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RESEARCH ARTICLE

IMPACT OF GOLD MINING ON FLORA: THE CASE OF THE SISSENGUÉ GOLD MINE (NORTHERN CÔTE D'IVOIRE)

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Abstract

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This study was initiated to contribute to the sustainable management of biodiversity in mining sites in Côte d'Ivoire. Its objective is to determine the impacts of gold mining activities on the flora of the Sissengué gold mine located in the department of Tengréla in northern Côte d'Ivoire. The flora inventory was conducted along a 500 m transect combined with the surface survey and roving inventory methods. The surface survey method consisted of delimiting a 25 m x 25 m (400 m^2) plot at the end of each transect. In total, nine (09) types of land use were identified in the site, namely annual crops, perennial crops, open forests, forest galleries, tree savannahs, shrub savannahs, burned areas, lakes or water reservoirs, and locality. The floristic inventories carried out in seven (07) types of land occupations allowed the identification of 207 plant species distributed among 155 genera and 61 families. In addition, thirteen (13) species with special ecological status and seven (07) species included in the IUCN red list, four of which are vulnerable. However, the floristic diversity is low in all plant formations with an average of 1.91. The shrubby savannahs record the highest densities with 1705 stems/ha while the forest galleries and open forests record the highest values of basal area, with respectively 37.2 m2/ha and 28.1 m2/ha. These vegetation formations are disturbed by the mine's gold mining activities. Efforts to conserve areas dedicated to biodiversity conservation must be a priority for mining sites in Côte d'Ivoire

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Introduction:-

Globally, the mining industry records significant impacts on forests and the people who live in them. Indeed, more than 60% of the material extracted in the world comes from surface mines that cause devastation to the ecosystems where they are installed (Tia et al., 2018). Indeed, these mining activities cause enormous damage to the environment regardless of the type of exploitation.

In Côte d'Ivoire, many mining companies installed throughout the territory operate mines without respecting the environmental code. Indeed, this country is confronted with the fall of the prices of the agricultural raw materials on

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the world market due to the climatic disturbances, the erosion of the grounds and also with the scarcity of the cultivable forest surfaces. Thus, Côte d'Ivoire has undertaken to increase the exploitation of its mining resources (Vroh et al., 2014). These mining companies are accused of negatively impacting the biodiversity found throughout their operating perimeter. Mining activities therefore constitute an additional pressure that accentuates those already existing due to logging and agriculture (Tiébré et al., 2016).

In light of these findings, this study aims to determine the impacts of gold mining activities on the flora of the Sissengué gold mine located in the Tengréla department in northern Côte d'Ivoire.

Material And Methods:-

Study site

The Department of Tengrela is located in the extreme north of Côte d'Ivoire, in the Bagoué region (Fig 1). The town of Tengrela, the capital of the Department, is located 150 km north of Boundiali (regional capital). The indigenous populations are Sénoufos, Malinkés and Dioulas. Geographically, this Department is located in a quadrilateral bounded by latitudes 10°43'51.4" and 10°14'45" North, and longitudes 6°12'28.1" and 6°43'32.8" West. More precisely, the exploitation perimeter is located between latitudes 10°23'00" and 10°13'59.1" North and longitudes 6°26'48.6" and 6°37'55.9" West (Fig 1). The exploitation perimeter is surrounded by villages such as Neguepié, Fimbiasso, Minasso and M'Bélé.

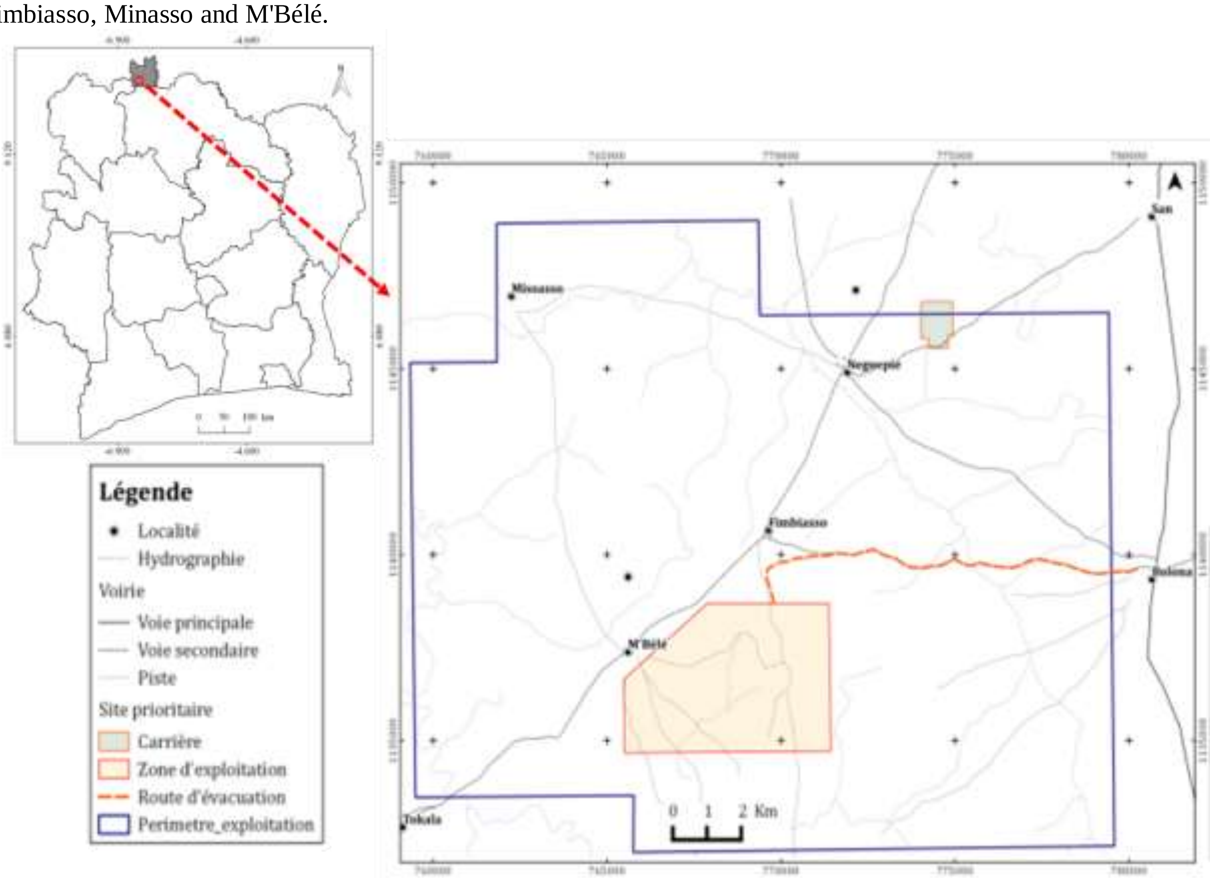


Fig1:- Carte de la zone d'exploitation comportant les villages cites.

Data collection

Acquisition of satellite data

The realization of this work required the acquisition of a basic parcel map (1/48000) on paper (A4 format) and digital of the project site. The spatial data consisted of Landsat OLI 197-55 satellite images of February 22, 2016 covering the operating perimeter. A Garmin Etrex GPS was used during the various survey missions to record geolocated points. These GPS points were used to perform and validate the classification of satellite images. The GGIS software was used to process the satellite images and produce maps.

Acquisition of floristic data

The flora inventory was conducted along a 500 m transect combined with two floristic survey methods. These were the area survey method and the roving inventory method (Kouakou et al., 2015; Sangne et al., 2019)

The area survey method consisted of delineating a 25 m x 25 m (400 m^2) plot arranged at the end of each transect. On each survey area, all woody, lianascent, and herbaceous plant species encountered were identified and their names recorded.

The roving inventory method involved walking the area in all directions noting all plant species encountered between surface surveys. This method made it possible to record all the species encountered in the plant formations that had not yet been recorded in the plots in order to complete the floristic lists obtained from the surface surveys.

Data analysis

Land Cover Mapping

The processing of satellite images for the selection of sampling sites consisted in performing the color composition (RGB) OLI5 (near infrared), 0LI6 and 7 (mid-infrared). These primary colors Red-Green-Blue have the advantage of highlighting woody-rich vegetation formations in red-green. The visual interpretation of the colored compositions allowed the identification and the appreciation of the spatial distribution of the different vegetation formations. On this basis, points (50) or sampling sites were selected. The choice of the sites was made around two (2) zones that are the priority zone for the execution of the project and the zone outside the priority zone. The priority areas for project implementation include the quarry near Neguepié, the ore mining site (Pit East and West) between Fimbiasso and M'Bélé, and the ore transport route (Fimbiasso-Bolona axis).

Floristic data

Floristic richness

The total number of species inventoried for the different plant formations was determined. For each of the species inventoried, the family and genus were noted. The importance of the flora and the ecological value of the different types of biotopes were determined through qualitative diversity. The aim was to identify species endemic to Côte d'Ivoire (GCi) and those endemic to the West African forest block (GCW). The identification was possible thanks to the list of species preestablished by Aké-Assi (2001; 2002). To these endemic species, were added the rare or endangered species of the Ivorian flora. Their status was reported based on the work of Aké-Assi (1998) and the IUCN red list (2018).

All floristic data were entered using Excel software. The Excel spreadsheet was used to create pivot tables and calculate species frequencies. The MVSP software was used to calculate diversity indices.

Species diversity

Specific diversity is a measure of the species composition of a stand that takes into account the number of species and their relative abundance (Shannon et al., 1948). Several indices allow us to assess this diversity. If we denote by N the number of S species considered, ni the number of individuals of a species i and Pi (ni/N) the relative abundance of the species i, then the Shannon index can be summarized in the following mathematical expression :

$$H' = -\sum_{i=1}^{s} P_i \ln P_i$$

This index varies from 0 (only one species present) to lnS (all species present have the same abundance). For a stand, the equitability provides information on the distribution of numbers between the different species. Thus, the calculation of the specific diversity index is always accompanied by that of equitability, because two stands with different physiognomy can havethe same diversity. The equitability E is obtained by relating the observed diversity to the maximum theoretical diversity. Equitability varies from 0 to 1. It tends towards 0 when almost all the species are concentrated on one species and towards 1 when all species have the same abundance. In the case where this index tends towards 1, the environment in question is said to be balanced. The equitability index is calculated according to the following mathematical formula:

$$E = \frac{H'}{\ln \times S}$$

Floristic similarity

The floristic similarity between two sites or biotopes was analyzed through the Sorensen's similarity index (1948). This coefficient makes it possible to compare the floristic list of environments two by two in order to identify a similarity or not.

$$CS = \frac{2c}{a+b} \times 100$$

It varies between 0 and 100. The hypothesis of similarity or resemblance is accepted when the coefficient is greater than 50% (CS > 50). In the opposite case (CS<50), there is no similarity between the floristic lists of the plots concerned.

Vegetation structure

In order to assess the state of the vegetation formation in each of the plant formationsvisited, the distribution of stems on the transects was estimated. The circumference values taken in the field were first converted to diameter according to the formula:

$$d = \frac{C}{\pi}$$

where (π= 3.14; c = Circumference and d = diameter)

Then, the individuals of the stands were divided into 14 diameter classes which are the classes of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm, 60-70 cm.

The basal area of the trees was calculated for the whole and in each plant formation according to the formula:

$$A = \frac{C^2}{4\pi}$$

With A = Basal area, expressed in m²/ha and C = Circumference and π =3.14.

Stem density (D) was determined as the ratio of the number of stems (N) in the transects considered to the total transect area (S) in hectares.

$$D = \frac{N}{S}$$

Results:-

Cartographic restitution of the land use of the study site

Nine (09) types of land use were identified, based on the spectral behavior of the types of biotopes encountered during pre-processing and validated in the field. The spatial distribution of land use types shows a dominance of shrubby savannahs, with an estimated surface area of 10458.72 ha or 35% of the exploitation perimeter (Figure 2). They are followed by cultivated areas (6985 ha, or 23.7%), fallow land (6060 ha, or 20.6%) and burned areas (2409 ha, or 8.5%).

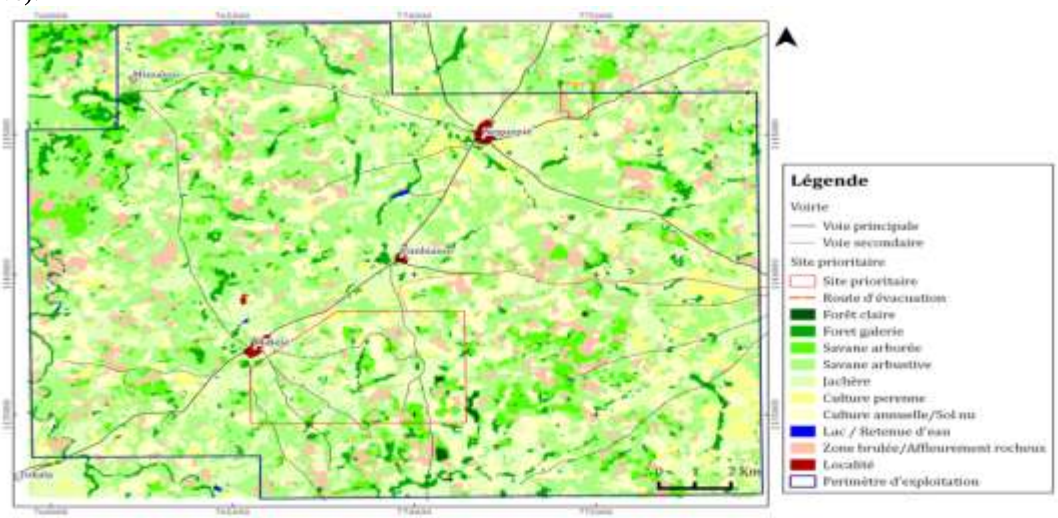


Fig2:- Land use map of the project area.

Qualitative diversity

Floristicrichness

At the end of the floristic inventories, 207 plant species were inventoried. They are distributed between 155 genera and 61 families. In the different plots inventoried, the overall average floristic richness is 11.88 species/plot. The lowest value was recorded in cashew and cotton plantations (3 species/plot) and the highest values were obtained in the savannah tree plots and forest galleries, with 21.8 and 20 species/plot respectively (Table 1). Considering the types of land use encountered, gallery forests are the richest with 135 species. They are followed by wooded savannahs with 87 species and crops are the least rich with more than 10 species (Table 1). Three genera are the richest in species. These are the genera Ficus (11 species) Combretum (7 species) and Terminalia (5 species). The best represented families are Rubiaceae (19 species), Caesalpiniaceae (15 species), Euphorbiaceae, Combretaceae and Fabaceae with 14 species each.

Table 1:- Summary of floristic richness by land use.

Biotope types	Species richness		Genus	Family	dominantFamille
	Overall	Average per plot			
Annual crop	18	3	18	14	Fabaceae (2) ; Mimosaceae (2) ; Poaceae (2) ; Bombacaceae (2)
Perennial crop	12	3	12	10	Fabaceae (2) ; Mimosaceae (2) ; Poaceae (2) ; Bombacaceae (2)
Open forest	25	13,5	24	15	Caesalpiniaceae (7) ; Sapotaceae (3)
Forest gallery	135	20	105	50	Rubiaceae (14), Caesalpiniaceae (12) ; Euphorbiaceae (12)
Tree savanna	87	21,8	67	37	Caesalpiniaceae (11) ; Combretaceae (7)
Shrubby savanna	63	10	54	30	Caesalpiniaceae (8) ; Rubiaceae (7)
Grand total	207	11,88	155	61	Rubiaceae (19), Caesalpiniaceae (15)

Specieswithspecialstatus

In all of the flora surveyed on the project site, 13 species with special ecological status were identified (Table 2). These include eleven (11) rare and/or endangered species and three (03) endemic species including *Hibiscus comoensis* (Fig 3).

Table 2:- List of special status species found in the study area.

Espèces	**Statut**	
	Endémismes	**Menaces**
Afzelia africana		VU
Centella asiatica		LC
Hibiscus comoensis	HG_Gci	AA
Isoberlinia doka		LC
Khaya grandifoliola		VU
Khaya senegalensis		VU
Lannea nigritana		AA
Leptoderris cyclocarpa	HG_GCW	
Pterocarpus santalinoides		LR/lc
Samanea dinklagei	GCW	
Syzygium guineense		AA
Syzygium guineense		AA
Vitellaria paradoxa		VU

VU: Vulnerable, LR/nt: Near Threatened, AA: Rare according to AkéAssi (1998).

Fig 3:- Overview of *Hibiscus comoensis*, endemic to Côte d'Ivoire.

Considering the IUCN red list, there are seven (7) species (Fig 4), four of which are vulnerable (VU) and three (3) species of minor concern (LR/lc and LC). These include *Khayasenegalensis* (VU) and *Pterocarpussantalinoides* (LR/lc). Four (04) species are known to be locally threatened, in reference to the list established by AkéAssi (1998). Among these species, *Hibiscus comoensis* and *Syzygiumguineense* have been recorded only in the forest galleries.

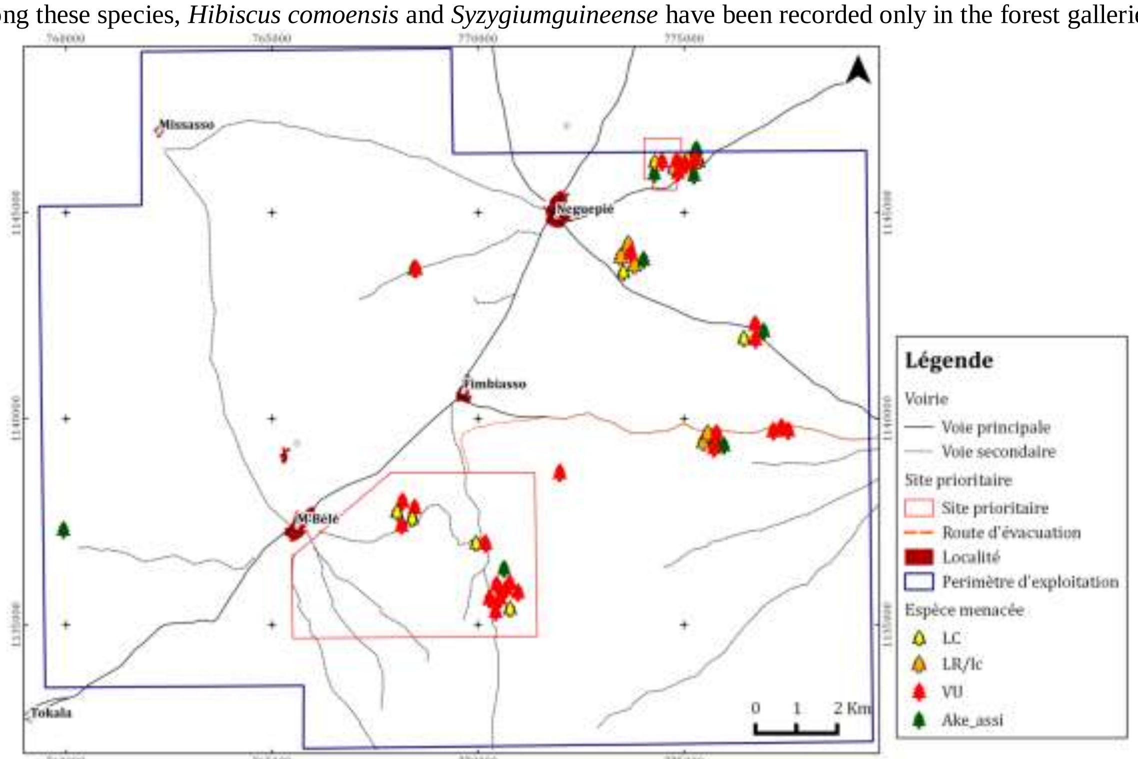


Fig 4:- Distribution spatiale des espèces rare et/ou menacées sur le site du projet.

Endemic species include *Samaneadinklagei*, endemic to the West African Forest Block (GCW). The other two species with two centers of endemism at once (Fig 6) are *Leptoderriscyclocarpa* (HG_GCW) and Hibiscus comoensis (HG_Gci).

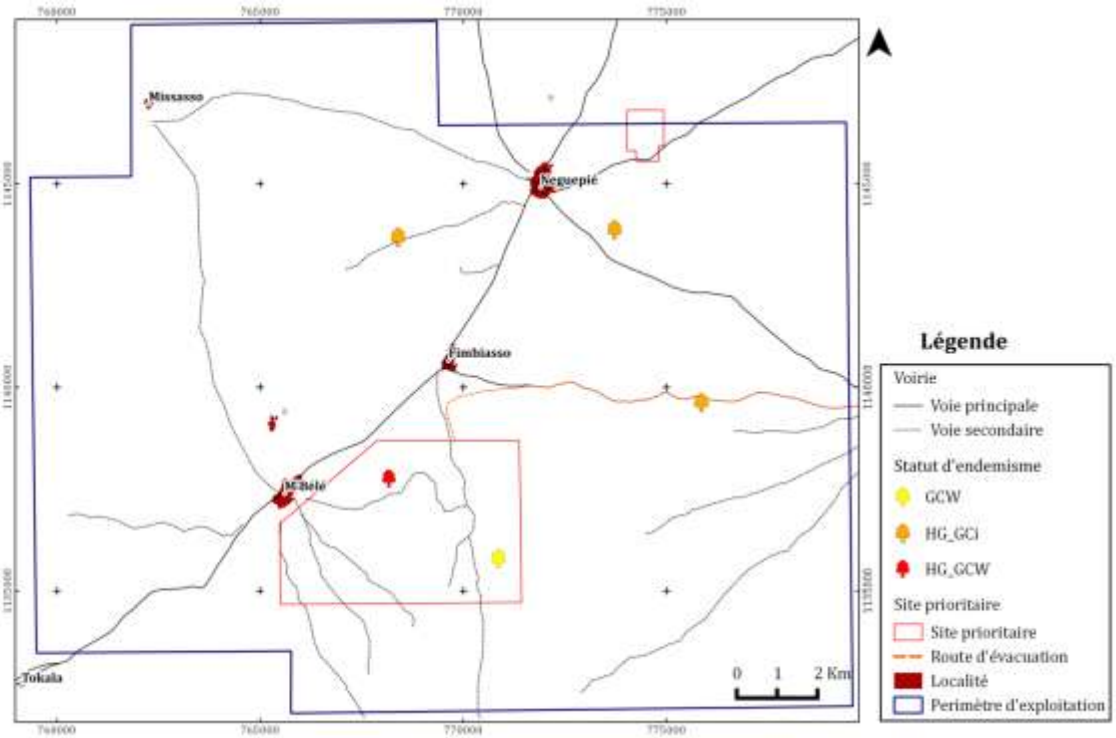


Fig 5:- Distribution spatiale des espèces endémiques sur le site du projet**.**

Quantitative diversity

Specificdiversity

Shannon diversity indices are low for all identified plant formations. The overall value is 1.91. The high values of this index are observed, in decreasing order, in forest galleries (2.65), tree savannas (2.57) and open forests (2.42). Cashew and cotton plantations had the lowest values (Table 3). The calculated equitability indices show three trends in the equi-repartition of species in the biotopes. There is a very even distribution of flora in open forest (0.93) and forest galleries (0.9). Next, to a lesser degree, are the tree and shrub savannahs with values of 0.83 and 0.80 respectively. The other ecological environments encountered have a low diversity of flora (Table 3).

Table 3:- Variation in calculated diversity indices by land use type.

Biotope	Shannon Index	Equitability Index
Open forest	2,42	0,93
Forest gallery	2,65	0,9
Annual crop	0,95	0,3
Cashew plantation	0,81	0,1
Woodedsavannah	2,57	0,83
Shrubbysavanna	2,05	0,8

Floristicsimilarity

The analysis of the calculated Coefficient of Similarity values shows that only the tree savannas and shrub savannas have a similarity between their different flora. The flora of the other plant formations encountered are dissimilar (Table 4).

Table 4: Variation in coefficients of similarity between land use types

Table 4:- Variation in similarity coefficients between land use types.

Biotopes Type	Open forest	Forest gallery	Annual crop	Cashew plantation	Woodedsavannah	Savane arbustive
Open forest	100					
Forest gallery	21,2	100				

Annual crop	0	0	100			
Cashew plantation	6,3	2,2	15,4	100		
Woodedsavannah	21,7	28,9	2,7	15	100	
Shrubbysavannah	11	21,1	3,7	16,4	57,9	100

Vegetation Structure of the Study Site

Density and basal area of vegetation formations

The overall density of stems with a diameter at breast height greater than or equal to 2.5 cm in all the plant formations inventoried is 608.5 stems/ha and the corresponding basal area is 18.6 m²/ha. However, the variations in density are significant from one plant formation to another.

The shrubby savannahs record the highest densities with 1705 stems/ha. The lowest values are obtained in annual crops and cashew plantations with 50 stems/ha and 25 stems/ha respectively.

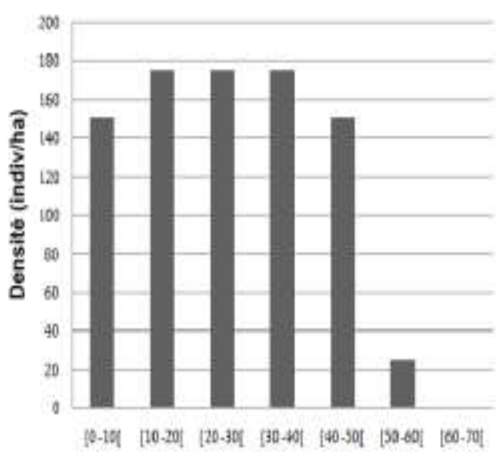
In the basal area, gallery forests and open forests have the highest values with 37.2 m2/ha and 28.1 m2/ha respectively. They are followed by wooded savannahs with an average basal area of 27.6 m2/ha. Annual crops and perennial crops have the lowest average basal area values (Table 5).

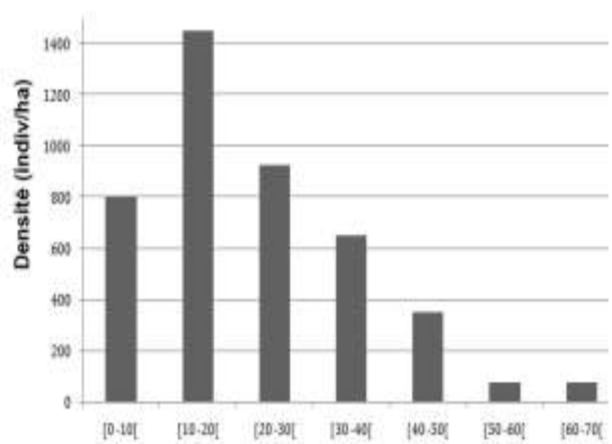
Table 5:- Variation in densities and basal areas of individuals by land use type.

Type of biotope	Density (Stems/ha)	Basal area (m²/ha)
Annual crop	50	1,6
Perennial crop	25	1,7
Open forest	425	28,1
Gallery forest	720,8	37,2
Shrubby savannah	1705	15,5
Wooded savannah	725	27,6
Medium	608,5	18,6

Distribution of individuals by diameter class

Stem distribution curves by diameter class show variable shapes depending on the type of land use. In general, the histograms show two shapes. In shrubby savannas, the distribution of stems is strong in the first three diameter classes. The histogram then presents an "inverted J" shape, which translates a good stability of the vegetation in this biotope. The histograms of the other vegetation formations have a "bell" shape reflecting a strong disturbance of the environment (Fig 6).





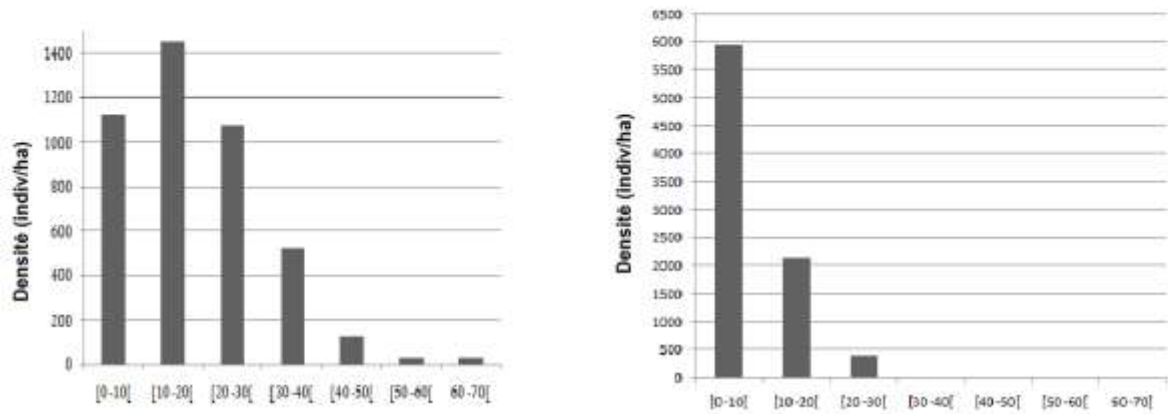


Fig 7:- Histograms of distribution of individuals of species by diameter classes according to land use types.

Discussion:-

A list of 207 plant species was compiled throughout the sentinel site. The floristic richness of this study area could have been greater had it not been for the effects of drought, fire, human activities (agriculture, logging) and the limited number of sampling sites given the time available for field data collection. Indeed, the drought, which has as a corollary the devastating effects of bush fires coupled with human activities, could be at the root of this low floristic richness. In the lower strata of clear forests, almost all species are dry. The same is true for shrub and tree savannas, which have lost most of their herbaceous species due to bush fires (Gbozé et al., 2020). All these factors have not allowed the identification of certain vulnerable or seasonal species. Indeed, the impacts of fire contribute to reducing the density and diversity of savannas (N'Da et al. 2008). In addition, the greater disturbance of this savanna by fire would explain the low equitability of species distribution in relation to land use types.

Nevertheless, the forest galleries record the highest number of species in that they are most often preserved by local populations, as they shelter watering points necessary for the irrigation of market gardening and allow animals to drink. In addition, the low species richness of young fallows could be explained by the felling of the majority of woody plants due to the development of plots and also by the intensity of agricultural activities on the same spaces such as cotton, maize and sorghum crops (Konaté et al., 2020). The species that were spared at the time of the establishment of crops are Parkiabiglobosa; Danielliaoliveri; Adansoniadigitata; Vitellariaparadoxa and Khayasenegalensis, for their different uses. Indeed these species are used for cattle feeding, fruit marketing or for medicinal purposes (Dro et al., 2013).

Of all the plant species inventoried, only 13 belong to the category of special status species. This low number is probably related to the devastating effects of fires and also to the dominance of savannas in this part of Côte d'Ivoire. Indeed, the presence of species in the different categories of the lists used seems to be linked for some to important and uncontrolled commercial exploitation, coupled with weak natural regeneration. For other species, it would be a reduction of habitats due mainly to agricultural activities (Adou Yao et al., 2013; Ouattara et al., 2013).

Crops (annual and perennial) are generally installed in forest galleries and wooded savannahs because of the moisture and fertility of the soil. Indeed, it was observed that the majority of species recorded in these environments belong to the Leguminosae family (Ceasalpiniaceae, Mimosaceae and Fabaceae). This suggests that forest galleries are refuges for legumes in savanna zones.

In addition, the use of bushfires for the establishment of crops constitutes a significant threat to the flora and vegetation. It is estimated that the burned areas are 2409 ha) on the satellite image of February 22, 2016. Indeed, every year, savannahs are crossed by fires that are devastating for savannah vegetation where some plant species are generally vulnerable (Soro et al., 2006).

Another important threat to the flora and vegetation is the cultivation of cashew trees, which expands every year on fertile land. This cultivation takes place preferably in forest areas or in wooded savannahs (Konaté et al., 2020).

Farmers generally cut down all the large trees, leaving only a few néré or karité trees. The monopolization of space by perennial crops leads to a transformation of the original vegetation and a reduction in biodiversity.

Illegal logging for timber beyond the 8th parallel in general and in the study area in particular is also a major pressure on plant species. This concerns species such as Pterocarpuserinaceus or Bois de Vène, Lophiralanceolata or Lophira des savanes and Khayasenegalensis or Caïcédrat.

Conclusion:-

The present study has shown that the sissengué mining site located in the department of Tengréla in the north of Côte d'Ivoire is home to 207 plant species. They are divided into 155 genera and 61 families. The inventories carried out in the nine types of land use identified indicate that gallery forests are the richest with 135 species followed by savannahs with 87 species. In addition, thirteen (13) species with special ecological status were identified. These are eleven (11) rare and/or endangered species and three (03) endemic species including Hibiscus comoensis. Floristic diversity is low in all plant formations with an average of 1.91. The shrubby savannahs record the highest densities with 1705 stems/ha while the forest galleries and open forests record the highest values of basal area, with respectively 37.2 m2/ha and 28.1 m2/ha. Most of the vegetation formations have a "bell-shaped" appearance reflecting a strong disturbance of the environment.

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