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# Preliminary study of the ecology and community structure of wasps (Hymenoptera) in the Luki biosphere reserve (Kongo-Central/Democratic Republic of Congo)

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**Abstract**
This study reports on the diversity, ecology and community structure of wasps in the Luki Biosphere Reserve. The importance and role of wasps are well known, especially for their impact on the ecosystem balance, and in the Democratic Republic of Congo (DRC), data on wasps are still lacking in many sites. Thus, special attention has been paid to the wasps of this Reserve. After the collections were carried out between January and July 2021 using windrow nets and cup traps, 502 specimens were counted divided between 22 species and 5 families. The Vespidae family is the best represented with 63% of the population, followed by the Pompilidae (23%) and the Sphecidae (12%). Synagris sp1 and Diplonyx campanulatus are especially the two most observed species with more than 28% of the observations. However, the heliophilic character of wasps was observed in this study, with a peak of activity evaluated between 10 and 12 hours.

**Keywords:** wasps, Luki biosphere reserve, eco-systemic balance and diversity

## 1. Introduction

The Living Planet Index 2020 shows that the world's animal population has declined by 68% on average in less than a century. In addition, according to the World Economic Forum's Global Risks 2020 report, the five most pressing challenges Africa will face over the next decade are, for the first time, all related to the environment, and include the loss of biodiversity [1]. With nearly 1.3 million species described [2], insects constitute 55% of animal biodiversity [3]. Their biomass is estimated 300 times greater than that of other classes in the animal kingdom. Insects are the most important class, playing a remarkable ecological role as bioindicators of the state of ecosystems [4-5]. Indeed, according to Wilson [1], insects are described as "*the little things that make the world go round*". Therefore, they interact at multiple levels within ecosystems and are responsible for different services and maintenance of biological systems [6-7].

In addition, according to Wiggins [8], our ecosystems would be inoperable without the presence of insects, as the ecological importance of the huge variety of insects makes them useful for the assessment of disturbances or environmental impacts of various types.

However, recently, insect populations have been declining remarkably due to several external pressures. Moreover, according to several researchers, the causes of these pressures appear to be multiple [9]. In Africa, the decline varies according to the species and several researchers agree that the causes are almost all of anthropogenic origin [10].

In the Democratic Republic of Congo (DRC), research on entomological diversity has been growing for more than 20 years [11]. Despite this work, information on the diversity and ecology of the entomofauna in certain regions of the country remains poorly known and fragmentary [12]. In addition to the provinces of Tshopo (ex-Oriental Province) [13-16] and Kinshasa [11, 17-21], which have been the subject of several entomological studies, the province of Kongo-Central is also following suit [11-12]. Moreover, all these studies conducted so far have focused much more on bees, mosquitoes, butterflies, and very little on beetles, while other more important groups of insects participate in the balance of our ecosystems and help to elucidate the health of the latter.

In this context, wasps would be the best example with other groups, such as Odonata, since they are at the top of the trophic chain of macroinvertebrates, which would allow us to draw information about the faunal richness of the environments and therefore allow us to detect the slightest disturbances in the ecosystems **[8]**.

By hunting many other insects, such as caterpillars, mosquitoes and aphids for food and larvae, wasps contribute to the good balance of ecosystems. In addition, according to IBGE [22], the adults feed on sugary materials by visiting flowers to feed and thus participate in the pollination of certain plant species [23].

The wasps constitute, with the bees and ants, the infra-order of Aculeates, a major group of the order Hymenoptera in the suborder Apocrites. The superfamily *Vespoidea* and *Apoid*ea have many species in the world with more than 9 000 described species without counting other superfamilies [24-26].

To date, entomological data on wasps in our regions are almost non-existent, and to our knowledge, no study has evaluated their diversity or abundance. It is in this perspective that the present preliminary study seeks to establish a systematic inventory while studying their ecology and community structure in the Luki Biosphere Reserve.

## 2. Materials and Methods

### 2.1. Study site

The studies were carried out in the Luki Biosphere Reserve, located in the western part of the province of Kongo-Central in the Democratic Republic of Congo (DRC). With an area of 33,811 ha, the Reserve extends from 5°29' to 5°42' South latitude and from 13°04' to 13°17' East longitude, in the Lower river district, about 110 km from the Atlantic Ocean [27].

Created in 1937 by order of the Governor of the Belgian Congo colony, the objective of the Reserve was to protect part of the Mayombe forest, which had fallen victim to rapid degradation caused by industrial timber exploitation [28].

In 1979, currently UNESCO as a Biosphere Reserve., the INERA, and the ERAIFT recognized it, Man, and Biosphere (MAB-DRC) operate together in its management. As foreseen in the UNESCO Man and Biosphere program, the Luki Biosphere Reserve is divided into three zones (Figure 1): the core zone (8,858 ha) is a strictly protected area, surrounded by a buffer zone (6,430 ha) where only activities compatible with sustainable ecological practices are allowed, such as scientific research.

Finally, in the transition zone (18,523 ha) extending to the borders of the Reserve, more human activities are allowed, contributing to the sustainable development of the region [29].

The climate characterizing the reserve is a humid tropical climate, AW5 according to Köppen's classification and marked by an important maritime influence [30]. The main dry season extends from mid-May to mid-October and a short dry season takes place in January and February. The average annual rainfall is very irregular, around 1,350 mm [27].

Belonging to the geological system of Mayombe, the Reserve, whose altitude varies between 150 and 500 m, is crossed by hills [31]. It hosts a semi-evergreen forest, guardian of extraordinary biodiversity, as evidenced by the 1,096 plant species listed by Lubini [32].

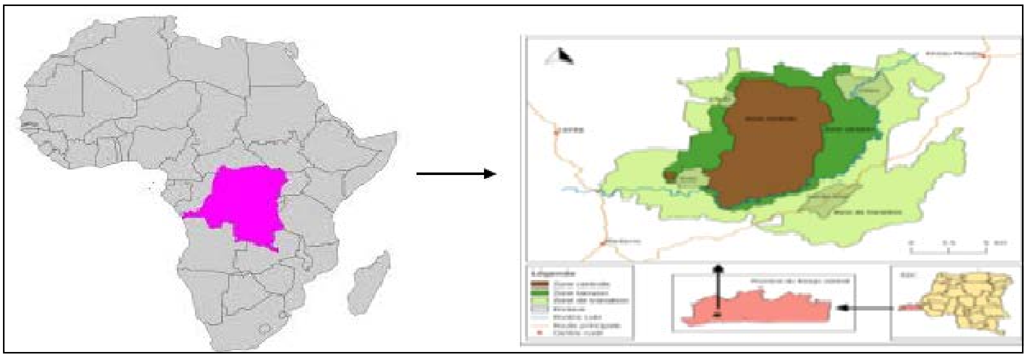

**Fig 1:** Location of the study area

### 2.2. Experimental design and insect collection

This study was conducted between January and July 2021 using two sampling techniques (Figure 2). Captures were made in four plots of 4 000 m² each along transects set up according to the method of Bartomeus *et al.* [33]. Two plots were selected in a closed environment and two others in an open environment.


**Fig 2:** Partial view of the plots with: a) cups installed and b) capture with a swath net

Harvesting was carried out between 7:00 and 17:00 according to Vereecken [34]. Captures were made with the swath nets and colored cups (Figure 2) arranged according to the pattern described in Figure 3. Six transects of 80 by 50 meters were selected, each 10 meters apart. The cup traps were interspersed between the transects, alternating and separated by 10 meters each. According to the model proposed by Pott *et al.* [35] on Hymenoptera, we used a set of cups of different colors, including blue, yellow and white (Figure 3).

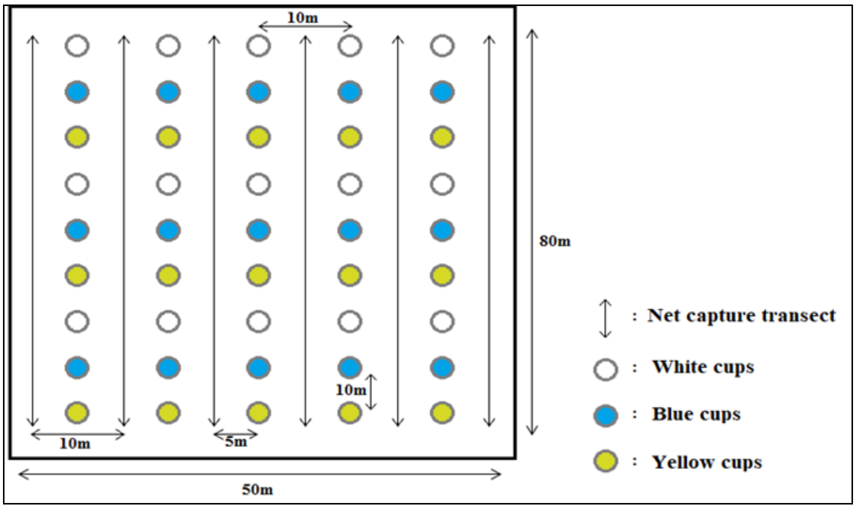


**Fig 3:** Experimental device used

### 2.3. Conservation and identification of collected insects

The insects collected in the nets and the cups were directly stored in pillboxes containing 70% alcohol, duly numbered and dated. In the laboratory, identification was carried out using some general and specific systematic keys for some wasp families [36-40] and completed morphologically by the insect gallery of Sub-Saharan Africa. Visual recognition was done under a BRESSER binocular loupe at 40X. Indeterminate species were also considered.

### 2.4. Identification of the flora

The plants were identified in the field and the samples were brought to the Herbarium IUK, Department of Biology of the University of Kinshasa.

### 2.5. Study of the influence of climatic factors

The temperature and humidity of the study station were recorded every 60 minutes from 7:00 am to 5:00 pm using a portable thermo-hygrometer brand KJM017 installed in the shade. The variation in the number of insects as a function of temperature and hygrometry allows us to evaluate the influence of these factors on their activity [41].

### 2.6. Use of ecological descriptors

- **Species richness**, a term introduced by Mc Intosh, is simply the number of species present in the taxocenosis under consideration. It is the simplest conceptual measure but practically the most delicate [43].
- **Frequency (Fi)** is defined as the percentage between the number of individuals of a species I (ni) in the entire environment and the total number of individuals caught of all species in the environment (N) [42].

  $Fi = (ni/N) \times 100$
- The Shannon Weaver index (H') is used to assess the spatial and temporal diversity of a given stand in a biotope or set of biotopes [43].

  $H' = -\Sigma\ pi*Log2\ (pi)$

  With: S: Number of species observed in a sample; N: Number of individuals in the sample; ni: Number of individuals of species i.
- The Piélou equitability (E) defined as the ratio of the real observed diversity to the theoretical maximum diversity. The latter corresponds to the diversity of a stand where the N species present would all have the same relative frequency. Equitability provides information on the structure of the ecosystem [42].

  $E = H'/\text{Log } S$

  The equitability represents the possibility that individuals have to distribute themselves between the different species. It is zero when one species is dominant and one when all species have the same abundance.
- Simpson's index (D) is related to the variations in abundance between the dominant species. This index tends toward a value of zero to indicate maximum diversity, and a value of one to indicate minimum diversity [42].

  $D = \Sigma Ni * (Ni\text{-}1)/N * (N\text{-}1)$

  With: Ni: Number of individuals of the given species; N: Total number of individuals.
- Hill's index (D) provides a measure of proportional abundance combining Shannon and Simpson indices [43].

  $D = 1/D/eH'$

  With: 1/D: The inverse of Simpson's index; eH': The exponential of Shannon's index.
- **The frequency of occurrence** is the ratio expressed as a percentage of the number of records containing the species under consideration to the total number of records [43].

  $F = Pi\ x\ 100P$

With: Pi: Total number of samples containing the species under consideration; P: Total number of surveys.

A species i is said to be ubiquitous if F = 100%; it is constant if 75 ≤ F < 100%; it is regular if 50% ≤ F≤ 75%; it is accessory if 25%≤ F≤ 50% and it is accidental if F≤ 25%.

## 2.7. Data processing

Data entry and figure making were done using Microsoft Excel 2016 and Origin Pro 8 software. These data were imported to XLSTAT 2020 software for analysis. Data processing is done using descriptive statistics (calculation of means, standard deviations and percentages), correlation coefficient (r) for the study of relationships between climate factors, t-test for the comparison of means of two samples and Chi-square ($\chi 2$) for the comparison of numbers at the 5% significance level.

## 3. Results

### 3.1. Systematic analysis

#### 3.1.1. Taxonomic composition of the studied fauna

The present study of wasps in the Luki Biosphere Reserve has made it possible to establish a faunal inventory of 502 specimens divided into 22 species and 5 families (Table 1). Among these species, 10 were identified to the specific level, 11 others to the generic level and one species belonging to the family *Vespidae* was not identified.

**Table 1:** List of wasp species collected (Nind: Number of individuals; % ind: Percentage of number of individuals)

| Superfamilies | Families | Subfamilies | Species | Nind | % ind |
|---|---|---|---|---|---|
| *Apoidea* | Crabronidae | *Philanthinae* | *Philanthus sp* Fabricius, 1790 | 12 | 2,39 |
| | Sphecidae | *Ammophilinae* | *Ammophila sp* Kirby, 1798 | 15 | 2,99 |
| | | Sphecinae | *Sphex sp* Linnaeus, 1758 | 30 | 5,98 |
| | | Sphecinae | *Sphex tomentosus* Fabricius, 1787 | 14 | 2,79 |
| *Chrysidoidea* | Chrysididae | Chrysidinae | *Chrysis lincea* Fabricius, 1775 | 2 | 0,40 |
| *Vespoidea* | *Pompilidae* | Pompilinae | *Agenioideus sp* Ashmead, 1902 | 25 | 4,98 |
| | | Pepsinae | *Hemi Pepsis sp* Dahlbom, 1844 | 28 | 5,58 |
| | | | *Diplonyx campanulatus* Saussure, 1887 | 62 | 12,35 |
| | *Vespidae* | Polistinae | *Belanogaster geurini* Saussure, 1853 | 15 | 2,99 |
| | | | *Belanogaster griseus* Fabricius, 1775 | 15 | 2,99 |
| | | | *Belanogaster juncea* Fabricius, 1781 | 12 | 2,39 |
| | | | *Belanogaster sp1* Saussure, 1854 | 32 | 6,37 |
| | | | *Belanogaster sp2* Saussure, 1854 | 17 | 3,39 |
| | | | *Polistes badius* Gerstacker, 1873 | 23 | 4,58 |
| | | | *Polistes sp* Latreille, 1802 | 43 | 8,57 |
| | | Eumeninae | *Delta emarginatum* Linnaeus, 1785 | 21 | 4,18 |
| | | | *Delta sp* Saussure, 1855 | 11 | 2,19 |
| | | | *Synagris cornuta* Linnaeus, 1758 | 27 | 5,38 |
| | | | *Synagris sp1* Linnaeus, 1758 | 82 | 16,33 |
| | | | *Synagris sp2* Linnaeus, 1759 | 4 | 0,80 |
| | | | *Synagris sp3* Linnaeus, 1759 | 9 | 1,79 |
| | | *Not identified* | *Not identified* | 3 | 0,60 |

The wasps inventoried belong to three superfamilies and five families in the order Hymenoptera. The relative abundance of each family is presented in Figure 4. Among these 502 specimens collected, the family *Vespidae* is mostly represented with more than 60% of the numbers followed by the *Pompilidae* with more than 16% of the numbers. The family *Chrysididae* is the least represented of all the families studied (Table 1). Moreover, as Table 1 points out, there is a great dominance of *Synagris sp1* over the other 21 species. It alone represents more than 16% of the total observed numbers. The species *Diplonyx campanulatus* follows with 62 individuals, that is to say, 12, 35%.

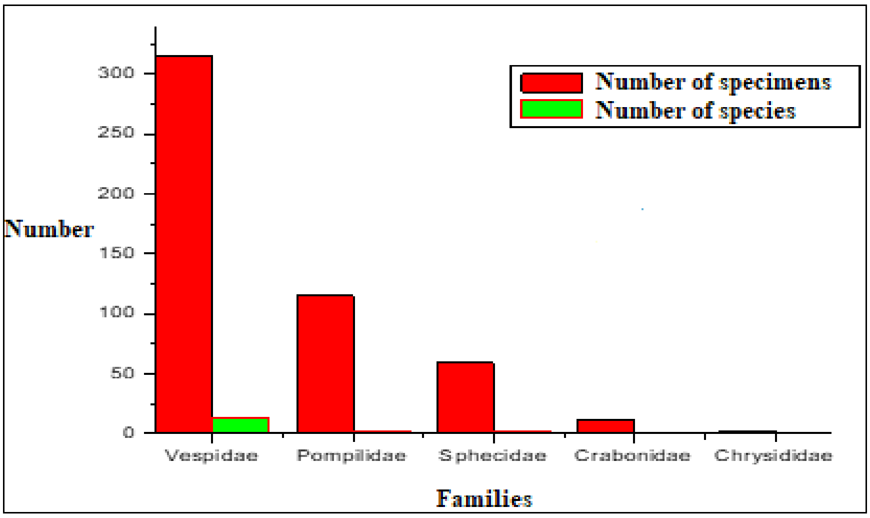


**Fig 4**: Distribution in number of specimens and species of the families of wasps captured

#### 3.1.2. Plants visited by wasps
During the study period, wasps were found on different plant organs in the study plots. Moreover, Table 2 lists 14 plant species on which wasps were observed.

**Table 2:** Plant species visited by wasps

| Families | Species |
|---|---|
| *Amaranthaceae* | *Gomphrena celosioides* Mart. |
| *Asteraceae* | *Chromolaena odorata* (L.) R.M.King & H.Rob |
| | *Tithonia diversifolia* (Hemsl.) A.Gray |
| *Cannaceae* | *Canna indica* L. |
| *Fabaceae* | *Pueraria javanica* (Benth.) Benth. |
| | *Mimosa pudica* L |
| *Lamiaceae* | *Ocimum basilicum* L. |
| | *Ocimum gratissimum* L. |
| *Lythraceae* | *Ammannia microcarpa* DC. |
| *Malvaceae* | *Waltheria Indica* L. |
| | *Sida acuta* Burm. F |
| *Moringaceae* | *Moringa oleifera* Lam. |
| *Poaceae* | *Panicum maximum* Jacq. |
| *Verbenaceae* | *Lantana trifolia* L |

The analysis of table 2 associated with figure 5 shows that *Malvaceae, Lamiaceae, Fabaceae* and *Asteraceae* are the four botanical families most visited by wasps, either to feed, rest or lay their eggs.

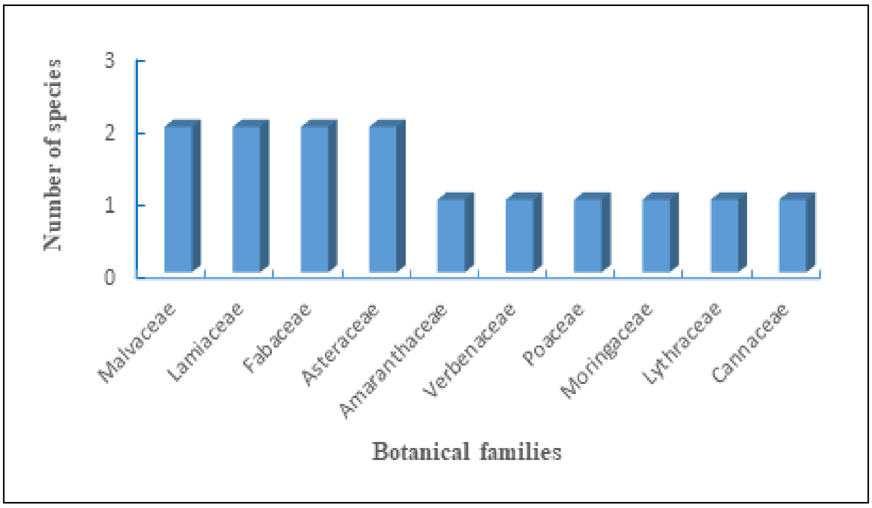


**Fig 5:** Distribution in some species of botanical families visited by wasps.

#### 3.2. Individuals collected by the techniques used
The collection campaigns conducted throughout the study period reported 502 specimens. The net technique was the most efficient with more than 80% of the numbers and 100% of the species richness (Figure 6). As for the cups used, wasps were slightly more attracted to the white and blue cups than the yellow ones.

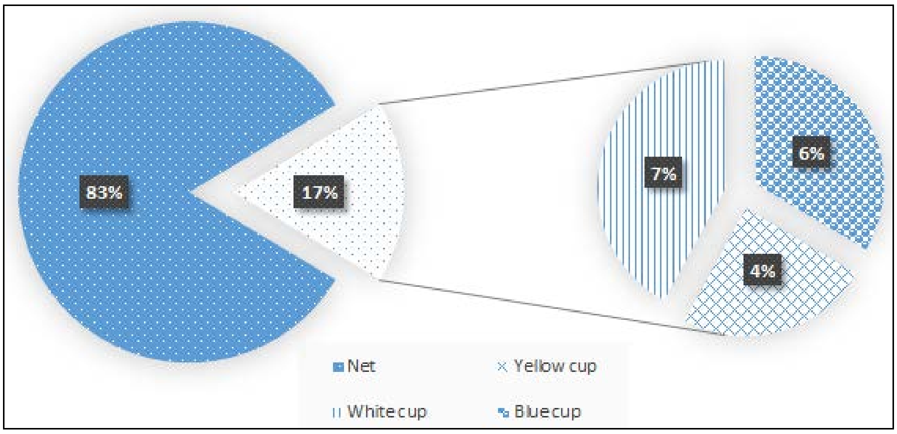


**Fig 6:** Distribution in the number of specimens of different sampling techniques used for the capture of wasps.

It can be noted that during the study period, net captures were regular, but as for the cups, the insects were not captured in February. The comparison of the numbers of insects caught by the different trapping techniques used by the chi-square test evaluated at the 5% probability threshold, reveals that the numbers were significantly different between the two collection techniques used (Table 3)

**Table 3:** Comparison of harvests and trapping techniques by Chi² test. ($X^2$ > 3.84: Significant (*); $X^2$ < 3.84: Not significant (**). At the 5% probability threshold, the critical $X^2$ for 2 degrees of freedom is estimated at 3.84)

| | | White cup | Blue cup | Yellow cup | Net |
|---|---|---|---|---|---|
| N°1 | White cup | - | 28 (*) | 28 (*) | 42 (*) |
| N°2 | Blue cup | 28 (*) | - | 21,78 (*) | 28 (*) |
| N°3 | Yellow cup | 28 (*) | 21,78 (*) | - | 28 (*) |
| N°4 | Net | 42 (*) | 28 (*) | 28 (*) | - |
| Total of specimens | | 36 | 29 | 21 | 416 |
| Total of species | | 6 | 7 | 5 | 22 |

## 3.3. Analysis of the composition

### 3.3.1. Temporal evolution of cumulative species richness

The evaluated cumulative richness shows that the curve reaches the plateau at the end of May (Figure 7).

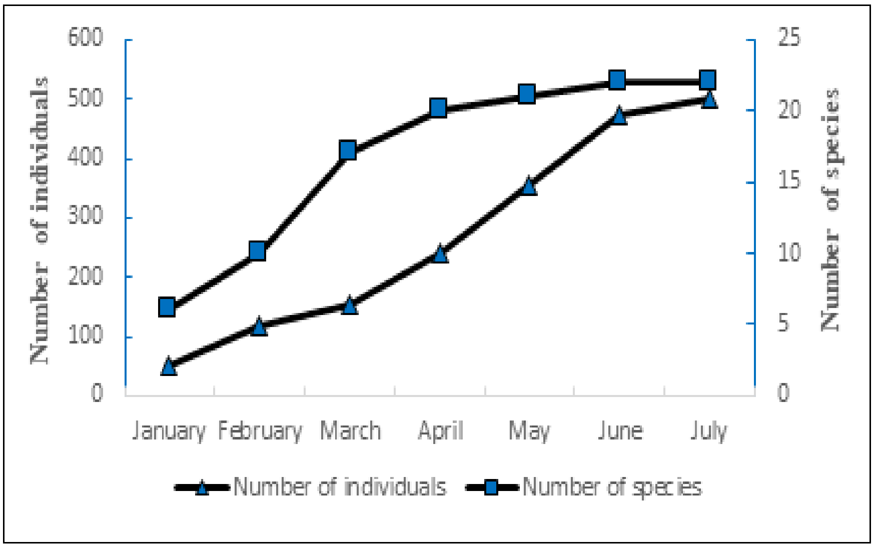


**Fig 7:** Temporal evolution of the cumulative species richness calculated based on the results obtained

The graphical representation of the number of cumulative species (figure 8) shows that regularly new species were captured. The graph shows three plateaus. Around the 11th, 17th and 29th sampling before reaching the asymptote. The coefficient of determination of the logarithmic curve tends towards 1 ($R^2$ = 0.8935), indicating a trend towards stabilization.

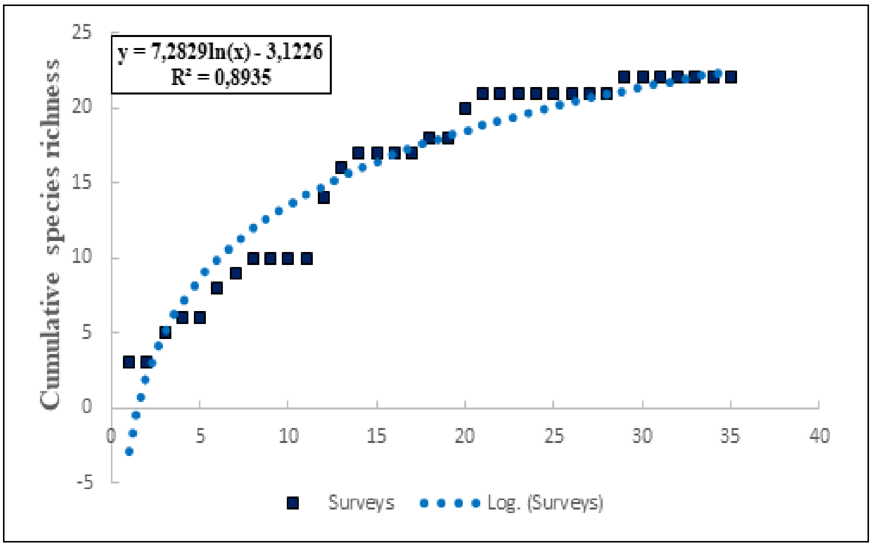


**Fig 8:** Logarithmic trend curves of cumulative total richness during the surveys.

The cumulative richness curve (Figure 8) results in a still fairly steep growth slope and very few species were observed from the 20th sampling onwards suggesting that, although the probability of finding new species during subsequent sampling is still high, these species should not be too numerous.

### 3.3.2. Distribution and Spatial Distribution of Species

The results of the distribution and spatial distribution of wasps are recorded in Table 4. The analysis of the distribution shows that only *Polistes badius* was regular in the environment, 11 species (or 50%) encountered were accidental and 10 species (or 45%) were incidental.

Looking at the same table 4, the distribution of the wasps studied shows that *Synagris sp2*, *Polistes badius* and *Belanogaster sp2* were distributed regularly, *Synagris sp3* in a random way and 18 remaining species (i.e. 81%) in an aggregative way.

**Table 4:** Distribution and spatial distribution of wasps (F: Frequency of occurrence; Ni: Number of individuals of species I; X: Mean; S2: Variance; I: Distribution index)

| Species | *Frequency of occurrence* | | *Spatial distribution* | | | | |
|---|---|---|---|---|---|---|---|
| | F (%) | Type of species | Ni | X | S² | I | *Distribution* |
| *Synagris cornuta* | 42,86 | Accessory | 27 | 9,00 | 28,00 | 3,11 | Aggregative |
| *Melanogaster geurini* | 14,29 | Accidental | 15 | 5,00 | 21,00 | 4,20 | Aggregative |
| *Diplonyx campanulatus* | 28,57 | Accessory | 62 | 20,67 | 344,33 | 16,66 | Aggregative |
| *Melanogaster sp1* | 14,29 | Accidental | 32 | 10,67 | 94,33 | 8,84 | Aggregative |
| *Melanogaster griseus* | 14,29 | Accidental | 15 | 5,00 | 7,00 | 1,40 | Aggregative |
| *Synagris sp1* | 42,86 | Accessory | 82 | 27,33 | 72,33 | 2,65 | Aggregative |
| *Sphex tomentosus* | 14,29 | Accidental | 14 | 4,67 | 16,33 | 3,50 | Aggregative |
| *Synagris sp2* | 14,29 | Accidental | 4 | 1,33 | 0,33 | 0,25 | Regular |
| *Ammophila sp* | 28,57 | Accessory | 15 | 5,00 | 21,00 | 4,20 | Aggregative |
| *Polistes sp* | 42,86 | Accessory | 43 | 14,33 | 65,33 | 4,56 | Aggregative |
| *Hemipepsis sp* | 28,57 | Accessory | 28 | 9,33 | 44,33 | 4,75 | Aggregative |
| *Polistes badius* | 57,14 | Regular | 23 | 7,67 | 1,33 | 0,17 | Regular |
| *Agenioideus sp* | 14,29 | Accidental | 25 | 8,33 | 94,33 | 11,32 | Aggregative |
| *Philanthus sp* | 42,86 | Accessory | 12 | 4,00 | 27,00 | 6,75 | Aggregative |
| *Delta sp* | 14,29 | Accidental | 11 | 3,67 | 30,33 | 8,27 | Aggregative |
| *Delta emarginatum* | 42,86 | Accessory | 21 | 7,00 | 91,00 | 13,00 | Aggregative |
| *Sphex sp* | 28,57 | Accessory | 30 | 10,00 | 36,00 | 3,60 | Aggregative |
| *Melanogaster sp2* | 14,29 | Accidental | 17 | 5,67 | 5,33 | 0,94 | Regular |
| *Melanogaster juncea* | 14,29 | Accidental | 12 | 4,00 | 19,00 | 4,75 | Aggregative |
| *Synagris sp3* | 14,29 | Accidental | 9 | 3,00 | 4,00 | 1,33 | Aggregative |
| *Non-identifiée* | 28,57 | Accessory | 3 | 1,00 | 1,00 | 1,00 | Random |
| *Chrysis lincea* | 14,29 | Accidental | 2 | 0,67 | 1,33 | 2,00 | Aggregative |

### 3.4. Activity rhythm and influence of Physico-chemical parameters

**Figure 9** shows the variation in wasp abundance as a function of time, temperature and humidity. Thus, the wasps seem to be active from 7H to 17H, with a peak located between 10H and 12H.

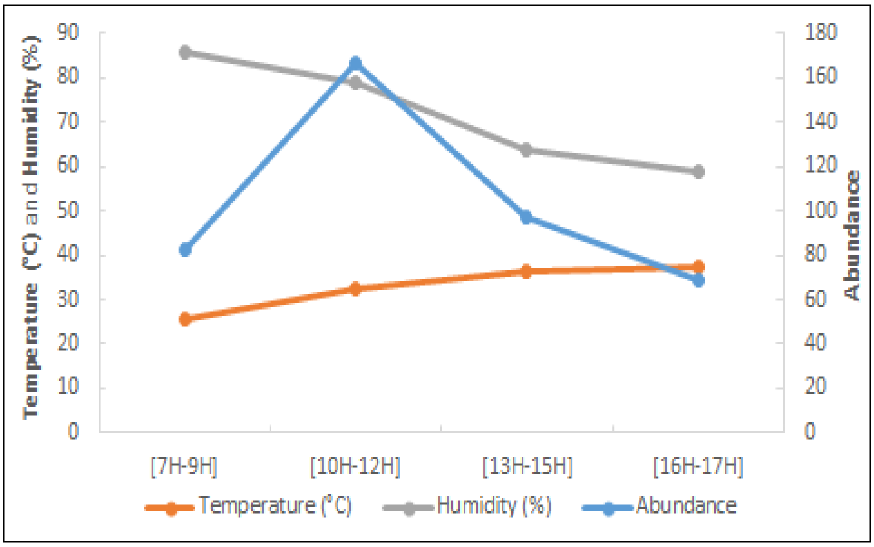


**Fig 9:** Average temperature, humidity and wasp abundance

The correlation between wasp abundance and relative humidity is positive and non-significant (r=0.41; *P*>0.05) while that between abundance and temperature appears negative and non-significant (r= -0.04; *P*>0.05) (Table 5). Thus, this analysis reveals that temperature and humidity did not significantly influence wasp activity.

**Table 5:** Results of tests of equality of means for temperature, humidity and abundance. (Significance levels: *P*<0.05: significant (*); P<0.01: highly significant (**); P<0.001: very highly significant (***); NS: not significant)

| | Abundance | Temperature | Humidity |
|---|---|---|---|
| Abundance | 1 | | |
| Temperature | 0,061 (NS) | 1 | |
| Humidity | 0,217 (NS) | 0,007 (**) | 1 |

### 3.5. Study of the specific diversity

Figure 10 shows that *Synagris sp1* is very abundant in the

Luki Biosphere Reserve. Thus, the Shannon diversity index evaluated is 4.04 bits. This value shows that the diversity of insect species collected is high. Piélou's equitability is equal to 0.90 (R>0.7), Simpson's index (0.07) and Hill's index (0.23). These results show a dominance of some species over others and the values obtained are significant and show regularity of the stands.

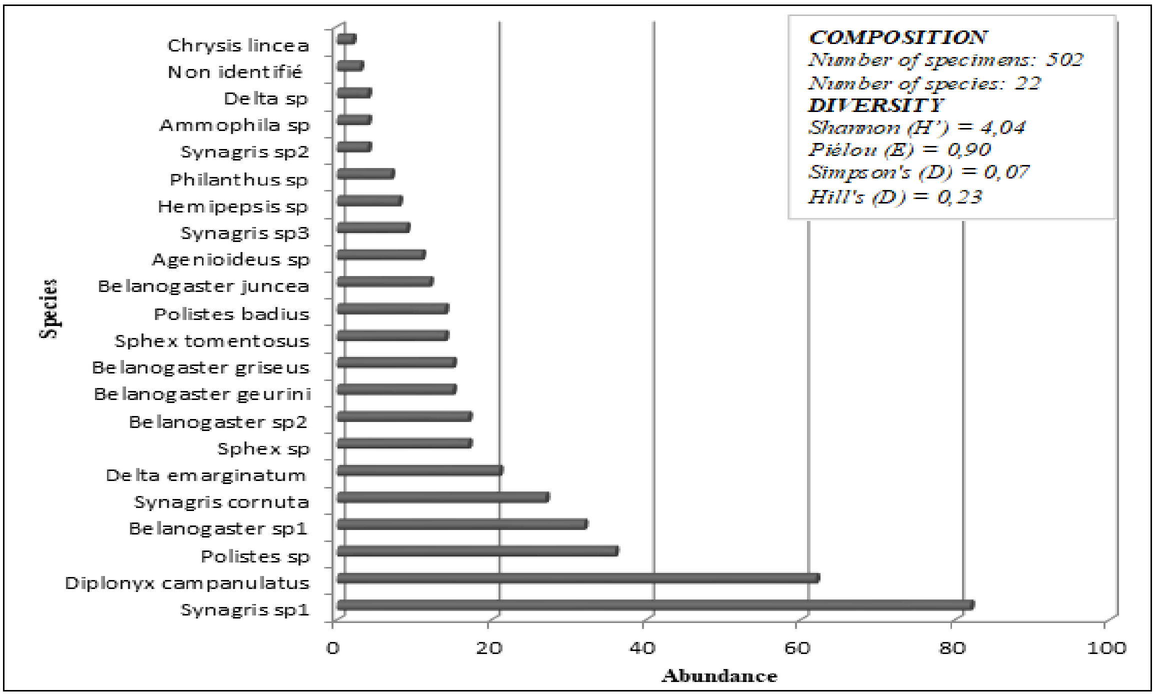


**Fig 10:** Presentation of wasp numbers and calculated ecological indices

## 3.6. Ecological preferences

### 3.6.1. Habitats

If we consider the species with more than 10 specimens, few of them were found in a closed environment, 38.84% and 61.16% of the wasps were collected in the open environment. Thus, the open environment seems to be largely appreciated by the wasps in the Luki Biosphere Reserve (Table 6).

*Synagris sp1* is more frequently found in open than in closed environments with 63 specimens found (i.e. 13% of the total number). Nevertheless, as for the closed environment, *Diplonyx campanulatus* gave a better preference with 40 specimens (or 8% of the total number).

**Table 6:** Distribution of species in the different plant formations. (N sp: Number of specimens)

| Species | N sp | Closed environment | Open environment |
|---|---|---|---|
| *Synagris cornuta* | 27 | 5 (18, 53%) | 22 (81, 48%) |
| *Melanogaster geurini* | 15 | - | 15 (100%) |
| *Diplonyx campanulatus* | 62 | 40 (64, 52%) | 22 (35, 48%) |
| *Belanogaster sp1* | 32 | 19 (59, 38%) | 13 (40, 63%) |
| *Belanogaster griseus* | 15 | 4 (26, 67%) | 11 (73, 33%) |
| *Synagris sp1* | 82 | 19 (23, 17%) | 63 (76, 83%) |
| *Sphex tomentosus* | 14 | 1 (7, 14%) | 13 (92, 86%) |
| *Ammophila sp* | 15 | - | 15 (100%) |
| *Polistes sp* | 43 | 19 (44, 19%) | 24 (55, 81%) |
| *Hemipepsis sp* | 28 | 2 (7, 14%) | 26 (92, 86%) |
| *Polistes badius* | 23 | 7 (30, 43%) | 16 (69, 57%) |
| *Agenioideus sp* | 25 | 19 (76%) | 6 (24%) |
| *Philanthus sp* | 12 | 1 (8, 33%) | 11 (91, 67%) |
| *Delta sp* | 11 | 10 (90, 91%) | 1 (9, 09%) |
| *Delta emarginatum* | 21 | 18 (85, 71%) | 3 (14, 29%) |
| *Sphex sp* | 30 | 16 (53, 33%) | 14 (46, 67%) |
| *Belanogaster sp2* | 17 | 7 (41, 18%) | 10 (58, 82%) |
| *Belanogaster juncea* | 12 | 1 (8, 33%) | 11 (91,67%) |
| Total | 484 | 188 (38,84) | 296 (61,16) |

## 4. Discussion

### 4.1. Systematic analysis

Apart from bees, the wasp fauna in particular is little known in the Democratic Republic of Congo (DRC). At the end of this study, 22 species were observed, distributed in 3 superfamilies and 5 families. The family *Vespidae* is the most Represented in terms of both abundance (63%) and species (64%). Already, in their work in the Botanical Garden of Kisantu (Central Kongo), Lukoki *et al.* [11] have highlighted the presence of *Vespidae* and *Sphecidae* with respectively two genera, *Belonogaster* and *Synagris*.

In addition, numerous inventories carried out in Kinshasa have also highlighted the presence of some families of wasps [11]. This shows the presence and the importance of wasps to colonize many ecosystems and to intervene in the eco-systemic balance [44-45].

This specific richness has also been observed in Cameroon, Algeria, Gabon and Burkina-Faso while highlighting the participation of these families in many ecosystem services [41, 46-49].

Abundance results show that *Synagris sp1*, *Diplonyx campanulatus* and *Polistes sp* are the three predominant species found in this study (37%), while *Chrysis lincea* is not very abundant. The impressive abundance of *Vespidae* in this study could be explained by the fact that the majority of them are predators and many of them nest or nested undercover and in the dark.

The plant diversity recorded reveals the multifunctional importance of certain botanical families. Moreover, 4 families, in this case, *Malvaceae, Lamiaceae, Fabaceae* and *Asteraceae* were more visited by wasps. These results corroborate those found by several researchers in Africa and elsewhere regarding bees [11, 17, 50]. This suggests that these families have elements and/or substances in common that they make available to both bees and wasps, especially since they are all hymenopterans. Molecular and survey studies on a larger number of sites and provinces are recommended to confirm or refute the current observations.

### 4.2. Data Collection

The most commonly used methods for studying Hymenoptera are numerous according to Wilson *et al.* and Benachour [51-52]. Two collection methods were chosen in the present work, nets and cups. The Chi-square test ($\chi 2$) comparing the two capture methods in terms of abundance give significantly different results. These results corroborate those found by Khalid [25] for *Sphecidae*. Indeed, the numbers in different months of the survey were different.

In addition, larger wasps were caught more in nets. This could be explained by the fact that they are generally very mobile and escape from the cups. According to Khalid [25], the use of this type of trap would allow, in future studies, to extend the sampling towards species that were not captured in the present work.

### 4.3. Compositional analysis

The analysis of the distribution of the wasps inventoried reported only one regular species, *Polistes badius*, 10 accessory species and 11 accidental species. The authors [45, 53] believe that temperature and precipitation have a physiological or even ethological effect on the distribution and frequency of occupation of the insects. This could be explained by the low presence of regular species since temperature did not influence the activities and abundances of the wasps studied.

The results of the spatial distribution of the wasps collected show 5% random species, 14% regular species and all the remaining species are distributed in an aggregated manner (i.e. 81%). This would be justified by a social predisposition of individuals to form groups or a low capacity of dispersion of individuals [54].

### 4.4. Activity rhythm and influence of Physico-chemical parameters

This study revealed a peak in wasp activity between 10H and 12H. This activity peak would be related to the period when temperature and humidity were almost maximal. This time slot is the one found by Sankara *et al.* [49]. Furthermore, temperature and humidity did not strongly influence the activity of the wasps studied. Thus, there was a positive and non-significant correlation between wasp abundance and air humidity (r=0.41; $P>0.05$) and a negative and non-significant correlation between wasp abundance and temperature (r=-0.04; $P>0.05$). These results are in agreement with those obtained by Dejace [55].

### 4.5. Study of the specific diversity

The monitoring of the species richness and the Shannon index allows us to deduce that these two indices show the same profile and evolve in the same way in space and time [8]. Thus, the present study gives a specific richness of 22 species and a Shannon index of 4.04. This reflects a high species diversity of wasps in the Luki Biosphere Reserve.

Moreover, the wasp population studied is in equilibrium since the value of the Piélou equitability calculated is close to 1. This translates to a fairly good regularity in the distribution of individuals between the different species. These results would support the hypothesis mentioned above about the negative effect of anthropogenic activities reported by Beaumont [56] not only on the abundance but also on the diversity of the wasps studied because of their nesting condition.

### 4.6. Ecological preferences

The wasps studied were found more in an open environment (61.16%) than in a closed environment (38.84%). Especially *Synagris sp1* was found more in an open environment with more than 60 specimens (12% of total numbers). These results are in agreement with those of Khalid [25] in Europe which report 51% of *Sphecidae* found in open areas. And according to Beaumont [56], wasps are generally heliophilous insects, which prefer warm, sunny and open environments.

## 5. Conclusion

For more than twenty years, entomological studies have experienced a remarkable rise in the DRC. Notwithstanding this, data are still fragmentary and the need to undertake studies in this direction is only increasing. Wasps constitute a group in the order of Hymenoptera that is the least studied, even though they participate in numerous ecosystem services and contribute to their balance. This study aimed at establishing a systematic inventory of wasps in the Luki Biosphere Reserve, while studying their ecology and community structure, shows that 502 specimens of wasps were recorded, divided into 22 species, 5 families and 3 superfamilies, with a remarkable abundance of the family *Vespidae*. It also appears that *Malvaceae, Lamiaceae, Fabaceae* and *Asteraceae* are the four botanical families that were more visited by wasps. Temperature and humidity did not influence the activity of wasps and that all the species studied were distributed in an aggregative way. More than 61% of the wasps inventoried showed a preference for the open environment, which confirms their heliophilic behavior. The number of wasp species inventoried during this study would still be much lower than the actual number of species found. Indeed, it is likely that by multiplying the study over several years and increasing the sampling effort that other species not observed in the present study could be found. Finally, the results obtained present a partial view of the wasps of the Luki Biosphere Reserve and constitute a base of preliminary data from which more in-depth studies must be conducted in all the zones (Central, Buffer and Transition) of the Luki Biosphere Reserve as well as in other protected areas or ecosystems of the DRC.

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