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FLORISTIC AND PHYSIOGNOMY CHARACTERISTICS OF THE VEGETATION FROM THE SUDANESE SECTOR OF COMOÉ NATIONAL PARK (NORTH-EAST OF CÔTE D'IVOIRE)

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ABSTRACT

The Comoé National Park is an area of extreme vegetation complexity, with an unpredictable mosaic of several vegetation types ranging from very open savannahs to closed forests. This complexity, linked to the park's position between the sub-Sudanese and Sudanese sectors, gives it a great wealth of flora. However, unlike the Sub-Sudanese sector, the Sudanese part has not been studied much. This study aims to contribute to a better knowledge of the flora of the Sudanese sector of Comoé National Park. To do this, phytosociological surveys were carried out using the Braun-Blanquet method in 210 plots of 900 m2 in the different plant formations. This made it possible to identify 546 species, divided into 326 genera belonging to 76 families. Among these species, 20 were inventoried for the first time in the Sudanese sector. The most abundant families are Fabaceae (24%), Poaceae (20%), Cyperaceae (17%) and Rubiaceae (11%). In addition, Phanerophytes dominate (52,26%) and a high proportion of species common to the Guinean-Congolese and Sudano-Zambézian regions (62,41%). This reflects a physiognomic change in the vegetation of the Sudanese sector of Comoé National Park.

Keywords: Floristic Diversity, Vegetation Physiognomy, Sudanese Sector, Comoé National Park.

1. INTRODUCTION

Located in the Sudanese domain, the Comoé National Park (CNP), a World Heritage site, is one of the largest protected areas in West Africa with a surface area of 1°148°756 hectares. This park is an area of extreme vegetation complexity, resulting in an unpredictable mosaic of several types of vegetation ranging from very open savannahs to closed forests. Its vegetation straddles the sub-Sudanese and Sudanese sectors of the Sudanese domain of Guillaumet & Adjanohoun (1971). It is this complexity of the vegetation that has prompted several scientific studies. Indeed, the flora and vegetation of the Comoé National Park have already been the subject of several works. These works have mainly addressed the issue of forest-savanna dynamics (Goetze *et al.*, 2006; Koulibaly, 2008) and the identification of characteristic plant species of each formation (Kouassi *et al.*, 2014). However, almost all of these studies focused on the flora of the sub-Sudanese zone of the park. The Sudanese part, with 667°888,95 ha and representing 58,14% of the total area of the park (Konan *et al.*, 2020), is very little known. This makes it impossible to report on the state of the vegetation of the CNP as a whole (Kouassi *et al.*, 2014). However, perfect knowledge of the physical attributes of the vegetation and its values is a prerequisite for the efficient management of a protected area.

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Thus, the main objective of this study is to contribute to a better knowledge of the flora of the Sudanese sector of the CNP. Specifically, the aim is to evaluate the floristic diversity of this part of the CNP and to determine the physiognomy of these formations by means of a few ecological parameters.

2.MATERIALS AND METHODS

2.1 Study site

The study was carried out in Comoé National Park, located in the north-east of Côte d'Ivoire, between latitudes 8°30' and 9°40' North and longitudes 3°10' and 4°20' West. It straddles three administrative regions (Hambol, Bounkani and Tchologo), most of which belong to the Bounkani region (Figure 1) according to the latest administrative division of Côte d'Ivoire.

The Sudanese sector is subject to a sub-arid tropical climate known as Sudanian. In this part of the park, annual rainfall varies between 800 and 1100 mm (Guillaumet & Adjanohoun, 1971), which makes this sector the driest zone with a tropical sub-arid climate known as Sudanian. Average annual temperatures vary between 25°C and 30°C.

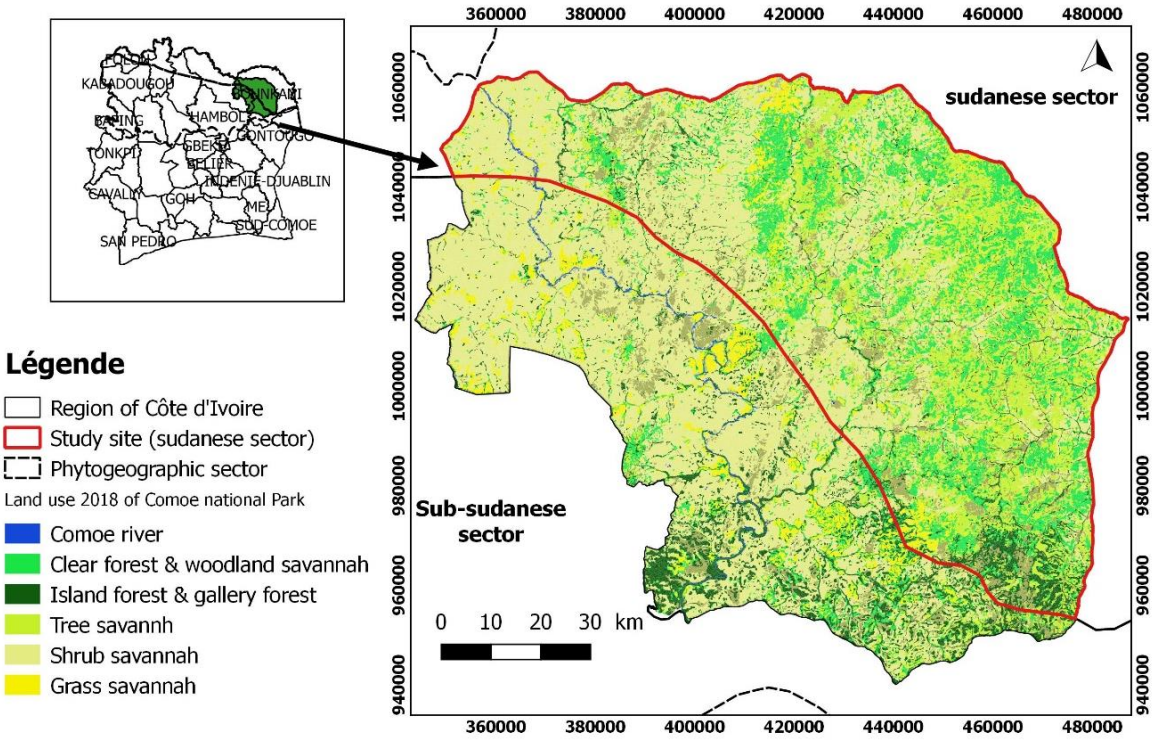

Figure 1. Geographical location of Comoé National Park.

2.2 Data Collection

Square plots of 30 m x 30 m (900 m^2) were delimited in different plant formations previously determined (Konan *et al.*, 2020). These are (*i*) island forests, (*ii*) gallery forests, (*iii*) clear forests, (*iv*) woodland savannahs, (*v*) tree savannahs, (*vi*) shrub savannahs and (*vii*) grass savannahs. Square or rectangular plots are better suited to studies of Sudanian and Sahelo-Sudanese

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vegetation (Salako *et al.*, 2013). Moreover, the 900m² surface area allows to reach, according to Thiombiano *et al.* (2016), the minimum area for West African savannah zones.

However, these surfaces can lead to a constraint in the visibility of herbaceous species in certain plant formations (Tiétiambou *et al.*, 2016). To compensate for this, a 10 m x 10 m (100 m²) sub-plot was set up within each 900 m^2 plot to survey herbaceous species. In total, floristic surveys were carried out in 210 plots for all plant formations in the Sudanese sector of the CNP.

In each plot, the species present were first identified to establish the species list. Phytosociological surveys were then carried out according to the classic stigmatist method of Braun-Blanquet (1932) modified by Dufrêne (1998 & 2003). This method is based on the principle of floristic homogeneity of the area studied. For each species inventoried, a coefficient of abundance-dominance is assigned (Table 1). This coefficient corresponds to the expression of the relative space occupied by all the individuals of this species. The modification of the Braun-Blanquet (1932) method makes it possible to switch from the abundance-dominance coefficient to numerical values during analyses (for analyses of specific diversity within each plant formation).

The data collection stage took place during the rainy season (June to October) of each year of 2018 and 2021. This allowed for a good representation of species that generally complete their development cycle before the dry season or the bushfire period.

Table 1: Correspondence between abundance-dominance coefficients (AD) and average cover values (RM)

Abundance-Dominance (AD) coefficients	Definition and average cover (RM) (%)
5	Any number of individuals, covering more than ¾ of the area so that's 87,5 %
4	Any number of individuals, covering ½ à ¾ of the area so that's 62,2%
3	Any number of individuals, covering ¼ to ½ of the area so that's 37,5%
2	Abundant or very abundant individuals, covering 1/20 to ¼ of the area so that's 15%
1	Abundant or very abundant individuals, covering 1/20 to ¼ of the area so that's 3%
+	Rare individuals with very low cover so that's 0,5%
R	Very rare individuals with negligible cover 0,1 %

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2.3 Data processing and analysis

2.3.1 Variability of the flora of the Sudanese sector of the CNP

2.3.1.1 Species richness of plant formations

The species richness of a given site is the number of species at that site regardless of their abundance (Sandjong *et al.,* 2018). For this purpose, floristic lists of each formation were compiled and divided into genus and family. This made it possible to produce a family spectrum that gives an overview of the distribution of species by botanical families.

2.3.1.2 Species diversity within the different plant formations

In order to evaluate the variability of specific diversity in the flora of the Sudanese sector, the Shannon & Wiener (1949) and Pielou (1966) indices were calculated respectively according to equations 1 and 2 for each type of plant formation.

The Shannon index is used to evaluate the diversity of environments (Legendre & Legendre, 1998; Hakizimana, 2012). According to these authors, this index varies according to the number of species present. Diversity is low when H' is less than 2,5, average if H' is between 2,5 and 4 and high when *H'* is greater than or equal to 4. It varies from 0 (only one species present) to $\log_2 S$ (all species present have the same abundance).

$$H' = -\sum_{i=1}^{s}\left(\frac{n_i}{N}\right)\log_2\left(\frac{n_i}{N}\right) \quad (1)$$

With n_i: the number of individuals or the cover of a species i,

N: the sum of the individuals or the cover of all species,

H' is the Shannon index (in bits).

As for the equitability index (E), it reflects the way in which individuals are distributed across species and varies between 0 and 1 (Adjakpa *et al.,* 2013). According to Inoussa *et al.* (2013), if *E* is between 0 and 0,5 it is weak, presence of dominance of certain species. On the other hand, if *E* is between 0,5 and 0,8, it is a medium and finally if *E* is between 0,8 and 1, equitability is high, absence of dominance.

$$E = \frac{H'}{H_{max}} \quad (2)$$

H' corresponds to the Shannon and Weaver index,

Hmax = ln S (with *S* = total number of species).

2.3.1.3 Comparison of floristic parameters

On the basis of these indices and the species richness, the different plant formations were compared. For this purpose, one-factor analyses of variance (ANOVA 1) were performed after checking the normality and homogeneity of the variables. In the presence of a significant difference (ANOVA 1 test) between the means for a given parameter, the Tukey test was immediately applied at the 5% threshold. The latter makes it possible to classify and determine which of the groups are different (Ouattara *et al.,* 2013). In the case of a lack of normality and/or homogeneity of the variables, non-parametric Kruskal-Wallis tests were applied. All these statistical analyses were performed with the R software version 3.6.1.

2.3.2 Characterization of physiognomy

2.3.2.1 Biological types

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Biological types are indices of the life strategy of species and, depending on their distribution, accurately reflect the ecological conditions of a region (Raunkiaer, 1934). They are illustrated with the help of raw and weighted spectra. The weighted spectrum is the percentage ratio between the cumulative species cover of one biological type and the cumulative species cover of all biological types (Habou *et al.*, 2015).

Information on biological types was sought from the literature through the identification of taxa inventoried in the flora. However, the biological types follow the classification of Raunkiaer (1934) modified for tropical areas (Aké Assi, 2001).

- MP: megaphanerophyte (tree or liana over 30 m high);
- mP: mesophanerophyte (tree or lianas 8 to 30 m high);
- mp: microphanerophyte (shrub or liana from 2 to 8 m high);
- np: nanophanerophyte (shrub or vine 25 cm to 2 m high)
- Ch: champhyte; these are woody or suffructive perennial plants (perennial plant from 0 to 25 cm high) whose renovation buds are located at a maximum of 50 cm from the ground;
- Th: therophyte: annual plant whose seed is the only organ of preservation during the unfavourable season;
- Ep: epiphyte, semi-epiphyte;
- G: geophyte: plants whose survival organs (bulb, tuber, rhizome) are buried in the soil and whose aerial part dies during the unfavourable season;
- H: hemicryptophyte; perennial plants whose renewal buds are above the soil surface;

2.3.2.2 Biogeographical distribution types

Phytogeographic distribution types reflect biological traits of the species in response to environmental conditions in a given area. The reasons why a species does not exceed the limits of its geographical range may vary according to climate, soil, history or isolation by natural barriers (Schnell, 1970). Information on phytogeographic distribution types was also sought in the literature after species identification.

The phytogeographical distribution of species used in this study follows the definitions of Aké Assi (2001).

- ✓ GC: species from the Guinean-Congolese region (dense humid forest);
- ✓ GCi: species endemic to Côte d'Ivoire;
- ✓ GCW: species endemic to the forest block in western Togo (Upper Guinea);
- ✓ GC-SZ: species common to the Guinean-Congolese region and the Sudano-Zambézian region (savannahs, open forests or steppes)
- ✓ GZ: species from the Sudano-Zambézian region (savannahs, open forests or steppes)

The biogeographical distribution of each species was also illustrated using the raw and weighted spectra. These calculations were made on the basis of the mean coverage corresponding to each abundance-dominance class.

3.RESULTS

3.1 Floristic characterisation of the flora of the Sudanese sector of the CNP

3.1.1 Specific richness

The flora inventory recorded 546 species, divided into 326 genera belonging to 76 families. Of these species, 20 were inventoried for the first time in the Sudanese sector (Table 2). The

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proportion of woody species was 62.04% and that of herbaceous species 37.96%. The most representative families (Figure 2) are Fabaceae (24%), Poaceae (20%), Cyperaceae (17%) and Rubiaceae (11%).

Table 2: Distribution of new species in the flora from the Sudanese sector of the CNP

Family	**Species**
Apocynaceae	*Parquetina nigrescens* ; *Secamone afzelii* ; *Strophanthus gratus*
Malvaceae	*Pterygota macrocarpa* ; *Sida acuta* ; *Triplochiton scleroxylon*
Rubiaceae	*Massularia acuminata* ; *Oldenlandia affinis* ; *Psydrax subcordata*
Poaceae	*Panicum maximum* ; *Paspalum scrobiculatum*
Euphorbiaceae	*Croton hirtus* ; *Euphorbia heterophylla*
Compositae	*Chromolaena odorata*
Cyperaceae	*Fimbristylis littoralis*
Convolvulaceae	*Ipomoea triloba*
Urticaceae	*Laportea aestuans*
Passifloraceae	*Passiflora foetida*
Urticaceae	*Pouzolzia guineensis*
Loganiaceae	*Spigelia anthelmia*

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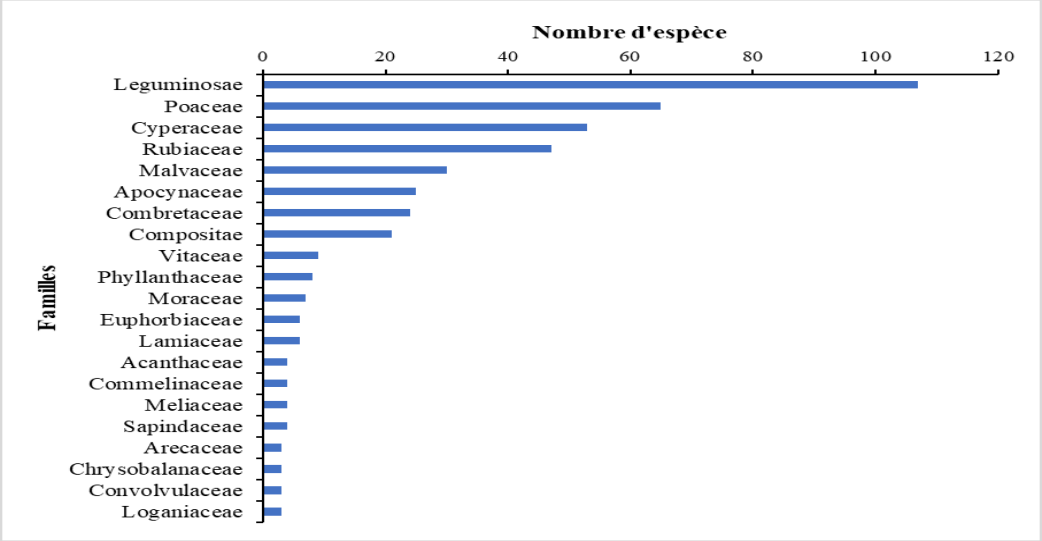

Figure 2. Spectrum of flora families in the Sudanese sector of Comoé National Park.

3.1.2 Variability of floristic parameters of the plant formations in the Sudanese sector

In the plant formations from the Sudanese sector of CNP, the average number of species differs from one formation to another (Table 3). The vegetation formation with a high number of species is the wooded savannah with 48 ± 2,8 and the one with a low number of species is the grassy savannah with 18 ± 1,84 (F= 9,18; P<0,001). Similarly, the Shannon diversity index of the different formations is roughly equal in the plant formations except for the savannah (F= 8; P<0,001). While Pielou's equitability index shows that there is no difference in the regularity of species within the vegetation formations (F=1,83; P>0,05).

Table 3: Variation in assessed ecological parameters of the plant formations in the Sudanese sector.

Plant formation	high number of species	Shannon index (H)	Pielou index (E)
IF	$40 \pm 5,32^{b}$	$2,84 \pm 0,49^{b}$	0,77 ± 0,05
FG	23 ± 4^{ab}	$2,74 \pm 0,29^{b}$	0,87 ± 0,02
FC	44 ± 3^{b}	$2,97 \pm 0,45^{b}$	0,81 ± 0,09
SB	$48 \pm 2,8^{b}$	$2,89 \pm 0,22^{b}$	0,75 ± 0,04
Sav_arbo	$31 \pm 2,32^{b}$	$2,95 \pm 0,13^{b}$	0,86 ± 0,05
Sav_arbu	$40 \pm 2,8a^{b}$	$2,95 \pm 0,39^{ab}$	0,79 ± 0,1
Sav_herb	$18 \pm 1,84^{a}$	$2,25 \pm 0,5^{a}$	0,78 ± 0,1
Paramètres statistiques	**P<0,001**	**P<0,001**	**p>0,05**

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For each line, the values followed by the same letter are not significantly different at the 5% level (Tukey test).

***Legend**: IF: forest island, FG: gallery forest, FC: clear forest, SB: woodland savannah, Sav_arbo: tree savannah, Sav_arbu: shrub savannah, Sav_herb: grass savannah.*

3.2 Biological characteristics of the flora of the Sudanese sector of the CNP

3.2.1 Biological types

The analysis of biological types shows that phanerophytes are strongly represented and abundant (52,26% of gross spectrum and 42,06% of weighted spectrum) in the vegetation of the CNP. In contrast, therophytes are poorly represented but relatively abundant (12,04% of gross spectrum and 28,08% of weighted spectrum).

Within the phanerophytes, microphanerophytes are highly representative and dominant (59,31% of the gross spectrum and 60,57% of the weighted spectrum) over the other types of phanerophytes (Figure 3A). Champherophytes are weakly represented, but with a remarkable dominance (2,58% of the gross spectrum and 14,13% of the weighted spectrum). In all plant formations, mocrophanerophytes are the most abundant except in grassy savannahs where therophytes are dominant (Figure 3B).

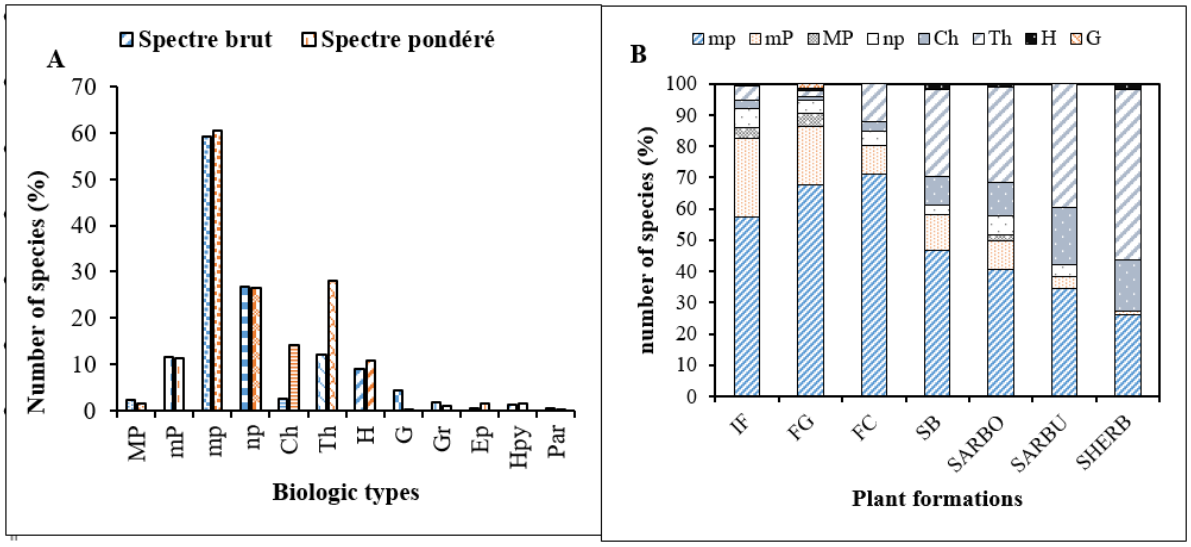

Figure 3. Spectrum of biological types of the flora of the Sudanese sector of Comoé National Park. A) the overall flora, B) the flora of the different formations.

***Legend**: IF: forest island, FG: gallery forest, FC: clear forest, SB: woodland savannah, Sav_arbo: tree savannah, Sav_arbu: shrub savannah, Sav_herb: grass savannah.*

3.2.2 Phytogeographic distribution

The analysis (Figure 4A) showed that the Sudanese sector of the CNP is dominated by taxa common to the Guinean-Congolese region and the Sudano-Zambezian region (62,41% gross spectrum and 62,53% weighted spectrum). They are followed by taxa from the Sudano-Zambezian region (27,37% of the gross spectrum and 32,06% of the weighted spectrum). However, the savannah formations are dominated by species from the Sudano-Zambezian region (SZ). Indeed, these species dominate 73,08% for shrub savannahs, 69,7% for tree savannahs,

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67,74% for wooded savannahs, 62,5% for grassy savannahs and finally 56,82% for open forests (Figure 4B). On the other hand, woodland formations are dominated by species common to the Guinean-Congolese and Sudano-Zambézian regions (50% for gallery forests, 48,39% for forest islands and 36,36% for open forests).

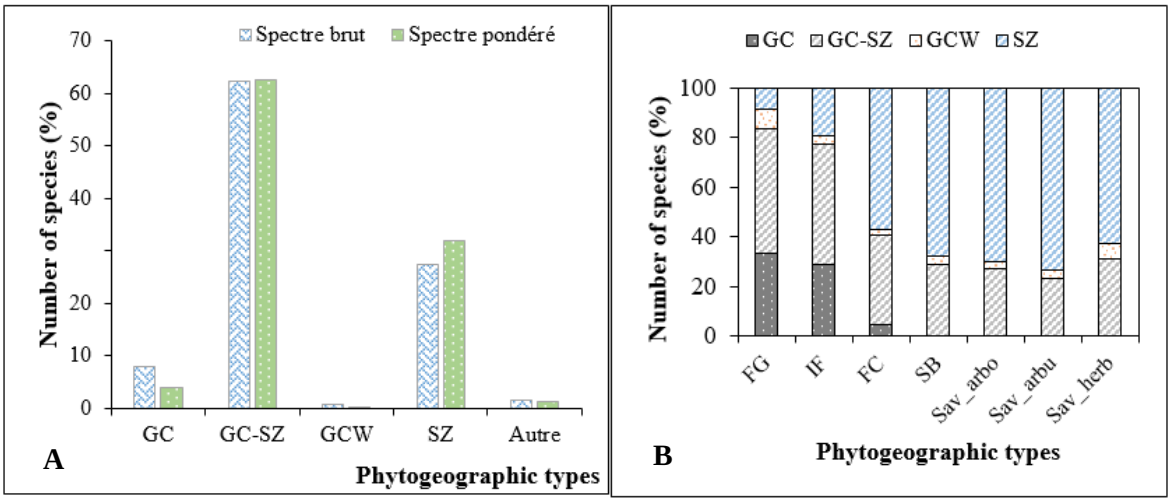

Figure 4. Spectrum of biogeographical types of the flora of the Sudanese sector of Comoé National Park. A) overall flora; B) flora of individual formations

Legend: *FG: gallery forest, IF: forest island, FC: clear forest, SB: woodland savannah, Sav_arbo: tree savannah, Sav_arbu: shrub savannah, Sav_herb: grass savannah*

4. DISCUSSION

A good knowledge of the flora on a local or regional scale is an essential tool for assessing its dynamics and implementing strategies for the sustainable use and conservation of biodiversity. The vegetation of Comoé National Park belongs to the Sudanese domain, whose main formations are open forests and savannah (Guillaumet & Adjanohoun, 1971). The complexity of the vegetation makes it difficult to classify the different formations that can be found there because of its position between the sub-Sudanese and Sudanese sectors. However, almost all floristic studies have focused on the flora of the sub-Sudanese zone of the park. The Sudanese part, with 667°888,95 ha and representing 58,14% of the total area of the park (Konan *et al.,* 2020), remains very little known. The aim of this study is to understand the flora of the Sudanese zone in the context of climate change.

The floristic inventory carried out in the Sudanese sector of the CNP identified 546 species, divided into 326 genera belonging to 76 families. According to Chatelain *et al* (2011), the floristic richness of the CNP is estimated at 1515 species. A comparison of the list obtained with this one gives an appreciable floristic richness insofar as it represents 36,03% of the total flora of the CNP. The floristic composition of the vegetation of the Sudanese sector of the CNP remains very close to the vegetation generally described for the Sudanian zone of Côte d'Ivoire and in West Africa in terms of species and families. Indeed, the investigations in this sector showed a predominance of Fabaceae and Poaceae, followed by Rubiaceae, Cyperaceae, Compositae and Combretaceae. This characteristic is similar to that described in Sudanian vegetation by certain authors (Adjanohoun & Aké Assi, 1967; Guillaumet and Adjanohoun, 1971; White, 1986).

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In addition, the sampled plant formations have on average a large average number of plant species, which varies from one formation to another. This variation in the different formations would be linked to the complexity of the landscape favouring a wide distribution of some species in the plant formations. Moreover, Piélou's equitability shows that there is no dominance of one or more species in the plant formations of the Sudanese sector. This explains the fact that the different plant formations in the Sudanese sector of the CNP have relatively high diversity indices. The highest Shannon diversity index values were observed in the open forests. This result could be explained by the heliophilic herbaceous undergrowth of the open forests and the long dry season that allows bushfires to penetrate and then favours the regeneration of the undergrowth during the rainy season.

In 1967, Adjanohoun & Aké Assi (1967) showed that therophytes are dominant in the Sudanian zone of Côte d'Ivoire. However, in this case study, phanerophytes predominate in the vegetation of the Sudanese sector of the CNP. This contradiction could be explained by the transformation of the current vegetation towards the original vegetation (Catinot, 1994). Indeed, following the annual loss of biomass by fire, the lower stratum of the savannahs is generally occupied by offshoots of woody species such as *Daniellia oliveri*, *Pseudocedrela kotschyi* (with the largest number of offshoots), *Detarium microcarpum* and *Bridelia ferruginea* (Koulibaly, 2008). In addition, the predominance of phanerophytes in this flora indicates a regeneration of certain woody species that multiply by buds, which constitutes a quantitatively important mode of regeneration.

Concerning the abundance of microphanerophytes, it reveals a preponderance of shrubby formations. This was also proven by the classification of the 2018 satellite images by Konan *et al.* (2020). Furthermore, the low proportion of mesophanerophytes may induce a tree structure while the low proportion of geophytes testifies to the aridity of the climate in the Sudanese zone (Kanga, 2016). Moreover, the presence of hemicryptophytes, even at a low proportion, reveals the stability of the soils and relatively acceptable moisture conditions for vegetation development (Fournier *et al.*, 2000). These results confirm the assertion of Schmidt *et al.* (2005) that biological types reflect not only structural parameters in a vegetation, but also various environmental conditions.

In addition to biological types, the phytogeographic distribution of the flora of the Sudanese sector shows a high proportion of species common to the Guinean-Congolese and Sudano-Zambezian regions (GC-SZ), followed by species from the Sudano-Zambezian region (SZ). The relative importance of species common to the Guinean-Congolese and Sudano-Zambezian regions (species with a wide phytogeographical distribution) is explained by the abundance of Fabaceae and Poaceae, which contain species with a wide phytogeographical distribution in general (Sinsin, 2001). However, Adjanohoun & Aké Assi (1967) showed that the Sudanese sector is dominated by species from the Sudano-Zambezian region. One would therefore expect to have a flora that has a strong affinity with Sudan-Zambezi species. These observed phytogeographical distributions therefore confirm a dynamic of plant communities in the Sudanese sector and in the whole of the CNP. Indeed, according to Melon *et al* (2015), phytogeographic types are good indicators of the dynamism or floristic stability of plant communities. Furthermore, phytogeographic distribution is an indicator of environmental conditions in that each species achieves its maximum abundance in its favourable station (Guinko, 1984).

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5. CONCLUSION

The floristic study of the Sudanese sector of the Comoe national Pork revealed an interesting species richness (546 species). These species are divided into 326 genera belonging to 76 families. The floristic parameters of the different plant formations in the Sudanese sector evaluated show that in the vegetation of the Sudanese sector of the CNP, the average number of species and floristic diversity are relatively high and differ from one formation to another. In addition, there is no dominance of one or more species within the vegetation formations.

The flora of the Sudanese sector of the CNP is dominated by phanerophytes followed by therophytes. The high number of phanerophytes in this flora indicates the regeneration of certain woody species leading the savannah formations towards the original vegetation (open forests). The biogeographical distribution of this flora shows a high proportion of species common to the Guinean-Congolese and Sudano-Zambezian regions (GC-SZ) followed by species from the Sudano-Zambezian region (SZ). This confirms the dynamics of the plant communities in the Sudanese sector and in the entire CNP.

The concept of biological types and biogeographical distribution is very important for the effective management of plant resources. These results are therefore a first step in the establishment of a database on the flora and vegetation of the CNP savannahs. Further development and expansion of the database will allow the establishment of a bioclimatic distribution map of the species and the drafting of a repertory of the entire flora of the CNP.

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