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# Succession pattern of cadaverous entomofauna in a semi-rural area of Bogotá, Colombia

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ABSTRACT

The main objective of this work was to examine the succession of insects colonizing three pig (*Sus scrofa*) cadavers in a semi-rural area of Bogotá. The 12 kg pigs were shot and put into metallic mesh cages to allow access by insects. Arthropods were then sampled at different intervals depending on the corresponding stage of decomposition. In total 5981 arthropods were collected during decomposition, 3382 adults and 2599 immature stages, belonging to 10 orders and 27 families. *Sarconesia magellanica* and *Compsomyiops verena* (Diptera: Calliphoridae) were the first species to colonize the corpses. Egg masses and 1st stage Calliphoridae larvae were associated with the fresh stage of decomposition, 1st and 2nd stage larvae of Calliphoridae and Sarcophagidae during chromatic and emphysematous stages, immature *Chrysomya albiceps* (Diptera: Calliphoridae), *Ophyra* sp. (Diptera: Muscidae) and *Oxellytrum discicolle* (Coleoptera: Silphidae) during the colliquative stage and mainly Coleoptera during the skeletization phase (plus some adult Diptera). The data obtained in the present investigation could be used for the estimation of postmortem interval (PMI) in real cases when the conditions to which a cadaver has been exposed are similar to those recorded during this work.



## 1. Introduction

Forensic entomology uses insects and other arthropods in medical-legal investigations, to determine the cause of death [1,2,3], when corpses have been moved, but in particular, in estimation of the postmortem interval (PMI) [4,5,6,7,8,9].

Insects can be used for estimating PMI in two ways; the first method is based on the rate of development of the insects' life-cycle. This approach generally focuses on Diptera from the family Calliphoridae which are usually the first to discover and colonize cadavers [10,11,12,13,9,14]. The second method involves the succession of insects present when a corpse is decomposing [15]. In those cases where remains are found weeks, months or even later after death, insects may represent the sole evidence and the only method for estimation of PMI [11].

The succession taking place in decomposing bodies has been named degradative succession, and occurs on a relatively brief scale of months or years [16]. A dead body forms an accessible resource providing protection, humidity and food in which insects and other organisms can rapidly develop [16,17]. Different species usually appear and disappear one after the other because, as a cadaver degrades, certain resources are used up and then become available to others whilst the changes occurring in the body favour first one species and then another [18]. This type of succession comes to an end only when available resources have become completely metabolized [16].

Arthropod communities in Latin-America associated with carrion in different settings have been reported by Carvalho et al. [19], Oliveira-Costa et al. [6,20] in Brazil, by Lannacone [21] in Perú and by Centeno et al. [22], Oliva [23] in Argentina; these authors have described families of Diptera as being the first to colonize cadavers and dominate early stages of decomposition, whilst Coleoptera dominate its final stages. Wolff et al. [24] carried out a preliminary study of insects associated with decomposing pigs in Medellín, Colombia; Pérez et al. [25] has studied cadaverous entomofauna succession in an urban area of Medellín. By contrast, Martínez et al. [26] studied insect colonization on a bleak upland

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**Table 1**
Matrix frequency of adult insects presented at different stages of decomposition from three pig cadavers *Sus scrofa* sampling of 97 days in a semi-rural area of Bogotá (Locality of Usaquén).

| Decomposition stage | | Fresh | | Chrom-Emphys. | | | | | | | Colliquative | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FAMILIA | Especie | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 16 | 17 | 18 | 20 |
| Calliphoridae | *Sarconesia magellanica* | 14.29 | 75 | 15.79 | 20 | 46.15 | 20 | 11.43 | 0 | 0 | 0 | 0 | 1.786 | 0 | 0 | 0 | 2.222 | 0 |
| | *Compsomyiops verena* | 0 | 0 | 0 | 10 | 15.38 | 5.714 | 14.29 | 37.93 | 48.57 | 20 | 59.21 | 26.79 | 25.93 | 1.667 | 0 | 17.78 | 16.35 |
| | *Chrysomya albiceps* | 0 | 0 | 0 | 0 | 7.692 | 5.714 | 5.714 | 6.897 | 14.29 | 12 | 10.53 | 1.786 | 7.407 | 6.667 | 0 | 11.11 | 8.654 |
| | *Calliphora nigribasis* | 0 | 0 | 10.53 | 40 | 0 | 0 | 0 | 3.448 | 0 | 2 | 0 | 3.571 | 0 | 1.667 | 2.941 | 0 | 1.923 |
| Fanniidae | *Fanniia* sp. | 0 | 0 | 0 | 0 | 0 | 5.714 | 5.714 | 0 | 0 | 0 | 0 | 1.786 | 0 | 2.5 | 2.941 | 8.889 | 13.46 |
| | *Fanniia* sp3. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.167 | 2.941 | 0 | 0 |
| Muscidae | *Synthesiomyia* sp. | 0 | 0 | 10.53 | 0 | 7.692 | 17.14 | 2.857 | 0 | 0 | 4 | 2.632 | 10.71 | 14.81 | 1.667 | 0 | 2.222 | 2.885 |
| | | 0000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1.31611 | 0 | 00 | 32.5 | 02.941 | 0 | 0.962 |
| | *Azelia* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.857 | 0 | 0 | 7.143 | 0 | 4.167 | 0 | 4.444 | 0 |
| Phoridae | | 0 | 0 | 15.53 | 0 | 0 | 0 | 2.857 | 3.448 | 0 | 0 | 0 | 0 | 0 | 0.833 | 0 | 0 | 0 |
| Piophilidae | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.571 | 6 | 1.316 | 8.929 | 0 | 10.83 | 2.941 | 4.444 | 0 |
| Sarcophagidae | | 85.71 | 25 | 10.53 | 20 | 15.38 | 0 | 5.714 | 0 | 0 | 2 | 3.947 | 0 | 3.704 | 0 | 0 | 0 | 1.923 |
| | *Sepsis* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 |
| Sphaeroceridae | *Leptocera* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 8.571 | 10.34 | 0 | 0 | 0 | 0 | 0 | 0 | 5.882 | 4.444 | 4.808 |
| | *Coproica* sp. | 0 | 0 | 5.263 | 0 | 7.692 | 28.57 | 11.43 | 10.34 | 2.857 | 20 | 1.316 | 23.21 | 0 | 23.33 | 41.18 | 2.222 | 0 |
| | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.824 | 0 | 0 |
| Dermestidae | *Dermestes maculatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.833 | 0 | 2.222 | 0 |
| | sp2. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0.962 |
| Histeridae | *Hister* sp. | 0 | 0 | 0 | 0 | 0 | 2.857 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.222 | 2.885 |
| Scarabaeidae | *Ontophagus* sp1. | 0 | 0 | 5.263 | 10 | 0 | 5.714 | 0 | 6.897 | 2.857 | 4 | 0 | 0 | 11.11 | 0.833 | 0 | 6.667 | 1.923 |
| Silphidae | *Oxellytrum discicolle* | 0 | 0 | 0 | 0 | 0 | 0 | 5.714 | 13.79 | 14.29 | 8 | 10.53 | 10.71 | 22.22 | 0.833 | 14.71 | 17.78 | 24.04 |
| Staphylinidae | sp2. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2.941 | 0 | 2.885 |
| Brachonidae | *Aphaereta* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.448 | 0 | 8 | 1.316 | 0 | 0 | 0.833 | 0 | 4.444 | 0 |
| Acari | | 0 | 0 | 26.32 | 0 | 0 | 8.571 | 25.71 | 3.448 | 5.714 | 8 | 7.895 | 3.571 | 14.81 | 4.167 | 11.76 | 8.889 | 16.35 |
| Total frequency | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

| Decomposition stage | | Skeletizationl | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Specie | 22 | 24 | 27 | 30 | 31 | 38 | 42 | 45 | 49 | 54 | 60 | 67 | 75 | 97 |
| Calliphoridae | *Sarconesia magellanica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Compsomyiops verena* | 2.083 | 3.125 | 7.018 | 3.846 | 8.511 | 0 | 8.861 | 0 | 14 | 0 | 0 | 0 | 0 | 0 |
| | *Chrysomya albiceps* | 6.25 | 0 | 5.263 | 3.846 | 2.128 | 0 | 12.66 | 0 | 12 | 0 | 8.108 | 16.67 | 0 | 0 |
| | *Calliphora nigribasis* | 0 | 3.125 | 0 | 5.769 | 0 | 0 | 1.266 | 0 | 0 | 0 | 2.703 | 11.11 | 0 | 0 |
| Fanniidae | *Fanniia* sp. | 6.25 | 6.25 | 5.263 | 1.923 | 8.511 | 0 | 13.92 | 0 | 8 | 0 | 8.108 | 8.333 | 0 | 0 |
| | *Fanniia* sp3. | 0 | 0 | 10.53 | 3.846 | 0 | 0 | 2.532 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Muscidae | *Synthesiomyia* sp. | 8.333 | 0 | 5.263 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 6.25 | 0 | 1.754 | 0 | 0 | 0 | 1.266 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | *Azelia* sp. | 6.25 | 9.375 | 3.509 | 5.769 | 0 | 0 | 1.266 | 0 | 12 | 0 | 0 | 0 | 0 | 0 |
| Phoridae | | 0 | 0 | 0 | 1.923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Piophilidae | | 0 | 0 | 1.754 | 1.923 | 0 | 0 | 3.797 | 0 | 2 | 0 | 21.62 | 13.89 | 0 | 0 |
| Sarcophagidae | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Sepsis* sp. | 0 | 0 | 0 | 7.692 | 2.128 | 0 | 10.13 | 0 | 22 | 0 | 8.108 | 0 | 0 | 0 |
| Sphaeroceridae | *Leptocera* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Coproica* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 1** (*Continued*)

| Decomposition stage | | Skeletizationl | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Specie | 22 | 24 | 27 | 30 | 31 | 38 | 42 | 45 | 49 | 54 | 60 | 67 | 75 | 97 | |
| Dermestidae | *Dermestes maculatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | sp2. | 2.083 | 0 | 0 | 0 | 0 | 0 | 1.266 | 0 | 0 | 0 | 0 | 2.778 | 36 | 0 | |
| Histeridae | *Hister* sp. | E6.25? | 0 | 1.754 | 1.923 | 0 | 0 | 8.861 | 5.263 | 0 | 7.143 | 5.405 | 2.778 | 12 | 100 | |
| Scarabaeidae | *Ontophagus* sp1. | 33.33 | 3.125 | 3.509 | 9.615 | 14.89 | 0 | 3.797 | 5.263 | 0 | 21.43 | 18.92 | 13.89 | 0 | 0 | |
| Silphidae | *Oxellytrum discicolle* | 6.25 | 43.75 | 36.84 | 25 | 36.17 | 70.83 | 29.11 | 47.37 | 18 | 35.71 | 24.32 | 27.78 | 52 | 0 | |
| Staphylinidae | sp2. | 0 | 3.125 | 7.018 | 1.923 | 0 | 4.167 | 1.266 | 5.263 | 2 | 7.143 | 2.703 | 2.778 | 0 | 0 | |
| Brachonidae | *Aphaereta* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Acari | | 16.67 | 28.13 | 10.53 | 25 | 27.66 | 25 | 0 | 36.84 | 8 | 28.57 | 0 | 0 | 0 | 0 | |
| Total frequency | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | |

Colombian moor. Camacho and Usaquén [27] studied the *Lucilia sericata* life-cycle in the environmental conditions found on the upland plain surrounding Bogotá. In most of these studies the same patterns of succession have been found, since most insect families, such as Calliphoridae, Muscidae, Sarcophagidae, Piophilidae, Fanniidae, Histeridae and Staphylinidae, were common to the various locations. However, the species abundance varied from place to place due to factors such as temperature, altitude, humidity, rainfall and photoperiod.

Here, studies were undertaken to establish a record of necrophagous insects, in one of Bogotá's semi-rural areas, thereby faciliting the use of insects data in the estimation of PMI.

## 2. Materials and methods

The investigation was carried out in a semi-rural area of Bogotá (on the San José de Guausa farm in the Usaquén locality). The area lies 2700 m above sea-level, has an average temperature of 14 °C, a relative humidity of 73.25% and an annual rainfall of 790 mm. Temperature can range from 27 °C during the day to 3 °C towards dawn. The area is characterized by pasture-land and large pines. This study area was chosen for the study for two reasons: it offers rapid access by highways and has also a wooded coverage where the cadavers could be hidden, avoiding possible disturbance by humans.

Four 12 kg pigs were used; they were sacrificed in the study area on the 1st of February 2006 by shooting. Following death, the pig cadavers were kept in 100 cm × 75 cm × 50 cm metallic mesh cages to avoid the action of predatory animals, but facilitating easy access to arthropods. There was direct contact between the cadavers in the cages and the ground which was covered by short grass. The cadavers were separated by 20 m. One of the pigs was used as control and no insects were collected from it.

The decomposition phases taken into account corresponded to fresh, chromatic, emphysematous, colliquative and skeletization stages; these stages are normally used by forensic pathologists for establishing the time of death [28]. The present investigation recorded the temperature of the cadaver, as well as abdominal perimeter and marking, the presence or absence of blisters, skin peeling and tissue loss. Sampling was done once a day during the first 18 days and then each 2 days until decomposition day 31. It was then carried out twice a week until day 49 and then once a week until decomposition day 97.

Arthropods were collected from above, around and below the cadavers. An entomological net was used for trapping flying insects; walking insects and immature specimens were collected by using forceps and by hand. Adult insects were killed with ethyl acetate and then preserved in 70% ethanol, whilst larvae were directly fixed in 70% alcohol. Environmental variables such as relative humidity, ambient temperature and climatic conditions were recorded during each sampling, recording each cadaver's rectal temperature using a mercury thermometer. Abdominal perimeter was measured using a tape-measure and corresponding photographs were taken. The insects collected during the succession were identified to genus and species using the keys of Mc Alpine [29,30], Mariluis and Peris [31] and Borror [32].

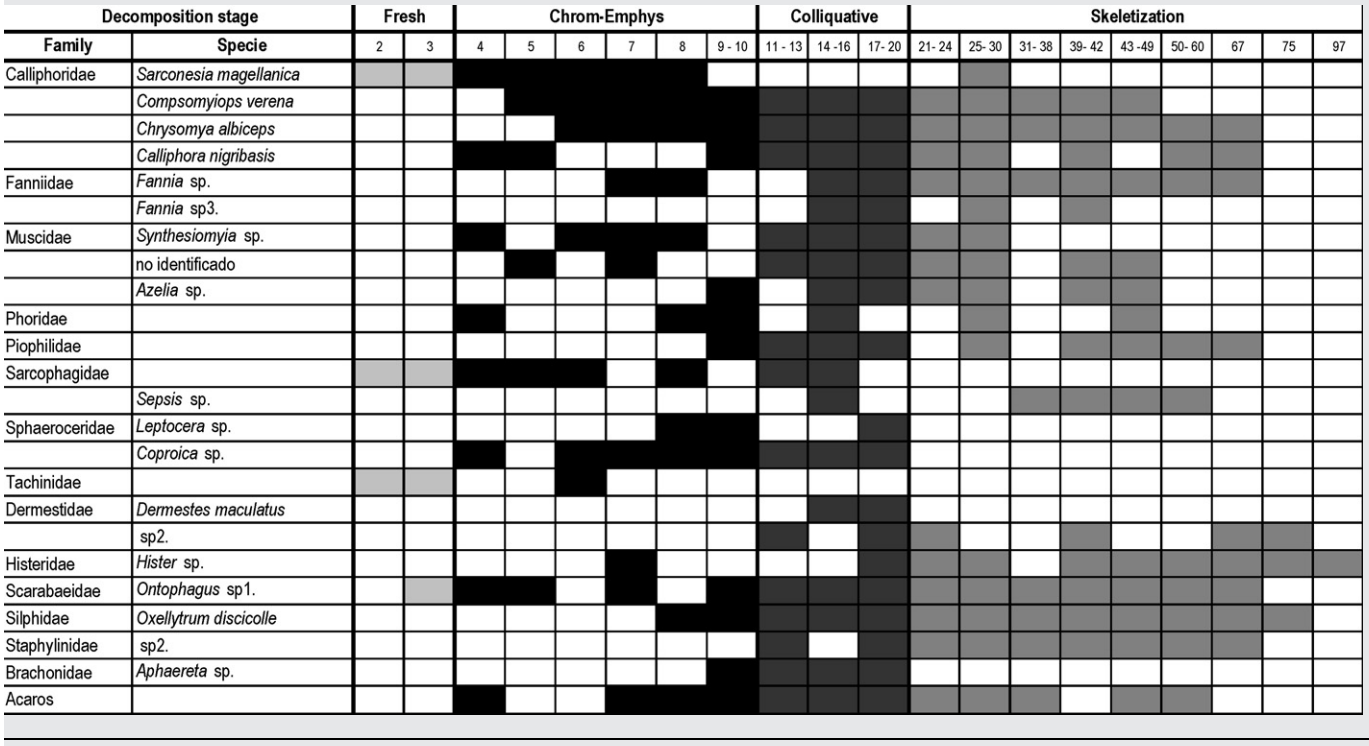
The arthropods collected during pig cadaver decomposition were assigned to one of five ecological categories, depending on how they used the cadavers or the fauna associated with them. (1) Necrophages feeding directly on the cadaver; (2) predators feeding on the fauna associated with the cadaver; (3) omnivores feeding on both the cadaver and the fauna associated with it; (4) parasites living at the expense of other arthropods associated with the bodies and (5) accidental arthropods reaching the cadavers by chance [14]. Occurrence matrix and frequency table were constructed for the main families of forensic interest from the orders Diptera, Coleoptera and Hymenoptera.

## 3. Results

5981 arthropods were collected during the process of pig cadaver decomposition, belonging to 10 orders and 27 families. The most abundant orders were Diptera and Coleoptera (65% and 26%, respectively), followed by Acari (8.1%) and Isopoda, Hymenoptera, Dermaptera, Odonata, Araneae, Lepidoptera and Orthoptera in descending order. The frequency of the various groups of insect present varied through the succession (Table 1).

The necrophagous insect category was made up of Diptera from the families Calliphoridae, Sarcophagidae, Muscidae, Piophilidae, Phoridae, Fanniidae and Sepsidae and Coleoptera from the families Dermestidae and Scarabaeidae. The predators consisted of Diptera from the Tachinidae, Coleoptera from the Staphylinidae and

**Table 2**
Occurrence matrix of adult insects during different stages of decomposition from three pig cadavers during a period of sampling of 97 days in a semi-rural area (the white colour indicates absence of insects and grey colours indicates the presence of insects).




Histeridae families, Dermaptera from the Forficulidae and some arachnids. The omnivores consisted of Silphidae, Coleoptera and a species of calliphorid *Chrysomya albiceps*, parasites consisted of Hymenoptera Brachonidae, and Acari and accidentals consisted of odonates from the family Coenagrionidae.

The fresh decomposition stage (days 1–3) was characterized by the early cadaverous phenomena of dehydration, *livor*, *algor* and *rigor mortis*, occurring 37 h after death. Cadaver temperatures decreased rapidly until they became equalized with ambient temperature. The 89.9% of the insects found during this stage were Diptera, mainly represented by adults, egg masses and first stage calliphorid larvae and first stage larvae from the Sarcophagidae, 3.8% Coleoptera, 2.5% Hymenoptera and odonates and 1.2% Dermaptera (Table 1). The first species colonizing the three cadavers were *Sarconesia magellanica* and *Compsomyiops verena* (Diptera: Calliphoridae).

Green marking was observed during the chromatic and emphysematous stages (days 4–10) on the iliac cavity which then extended towards the abdomen and became generalized. There was evident swelling of the cadavers; at death they presented a 54 cm abdominal perimeter, reaching maximum perimeter on day 8 following death (69.1 cm). Increased body temperature was recorded, reaching 25 °C 8–10 days postmortem. In order of abundance, the adult Diptera associated with this decomposition stage, were *C. verena*, followed by *S. magellanica*, *Coproica* sp. (Diptera: Sphaeroceridae), *C. albiceps*, *Sinthesiomyia* sp. (Diptera: Muscidae), Sarcophagidae, *Calliphora nigribasis* (Diptera: Calliphoridae), *Leptocera* sp. (Diptera: Sphaeroceridae) and *Fannia* sp. (Diptera: Fanniidae) (Tables 1 and 2), as well as 1st and 2nd stage larvae of the Calliphoridae and Sarcophagidae. The first *Oxellytrum discicolle* adults (Coleoptera: Silphidae) appeared at the end of this period (Table 3). Diptera represented 87.6% of total fauna during this period, mites 5.9%, Coleoptera 5.1%, along with very low percentages of other orders such as Isopoda (0.8%), Hymenoptera (0.24%), Odonata and Orthoptera (0.08% c/u) (Table 1).

Tissue splitting and the expulsion of some organs from the cadavers were seen during the colliquative stage (days 11–20). Calliphorid community structure became modified since adult *S. magellanica* totally disappeared, *Fannia* sp. larvae, *C. albiceps* 1st, 2nd and 3rd stage larvae and 2nd and 3rd stage of *Ophyra* sp. were found. *O. discicolle* larvae became established and the first Dermestidae were collected from areas of the bodies which had become dry (Tables 2 and 3). 73% of the cadaverous fauna consisted of Diptera, 16.9% Coleoptera, 9% mites and 1.06% of orders such as Isopoda, Hymenoptera and Araneae (Table 1).

The final decomposition stage corresponded to the skeletization period (days 21–97); the soft tissues disappeared during this stage in the following order: maxilla, mandible, cranium, limbs and ribs, leaving some skin, hair and bone. Coleoptera from the Histeridae, Silphidae and Staphylinidae predominated during this stage, constituting 51.5% of the fauna; a very few Dermestidae were present. Diptera abundance and diversity became considerably reduced (38.2%), mites forming 8.8% and Isopoda, Hymenoptera, Dermaptera, Araneae and Lepidoptera constituting 1.5% (Table 1).

One factor analysis of variance shared that there were no statistically significant differences between the abundance of the all arthropods collected form the three pigs during the decomposition (ANOVA, $F = 0.13$, df = 2, $n = 5981$, $P > 0.05$).

## 4. Discussion

The colonization observed by Calliphoridae agreed with that reported in previous studies from both tropical and temperate regions, with species from this family being the first to discover and colonize cadavers [33,34,19,35,22,18,23,36–38]. The presence of *C. verena* and *S. magellanica* as the first colonizers in Usaquén has also been reported in a prior study of the same study area, but at a

**Table 3**
Pattern successional of immature and adult insects species of forensic importance associated with different stages of decomposition from three pig cadavers. E = eggs; L = larvae; A = adult.

| Order | Family | Specie | Decomposition stage | | | |
|---|---|---|---|---|---|---|
| | | | Fresh | Chrom-Emphys. | Colliquative | Skeletization |
| Diptera | Calliphoridae | *Calliphora nigribasis* | | AL | A | A |
| | | *Chrysomya albiceps* | | A | AL | A |
| | | *Compsomyiops verena* | AEL | AL | A | A |
| | | *Sarconesia magellanica* | AEL | AL | | |
| | Fanniidae | *Fanniia* sp. | | A | AL | AL |
| | | *Fanniia* sp3. | | | A | A |
| | Muscidae | No identification | | A | A | A |
| | | *Azelia* sp. | | A | A | A |
| | | *Synthesiomyia* sp. | | A | A | A |
| | | *Ophyra* sp. | | | L | L |
| | Phoridae | | | A | A | |
| | Piophilidae | | | A | A | A |
| | Sarcophagidae | | AL | A | A | |
| | Sepsidae | *Sepsis* sp. | | | A | A |
| | Sphaeroceridae | *Coproica* sp. | | A | A | |
| | | *Leptocera* sp. | | A | A | |
| | Tachinidae | | A | A | | |
| Coleoptera | Dermestidae | sp2. | | | A | A |
| | | *Dermestes maculatus* | | | A | |
| | Histeridae | *Hister* sp. | | | A | A |
| | Scarabaeidae | *Ontophagus* sp1. | | A | A | A |
| | Silphidae | *Oxellytrum discicolle* | | AL | AL | A |
| | Staphylinidae | sp2. | | | A | A |
| Hymenoptera | Brachonidae | *Aphaereta* sp. | | AL | AL | |
| Acari | | | | A | A | A |

different time of year [35]. However, colonizing insect composition may vary from place to place due to factors such as human impact. *S. magellanica*, which was one of the first colonizing species in this study, has a weak relationship with human settlement, and was found to be abundant in the study area since the site is not associated with human settlement. In contrast *L. sericata*, which is often a synanthropic species, was found to be the first colonizer in an urban area of Bogotá [27], showing a strong relationship with human settlement.

On the other hand, environmental conditions also play an important role, since there are species such as *Calliphora* spp., which tolerate cold better than others [11,14]. Even though *C. nigribasis* was not one of the first dipteran colonizers in the present study, it was found during the chromatic and emphysematous stages. However, Martínez reported this species as a colonizer in a Colombian paramo in 2007 [26]; on the contrary, species from of *Calliphora* have not been recorded in warm climates [25,24].

The decomposition stages used in the present investigation are used by forensic pathologists for PMI estimation; such decomposition phases or stages are determined by physical changes in the cadaver. However, even though decomposition follows the same patterns, how these stages are denominated in cadaverous entomofauna succession studies differs from author to author. The five decomposition stages recognized during the present study (fresh, chromatic, emphysematous, colliquative and skeletization) agree with the stages recognized by Goff (fresh, swelling, decay, post-decay and skeletization) [39] and Wolff (fresh, swelling, active decomposition, advanced decomposition and dry remains) [24]. Even though the denomination of decomposition stages varies between this work and these previous studies, the fresh stage was common to the three studies, as was emphysematous (corresponding to swelling). However, the chromatic stage or appearance of abdominal green marking was not mentioned by Wolff or Goff. On the other hand, the colliquative stage may correspond to the decay and post-decay stages recognized by Goff and active decomposition recognized by Wolff. Skeletization was the same as to that reported by Goff, whilst skeletization is included in the advanced decomposition and dry remains stages recognized by Wolff deal with skeletization.

Duration of the fresh decomposition stage was the same as that described in Martínez's study, but 2 days longer when compared to studies by Pérez and Carvalho [25,19]. The foregoing can be partly explained by the low temperatures and the heavy rainfall in the study area during the first days of sampling. However, this stage was characterized by the presence of first egg masses and 1st stage larval Calliphoridae, coinciding with that described in investigations carried out in different geographical regions [33,19,22,11] and insects colonizing a human cadaver found on the Iberian peninsula [4].

High cadaverous temperatures were recorded during the emphysematous stage due to bacterial activity and the heat generated by larval masses consuming the tissues. First and 2nd stage larvae of Calliphoridae and Sarcophagidae and adult Calliphoridae, Sarcophagidae, Muscidae, Fanniidae and Sphaeroceridae families also appeared. The findings during this stage of decomposition agreed with those reported by Martínez in the Páramo de Chingaza and from Medellín by Wolff and Pérez [26,25,24]. The similarity of these findings represents a good indicator for narrowing the time of death regarding decomposition stages in the different areas of the country being studied. The presence of adult *O. discicolle* forms during the last part of this stage marked the beginning of the colliquative stage of decomposition.

Immature *C. albiceps*, *Ophyra* sp. forms and *Oxellytrum* sp. adults and larvae were colliquative stage indicators for the cadavers used in the present study. *S. magellanica* adults completely disappeared from the cadavers following this stage. Findings from this decomposition stage partly coincided with that, reported by Wolff, since she described the presence of immature *C. albiceps* forms and *Oxellytrum* sp. adult forms during the active decomposition stage,

as well as the appearance of immature *Ophyra* sp. forms during the advanced decomposition stage. Pérez reported the same findings, except for the presence of *Oxellytrum* sp. [25,24]. The similarity of the fauna collected during this decomposition stage from the differing places confirms the fact that these insects are good indicators of the colliquative stage in Bogota locality, as well as in the other Colombian areas being studied.

Coleoptera generally prevailed during the skeletization stage or the final decomposition stages [25,11,24,19,13,14]. The Silphidae and Dermestidae families have been reported as being dominant during the final stages of decay [26,25,22,24]. Even though the Histeridae, Staphylinidae, Silphidae and Dermestidae families have been found during the previous decomposition stage in the present work, it was during the skeletization stage that they increased their abundance once the Diptera had completely disappeared.

In the environmental conditions found on the savannah of Bogotá (2600 masl), the time taken for decomposition to be completed was 97 days, contrasting with the 83 days reported for a Colombian paramo (3035 masl) [26] and 36 days recorded by Pérez in an urban area of Medellín (1409 masl) [25]. The difference in decomposition time between previous work and this one can be explained by the typical environmental conditions found in each place, since the ambient temperature in Medellín is higher than that in Bogotá. By contrast, decomposition in the Páramo de Chingaza (where the temperature is lower than that recorded in Bogotá) was very similar. The small time difference may have been because of the size of the pigs used, since pigs weighing more than 2 kg were used in the present investigation. Some investigations using pigs of different body weight have indicated that the decomposition phase duration varies, though not the structure of the cadaverous arthropofauna community, this being specific in each area being analyzed geographically [40].

It can be inferred from the results obtained and the environmental variables recorded during the decomposition of the cadavers in the present study that if a cadaver is found with 1st stage Calliphorid larvae then PMI estimation could be between 2 and 3 days. On the other hand, if 3rd stage larvae of *C. albiceps* and *Ophyra* sp. larvae are found, together with *O. discicolle* larvae, then PMI estimated can be 15–20 days. Nevertheless, a time greater than 75 days must be considered if just Coleoptera from the Dermestidae, Histeridae Scarabaeidae, Silphidae and Staphylinidae families but no dipterous adults are found. However, the particular conditions of the site where a cadaver is found must be taken into account, since a large number of variables, such as place (open or closed countryside), environmental conditions, soil type, height (masl) and surrounding vegetation will influence the duration and cadaverous insect community present in each decomposition phase and hence PMI estimation.

## 5. Conclusions

The pig cadavers' stages of decomposition in the present study revealed known decomposition patterns; however, the duration time of each of them depended on the area's particular environmental conditions and also on the activity of the insects associated with the bodies. It was observed in cadaverous entomofauna succession that Diptera predominated in the initial stages and Coleoptera in the final ones. IPM can be inferred for human cases in this area of Bogotá, Colombia, from the bio-model used in this study and the results so obtained.

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