

Phenology of wild and honey bees (Hymenoptera: Apoidea) in the Sudanian Savannas of West Africa

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Abstract

Wild and honey bees in West Africa are very crucial for plant pollination and ecosystem functioning. However, the study on the phenology of bee species in this region is poorly documented, jeopardizing their conservation. The current study was carried out in three localities across two climatic zones in Southern Burkina Faso. During one-year fieldwork, 19,022 specimens of bees were captured using colored pan traps (UV: white, blue and yellow). Bees were identified at the species level in the Royal Belgian Institute of Natural Sciences. A total of 105 bee species belonging to 32 genera and 4 families (Apidae, Megachilidae, Halictidae and Colletidae) were identified. Halictidae was the most diverse family. The diversity of bee species varied between land-use intensity and climatic zones. The highest diversity was found in low-disturbed zone ($H' = 2.73$) and in the most humid zone. The lowest richness of bees (17 species) was recorded in January corresponding to the coolest period, while the highest richness was obtained in August (62 species). The high abundance of bee species was recorded during the wettest months (July and August) whereas lower abundance was observed in the dry season (October). According to the phenology diagrams, seven wild bee species *Braunsapis* sp. 1, *Braunsapis* sp. 2, *Braunsapis* sp. 3, *Ceratina* sp. 1, *Hypotrigona gribodoi*, *Pseudapis interstitinervis*, *Seladonia jucunda* and the honeybee *Apis mellifera* were present throughout the year. The other bee species were encountered at different periods of the year. The knowledge of bee phenology constitutes an important database for bee monitoring and bee conservation and their ecosystem services that they provide free to humans.

Keywords: Bees; Phenology; Pan Trap; Ecosystem services; Burkina Faso

1. Introduction

The ecosystem services provided by bees are crucial for biodiversity conservation. Some bee species including *Apis mellifera*, produce honey and other highly appreciated products such as propolis, wax and royal jelly. This has promoted the practice of beekeeping worldwide, and particularly in Africa, where trading apiculture products considerably improves household incomes, especially in rural areas [1]. In addition, animal pollination enhances the sexual

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reproductive success of most wild and cultivated plants [2]. The pollination of flowering plants by insects is of a significant importance in terrestrial ecosystems, as it provides vital ecosystem services to human well-being [3]. Indeed, about 75% of agricultural production depend to some degree on animal pollination, and about a third benefit from cross-pollination by developing a greater quantity and/or quality of fruit [4,5]. Among these insects, bees are considered as the main pollinators worldwide [6,7]. A decrease of pollination service could potentially reduce crop yields by around 40% [4]. The pollinating efficiency of bees is certainly linked to several factors, but their dependence on certain plant species is a major factor. Maintaining the ecosystem services provided by bees necessarily involves the protection and conservation of bee communities. One of many alternatives for conserving bee diversity remains the rigorous management of their habitats, and particularly the maintaining of food resources (melliferous plants) they depend on. Indeed, bee diversity in an environment depends on the multiplicity of plant species. Unfortunately, these plants flower at different periods of the year. Some plants flower in the dry season and others in the rainy season. Since bees are not all generalists, these different flowering periods of plants lead to either the appearance or the disappearance of certain bee species at a certain period of the year. The phenological study of bees makes it possible to understand all the changes likely to take place over the course of a year within a bee community. It provides information on the needs and availability of a bee species in its environment. In Burkina Faso, where agriculture plays an important role, crop yields are relatively low due to the effects of climate variability. The ecosystem services provided by bees could help to improve the resilience of agricultural systems. However, in the Sudanian savanna of West Africa the phenology of bees is poorly studied. Such lack of empirical data constrains the management of bee populations. This study aims to fill knowledge gaps on the composition and phenology of bee populations in West Africa.

2. Material and methods

2.1. Study area

The study was carried out in three localities in the South Sudanian zone of Burkina Faso (Figure 1). The study sites were chosen in these three localities, which are Nazinga game ranch (11°06'34.998" N, 001°29'07.181" W), the Bontioli wildlife reserve (10°48'26.393" N, 003°04'39.564" W) and the fallow areas of Dano (11°08'56.566" N, 003°03'36.446" W). Nazinga belongs to the Sudanian-Sahelian zone, while Dano and Bontioli belong to the Sudanian zone. The study area has a unimodal rainfall regime, characterized by a short rainy season (June to September) which alternates with a dry season (November to May) [8] (Figure 2). Average annual rainfall is between 800 and 1,000 mm with an average annual temperature between 27 and 28°C. Elevations in the study area range from 271 m to 448 m above sea level [9]. Most of vegetation is composed of woodlands and savannas. There is a fairly dense cover of tall grass and variable densities of trees and shrubs [10]. This vegetation forms an open canopy and are mainly pollinated by bees [11]. The natural vegetation has undergone a strong modification in favor of fields or fallows [11]. All study areas are characterized by a mosaic of agricultural lands, villages and fragments of near-natural savanna (Figure 1). The anthropogenic activities leading to different levels of disturbance were an essential element in the choice of sites. Among these criteria, we note the percentage of forest cover (including herbaceous, shrub and tree savannas) and the cover of crop land (farms and fallows) at a landscape scale. Study areas were categorized as low, medium or high disturbance, based on land use/land cover data via multi-temporal Landsat imagery [12,13] (for details on methods, see Dimobe and collaborators). According to Burkina Faso legislation, the Nazinga ranch is a protected, classified as a "wildlife reserve". Its surface area is approximately 97,536 ha [14]. Inside, it still possible to find tree species typical of pristine savanna forests (e.g. *Terminalia macroptera* Guill. & Perr., *Detarium microcarpum* Guill. & Perr. and *Prosopis africana* (Guill. & Perr)). There are rare activities linked to human. However, fires are frequently reported at the beginning of the dry season, but they are quickly managed by the people living in small settlements on the margin of the reserve [11]. The forest coverage is approximately 88.2% and that of crop land is 0.8% [13]. For our study, Nazinga area was considered to be little disturbed. The Bontioli Nature Reserve is also a protected area, but categorized as a "Nature Reserve" according to Burkina Faso legislation [15]. The area of the Bontioli savanna was approximately 25,000 ha dominated by trees such as *Terminalia laxiflora* Engl. & Diels and *Vitellaria paradoxa* C.F. Gaertn. This area was moderately disturbed compared to the other two areas due to human activities such as agriculture, grazing, fires, uncontrolled logging and timber extraction, occurring even within the reserve [11]. Several villages associated with an intense agricultural production are located on the outskirts of the reserve. The forest coverage is approximately 77.85%, and that of crop land is 12.59% [12]. As for the Dano area, it includes a small city of around 50,000 inhabitants. Its population is growing rapidly due to the extensive practice of agriculture and the proliferation of gold mining sites. As a result, there are very few natural savanna habitats. Regarding tree species, only economically relevant ones such as shea (*Vitellaria paradoxa*) and nere (*Parkia biglobosa* [Jacq.] R.Br. ex G.Don) were left. Very high habitat disturbance is observed at Dano compared to the other two study sites, thus forming an agricultural landscape with degraded soils and intense grazing, fires and logging. The forest cover is 52.9% that of crop land is 37.2% (K. Dimobe, unpublished data). For our study, we considered that Dano was strongly disturbed.

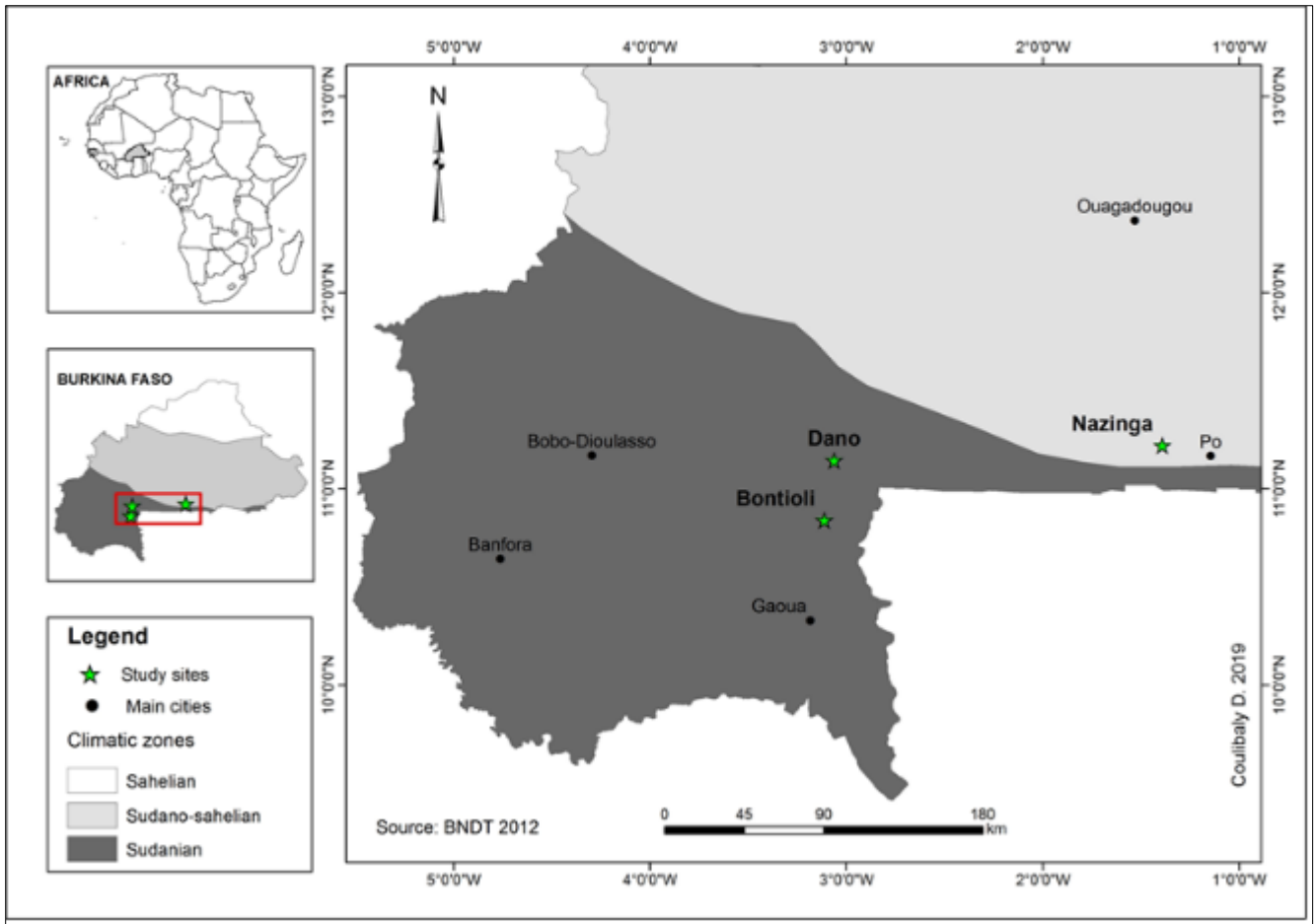
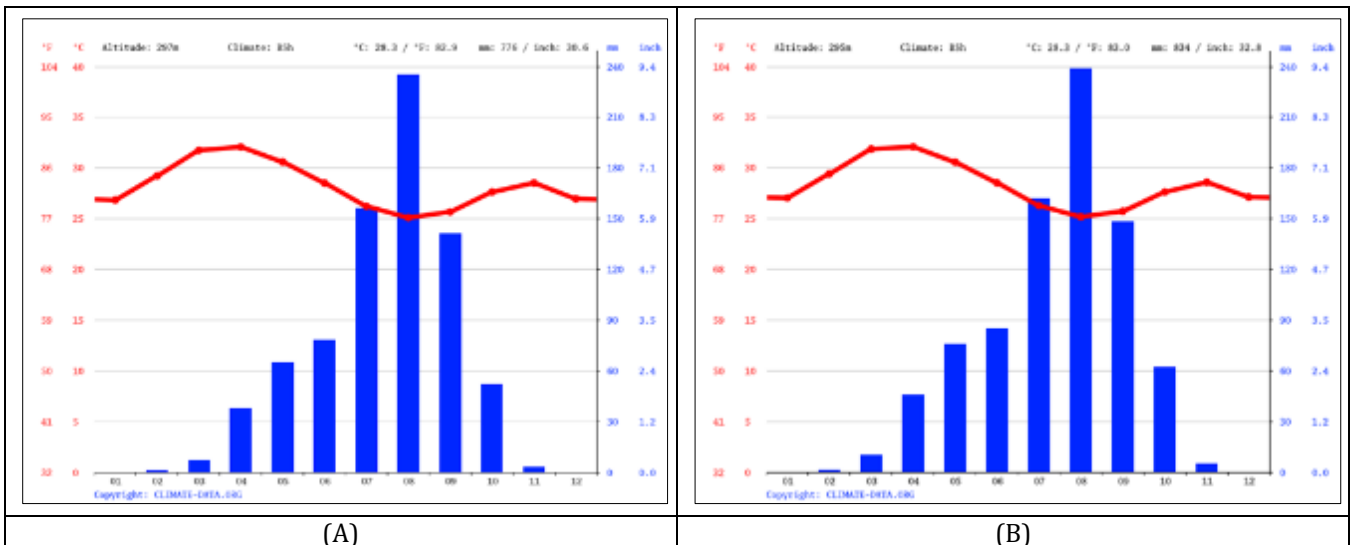


Figure 1 Location of the study sites



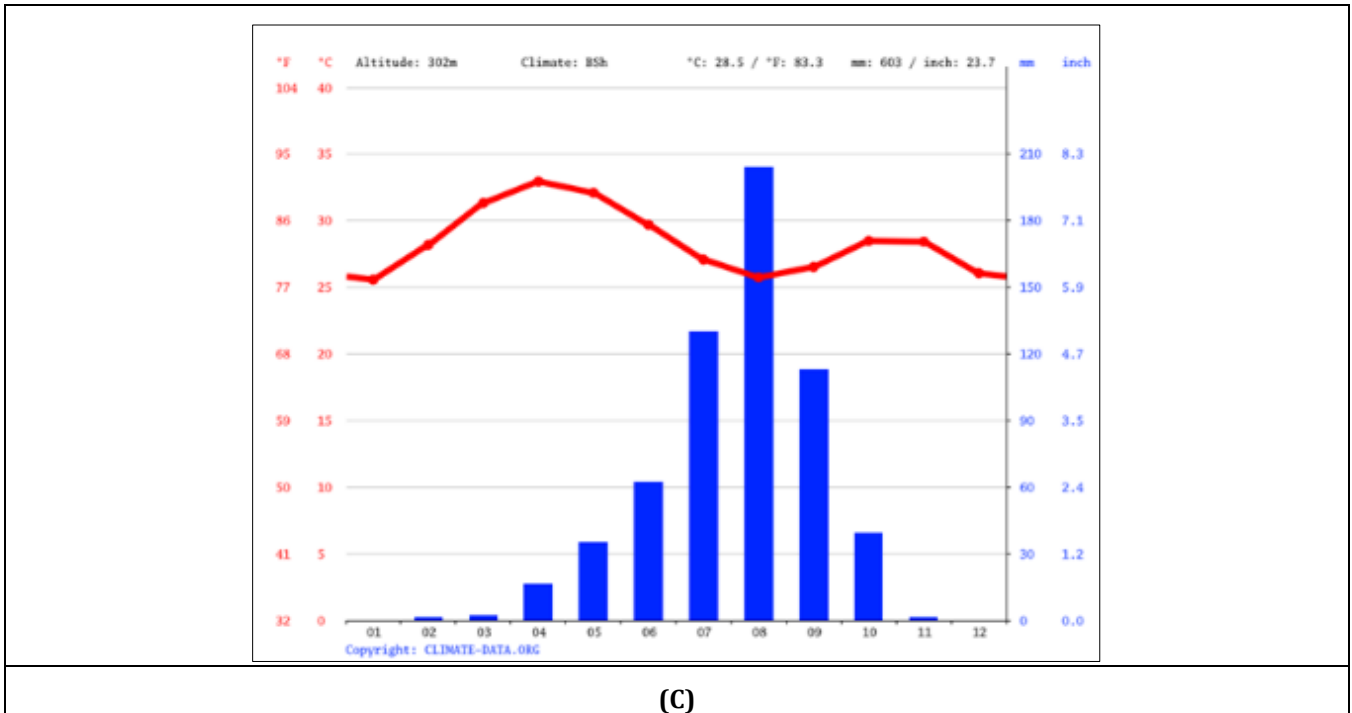


Figure 2 Ombrothermal diagrams of the three study areas: Dano (A), Bontoli (B) and Nazinga (C)

2.2. Bee sampling

In each of the three study areas (Nazinga, Bontoli and Dano), we randomly selected four savanna sites of 1 ha (100 m x 100 m) in size. At each savanna site, four plots of 60 m x 90 m each, were set up. In each plot, 24 pan traps were installed with a minimum distance of 15 m between two consecutive traps (96 traps per savanna site) [11]. Bee data were continuously collected during both seasons within the installed plots for a period of 12 months. Bees were sampled once a month at the savanna site level. Bees were sampled using pan traps placed in a height of 1 m above the ground [11]. We installed 288 pan traps located in Nazinga, Bontoli and Dano. Each pan trap consisted of a 500 ml UV-bright yellow, white and blue plastic bowl that was filled with salt (NaCl) saturated water and a small drop of detergent. The traps were left activated for 72 hours during each sampling turn [11]. Specimens of bees were collected, stored in ethyl alcohol, and thereafter pinned and identified to genus or species level where possible. We identified the species using the reference collections of the Royal Belgian Institute of Natural Sciences, Brussels, Belgium.

2.3. Data analysis

The phenology of each bee species was determined through monthly monitoring of their specific species and abundance. Three diversity indices were used to assess the diversity of bee species in the study area: species richness, Shannon entropy ($H' = -\sum ((N_i/N) * \log_2 (N_i/N))$) and Pielou's species evenness ($E = H'/H'_{\max}$ ($H'_{\max} = \log_2 S$)). We also assessed the temporal variation in the abundance of bee species in the study area. Jaccard's similarity index ($J = N_c / (N_1 + N_2 + N_c)$) were used to compare the specific composition of bees in the different areas. To assess the effect of land use intensity and climate on the variation in bee species abundance and diversity land-use disturbance and climatic zone, species richness and the average abundance of bees were compared between the three levels of disturbances and climatic zones using the nonparametric Kruskal-Wallis test at the 5% threshold. However, data regarding the phenology of bees were presented globally. The software STATISTICA version 7.1 was used for the statistical analysis.

3. Results

3.1. Diversity of bees

3.1.1. Taxonomic richness of bee species

In total, we found 105 bee species belonging to 32 genera and 4 families (Apidae, Megachilidae, Halictidae and Colletidae) across the three study sites. The family Halictidae was the most diverse (41 species), followed by Apidae (31 species), Megachilidae (31 species), and Colletidae (2 species). The highest richness of bees was recorded in August (62

species) and July (53 species). These two months are the most humid months in Burkina Faso. Regarding each area, 62 bee species were captured in Dano, 66 species in Bontioli and 77 species in Nazinga.

3.1.2. Bee diversity across land-use intensity and climatic zones

The analysis of diversity indices showed a significant variation between bee diversity with land-use intensity and climatic zones. The value of Shannon index was higher in the low disturbance site ($H' = 2.73$) compared to the high disturbance site ($H' = 1.41$). Shannon's index was also lower in the moderately disturbed site ($H' = 1.45$) compared to the low-disturbed site. Similar trend was also observed for Pielou's evenness which was higher in the low-disturbed site ($E = 0.44$) compared to the other sites ($E = 0.24$) (Table 1).

Table 1 Indices of Shannon

Study areas	Indices of Shannon (H')	Pielou's species evenness (E)
Dano	1.41	0.24
Bontioli	1.45	0.24
Nazinga	2.73	0.44

3.1.3. Abundance of bees

A total of 19,022 bee specimens were captured during the study. The statistical analysis revealed a significant difference in the average abundance of bees between Bontioli (882.75 ± 11.04) and Nazinga (170.58 ± 8.23) ($p = 0.013$) and between Dano (531.75 ± 9.33) and Nazinga (170.58 ± 8.23) ($p = 0.034$). However, no difference was observed in the average abundance of bees between Bontioli (882.75 ± 11.04) and Dano (531.75 ± 9.33) ($p = 0.37$). Apidae was the most abundant family (1956.33 ± 13.36) compared to Halictidae (139.11 ± 5.88), Megachilidae (17.33 ± 1.74) and Colletidae (0.66 ± 0.01) ($p = 0.025$) (Table 2). The wild stingless bee *Hypotrigena gribodoi* with 14,180 specimens represented 74.6% of bee specimens captured. Other wild bee species, *Seladonia jucunda* (849 specimens; 4.46%), *Pseudapis interstitinervis* (667 specimens; 3.5%) and *Braunsapis* spA (526 specimens; 2.76%) were relatively abundant. The honey bee *Apis mellifera* with 615 specimens represented only 3.23% of bee specimens. A total of 11,053 bee specimens were recorded in the dry season, 7,009 specimens in the rainy season and 960 specimens in October corresponding to the transition month between dry and rainy seasons. However, the highest abundance of bees was recorded in July (2027 specimens) and August (1900 specimens).

Table 2 Comparison of the average abundance of bee families

	Apidae	Halictidae	Megachilidae	Colletidae	p-value
Dano	1973.67 ± 23.91^c	136 ± 12.52^b	17.33 ± 5.33^a	0	0.023
Bontioli	3273.67 ± 31.12^c	236.67 ± 9.78^b	20 ± 2.13^a	0.67 ± 0.01^a	0.013
Nazinga	621.67 ± 17.46^b	44.67 ± 6.17^a	14.67 ± 1.19^a	1.33 ± 0.02^a	0.026
Average	1956.33 ± 13.36^c	139.11 ± 5.88^b	17.33 ± 1.74^a	0.66 ± 0.01^a	0.025

3.2. Specific composition of bees

Some bee species were specific to each study area. Indeed, 15 species of bees were captured only in Dano, 6 species only in Bontioli and 21 species only in Nazinga. On the other hand, 9 species of bees were common to Dano and Bontioli, 5 species common to Dano and Nazinga and 18 species common to Bontioli and Nazinga. "Jaccard's similarity index showed overall very small similarities between areas, with Bontioli and Nazinga being the most similar ones ($J = 0.11$), followed by Bontioli and Dano ($J = 0.07$), while Nazinga and Dano were the least similar ($J = 0.03$)".

3.3. Phenology of bee species

Phenological diagrams were established for all bee species captured in the study area. These diagrams provide information on the abundance of each bee species during the year (Figures 3a; 3b; 4a; 4b; 5a; 5b; 5C and 6). The table 3 present the number of bee specimens captured with the pan traps, the males being separated from the females. For the social species such as *Apis mellifera*, only the workers are caught by the pan traps. The social species were represented in gray.

Table 3 Phenology of bee species captured by pan traps (UV-bright yellow, white and blue) in the savannas of Burkina Faso. In bold the social bees, in darker gray the rainy season, in light gray the transition month, in white the dry season

Species	Total	Male Fem	Year 1			Year 2								
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Apidae														
<i>Amegilla acraensis</i> (Fabricius, 1793)	4	4										1	3	
<i>Amegilla nubica</i> (Lepeletier, 1841)	3	3										3		
<i>Amegilla</i> sp. 1	14	2 12	1	5	1							2	1 3	1
<i>Amegilla</i> sp. 2	29	12 17		1	1					2 12	1 4	2	2 1	3
<i>Amegilla</i> sp. 3	7	7		5	2									
<i>Amegilla</i> sp. 4	7	7		2		4		1						
<i>Amegilla</i> sp. 5	1	1						1						
<i>Amegilla</i> sp. 6	141	28 113			5 10	6 18	1 25	3 17	6 9	2 15	1 9	7	4 4	
<i>Amegilla</i> sp. 7	8	2 6											1	1 6
<i>Amegilla torrida</i> (Cockerell, 1946)	4	4										2	2	
<i>Apis mellifera</i> (Linnaeus, 1758)	615	615	18	79	69	77	74	77	88	54	25	19	16	19
<i>Braunsapis</i> sp. 1	526	58 468	3 20	8 45	5 50	9 39	7 53	1 64	6 24	5 49	5 19	3 41	4 44	2 20
<i>Braunsapis</i> sp. 2	204	37 167	3 9	2 17	5 10	2 15	2 8	5 9	2 11	7 23	1 10	2 15	5 10	1 30
<i>Braunsapis</i> sp. 3	223	41 182	3 12	2 9	5 9	2 20	3 18	6 11	4 14	6 9	3 21	2 29	1 20	4 10

<i>Ceratina</i> sp. 1	140	52 88	1 2	2 5	3 6	4 7	5 6	4 8	4 10	8 10	6 9	8 9	2 9	5 7
<i>Ceratina</i> sp. 2	13	2 11	2	1							1 1	1 1	5	2
<i>Ceratina</i> sp. 3	5	5										2	2	1
<i>Compsomelissa borneri</i> (Alfken, 1924)	5	1 4							1 3		1			
<i>Hypotrigena gribodoi</i> (Magretti, 1884)	14180	14180	672	1034	1042	1183	1231	1282	1254	1134	1032	1552	1406	1358
<i>Hypotrigena</i> sp. 2	106	106					15	21	17	9	12	15	8	9
<i>Hypotrigena squamuligera</i> (Benoist, 1937)	28	28			12			4	3	2	3	1	2	1
<i>Liotrigona</i> sp. 1	20	20			4	3		2		1	2	4	3	1
<i>Meliponula togoensis</i> (Stadelman, 1895)	249	249									4	71	107	67
<i>Plebeina armata</i> (Magretti 1895)	80	80		4			2		12		17	24	12	9
<i>Tetralonia fraterna</i> (Friese, 1911)	56	22 34		1 1		2 3	4 5	2 4	1 2	1	4 6	2 4	3 6	2 3
<i>Xylocopa inconstans</i> (Smith, 1874)	7	7			1			1		2		2	1	
<i>Xylocopa modesta</i> (Smith, 1854)	27	15 12	2	3 2	1		3 3		3 1		1 4	2	1	1
<i>Xylocopa olivacea</i> (Fabricius, 1778)	37	7 30		2 12	1 7		2	1 3		1		1 4		3
<i>Xylocopa scioensis</i> (Gribodo, 1884)	21	2 19	1 12	7	1									
<i>Xylocopa</i> sp.	2	2		2										
<i>Xylocopa ustulata</i> (Smith, 1854)	3	1 2			2			1						
Megachilidae														
<i>Anthidium</i> sp. 1	4	1 3											3	1

<i>Chalicodoma mephistolica</i> (Pasteels, 1965)	10	8 2					6 1	2 1					
<i>Creightonella discolor</i> (Smith, 1853)	16	12 4		4 1			6 2	2 1					
<i>Heriades</i> sp. 1	5	2 3					1 2				1 1		
<i>Heriades</i> sp. 2	2	2					2						
<i>Lithurgus</i> sp. 1	48	9 39	2 6	3 18	2 10							2	5
<i>Megachile eurymera</i> (Smith, 1854)	7	5 2					5			1	1		
<i>Megachile</i> sp. 1	3	1 2							2		1		
<i>Megachile</i> sp. 4	3	3								3			
<i>Megachile</i> sp. 5	14	2 12		1 2				4	1		2	3	1
<i>Megachile</i> sp. 6	2	2						2					
<i>Megachile</i> sp. 7	10	8 2						8			1	1	
<i>Megachile</i> sp. 8	7	1 6					1 3		3				
<i>Megachile</i> sp. 9	4	4					4						
<i>Megachile</i> sp. 10	4	4				1	3						
<i>Megachile</i> sp. 11	4	4		1			3						
<i>Megachile</i> sp. 12	4	4		2				2					
<i>Megachile</i> sp. 13	2	2					2						
<i>Megachile</i> sp. 14	4	4					1	2	1				
<i>Megachile</i> sp. 15	5	5				1	4						

<i>Megachile</i> sp. 16	3	3							3				
<i>Megachile</i> sp. 17	2	2		2									
<i>Megachile</i> sp. 18	2	1 1		1		1							
<i>Megachile</i> sp. 19	3	3							3				
<i>Megachile</i> sp. 20	3	3						2	1				
<i>Megachile</i> sp. 21	3	3					3						
<i>Megachile</i> sp. 22	3	3						1	2				
<i>Megachile</i> sp. 23		1 2					1 2						
<i>Megachile</i> sp. 24		1 1										1 1	
<i>Megachile</i> sp. 25		1 2										1	2
<i>Megachile</i> sp. 26		1 1											1 1
Halictidae													
<i>Acunomia ivoiriensis</i>	3	1 2										2	1
<i>Acunomia senticosa</i> (Vachal, 1897)	5	2 3								1	1 2	1	
<i>Austronomia</i> sp. 1	3	3		2	1								
<i>Austronomia</i> sp. 2	8	2 6	1									1 2	2 2
<i>Ceylalictus muiri</i> (Cockerell, 1909)	2	1 1						1				1	
<i>Crociaspidia chandleri</i> (Ashmead, 1899)	3	3										1	2
<i>Lasioglossum (Ctenonomia) nairobiensis</i>	4	4	1	2								1	

<i>Lasioglossum (Ctenonomia) atricrum</i> (Vachal, 1903)	9	1 8	1		1						2	1	3	1
<i>Lasioglossum (Ctenonomia) audasi</i> (Cockerell 1945)	3	3										2	1	
<i>Lasioglossum (Ctenonomia) scobe</i> (Vachal, 1903)	5	1 4	1									1 1	2	
<i>Lasioglossum (Ctenonomia) sp. 1</i>	11	3 8		1	1				1	5		1	2	
<i>Lasioglossum (Ctenonomia) sp. 2</i>	4	1 3							2			1	1	
<i>Lasioglossum (Ctenonomia) sp. 3</i>	3	1 2								2			1	
<i>Lasioglossum (Ctenonomia) sp. 4</i>	74	12 62	1 7	2 6	2		1 3		1	1 6	1 6	1 10	3 18	1 4
<i>Lasioglossum (Ctenonomia) sp. 5</i>	33	8 25	1 6									2 10	2 3	3 6
<i>Lasioglossum (Ctenonomia) sp. 6</i>	23	4 19	1			1	1						1 4	6
<i>Lasioglossum (Ctenonomia) sp. 7</i>	7	1 6						1						
<i>Lasioglossum (Ctenonomia) sp. 8</i>	4	4								1	3			
<i>Lasioglossum (Ctenonomia) transvaalensis</i>	2	2										1	1	
<i>Lasioglossum (Ctenonomia) saegeri</i> (Pauly, 1981)	13	2 11	2	1							4		5	1
<i>Lasioglossum (Oxyhalictus) saegeri</i> (Pauly, 1981)	17	5 12	2	4					1			1	2 5	1
<i>Leuconomia bouyssoui</i> (Vachal, 1903)	3	3							1			2		
<i>Leuconomia candida</i> (Smith, 1875)	3	1 2								1			2	

<i>Leuconomia clypeonitida</i> (Pauly 2000)	3	3							1				1	1
<i>Leuconomia granulata</i> (Vachal, 1903)	30	5 25	1 6					1 4	3		2	6	1 4	2
<i>Leuconomia microlutea</i> (Pauly, 2000)	2	1 1										2		
<i>Macronomia armatula</i> (Dalla Torre, 1896)	2	1 1										1	1	
<i>Macronomia</i> sp. 1	4	1 3									1 1		2	
<i>Macronomia</i> sp. 2	2	1 1										1	1	
<i>Pachynomia amoenula</i> (Gerstaecker, 1870)	49	11 38	1 5	4					5	2	2 7	2 8	3 5	1 4
<i>Pachynomia flavicarpa</i> (Vachal, 1903)	103	4 99	1 10	7		1 24		12	3	5	2 15	9	14	
<i>Pseudapis interstitinervis</i> (Strand, 1912)	667	121 546	10 37	6 49	14 50	11 40	6 68	9 70	11 50	6 77	11 37	14 20	12 20	11 28
<i>Pseudapis</i> sp. 1	3	1 2									2	1		
<i>Seladonia jucunda</i> (Smith, 1853)	849	214 635	15 71	17 47	19 64	27 54	13 54	21 67	16 55	33 58	22 30	13 55	7 40	11 40
<i>Seladonia lucidipennis</i> (Smith, 1853)	14	4 10	2	3								1	2 5	1
<i>Seladonia</i> sp. 1	8	1 7					2	3		1	1		1	
<i>Steganomus junodi</i> (Gribodo, 1895)	19	5 14	2	2					2	1	1 3	3	1	3 1
<i>Steganomus</i> sp.	2	1 1										1	1	

<i>Thrinchostoma petersi</i> (Blüthgen, 1930)	6	2 4	1		1							1	2	1
<i>Trinomia cirrita</i> (Vachal, 1903)	46	8 38	1 3	1 2		2 6				2		1 6	8	1 13
<i>Trinomia orientalis</i> (Friese, 1909)	11	1 10	1	1						3		1	5	
Colletidae														
<i>Hylaeus</i> sp. 1	4	1 3						1		2	1			
<i>Hylaeus</i> sp. 2	3	1 2						1		2				
Total specimens	19022		960	1445	1418	1562	1655	1754	1653	1566	1363	2027	1900	1719
Total species	105		30	39	26	17	29	34	37	32	38	53	62	40

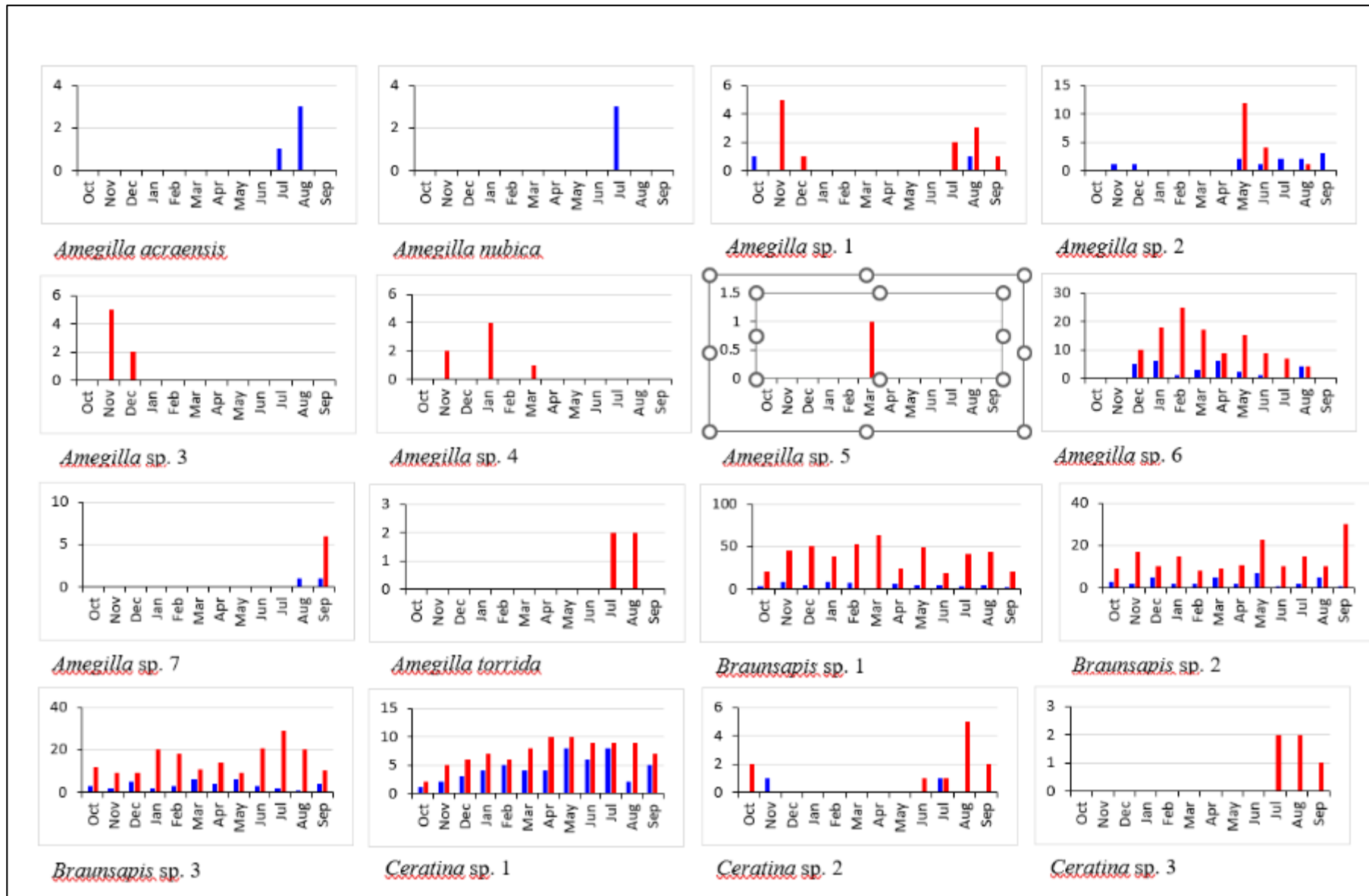


Figure 3a Phenological diagrams of Apidae family from Burkina Faso (Male in blue and Female in red)

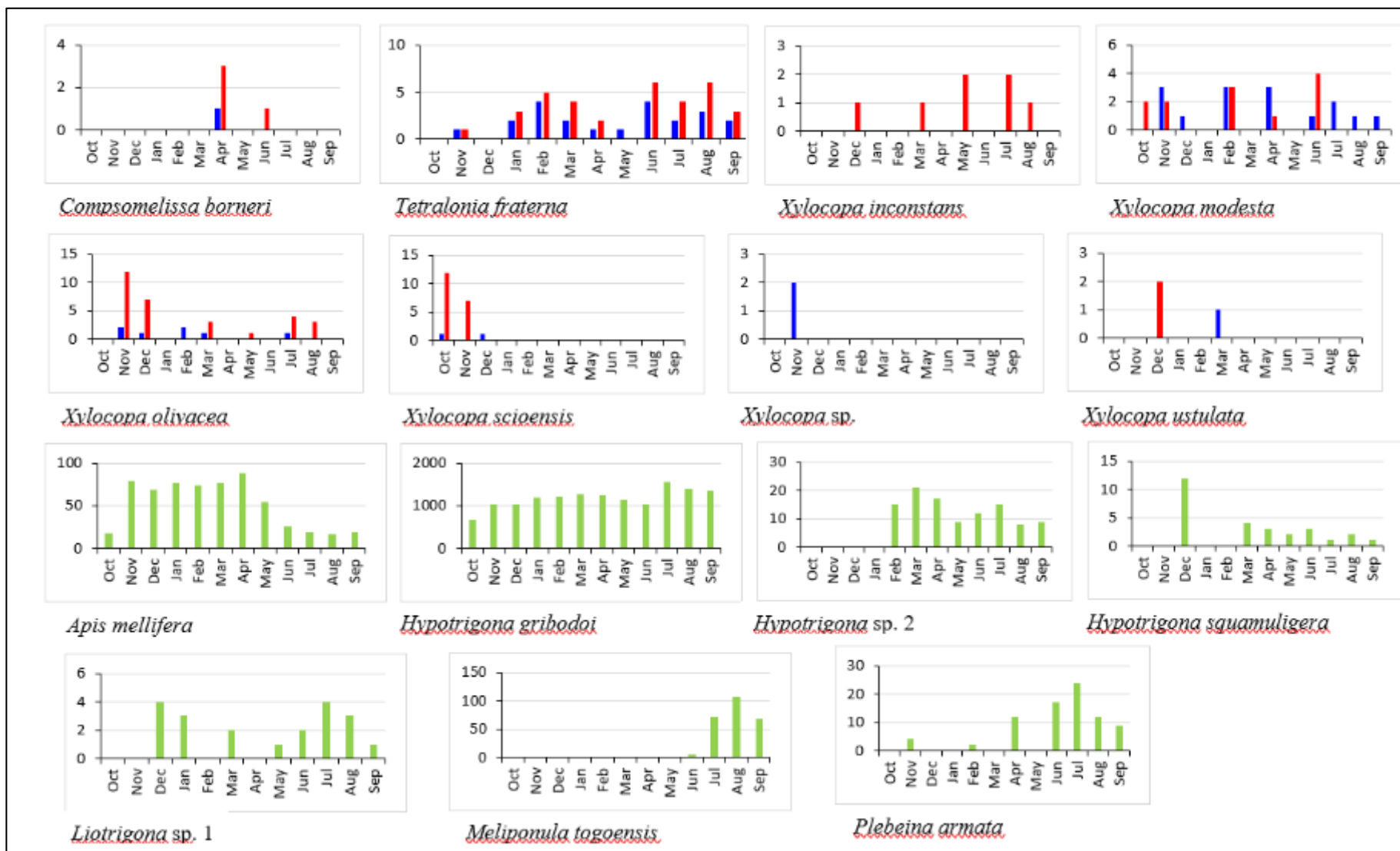


Figure 3b Phenological diagrams of Apidae family from Burkina Faso (Male in blue, Female in red and Workers in green)

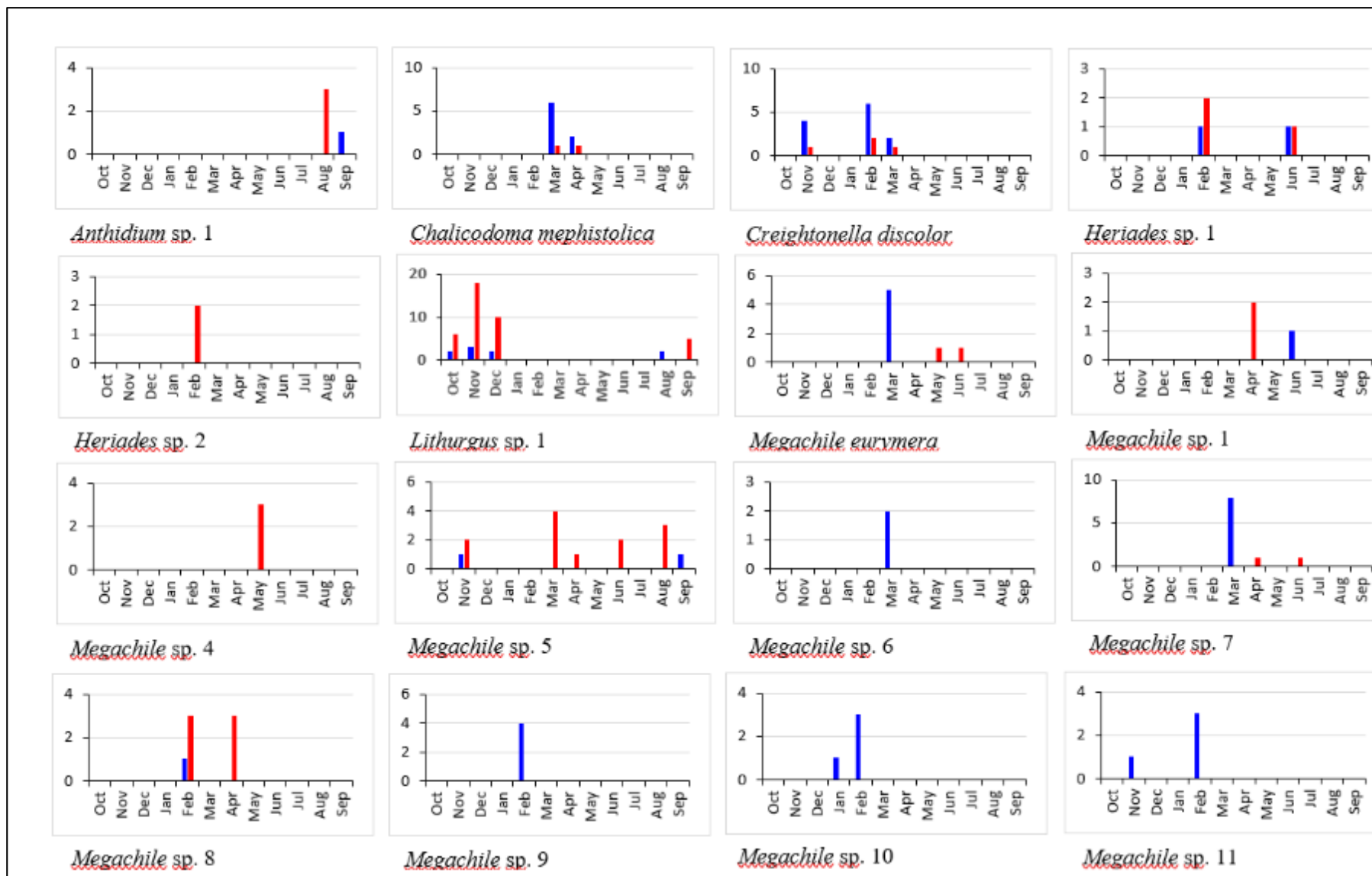


Figure 4a Phenological diagrams of Megachilidae family from Burkina Faso (Male in blue and Female in red)

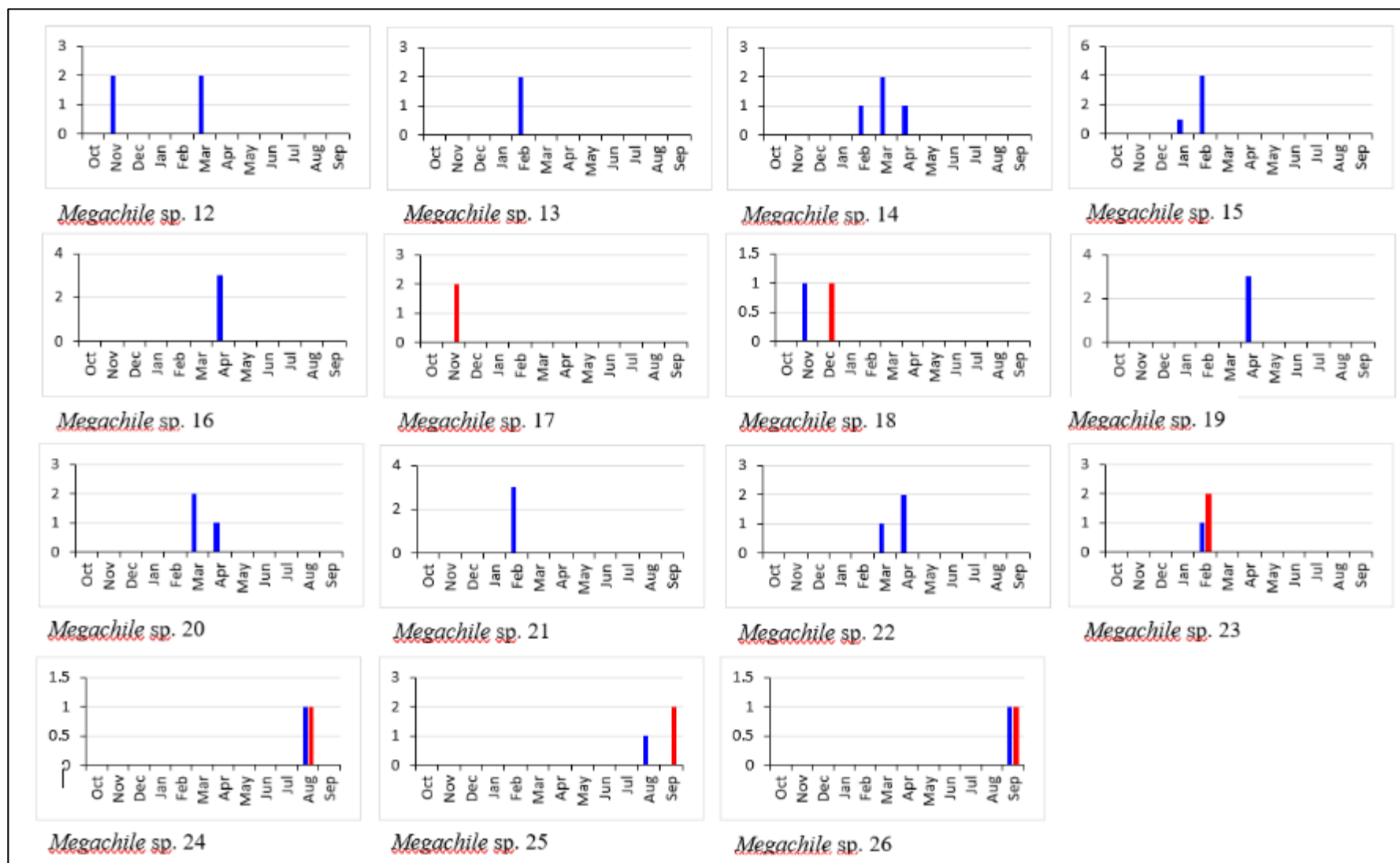


Figure 4b Phenological diagrams of Megachilidae family from Burkina Faso (Male in blue and Female in red)

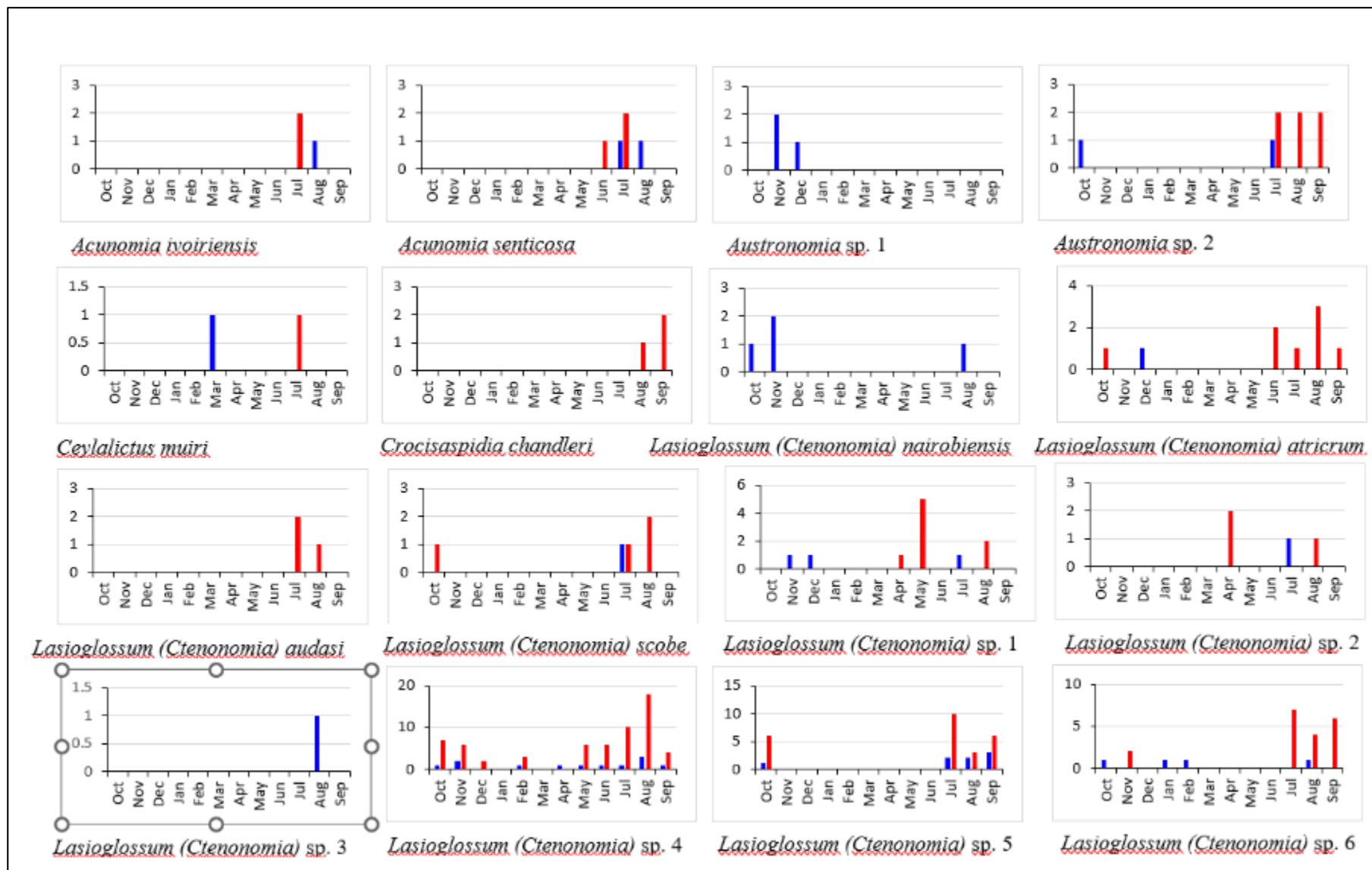


Figure 5a Phenological diagrams of Halictidae family from Burkina Faso (Male in blue and Female in red)

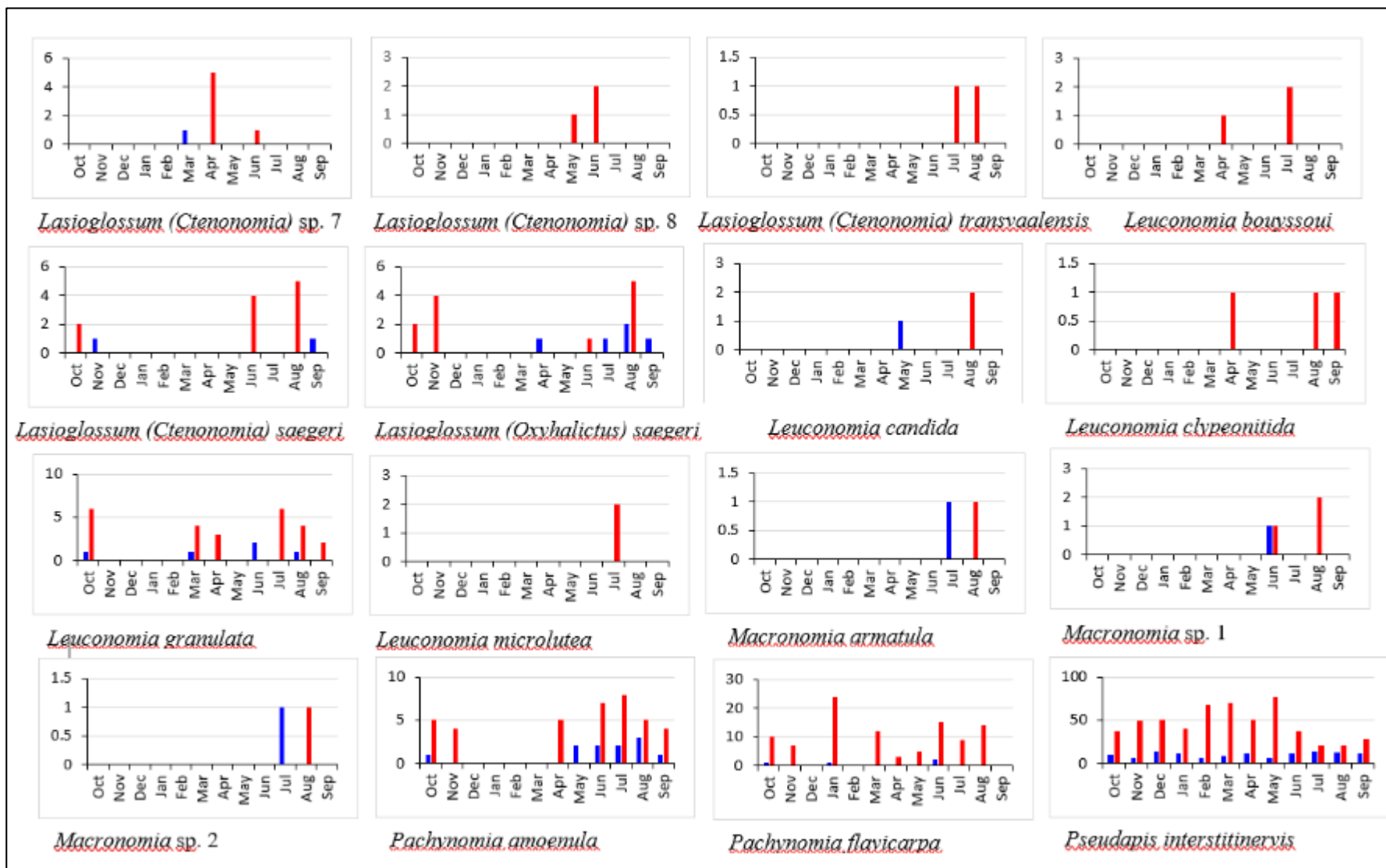


Figure 5b Phenological diagrams of Halictidae family from Burkina Faso (Male in blue and Female in red)

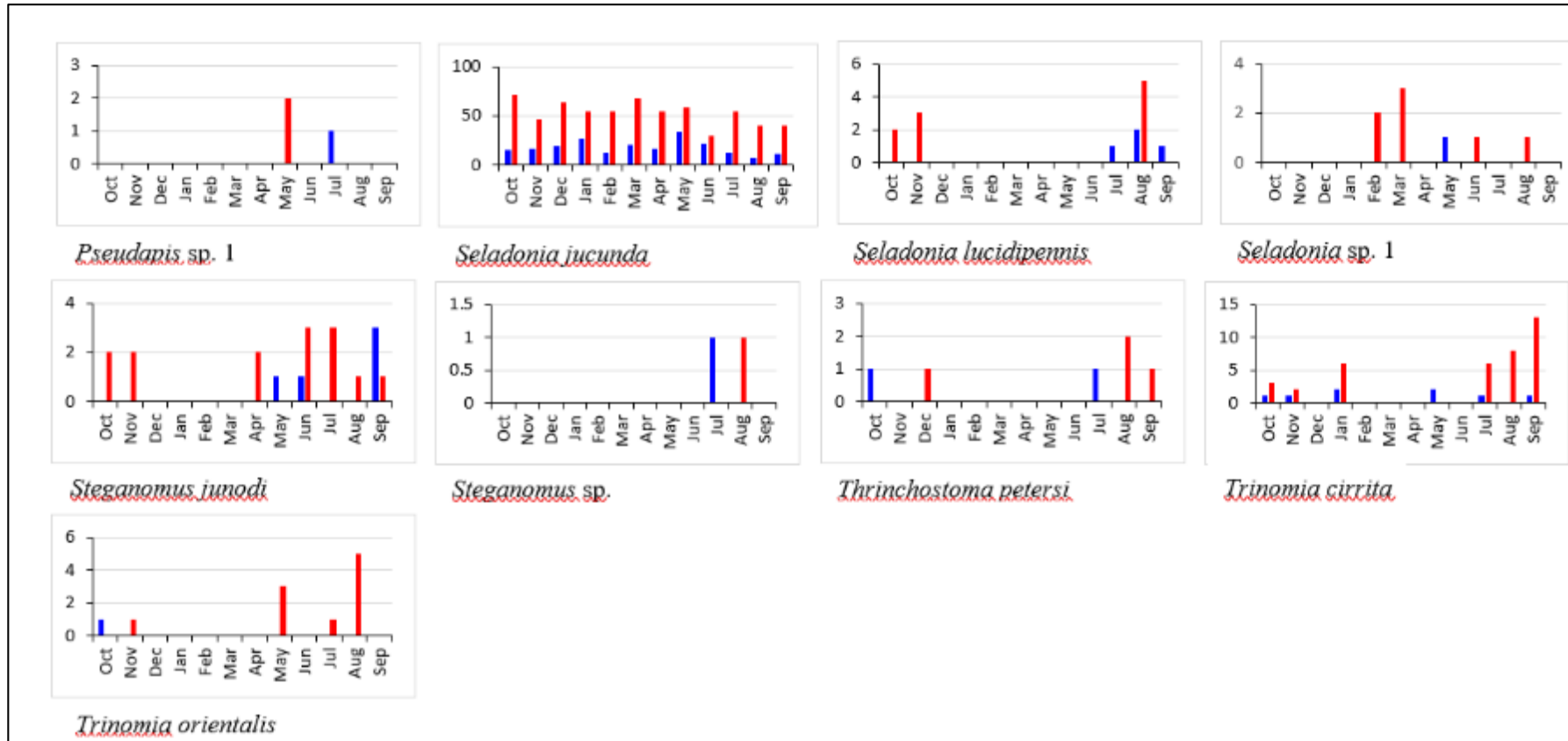


Figure 5c Phenological diagrams of Halictidae family from Burkina Faso (Male in blue and Female in red)

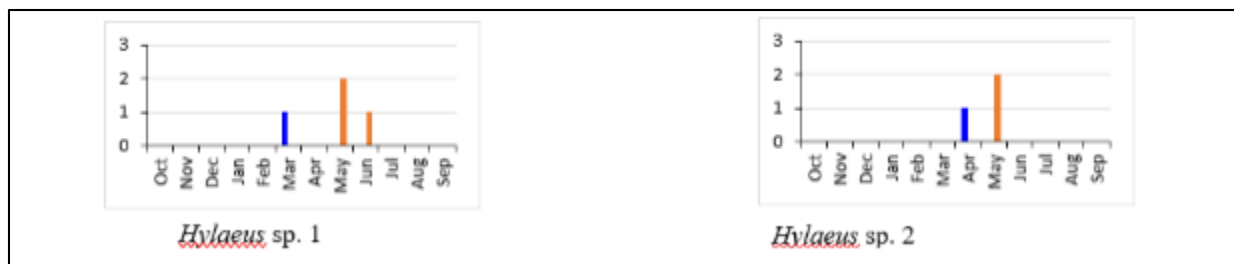


Figure 6 Phenological diagrams of Colletidae family from Burkina Faso (Male in blue and Female in red)

Five wild bee species belonging to Apidae, *Braunsapis* sp. 1, *Braunsapis* sp. 2, *Braunsapis* sp. 3, *Ceratina* sp. 1, *Hypotrigona gribodoi* and the honeybee *Apis mellifera* were captured during all the 12 months of year. Two other wild bee species belonging to the family Halictidae, *Pseudapis interstitinervis* and *Seladonia jucunda* were also captured throughout the whole year. The other bee species were encountered at different periods of the year (Table 3). Among the family Apidae, 6 bee species were captured only in the rainy season, whereas 6 bee species were captured only in the dry season. For Megachilidae, 4 bee species were captured only in the rainy season and 21 species only in the dry season. For Halictidae, 11 bee species were captured only in the rainy season against one single species only in the dry season. For Colletidae, a single specie was captured only in the rainy season and one other species in the dry season and beginning of the rainy season

4. Discussion

Following the results published by Stein and collaborators on the bee community of Burkina Faso, we present for the first time empirical data on the phenology of bees in the Sudanian savannas of Burkina Faso. The findings contributes to assess bee diversity in the West African ecosystems. These ecosystems are subject to enormous anthropogenic pressure due to unsustainable land use resulting from the population growth and extensive agriculture which, at the same time, requires a high demand for pollination services provided by bees to maintain natural vegetation and secure crop yields [11]. Among all families, Halictidae exhibited the highest species richness. Indeed, the solitary character of Halictidae favors their dispersion in the environment. In addition, the multiplicity of habitat types suitable for Halictidae in our study site could explain the presence of different species. The same findings was reported by Pauly and collaborators who stated the high diversity of Halictidae in sub-Saharan Africa [16]. The findings could be also due to the preference of Halictidae for a wide range of plants compared to other bee families. Indeed, Apidae represented by Meliponini tribe and by the honey bee *Apis mellifera* are very polytrophic but, they visit only a single variety of plant each time they go out. The Megachilidae are limited in their choice by the accessibility of the stamens to the movements of their ventral brush. There are only two genera of Colletidae more frequent during the dry season [17]. The average number of bee specimens is higher in the dry season compared to the rainy season. Indeed, the sampling period is longer in the dry season (7 months) compared to the rainy season (4 months). In addition, several woody species flower during the dry season and provide food resources to bees. The number of bee species increases in July and August, corresponding to the rainy season. Indeed, in addition to the woody species, many herbaceous and cultivated plants flower during this period. The multiplicity of flowering plants offers a wide range of food resources to bees, which could explain their strong diversity. The species richness of bees decreases in January, probably because this month corresponds to the coolest period with the presence of "harmattan wind". The stingless wild bee species *Hypotrigona gribodoi* (74.6% of specimens) is a highly invasive social species living in colonies in the West Africa Sudanian savanna. Its nesting sites being quite diverse, allow it to quickly colonize large areas (agricultural and natural environments). As for *Apis mellifera*, its constancy and abundance are due to the regular practice of beekeeping activities throughout the region. Although solitary, *Braunsapis* nest in stems and twigs and *Ceratina* nest generally in woody material in a variety of locations, mostly in shady environments. The diversity and ease of access to their breeding sites explains their presence throughout the year. Taking into account the different phenological graphs for each species: For Apidae family represented by the Figures 3a to 3b, the solitary bees, *Amegilla acraensis*, *Amegilla nubica*, *Amegilla* sp. 7, *Amegilla torrida*, *Ceratina* sp. 3, and the social bee species, *Meliponula togoensis* were captured only in the rainy season. Maybe, because these species are more abundant during this period or either, the plants on which they depend, flower abundantly. Moreover, the scarcity of host plants for these bees can lead them to traps that they could consider as a source of food. These factors will need to be elucidated for proper management of bee communities. Unlike previous bee species, *Amegilla* sp. 3, *Amegilla* sp. 4, *Amegilla* sp. 5, *Xylocopa scioensis*, *Xylocopa ustulata* and *Xylocopa* sp were captured only in the dry season. These species seem to have their food resource in the dry season as also reported by Ndayikeza and collaborators [18]. Only the species captured in Kibira are different from those captured in our study. For Megachilidae family represented by the Figure 4a to 4b, *Anthidium* sp. 1, *Megachile* sp. 24, *Megachile* sp. 25 and

Megachile sp. 26 were captured only in the rainy season. The bee species *Chalicodoma mephistolica*, *Creightonella discolor*, *Heriades* sp. 2, *Megachile* sp. 4, *Megachile* sp. 6, *Megachile* sp. 8, *Megachile* sp. 9, *Megachile* sp. 10, *Megachile* sp. 11, *Megachile* sp. 12, *Megachile* sp. 13, *Megachile* sp. 14, *Megachile* sp. 15, *Megachile* sp. 16, *Megachile* sp. 17, *Megachile* sp. 18, *Megachile* sp. 19, *Megachile* sp. 20, *Megachile* sp. 21, *Megachile* sp. 22 and *Megachile* sp. 23 were captured only in the dry season. It can be seen that Megachilidae are captured during all seasons. Bee specimens in these groups have not been identified to the species level during this study. Ndayikeza and collaborators also captured Megachilidae during all seasons in their study [18]. For Halictidae family represented by the Figures 5a to 5b, *Acunomia ivoiriensis*, *Acunomia senticosa*, *Crociaspidia chandleri*, *Lasioglossum (Ctenonomia) audasi*, *Lasioglossum (Ctenonomia) sp. 3*, *Lasioglossum (Ctenonomia) transvaalensis*, *Leuconomia microlutea*, *Macronomia sp. 1*, *Macronomia sp. 2*, *Macronomia armatula*, and *Steganomus* sp., were captured only in the rainy season. Only the bee species, *Austronomia* sp. 1 was captured only in the dry season. For Colletidae family represented by the Figure 6, the bee species *Hylaeus* sp. 1 was captured in the dry season and beginning the rainy season contrary to *Hylaeus* sp. 2 which was captured only in the dry season.

5. Conclusion

This study contributes to fill knowledge gaps on the phenology of bee species in Burkina Faso. It showed that some bee species are present the whole year in the Sudanian savannas of West Africa. However, other bee species are periodic and can be encountered only at a specific period of the year. The findings serve as important database for monitoring bee communities in relationship to the plant pollination, particularly cash crops of Burkina Faso. In our next study, we will take into account the plants foraged by each bee species in order to relate the flight periods observed with the flowering cycles of both herbaceous and ligneous plants.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

Authors’ Contributions

DC, KS and SK designed the study. DC and LHB collected data in the field. DC determined bee species and their traits. DC and KS analysed and plotted output data. DC wrote the first draft of the manuscript. YT and MK contributed to improve the draft. All authors contributed substantially to revisions.

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