International Journal of Fauna and Biological Studies
Available online at www.faunajournal.com

IJFBS International Journal of Fauna And Biological Studies

E-ISSN 2347-2677
P-ISSN 2394-0522
www.faunajournal.com
IJFBS 2021; 8(5): 23-29
Received: 18-07-2021
Accepted: 20-08-2021

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Diversity and activity rate of a bat communities in a voluntary nature reserve in the Agneby-Tiassa region (South-East, Côte d'Ivoire)

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DOI: https://doi.org/10.22271/23940522.2021.v8.i5a.853

Abstract
In order to provide basic data on the specific diversity of bats in a private forest of fifty hectares, located in the Agnéby-Tiassa region (Southeastern Côte d'Ivoire), a study was carried out there from August 26 to October 15, 2018. This was conducted in three types of habitats represented by a forest, a wetland and an edge zone. Sixty-three individuals were captured using mist nets during 38 days, from 18h00 to midnight. Twelve species of bats belonging to nine genera and five families have been inventoried. This community is dominated by *Epomops buettikoferi, Scotonycteris zenkeri, Nanonycteris veldkampi, Macronycteris gigas, Hipposideros caffer* and *Mops thersites*. The activity study has shown that Microchiroptera are most active from 18h30 to 20h while bats' activity is most intense from 21h30 to 23h00. The forest, the wetland and the edge zone are respectively the most diversified in species of bats. *Epomops buettikoferi, Nanonycteris veldkampi* and *Hipposideros caffer* activities are positively correlated with forest and edge zone while *Macronycteris gigas, Mops thersites, Scotophilus nux* and *Eidolon helvum* have a greater affinity for the wetland.

Keywords: Chiroptera, communities, voluntary natural reserve, Agnéby-Tiassa Region, Côte d'Ivoire

1. Introduction
Bats (Chiroptera) are the only mammals that move by flight and whose habits are insufficiently known. This lack of knowledge is exacerbated by their nocturnal activities, which make them difficult to study (Kunz *et al.*, 2011; Kadjo, 2015) [1, 2]. However, they are of various systematic, ecological, veterinary, medical, economic and conservation interests (Kunz *et al.*, 2011) [1].

Thus, these animals provide important ecological services in terms of flower pollination, dispersal, germination and replenishment of pioneer plant communities, some of which are threatened by overexploitation (Myers *et al.*, 2000; Kankam and Oduro, 2009; Niamien *et al,*. 2010; Kunz *et al.*, 2011; N'zuki *et al.*, 2011; Kadjo, 2015) [3, 4, 1, 5, 2]. Fruit bats or Megachiroptera play a key role in the maintenance and regeneration of forests after natural or anthropogenic disturbances (Taylor *et al.*, 2013; Djossa *et al.*, 2008, 2010; Kunz *et al.*, 2011) [6, 7, 8, 1]. Unfortunately, they are rarely taken into account in the management of protected areas and in biological inventories of these environments (Bakwo *et al.*, 2014) [9].

Chiropterans have been the subject of a few scattered studies in Côte d'Ivoire (De Vree, 1971; Bergmans *et al.*, 1974; Thomas, 1983; Brosset, 1985; Koné, 1996; Lim and Van Coeverden De Groot, 1997; Gordon, 2001; Fahr and Ebigbo, 2003; Niamien *et al.*, 2010, 2015; Bitty *et al.*, 2013; Kadjo, 2015) [10, 11, 12, 5, 13, 14, 2]. On the other hand, the sites surveyed to study them remain limited and are mainly protected areas. These include the Lamto Reserve in the pre-forest savannah zone (Bergmans *et al.*, 1974; Thomas, 1983) [11, 12], the Taï National Park (Gordon, 2001; Henry *et al.*, 2004; Koné, 1996) [15, 16, 17] and Azagny (Nesi *et al.*, 2013) [18] in the evergreen forest zone, the Comoé and Mont Sangbé National Parks in the Sudanian savannah zone (Fahr and Ebigbo, 2003) [12], the Mont Nimba Integrated Reserve in the mountain forest zone (Brosset, 1985; Denys *et al.*, 2013; Monadjem *et al.*, 2013, 2016; Simmons *et al.*, 2021) [18, 19, 20, 21, 22] and the breeding colonies of the African straw bats (*Eidolon helvum*) in the Plateau-Abidjan commune (Niamien *et al.*, 2010, 2015, 2017) [5, 13, 23]. Studies carried out in the Taï and Comoé National Parks and those from other sources estimate the species richness of chiropterans in Côte d'Ivoire to be between 42 and 87 species in these

richest massifs in Côte d'Ivoire (Brosset, 1985; Fahr and Kalko, 2010; Kadjo, 2015) [18, 24, 2]. The latest studies on Chiroptera in Mount Nimba give 62 species to date (Simmons *et al.*, 2021) [22]. In addition to habitat fragmentation and loss, numerous species including *Eidolon helvum* are facing poaching (Niamien *et al.*, 2015) [13]. To fight again the massive and continuous destruction of forests, the Ivorian state has instituted the creation of Voluntary Nature Reserves (RNV) (Vroh *et al.*, 2010) [25]. According to this law, a Voluntary Nature Reserve is a partial nature reserve created on the initiative of a local authority, a public institution or a private individual (Ouattara *et al.*, 2013) [26].

The objective of this study is to document the diversity of chiropterans in the remnants and fragments of forests in southern Côte d'Ivoire. It specifically aims to (i) inventory bat populations, (ii) document the habitat preference of the different species inventoried and (iii) study their activity rate.

2. Material and methods

2.1 Survey site

The YAPI Daniel Private Forest is located in the southeast of Côte d'Ivoire in the locality of Allany between 6° 11' 45.3" - 6° 11' 44.02" North and 4° 17' 22.45" - 4° 17' 25.34" West (Figure 1). This village is located in the sub-prefecture of Rubino, in the department of Agboville and in the administrative region of Agneby-Tiassa. This forest is bounded to the north by the classified forest of Séguié and surrounded by plantations in its other boundaries. Consequently, it is the only larger forest block within the rural domain, with an area of 50 hectares. The villages and settlements bordering the private forest are the village of Allany, Bouapô and the settlement of Apatampô. In addition, the Assoko and Tiémélêkoi rivers which irrigate the estate during the rainy season and constitute its northern and eastern borders respectively (Figure 1). Fruit trees such as *Ficus exasperata* Valh (Moraceae) and *Carica papaya* L. (Caricaceae) are abundant in this forest (Ehikpa, 2018) [27]. The climate is Guinean with four seasons: a long dry season (December to March), a long rainy season (April to July), a short dry season (August to September) and a short rainy season (October to November). Three habitats (wetland, the edge area and the forest) were identified and sampled in this mosaic of environments.

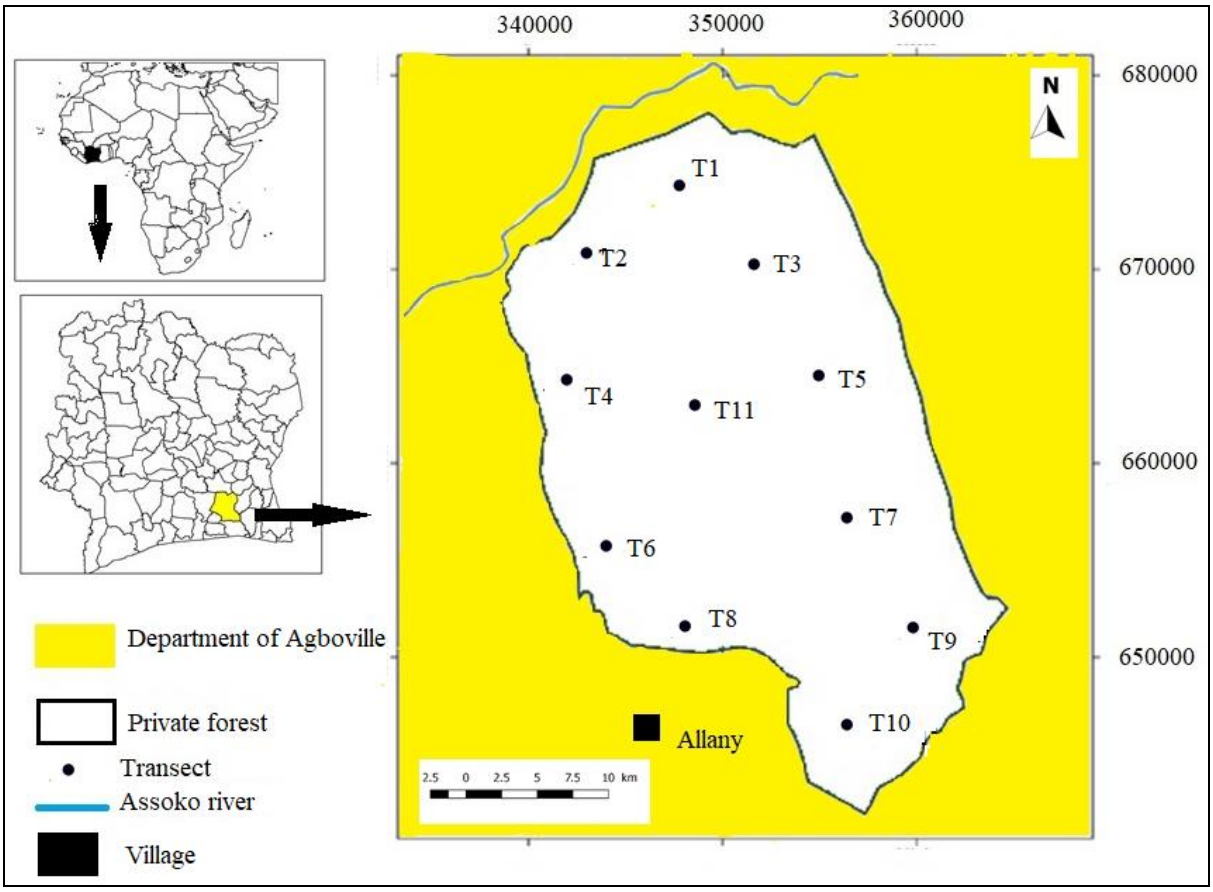

Fig 1: Location map of the modified private forest (Ehikpa, 2018) [27]

Forest

This habitat is represented by an understory forest and fragments of degraded forest (18 ha). The woody vegetation in these environments is multi-layered. The tops of the trees are jointed, allowing little light to filter through in places. The species present in this formation are *Aidia genipiflora* (DC.) Dandy, *Antiaris toxicaria* Lesch. *var. africana* Engl, *Baphia nitida* Lodd, *Ceiba pentandra* (L.) Gaerth, *Celtis zenkeri* Engl, *Cola caricaefolia* (G. Don) K. Schum. Schum, *Corynanthe pachyceras* K. Schum, *Morus mesozygia* Staph ex A.Chev, *Myrianthus libericus* Rendle, *Strombosia pustulata* Oliv. *var. pustulata*, *Terminalia superba* Engl. and Diels, *Triplochiton scleroxylon* K. Schum. and the herbaceous undergrowth with very few grasses is composed of species like *Anchomanes difformis* (Blume) Engl., *Olyra latifolia* L., *Oplismenus hirtellus* (L.) P. Beauv. In the most degraded parts, the following species remain: *Albizia zygia* (DC.) J. Macbr, *Chromolaena odorata* (L.) R. King and H. Robinson,

Trema orientalis (L.) Blume, *Trichilia monadelpha* (Thonn.) De Wilde. Transects T3, T5, T6, T8 and T11 were used for the net catching device.

Edge zone

This habitat is characterised by the interface between forest and cocoa plantations (*Theobroma cacao* L, Sterculiaceae), fallow land, yam fields, unharvested old-growth forest, secondary forest, small forest blocks or fragments and lowlands. It is also the boundary between (or intersection of) these different formations that gives a binary landscape. This habitat also represents an environment in reconstitution with vegetation regrowth. The area is 21ha and the nets were placed on the transects T7, T9 and T10.

Wetland

This habitat is dominated by the Assoko River and the lowlands. The vegetation formations that make up this habitat run along the Assoko River and cover an area of 11ha. They are narrow, closed vegetation with *Ceiba pentandra* (L.) Gaerth, *Commelina diffusa* Burm. f. *Subsp. diffusa*, *Monodora tenuifolia* Benth. This habitat was sampled using transects T1, T2 and T4.

2.2 Bat survey

In each of the three sampled sites (forest, edge area and wetland), five to eight black nylon mist nets (length: 6 m or 12 m, height: 2.80 m, 5 stages, mesh size: 16 mm, denier 70/2) were erected on poles. Nets were opened between 18h00 and 22h00 h at each site for 38 trapping nights. The nets were set up and opened from 18h00 to 00h00. They were regularly visited to remove the captured bats, according to the intensity of capture. Each bat captured was placed individually in a cotton capture bag. The time of capture of each individual and the level of the capture stage of the net was noted. Each captured bat was then weighed with a Pesola® scale with an accuracy of 0.25 g, 1 g or 2 g depending on the sample size. The bat's forearm was measured with a caliper with an accuracy of 0.1 mm. For each specimen, the following parameters were recorded: sex, age (juvenile, sub-adult, young-adult or adult), reproductive status (testes in the abdomen or testes in the scrotum for males; nulliparous, pregnant, lactating or post-lactating for females) Species identification was carried out using an identification key and guide (De Vree, 1971; Koopman *et al.*, 1995; Nesi *et al.*, 2013; Kadjo, 2015) [10, 28,18,2].Voucher samples were deposited at the Zoology and animal biology Lab at UFR Biosciences, Félix HOUPHOUET-BOIGNY University (Côte d'Ivoire).

2.3 Trapping effort

Trapping effort (TE) is a parameter to assess the logistical means used for sampling. It is expressed in net hours (Net hour) and corresponds to the product of the number of nets deployed by the amount of time these nets were open (six hours: from 18h00 to 00h00). It is accessed through the following formula: TE = *number of nets x number of trapping hours per day x number of days.*

2.4 Trapping efficiency

Trapping success (TS) expressed in number of bats caught (nC) per net hour (bats/net hour). It corresponds to the ratio of the number of animals captured by the number of nets (n) during six hours (from 18h to 00h). It is accessed through the following formula: $TS = Nc / n \times h$

2.5 Data analysis

Specific diversity was calculated on the basis of species richness and abundances per habitat. Thus the Shannon, Piélou and Simpson indices were calculated and the non-parametric Chao-1 has been used to assess the specific diversity of the study site using the PAST statistical software (Dieumegard 2009) [29]. The characterisation of species according to habitats was carried out using principal component analysis with the software Past (Version 1.0). The Generalized Linear Model was used to compare the capture frequencies of chiropterans and tested the effect of environments on the distribution of bat species. This analysis was carried out with Statistica software (Version 7.1).

We calculated species accumulation curves Chao-1 species richness estimator using EstimateS (Colwell 2013) [30]. This non-parametric estimator was used to estimate the number of unobserved species from those observed once or twice during sampling. It is used to estimate the number of potential species in the study site

3. Results

3.1 Diversity and abundance

The cumulative capture effort for the three types of habitat gives 4,974 net hours with an average of 261.78 net hours. This sampling effort allowed to capture 63 bats, with a capture success rate of 0.013 bats per net-hours.

A total of 63 bats were captured. These individuals are divided into twelve species, nine genera and grouped into five families (Table 1). The family Pteripodidae is the most diverse with six species (50%). It is followed by the family Hypposideridae with three species (25%) and finally the families Nycteridae, Molossidae and Vespertilionidae with one species each (8.33%) (Table 1).

In terms of species richness, the forest with nine species out of a total of 12 was the most species-rich environment (75%). This environment is followed by the wetland (N=5: 41.67%) and finally the edge zone (N=3: 25%) (Table 1).

In terms of characterisation, a total of nine species (75%) are specific to the different habitats. Among these species, three (33.33%) are found exclusively in wetlands. These are *Eidolon helvum*, *Mops thersites* and *Scotophilus nux*. The other six species (66.67%) are only found in the forests. These are *Megaloglossus azagnyi*, *Epomops franqueti*, *Scotonycteris zenkeri*, *Nycteris arge*, *Hipposideros caffer* and *Doryrhina cyclops* (Table 1).

The most abundant species is *Mops thersithes* (31.74%) a Microchiroptera, followed by a Megachiroteran, *Epomops franqueti* (20.63%), *Macronycteris gigas* (15.87%) and *Nanonycteris veldkampi* (15.87%). In terms of their conservation status, only one species out of a total of 12 (8.3%) is classified on the International Union for Conservation of Nature's red list. This is *Eidolon helvum*, a Near Threatened (NT) species (Table 1).

3.2 Habitat preference

The greatest number of bats was collected in the wetland (N=30: 47.62%) and in the forest (N=27: 42.86%) respectively, and low numbers were recorded in the edge zone (N=6: 9.52%). The number of captured females was 43, or 68.25%. Most of the Megachiroptera females captured were

either pregnant or lactating (Table 1).

Based on the number of species per habitat, the species *Mops thersites* is the most abundant in the wetland (N=20: 66.67%). *Macronycteris gigas* (N=5: 16.67%) and *Scotophilus nux* (N=3: 10%) are moderately represented, while the other species are weakly present (N=1: 3.33%) (Table 1).

In the edge zone, *Macronycteris gigas* is the dominant species (N=3: 50%). The species *Nanonycteris veldkampi* is moderately abundant (N=2: 33.33%) while *Epomops buettikoferi* is in very low numbers (N=1: 16.67%) (Table 1). *Epomops buettikoferi* is the species best represented on the forest facies (N=11: 40.74%). It is followed by *Hipposideros caffer* (N=6: 22.22%) and finally other species (N=1-3: 3.70%-11.11%) (Table 1).

The species diversity is higher in the forest (H' = 1.74), wetland (H' = 1.02) and edge zone (H' = 1.01). The value of the Shannon-Wiener index (H') varies from 1.01 to 1.74. The value of the Piélou equitability index varies from 0.63 to 0.92. Therefore, it tends towards 1. For habitats with Sn ≠ 0, the Chao-1 estimator shows that the expected species diversity for each habitat is in Wetland (Szh = 6); in Edge (SL= 3) and in Forest (SF = 14). This gives a total of 23 expected species (Table 2). Thus, the average for this inventory is 52% of the specific diversity of chiropteran communities in this forest. The Generalized Linear Model confirms these observations by revealing that habitats influence the distribution of bat species in the Yapi Daniel private forest (GLM: ddl=3; W=9.81; $p< 0.05$).

Table 1: Summary bats catching in the three habitats and their conservation status in the Yapi Daniel private forest from August 2018 to October 2018

	IUCN statut UICN	Wetland	Edger zone	Forest	Total Total
Trapping effort (net-hours)		1674	1653	1647	4974
Species					
Pteropodidae					
Eidolon helvum (Kerr, 1792)	NT	1			1
Epomops buettikoferi (Matschie, 1899)	LC	1	1	11	13
Epomops franqueti (Tomes, 1860)	LC			1	1
Megaloglossus azagnyi Nesi, Kadjo and Hassanin, 2013	LC			1	1
Nanonycteris veldkampi (Jentink, 1888)	LC		2	3	5
Scotonycteris zenkeri Matschie, 1894	LC			1	1
Hypposideridae					
Doryrhina cyclops (Temminck, 1853)	LC			1	1
Hipposideros caffer (Sundevall, 1846)	LC			6	6
Macronycteris gigas (Wagner, 1854)	LC	5	3	2	10
Molosidae					
Mops thersites (Thomas, 1903)	LC	20			20
Nycteridae					
Nycteris arge Thomas, 1903	LC			1	1
Vespertilionidae					
Scotophilus nux Thomas, 1904	LC	3			3
Bat richness		5	3	9	
Number of bats caught		30	6	27	63
Trapping success (bats per net-hour)		0,0197	0,0036	0,0108	0,0126

Table 2: Diversity index in the three habitat types

Diversity index	Wetland	Edge zone	Forest
Simpson_1-D	0,51	0,61	0,75
Shannon_H	1,02	1,01	1,74
Equitability_J	0,63	0,92	0,79
Chao-1	6	3	14

3.3 Activity pattern

Bats activities comparison comparison and classification shows that the highest activity occurred between 18h30 and 19h30 for Microchiroptera. Whereas this activity for Megachiroptera, was higher between 22h30 and 23h00 and low in all other following time periods (Figure 2). The Generalized Linear Model reveals a highly significant difference in the activity rhythms (capture frequencies) of Microchiroptera (ddl=5; F=129.15; $p< 0.0001$). Megachiroptera activity rhythms vary highly significantly according to the Generalized Linear Model (ddl=5; F=128.03; $p< 0.0001$). Activity is highest between 22h30 and 23h00. They are average between 21h30 and 22h00 and low in the rest of the time slots (Figure 2).

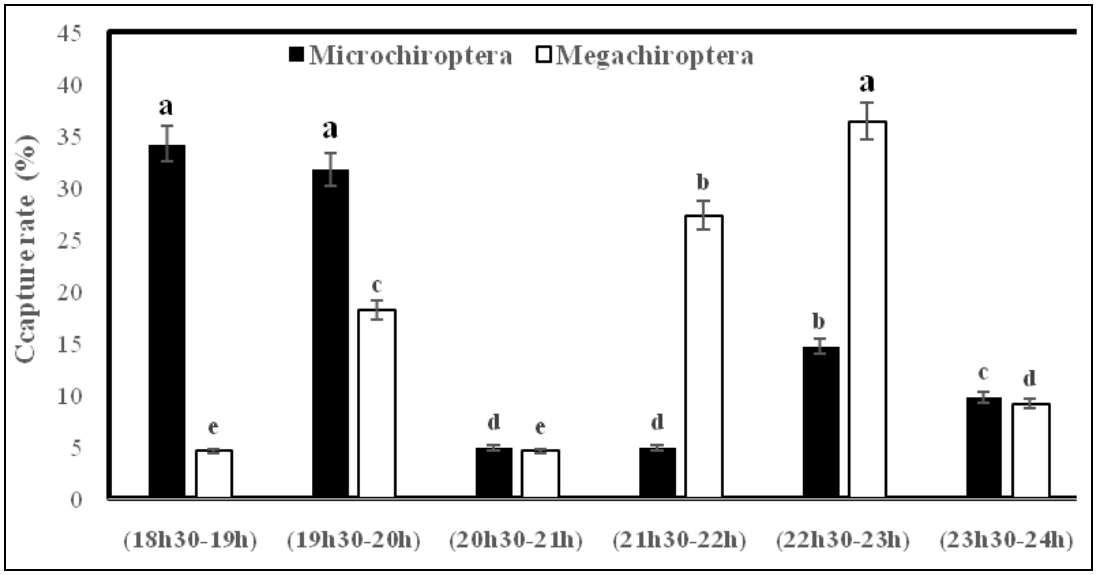

Fig 2: Rhythm of Chiropteran activity from August to October 2018

4. Discussion

The cumulative trapping effort is 4 974 net-hours with a capture success of 0.012 bat per net-hour, i.e. 1.2%. These capture successes are relatively low compared to other sites in the sub-region. In Ghana, Decher *et al.* (2021) [31] obtained trapping success varies between two and 12 times. According to the non-parametric Chao-1 estimator, about half of the expected species in our study area were not recorded. This could be particularly true for Microchiroptera that avoid regularly the nets (Marques *et al.*, 2013; Kadjo, 2015) [32, 2].

This low capture success could be explained by the fact that we only used net sampling. This certainly contributed to the absence of many Microchiroptera species and to underestimate their specific diversity. The detection of these species through their acoustic footprints significantly increases their number in the inventories (Decher *et al.*, 2010, 2021; Weber and Fahr, 2007; Monadjem *et al.*, 2013) [33, 31, 20]. This information makes it possible to update the phylogenetic classification of these species. Thus, he highlighted the existence of two new genera within the family Hipposideridae, which is now split into three genera *Doryrhina*, *Hipposideros* and *Macronycteris* (Patterson *et al.*, 2020) [35].

In this study, we had as many species of Microchiroptera as Megachiroptera (N=6), compared to the study conducted in Banco National Park where the number of Microchiropeta species was the highest (N= 9) (Bitty *et al.*, 2013) [14]. This difference could be related to the presence of fruit trees like *Ficus exasperata* Valh (Moraceae) and *Carica papaya* L. (Caricaceae) in the private forest of Yapi Daniel (Ehikpa, 2018) [27]. The fruits of these tree species are abundantly consumed by fruit bats (Niamien *et al.* 2010, 2017) [5, 23].

Furthermore, the fact that the YAPI Daniel Private Forest is home to bat species of conservation interest makes it a potentially privileged site for biodiversity preservation. Indeed, among the species close to the threat, the strawberry bat *Eidolon helvum* is present. This species provides important ecosystem services beneficial to humans in terms of flower pollination, seed dispersal and hence regeneration of plant communities (Niamien *et al.*, 2015; Abedi-Lartey *et al.*, 2016) [13, 36]. According to Abedi-Lartey *et al.* (2016) [36], *E. helvum* is able to disperse seeds from the fruits it feeds on, up to 75 km from its roosting site. Unfortunately, this species is threatened throughout its range by poaching which decimates their populations, classifying it as Near-threatened (NT) (Denys *et al.*, 2013; Niamien *et al.*, 2015; IUCN, 2020) [19, 13, 2].

In addition, many Microchiroptera species reported from the southern forest region of Côte d'Ivoire are absent from our list of captured species (Koopman *et al.*, 1995; Lim and Van Coeverden De Groot, 1997; Fahr and Ebigbo, 2003; Bitty *et al.*, 2013) [28, 39, 12, 14]. Among the Microchiroptera species we inventoried, *Macronycteris gigas* is considered a rare species in Côte d'Ivoire. The species is known in Côte d'Ivoire in the Taï and Mont Sangbé National Parks (Fahr and Ebigbo, 2003) [12] but also in the Banco and Azagny National Parks and a few sites in the Nawa region, in Soubré (Kadjo, 2015) [2].

The habitats inventoried in this study appear to be relatively poor in bats (N=12), compared to other sites in Central and West Africa. Thus, in the southern forest zone of Cameroon, 29 species of bats were recorded and the Microchiroptera represent 72.4% of the diversity (Bakwo fils 2009) [41]. This diversity is 18 species in the northern region of Cameroon (Bakwo fils *et al.*, 2014) [9]. In central Cameroon, this diversity is 36 species (Waghiiwimbom *et al.*, 2019) [43]. In West Africa, the Mount Nimba region concentrates the highest diversity of Chiroptera with 62 species known to date (Simmons *et al.*, 2021) [22]. In Burkina Faso, a study of the diversity of bats in Burkina Faso, based on museum and capture data, lists between 36 and 51 species (Kangoyé *et al.*, 2012) [44]. In Benin, Djossa et al. (2010) [8]. increased the species diversity of bats in the forest zone to 54 species.

The bat species *Epomops buettikoferi*, *Nanonycteris velkampi* and *Hipposideros caffer* are characteristic of the forest and edge habitats, whereas the species *M. gigas* and *Mops thersites* are wetland specialists. Indeed, the Generalized Linear Model (GLM) analysis confirms these observations. This fact seems to be related to security and feeding conditions (Fahr and Kalko, 2010; Niamien *et al.*, 2017) [24, 23]. Indeed, in the wetland habitat there is an entomofauna that insectivorous bats feed on and this type of habitat is also used for hydration (Nyssen, 2015) [45].

Insectivorous bats are most active between 18h30 and 20h00, whereas fruit bats are most active between 22h30 and 23h00. The activity period of Microchiroptera coincides with is adapted to that of the insects on which these bats feed (Kadjo,

2015) [2]. For Megachiroptera, this slightly later activity period could be explained by the dispersal of individuals in search of fruit trees to feed on (Niamien *et al.*, 2018) [46]. Thus *Eidolon helvum* is capable of travelling long distances, i.e. between 75 and 100 km around their roosting site (Abedi-Lartey *et al.*, 2016; Niamien *et al.*, 2017) [36,23]. An average activity rate of more than 80% was recorded between 18h00 and 00h00. Beyond these hours, activity drops significantly for the different species. Consequently, it is desirable to stop the capture of bats at 00h00. This would make it possible to reduce the trapping effort by half (06 hours), thus allowing capture yields (Weber and Fahr, 2007) [34].

The Ivorian government's policy of encouraging the setting aside of forest areas through Voluntary Nature Reserves (RNV) is beneficial for the fauna of these regions where these forests exist. Indeed, these habitats could represent the only refuges for residual fauna, particularly for bats and birds that are able to move over long distances (Okon, 2013; Abedi-Lartey *et al.*, 2016; Niamien *et al.*, 2017; Nkrumah *et al.*, 2017) [48, 36, 23, 47].

5. Conclusion

Between three habitats sampled, the forest, the wetland and the edge zone are respectively the most diversified in species of bats. This community is dominated by has six species, including three species of microchiroptera and Megachiroptera each with approximately 52% of the expected species recorded. The most abundant species are *Mops thersithes* followed by *Epomops franqueti*, *Macronycteris gigas* and *Nanonycteris veldkampi*. Among these species, one is Near-Threatened namely *Eidolon helvum.* Megachiroptera and Microchiroptera show different patterns of active are different. In fact, the highest activity occurred between 18h30 and 19h30 for Microchiroptera. Whereas this activity for Megachiroptera, was higher between 22h30 and 23h00 and low in all other following time periods. These kind of private forests are beneficial for the fauna of these regions and could represent the only refuges for residual animal communities mainly for bats and birds.

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