pichod, 1991) expresses the distribution of species within the stand. It is calculated using the formula :

$E = \frac{H'}{H\ max}$ Whith, $H_{max} = log_2 S$ which is the maximum specific diversity. The value of equitability varies from 0 to 1 (Legendre and Legendre, 1984). It is 1 when all species have the same abundance and tends towards 0 when almost all the numbers are concentrated on a single species. That is, equitability tends towards 0 when one species has a very high recovery and tends towards 1 when all species are equally important.

Shrub density: The shrub density of the savannah is calculated by the following formula:

$$D\ (arbuste\ au\ 100\ m2) = \left(\frac{ni}{Ni}\right)$$

With:
D: shrub density;
ni: number of shrubs per species or for all species;
Ni: total number of shrubs per species or for all species.

***Carrying capacity*:** The carrying capacity of an environment refers to the optimum number of animals that a given area can tolerate without irreparable degradation of the plant resource or soil (Agonyissa and Sinsin, 1998). In the context of livestock farming, cattle must produce milk or gain weight during their stay on pasture without deteriorating. The method used is that proposed by (Boudet, 1978).

This method assumes that the potential production consumed by cattle weighing an average of 250 kg (live weight) and consuming 2.5 Kg/MS/100Kg/D, i.e. 6.25 kg of dry matter for 250 Kg of live weight, is estimated at 1/3 of the total biomass. The results obtained are expressed in LU/ha/year (LU: tropical cattle unit). This method is applied by the following ratio:

$$CC = Ki\ x\ \left(\frac{Q}{6{,}25\ x\ 365}\right)$$

With:

CC: carrying capacity in LU/ha/year ;
Q: quantity of phytomass produced in Kg DM/ha
Ki: 1/3 (potential consumable biomass).

Indications for the interpretation of soil contents: Some indications on the interpretation of soil levels of different elements have been taken into account to assess the physico-chemical properties of soils (Riche, 1975) as shown in Table 1.

Table 1. Some indications of soil organic matter, total nitrogen and total phosphorus levels (Riche, 1975)

Soil element	Content	Indication
Organic matter (%)	< 1,5	Low rates
	1,5 - 3	Average rate
	>3	High rate
Total nitrogen (%0)	<1	Low rates
	1 - 2	Average rate
	>2	High rate
Total phosphorus (%0)	<0,25	Low rates
	0,25-0,75	Average rate
	>0,75	High rate

RESULTS

Floristic diversity: The species richness and the Shannon diversity, maximum diversity and Pielou equitability indices of the 4 sampled plots are presented in Table 2.

Table 2. Species richness, Shannon diversity index, maximum diversity index and Pielou equitability of the *Hyparrhenia diplandra* (Hack) Stapf savanna

Plot	Species richness(S)	Shannon index (H')	Maximum diversity index (Hmax)	Pielou equitability (E)
Plot 1	22	3,02	4,45	0,67
Plot 2	19	2,10	4,24	0,49
Plot 3	13	1,58	3,70	0,42
Plot 4	9	1,39	3,16	0,43

Table 3. Herbaceous above-ground phytomass and carrying capacity of the *Hyparrhenia diplandra* (Hack) Stapf savanna

Site	Plot	Herbaceous above-ground phytomass (t DM/ha)	Carrying capacity (LU/ha/year)
Site 1	Plot 1	6,85	1,00
	Plot 2	6,48	0,95
Site 2	Plot 3	5,61	0,82
	Plot 4	4,75	0,69

The highest species richness was found in plot 1 (site 1), with 22 species followed by plot 2 (site 1) with 19 species.

Table 4. Distribution of shrub species with their density in the *Hyparrhenia diplandra* (Hack) Stapf savannah

Plot	Species	Number of shrubs per species (per 100 m^2)	Total number of shrubs (per 500 m^2)	Shrub density (per 100 m2)
Plot 1	*Bridelia ferruginea* Benth.	30	47	9,4
	Hymenocardia acidaTul.	12		
	Maprounea africana Mull.-Arg	3		
	Sporospermum febrifugum auct.	2		
Plot 2	*Annona senegalensis* pers	5	24	4,8
	Vitex madiensis Oliv.	1		
	Bridelia ferruginea Benth.	16		
	Sporospermum febrifugum auct.	2		
Plot 3	*Annona senegalensis* pers	8	43	8,6
	Hymenocardia acidaTul.	16		
	Maprounea africana Mull.-Arg	2		
	Sporospermum febrifugum auct.	5		
	Visgnia sp	1		
	Bridelia ferruginea Benth.	11		
Plot 4	*Annona senegalensis* pers	6	45	9
	*Hymenocardia acida*Tul.	8		
	Maprounea africana Mull.-Arg	4		
	Sporospermum febrifugum auct.	14		
	Bridelia ferruginea Benth.	13		

Table 5. Soil particle size data for the *Hyparrhenia diplandra* (Hack) Stapf savannah study plots

Site	Plot	Clay (%)	LF (%)	LG (%)	SF (%)	SG (%)	Moisture (%)	OM (%)
Site 1	Plot 1	3,00	2,50	1,47	57,98	30,83	1,06	2,77
	Plot 2	3,50	2,00	0,75	54,78	35,63	0,82	2,39
Site 2	Plot 3	4,50	2,00	0,92	55,19	33,89	1,06	2,53
	Plot 4	4,50	0,00	0,55	55,50	35,55	0,90	2,16

Legend: LF: fine silt; SF: fine sand; SG: coarse sand; OM; organic matter

Table 6. Soil chemistry of the *Hyparrhenia diplandra* (Hack) Stapf savannah study plots

Type de Savane	Parcelle	PH	C (%)	N (%)	P (%)	Ca (%)	C/N(%o)
Site 1	Parcelle 1	4,46	1,61	0,12	0,04	< 0,001	13,41
	Parcelle 2	4,36	1,39	0,12	0,04	< 0,001	11,58
Site 2	Parcelle 3	4,28	1,47	0,11	0,03	< 0,001	13,36
	Parcelle 4	4,19	1,25	0,11	0,04	< 0,001	11,36

Plots 3 and 4 (site 2) have a lower species richness (13 and 9 species respectively). The value of the Shannon Weaver index ranged from 1.39 to 3.02, depending on the plot. The highest values were recorded in plot 1 (3.02) and in plot 2 (2.10). The maximum diversity index is between 3.16 and 4.45. The highest value was obtained in plot 1 (4.45) and the lowest in plot 4 (3.16). These values showed that plot 1 appears to be diverse, unlike the other plots. Site 1 (plot 1 and 2) therefore appears to be more diverse than site 2 (plot 3 and 4). The equitability index variesd between 0.43 and 0.67. These results showed that the distribution of species in this sampled savannah is not equitable.

Herbaceous above-ground phytomass and carrying capacity: The phytomass and carrying capacity values for these two *Hyparrhenia diplandra* (Hack) Stapf savanna sites in the Ignié area are presented in Table 3. These values varied from 4.75 to 6.85 t DM/ha for phytomass and from 0.69 to 1.00 LU/ha/year for carrying capacity, depending on the study plots. These results showed that plots 1 and 2 (site 1) appear to be more productive than the other two, with phytomass of 6.85 and 6.48 t DM/ha respectively. Therefore, plots 1 and 2 had slightly higher carrying capacities (1.00 LU/ha/yr and 0.95 LU/ha/yr) than plots 3 and 4 (site 2). Overall, site 1 appaearsed to be more favourable for pastoral farming than site 2.

Shrub density: Table 4 shows the distribution of shrub species with their density in the sampled savannah. Shrub density ranged from 4.8 to 9.4 shrubs per 100 m2 , or 480 to 940 shrubs/ha, in site 1 and from 8.6 to 9 shrubs per 100 m2 , or 860 to 900 shrubs/ha, in the second site. Plot 1 appears to be denser in shrubs (9.4 shrubs per 100 m2), followed by plot 3 (8.6 shrubs per 100 m2).

Soil characteristics

Particle size data: Overall, the soils of all the *Hyparrhenia diplandra* (Hack) Stapf savanna plots were sandy, rich in fine sands (55.19-57.98%), poor in clay (3.00-4.50%), with medium organic matter levels (2.16-2.77%) and very poor in silts (Table 5). There was almost no difference between the soils of these plots.

Chemical data: Chemical data for soils under the *Hyparrhenia diplandra* (Hack) Stapf savannah in the Ignié area show that these soils are generally acidic (pH ranging from 4.19 to 4.46), with average levels of total nitrogen (0.11 and 0.12%, or 1.1 and 1.2%0) and phosphorus (0.3 and 0.4%0), and almost devoid of calcium (Table 6). The C/N ratio varies from 11.36 to 13.41

DISCUSSION

Floristic diversity: The values of the maximum diversity index and the Shannon index ranged respectively from 3.16 to 4.45 and from 1.39 to 3.02 depending on the plots. In view of these results, the flora of the studied savannah appears to be less diverse overall. The value of Pielou's equitability index, varying between 0.42 and 0.67, showed that the distribution of species in this savannah is not equitable. These results are similar to those of Tambika (2014) who found Shannon index values ranging from 1.75 to 3 and Pielou equitability values ranging from 0.45 to 0.75, at Essimbi Ranch, in the Congolese Cuvette. They are also close to those of Assiala *et al*. (2019), who found maximum diversity, Shannon and equitability index values ranging respectively from 2.58 to 3; from 2.68 to 2.91 and from 0.59 to 0.66 in the Hyparrhenia diplandra (Hack) Stapf savannah of the Lékana area, Plateau Koukouya, where agricultural and pastoral activities are practised. The low diversity of the flora and the non-equitable distribution of species of the *Hyparrhenia diplandra* (Hack) Stapf savannah in the Ignié zone could be explained by anthropic action characterised by agricultural activities. This is certainly a savannah in reconstitution after degradation by mechanised and traditional agriculture, as the Ignié zone, located around 45 km north of Brazzaville, is much in demand for agricultural and pastoral activities. These activities have negative impacts on the vegetation (reduction in floristic diversity, reduction in herbaceous aboveground phytomass).

Herbaceous above-ground phytomass and carrying capacity: The herbaceous above-ground savannah phytomass recorded in the *Hyparrhenia diplandra* (Hack) Stapf savannah of the Ignié zone ranged from 4.75 to 6.85 t DM/ha across the plots at the two sites sampled. These values are lower compared to those obtained by Diamouangana (2000), Yoka *et al.* (2013), Assiala *et al*, (2019), and Yoka *et al.* (2020a) who respectively find values ranging from 9.5 and 9.4 t DM/ha in the Dihessé savannahs (Niari Valley); 3.32 to 10.04 t DM/ha in the Cuvette congolaise; 8.67 to 9.6 t DM/ha in the Hyparrhenia diplandra savannah in the Lekana area (Koukouya plateau); 11.93 t DM/ha in the unexploited savannah and 9.57 t DM/ha in the exploited savannah of the floodplains of Moussaka (Cuvette Congolaise) The difference between the results of the present study and those of the authors cited above could be explained by the fact that the Ignié area seems to be more disturbed by agricultural and pastoral activities than the other areas.

The carrying capacity values obtained in the present study ranged from 0.69 to 1.00 LU/ha/year. These values are similar to those found by Bokatola *et al* (2017) who reported values ranging from 0.6 to 0.91 LU/ha/year at Essimbi Ranch in the Congolese Cuvette. However, they are lower than those found by Yoka (2009) in the *Hyparrhenia diplandra* (Hack) Stapf savannah of the Ollombo and Makoua areas in the Congolese Cuvette (1.42 to 1.57 LU/ha/yr) and those found by Yoka *et al*. (2020a) in the *Hyparrhenia diplandra* (Hack) Stapf savannah in the floodplain of Mossaka in the Congolese Cuvette (1.38 to 1.74 LU/ha/yr). These results indicate that areas that are subject to more anthropogenic activities experience a decrease in phytomass production and consequently in potential carrying capacity. In the Ignié zone, the *Hyparrhenia diplandra* (Hack) Stapf savannah could be used for agriculture and pastoral livestock. However, in the context of pastoral livestock farming, respect for the pastoral load is essential for the sustainable management of this area.

***Soil characteristics*:** The soils of *Hyparrhenia diplandra* (Hack) Stapf savannah in the Ignié area are acidic (pH ranging from 4.19 to 4.46) and sandy (rich in fine sands) with very low levels of clay, ranging from 3.0 to 4.50%, and average levels of organic matter, nitrogen and phosphorus. The C/N ratio varies from 11.36 to 13.41. These results are different from those found by Assiala *et al* (2019) in the *Hyparrhenia diplandra* (Hack) Stapf savannah of the Lékana zone, in the Koukouya hills with regard to fine silt, clay and organic matter. These authors showed that in the Lékana zone, the soil under the *Hyparrhenia diplandra* (Hack) Stapf savannah has less than 50% fine sands, very high clay rates, varying from 27 to 34%, with very high organic matter rates (6.61 to 10.63%). Yoka *et al* (2020b) showed that the soil under the *Hyparrhenia diplandra* (Hack) Stapf savannah in the floodplain of Mossaka is acidic (pH ranging from 4.27 to 4.81) and has fine sands ranging from 2.30% to 37.40%; clay ranging from 22.50% to 40.50% and organic matter from 5.69 to 13.38%. From all these results, it should be noted that *Hyparrhenia diplandra* (Hack) Stapf savannah is adapted to sandy and clayey soils. As a result of this adaptation, this savannah covers large areas of sandy land in the Batéké hills (Makany, 1976; Apani, 1990) and in the Congolese district (Yoka *et al*., 2010a; Yoka *et al*., 2020b). The characteristics of soils under savannahs depend on the intensity of anthropogenic activities in the area of distribution of these savannahs. The present study showed that the C/N ratio was lower and ranged between 11.36 and 13.41. This result indicate that the decomposition of organic matter in the soil (Yoka, 2009; Assiala *et al*., 2019; Yoka *et al.*, 2020b). The soil of the *Hyparrhenia diplandra* (Hack) Stapf savannah in the Ignié area could be used for agricultural activities. As these soils are sandy, they should be developed rationally to avoid their degradation.

CONCLUSION

The study provided information on floristic diversity, phytomass produced, carrying capacity, shrub potential and the physico-chemical state of the soils of the *Hyparrhenia diplandra* (Hack) Stapf savannah in the Ignié area, in the Mbé plateau in Congo. The flora of this savannah is generally less diverse, with an uneven distribution of species within this plant community. The shrub layer is dominated by two species: *Bridelia ferruginea* Benth. and *Hymenocardia acida* Tul.

The phytomass produced offers the possibility of exploiting this savannah for pastoral purposes with an optimal load varying from 0.69 to 1 UBT/ha/year, in relation to the plots. The soils are acidic, sandy and rich in fine sand, with average levels of organic matter, nitrogen and phosphorus, with a C/N ratio that allows for rapid recycling of organic matter. Taking into account the estimated pastoral load and the physico-chemical state of the soils, *Hyparrhenia* d*iplandra* (Hack) Stapf savannah in the Ignié area could be used for agricultural and pastoral production. This study constitute basic data for further research on the savannahs of the zone and will be helfull in decision-making on the sustainable management of savannah ecosystems in Congo..

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