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What have we learned from the dead? A compilation of three years of cooperation between entomologists and crime scene investigators in Southern Brazil

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ABSTRACT

With homicide rates higher than the world average, Brazil stands out as one of the most violent countries worldwide. Time of death estimation based solely on body changes can be biased or inaccurate; forensic entomology can play a determinant role in such cases. Accurate knowledge of necrophilous fauna is essential to validate experimental data and allows for the application of entomological evidence in forensic investigations, which benefits scientists, investigators, and society in general. Entomological evidence from Curitiba and 22 nearby cities were collected by crime scene investigators from the Scientific Police of Paraná. The corpses were found in diverse environments and specimens from each species were collected from all life stages. We present data from 25 cases from 2011 to 2014, including associated species, new records, and comparisons between existing experimental data and data from species collected in the cases presented. We identified 23 total species, of which eight species of Coleoptera and two species of Diptera have not previously been recorded on corpses. In all cases, Calliphoridae (76%) and Silphidae (48%) were the most numerous families collected. Working together with the scientific police gave us insight into which species lacked detailed records and enabled us to collaboratively focus on resolving deficits in our knowledge of necrophagous insects.

Introduction

Forensic entomology is known as the use of insects and other arthropods as evidence in legal cases (Catts and Goff, 1992). When insect specimens are collected from a death scene, the *postmortem interval* (PMI), or time elapsed between death and discovery of the body, can be estimated by evaluating the period insect activity on the corpse (Tomberlin et al., 2011). The application of this science is heavily dependent on available knowledge of necrophilous species, such as taxonomy, biology, behavior, ecology, and successional pattern (e.g. Byrd and Castner, 2010; Smith, 1986).

Historically, the first forensic entomology publications in Brazil date from the early 1900s (Freire, 1914a, 1914b; Roquete-Pinto, 1908). However, basic research formally started in the late nineties with Souza and Linhares (1997) and Moura et al. (1997) presenting information about successional patterns of necrophagous species of potential forensic interest. The medico-legal application of forensic entomology has produced few case reports since then (Kosmann et al., 2011; Oliveira-Costa and Lopes, 1999; Oliveira-Costa and Mello-Patiu, 2004; Pujol-Luz et al., 2006, 2008a; Souza et al., 2014; Vairo et al., 2015b, 2017; Vasconcelos et al., 2014). The small number of case reports can be attributed in part to the lack of collaboration between academia (i.e. universities and research centers) and Brazilian law enforcement agencies (Pujol-Luz et al., 2008b).

Brazil is the fifth largest country in the world with remarkable fauna and a complex array of biomes. The number of identified insect species is around 90,000, but is estimated to be around 400,000 (Rafael et al., 2012). Therefore, surveys in all ecological regions of the country are of critical importance to assess species of potential forensic interest and direct studies to allow the use of relevant species in investigations. The review presented by Pujol-Luz et al. (2008b) mentioned the need of regional databases, while Oliveira and Vasconcelos (2010) and Vasconcelos and Araujo (2012) addressed the state of art in Northeast region. Nevertheless,

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Brazilian forensic entomologists face a major issue: the lack of available data for PMI estimation.

It is well known that Brazil has high rates of violent crimes. According to recent reports, Brazilian homicide rates are four times higher than the world average (Butchart, 2014). In some cases, homicide investigations can be compromised by uncertainties in PMI estimation. Forensic entomology has the potential to provide decisive input in these instances. However, recorded data regarding the diversity of necrophilous fauna is usually restricted to the results of experiments with animal models. Thus, the validation of experimental data is necessary to reliably make use of entomological evidence. There is no doubt that collaborations between scientists and investigators benefit both sides.

The main objective of this paper is to present the results of the collaboration between Paraná State Scientific Police and the Federal University of Paraná (Universidade Federal do Paraná – UFPR). We present data from 25 cases between 2011 and 2014, including associated species, new records, and comparison between experimental data and the species found on corpses. With our results, we expect to contribute to the improvement of the local database of necrophilous insects and Brazilian forensic entomology.

Material and methods

Locality

Paraná (199.307,945 km^2) is a state located in Southern Brazil with estimated population of 11,163.018 in 2015 (IBGE, 2015). The climate is divided in three types including tropical and subtropical with variations on temperature and rain (Af, Cfa and Cfb on Koppen classification). The capital, Curitiba, has the largest population in Southern Brazil and is the eighth most populated city in the country with over 1.8 million people (IBGE, 2015). The metropolitan area comprises of 26 cities and over 3.2 million inhabitants (Prefeitura Municipal de Curitiba, 2015).

Curitiba has been one of the most dangerous cities in Southern Brazil for the past 6 years (SESP-PR, 2015; SSP-RS, 2015; SSP-SC, 2015), and has been the most violent city in Paraná since 2011 (SESP-PR, 2015). According to government reports, the rates of homicide (343), robbery followed by death (22), and injury resulting death (5) in Curitiba were at least four times higher than the second highest ranked city in 2015 (SESP-PR, 2015).

Data collection

Entomological evidence from 25 death investigations were collected by crime scene investigators from Paraná State Scientific Police (Polícia Científica do Paraná) between 2011 and 2014. Specimens and materials collected from the death scenes were sent to the UFPR Forensic Entomology Group for rearing and identification. Case data was taken from 11 cities under the jurisdiction of Scientific Police investigators (Fig. 1), which includes Curitiba and 22 of its surrounding cities (SESP-PR, 2015).

The corpses were found in diverse environments including rural and urban, and indoor and outdoor locations. Data from cases include municipality, geographical coordinates, habitat (rural or urban), ambient (indoor or outdoor), species collected, and developmental stage (egg, larvae, pupae, or adult).

To evaluate the relative presence of species and families in each case, we calculated the proportion (or relative frequency). The proportion (P) is the number of observations (NO) of a category (species/family) divided by the total number of observations (TO) multiplied by 100.

$$P = \left(\frac{\mathrm{NO}}{\mathrm{TO}}\right) \times 100.$$

Species identification and rearing procedures

As a standard procedure, around 30% of the immature specimens (eggs, maggots, larvae, and pupae) collected were fixed and preserved in 70% alcohol. The remaining specimens were reared in ground beef under controlled conditions (25 °C, 70% RH) to adulthood. Adult specimens collected were pinned and identified using the available literature (e.g. Carvalho and Mello-Patiu, 2008; Navarrete-Heredia et al., 2002; Vairo et al., 2011, 2015a) and consulting specialists.

All specimens received were deposited at Padre Jesus Santiago Moure Entomological Collection (DZUP) at UFPR.

Results

General description of cases and entomological evidence

The corpses were found in diverse environments including rural/urban, indoor/outdoor locations. We compilated all information data in a table that includes municipality, geographical coordinates, habitat (rural or urban), ambient (indoor or outdoor), species collected, and developmental stage (egg, larvae, pupae, or adult) (Table 1). Most cases were in rural (72%) and outdoor (76%) areas. It is important to note that all urban cases, with one exception, were indoor. Nine (36%) cases were located in Curitiba, with cases split 55:45 urban to rural and 55:45 outdoor to indoor. Four of the six indoor cases reviewed were in Curitiba.

Twenty-six insect species from ten families were collected (Table 2). Eleven species of Coleoptera belonging to five families were recorded: *Dermestes maculatus* (DeGeer, 1774), *Dermestes peruvianus* Laporte, 1840 (Dermestidae), *Euspilotus azureus* (Sahlberg, 1823), *Hister cavifrons* Marseul, 1854 (Histeridae), *Pelossoma* aff. *lafertei* Mulsant, 1844 (Hydrophilidae), *Oxelytrum discicolle* (Brullé, 1840), *Oxelytrum erythrurum* (Blanchard, 1840) (Silphidae), *Aleochara pseudochrysorrhoa* Caron, Mise, Klimaszewski, 2008, *Creophilus variegatus* Mannerheim, 1830, *Philonthus hepaticus* Erichson, 1840, *Philonthus* sp. (Staphylinidae). Fifteen species of Diptera from five families were recorded: *Chrysomya albiceps* (Wiedermann, 1819), *Chrysomya putoria* (Wiedermann, 1830), *Cochliomyia macellaria* (Fabricius, 1975), *Hemilucilia semidiaphana* (Rondani, 1850), *Lucilia eximia* (Wiedmann, 1819), *Lucilia sericata* (Meigen, 1826), *Paralucilia pseudolyrcea* (Mello, 1969) (= *Paralucilia xanthogeneiates* Dear 1985), *Sarconesia chlorogaster* (Wiedemann, 1830), Calliphoridae sp. (Calliphoridae), *Musca domestica* Linnaeus, 1758, *Ophyra aenensis* (Wiedemann, 1830) (Muscidae), Phoridae sp. (Phoridae), *Piophila casei* (Linnaeus, 1758) (Piophilidae), *Microcerella halli* (Engel, 1931), *Peckia* (*Pattonella*) *resona* (Lopes, 1935) (Sarcophagidae).

Among the forensically relevant families, Calliphoridae (76%) and Silphidae (48%) were the most frequently encountered at the death scenes. The most recurrent species were *O. discicolle* (11 cases), *C. albiceps* (10 cases), *H. semidiaphana* (6 cases), and *P. pseudolyrcea* (5 cases). Calliphoridae (9) and Staphylinidae (4) were the richest families in terms of the number of identified species.

For comparison purposes, regional data gathered from previous carrion ecology studies and authors that collected the species observed are listed in Table 3. On this table, only specimens identified at species level are present. Coleoptera had ten species collected on previous experiments; however, only *D. maculatus* has previous records on human bodies. For Diptera, eleven species were collected on previous experiments, and twelve species were recorded in case studies or collected on corpses. Considering species with known forensic importance (i.e. reported in case studies or collected on human bodies), our results include ten species without previous record in forensic studies, eight in Coleoptera and

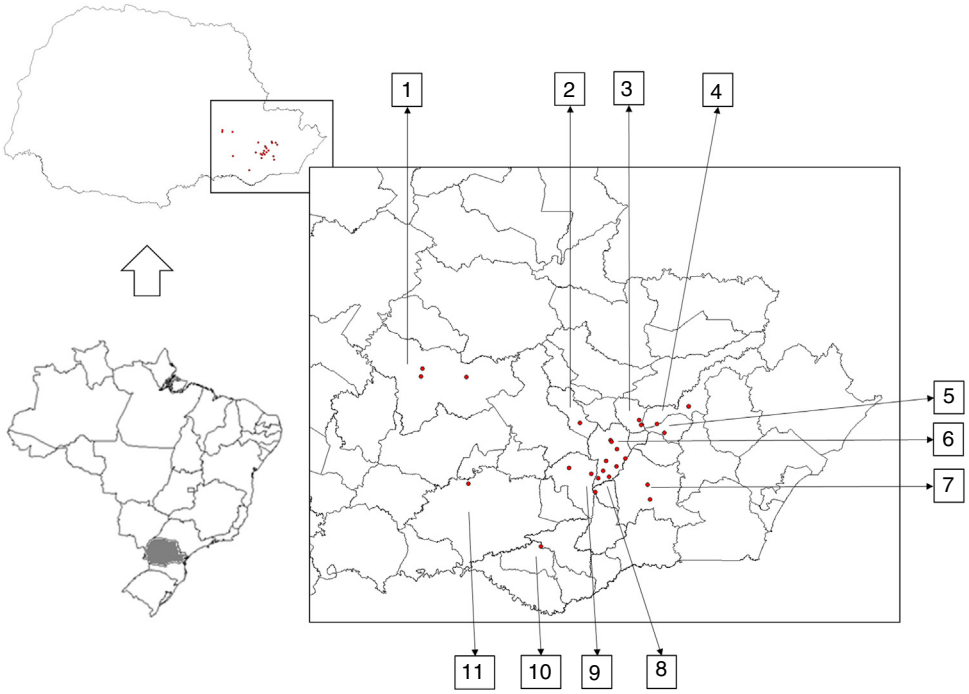

Fig. 1. Location of Paraná State (Southern Brazil) and municipalities where the cases occurred in detail. (1) Ponta Grossa, (2) Campo Magro, (3) Colombo, (4) Campina Grande do Sul, (5) Quatro Barras, (6) Curitiba, (7) São José dos Pinhais, (8) Fazenda Rio Grande, (9) Araucária, (10) Campo do Tenente, (11) Lapa.

two in Diptera. Detailed information with all species collected in regional studies is available in the supplementary material.

Discussion

Forensic entomological experimental methodology assumes that fauna found on animal remains and human remains are similar. Due the restrictions on the experimental use of human bodies (mostly moral, ethical, or religious), surveys using animal models or baits are the standard procedure (see Catts and Goff, 1992; El-Kady, 1999). Studies with animal models can provide an idea of species present in a specific region before actual application in forensic entomology cases. Even with the possibility of overestimation, survey results (Oliveira and Vasconcelos, 2010) still play a significant role as a database of species of potential importance in forensic entomology.

From the 23 species collected from the cases reviewed, 17 (68%) had previous records in regional literature and 12 (48%) were recorded in studies with human bodies in Brazil (Table 3). *Dermestes peruvianus*, *P. lafertei*, *C. variegatus*. *P. hepaticus*, *C. macellaria*, and *P. casei* were not collected in previous experiments. Globally, as in Brazil, most published cases concerning forensic entomology are focused on Diptera. As a result, 90% of Coleoptera species collected as part of forensic investigations or studies do not have previously recorded interactions with human bodies.

Coleoptera has several species with relevance to forensic entomology (e.g. Özdemir and Sert, 2009; Payne and King, 1970; Smith, 1986). However, the forensic impact of Coleoptera is frequently underestimated due to taxonomic difficulties and a lack of ecological and behavioral knowledge (Almeida et al., 2015). Although multiple surveys have been performed in the Curitiba area, four species noted in this investigation have never been noted on human bodies in this region, and only *D. maculatus* and *O. discicolle* have previously been noted on human bodies in Brazil. The results of this study demonstrate that reliance on existing experimental data can lead to underestimation of the range of fauna found on corpses.

Silphidae was present on 12 cases (48%), represented by the genus *Oxelytrum*. Adults of this genus are omnivorous and both feed on the corpse and prey on maggots, while larvae are purely necrophagous (Oliva and di Lorio, 2008). Despite being the second most abundant family after Calliphoridae (Diptera), there are no records of *O. erythrurum* or *O. discicolle* being associated with human bodies in Brazil (see Almeida et al., 2015). In three cases (Table 1 – cases 7, 20, 23), *O. discicolle* was collected at larval stage and was the primary species for PMI estimation. The necrophagous habit of larvae, presence during initial stages of decomposition, and high sampling in cases in the present study highlights the importance of *Oxelytrum* species and their biological data.

Dermestidae is one of the most important families associated with carcasses, corpses, and stored products (Byrd and Castner, 2010). Charabidze et al. (2013) gathered information pertaining to *Dermestes* presence on 81 forensic cases and found *D. maculatus* present on 7.4% of cases and *D. peruvianus* present on 12.3% of cases. Among the 25 cases evaluated in the present study, Dermestidae was represented in 12% of cases, with *D. maculatus* present in 8% of cases and *D. peruvianus* present in 4% of cases. Both species were collected in indoor locations, *D. maculatus* as larval specimens (Case 24) and *D. peruvianus* as adult specimens (Case 4) (see Table 1). Our results are consistent with Charabidze et al. (2013) with most records for indoor cases. Due their status as urban pests, species of Dermestidae tend to be more related with urban areas than other forensically relevant Coleoptera and are more likely to be found in indoor death scenes. Prior to this investigation, *D. peruvianus* is only mentioned in a forensic context in Souza and Linhares (1997) study with pig carrion, in which the presence of *D. maculatus* was also noted.

There is no literature concerning *P. lafertei* biology or behavior. According to Forbes and Dadour (2010), specimens belonging to the same family can be observed feeding on eggs and maggots during the first stages of decomposition of pig carcasses. Hydrophilidae, mostly in regards to Sphaeridinae, a semi-aquatic species, is a family with potential forensic importance that should be determined

Table 1
General view of the cases. Municipalities were the corpses were found, habitat (rural or urban), ambient (outdoor or indoor), and species collected on each case. (E) egg, (L) larvae, (P) pupae, (A) adult.

Case	Municipality (coordinates)	Habitat	Ambient	Species
1	Colombo (−25.354811, −49.140069)	Rural	Outdoor	*Hemilucilia semidiaphana* (L), *Musca domestica* (A)
2	Curitiba (−25.568583, −49.315025)	Rural	Outdoor	*Chrysomya albiceps* (E), *Paralucilia pseudolyrcea* (E)
3	São José dos Pinhais (−25.700039, −49.099119)	Rural	Outdoor	*Hister cavifrons* (A), *Oxelytrum discicolle* (A), *Pelosoma* aff. *lafetertei* (A), *Philonthus* sp. (A)
4	Curitiba (−25.426317, −49.280983)	Urban	Indoor	*Chrysomya albiceps* (L), *Dermestes peruvianus* (A)
5	Campina Grande do Sul (−25.25427, −48.9179)	Rural	Outdoor	*Oxelytrum discicolle* (A), *Sarconesia chlorogaster* (A)
6	Curitiba (−25.547053, −49.25295)	Urban	Indoor	*Chrysomya albiceps* (E/L), *Hemilucilia semidiaphana* (E/L), *Lucilia sericata* (E/L), *Sarconesia chlorogaster* (P)
7	Campo do Tenente (−25.91785, −49.603281)	Rural	Outdoor	*Chrysomya albiceps* (A), *Ophyra aenensis* (A), *Oxelytrum discicolle* (L), *Paralucilia pseudolyrcea* (A)
8	Araucária (−25.555481, −49.4719)	Rural	Outdoor	Calliphoridae sp. (L)
9	Curitiba (−25.46825, −49.251617)	Urban	Indoor	*Chrysomya albiceps* (E)
10	Lapa (−25.627031, −49.939008)	Rural	Outdoor	*Aleochara pseudochrysorrhoa* (A), *Oxelytrum discicolle* (A), *Oxelytrum erythrurum* (A), *Philonthus hepaticus* (A)
11	Araucária (−25.582414, −49.370833)	Rural	Outdoor	*Oxelytrum discicolle* (A), *Oxelytrum erythrurum* (A), *Peckia* (*Pattonella*) *resona* (A)
12	Curitiba (−25.595833, −49.288333)	Rural	Outdoor	*Hemilucilia semidiaphana* (L), *Paralucilia pseudolyrcea* (L)
13	Curitiba (−25.521317, −49.301283)	Urban	Outdoor	*Sarconesia chlorogaster* (L)
14	Fazenda Rio Grande (−25.63155, −49.110728)	Rural	Outdoor	*Chrysomya albiceps* (L/A), *Cochliomyia macellaria* (A), *Creophilus variegatus* (A), *Hemilucilia semidiaphana* (A), *Ophyra aenensis* (A), *Oxelytrum erythrurum* (A)
15	Quatro Barras (−25.392161, −49.032953)	Rural	Outdoor	*Oxelytrum discicolle* (A), *Paralucilia pseudolyrcea* (L)
16	Curitiba (−25.50985, −49.213311)	Rural	Outdoor	*Chrysomya albiceps* (L), *Oxelytrum discicolle* (A)
17	Curitiba (−25.433272, −49.276792)	Urban	Indoor	*Microcerella halli* (L/P), *Sarconesia chlorogaster* (L)
18	Campo Magro (−25.3461, −49.422619)	Rural	Outdoor	*Hemilucilia semidiaphana* (L), *Oxelytrum discicolle* (A), *Oxelytrum erythrurum* (A)
19	Colombo (−25.332906, −49.149128)	Rural	Outdoor	*Chrysomya albiceps* (E/L), *Hemilucilia semidiaphana* (E/L), *Paralucilia pseudolyrcea* (E/L), *Peckia* (*Pattonella*) *resona* (E/L)
20	Araucária (−25.665444, −49.351297)	Rural	Outdoor	*Euspilotus azureus* (A), *Oxelytrum discicolle* (L/A), *Philonthus* sp. (A)
21	Ponta Grossa (−25.131439, −50.157911)	Urban	Indoor	*Chrysomya putoria* (E/L/A)
22	Campina Grande do Sul (−25.350311, −49.065567)	Rural	Outdoor	*Lucilia eximia* (E)
23	Curitiba (−25.601817, −49.33875)	Rural	Outdoor	*Oxelytrum discicolle* (L/A)
24	Ponta Grossa (−25.13303, −49.94755)	Rural	Outdoor	*Chrysomya albiceps* (L/P/A), *Dermestes maculatus* (L), *Euspilotus azureus* (A), *Oxelytrum discicolle* (L/A), *Piophila casei* (L/P)
25	Ponta Grossa (−25.095525, −50.15275)	Urban	Indoor	*Chrysomya albiceps* (L), *Dermestes maculatus* (L), Phoridae sp. (L)

through greater efforts toward collection and identification (Corrêa et al., 2014).

The predatory families Staphylinidae and Histeridae represent half of the identified Coleoptera species (Table 3). Staphylinidae had three collected species, none with previous records on human corpses. *Aleochara pseudochrysorrhoa* is the only with previous records in experiments. According to Mise et al. (2007), this species is prevalent during spring and summer, making it an important seasonal indicator. Adults of *A. pseudochrysorrhoa* prey on maggots, and larvae are parasitoids of pupae, leaving the host as third instar larvae and pupating in the soil (Rothe et al., unpublished data). *Creophilus variegatus* was first recorded by Luederwaldt (1911) and is the only known record of its genus in Brazil (see Almeida et al., 2015). The last Staphilinidae species is *P. hepaticus*, also a not previously recorded in either experimental studies or case studies. *Philonthus* is consistently reported by several researchers (e.g. Mise et al., 2007; Santos et al., 2014; Souza and Linhares, 1997) who conducted carrion ecology studies. However, the great taxonomic difficultly of classifying Staphylinidae rarely allow species level identification. The Histeridae species presented on this study were previously reported by Mise et al. (2007). Although *H. cavifrons* was later identified by Celli et al. (2015), both species recorded in the present study were noted for the first time on human bodies. *Euspilotus azureus* was noted in experiments carried out on other Brazilian regions (Souza and Linhares, 1997; Souza et al., 2008). It is known that both larvae and adults of *E. azureus* prey on Diptera eggs and maggots, and life cycle and development equations for this species were presented by Caneparo et al. (2017). There is little information available for *H. cavifrons*, though Caterino (1999) states this species shows preference for moist habitats.

Diptera provides the bulk of entomological evidence in most death investigations and are the most studied group in forensic

Table 2
Complete list of identified species collected at death scenes by the CSI personnel. Including number of cases with each species and family, and the proportion (=relative frequency) of occurrence of species and families.

Order	Family	Species	Cases	Cases (family)	Proportion – species (%)	Proportion – family (%)
Coleoptera	Dermestidae	*Dermestes maculatus*	2	3	8	12
		Dermestes peruvianus	1		4	
	Histeridae	*Euspilotus azureus*	2	3	8	12
		Hister cavifrons	1		4	
	Hydrophilidae	*Pelosoma* aff. *lafetertei*	1	1	4	4
	Silphidae	*Oxelytrum discicolle*	11	12	44	48
		Oxelytrum erythrurum	4		16	
	Staphylinidae	*Aleochara pseudochrysorrhoa*	1	4	4	16
		Creophilus variegatus	1		4	
		Philonthus hepaticus	1		4	
		Philonthus sp.	2		8	
Diptera	Calliphoridae	*Chrysomya albiceps*	10	19	40	76
		Chrysomya putoria	1		4	
		Cochliomyia macellaria	1		4	
		Hemilucilia semidiaphana	6		24	
		Lucilia eximia	1		4	
		Lucilia sericata	1		4	
		Paralucilia pseudolyrcea	5		20	
		Sarconesia chlorogaster	4		16	
		sp.	1		4	
	Muscidae	*Musca domestica*	1	3	4	12
		Ophyra aenensis	2		8	
	Phoridae	sp.	1	1	4	4
	Piophilidae	*Piophila casei*	1	1	4	4
	Sarcophagidae	*Microcerella halli*	1	3	4	12
		Peckia (Pattonella) resona	2		8	

entomology (e.g. Alves et al., 2014; Greenberg, 1991). Considering available regional data, only *C. macellaria* and *P. casei* were not previously noted in the region. *Paralucilia pseudolyrcea* and *P. resona* were noted for the first time on human bodies (Table 3).

Among the five families collected, Calliphoridae was present in 76% of the cases studied. Eight species were recorded from this family. *P. xanthogeineates* was the only species not previously recorded on human bodies in Brazil (Table 3). *Chrysomya albiceps* is one of the most common necrophagous species and was the second most frequent species present among cases. Although *C. albiceps* is one of the most cited species in Brazilian forensic entomology cases (Kosmann et al., 2011; Vairo et al., 2015b; Vasconcelos et al., 2014) and experiments (e.g. Carvalho et al., 2000; Moura et al., 2005; Souza and Linhares, 1997), there is no published biological data for the Brazilian *C. albiceps* population using natural diets (Estrada et al., 2009 used artificial diets). *Chrysomya putoria* was collected in one indoor case. It is worthwhile to note that while some authors claim carrion is not the preferred medium for oviposition (Souza and Linhares, 1997) for this species, others have observed this species colonizing human bodies (Oliveira-Costa et al., 2001). *Cochliomyia macellaria* was observed in just one case. Its presence in a rurally located case supports Byrd and Castner's (2010) observation that this species is rarely recovered from indoor habitats. This species, responsible for cases of secondary cutaneous myiasis in animals and humans, is also of medical and veterinary importance (Koller et al., 2011). *Hemilucilia semidiaphana* was the third most frequent species, although previous records from cadavers are limited to Carvalho et al. (2000) (ILM collection) and Vairo et al. (2015b) (Case 6). Two species of *Lucilia* were collected in two separate cases, *L. eximia* in a rural location and *L. sericata* in an indoor urban case. *Lucilia eximia* was reported by Carvalho et al. (2000) and in Oliveira and Vasconcelos's (2010) regional experiments at ILM, during which the species was collected in a forest fragment area. Vairo et al. (2015b) described the occurrence of *L. sericata* in an indoor case (case 6). No data was available before this publication. *Paralucilia pseudolyrcea* was collected only in rural areas, a finding also reported by Moura et al. (2005). This study is the first instance of this species in a forensic entomology case in Brazil. The last Calliphorid, *S. chlorogaster*, has been noted in previous experiments and is mentioned in two published case studies (based on cases 6 and 17 – Table 1). *Sarconesia chlorogaster* is a highly prevalent species in Southern Brazil and the available biological data (Lecheta et al., 2015) allows for its use in PMI estimation.

Both species of Muscidae were collected on previous field studies (Moura et al., 2005; Silveira, 2007) and reported on ILM premises (Oliveira-Costa et al., 2001; Oliveira and Vasconcelos, 2010). *Musca domestica* is a common species associated with human dwellings and is usually not found on fresh corpses (Byrd and Castner, 2010). One adult specimen was collected on Case 1 in a rural area, but the specimen was not used for PMI estimate. Adults of *O. aenensis* were collected on rural areas on two cases (Cases 7 and 14). Despite not being used for PMI estimate, both species, *M. domestica* and *O. aenescens*, have potential forensic importance due to their sarcosaprophagous habits, and have been mentioned in carrion ecology studies (Barbosa et al., 2009). Although Muscidae has a consistent presence in carrion ecology studies and ILM collections, the potential use of the family in PMI estimation has yet to be assessed in Brazil.

Piophila casei was the only Piophilidae recorded in this study, recovered in case 24 as larval and pupal specimens on a corpse in a rural location. The species has not been reported in regional studies, although *Piophilidae* sp. was collected by Moura et al. (2005). Carvalho et al. (2000) was the only one to collect this species in an ILM. Larvae of *P. casei*, known as "cheese skippers", are a common stored product pest with cosmopolitan distribution (Smith, 1986). When present on dead bodies, larvae of this species are usually associated with later stages of decomposition (Byrd and Castner, 2010). Biological data on the species is available (Russo et al., 2006), but was not referenced due to the presence of better indicators and the impossibility of species identification at the time.

Microcerella halli and *Peckia resona* were reported in experiments by Moura et al. (1997, 2005) and Vairo et al. (2011). Only *M. halli* has been collected on a Brazilian death scene (Vairo et al., 2017 – Case 17). Sarcophagidae species were recovered from three cases:

Table 3
Species collected on cases in comparison with previous information from regional studies and their forensic importance.

Order	Family	Species	Regional experimental data	Potential forensic importance (Brazil)
Coleoptera	Dermestidae	*Dermestes maculatus*	Mise et al. (2007)	Carvalho et al. (2000)[b]
		Dermestes peruvianus		First record[c]
	Histeridae	*Euspilotus azureus*	Mise et al. (2007, 2013)	First record[c]
		Hister cavifrons	Mise et al. (2007) (after Celli et al., 2015)	First record[c]
	Hydrophilidae	*Pelosoma* aff. *lafetertei*		First record[c]
	Silphidae	*Oxelytrum discicolle*	Moura et al. (1997) and Mise et al. (2007)	First record[c]
		Oxelytrum erythrurum	Almeida et al. (2015)	First record[c]
	Staphylinidae	*Aleochara pseudochrysorrhoa*	Corrêa et al. (2014), Mise et al. (2007, 2013)	First record[c]
		Creophilus variegatus		First record[c]
		Philonthus hepaticus		First record[c]
Diptera	Calliphoridae	*Chrysomya albiceps*	Silveira (2007)	Kosmann et al. (2011)[a], Vairo et al. (2015b)[a], Vasconcelos et al. (2014)[a]
		Chrysomya putoria	Silveira (2007)	Oliveira-Costa et al. (2001), Salviano (1996)[b], Vasconcelos et al. (2014)[a]
		Cochliomyia macellaria		Carvalho et al. (2000)[b], Oliveira-Costa and Mello-Patiu (2004)[a]
		Hemilucilia semidiaphana	Moura et al. (1997, 2005), Silveira (2007)	Carvalho et al. (2000)[b], Vairo et al. (2015b)[a]
		Lucilia eximia	Moura et al. (1997, 2005), Silveira (2007)	Carvalho et al. (2000)[b], Oliveira and Vasconcelos (2010)[b]
		Lucilia sericata	Moura et al. (2005)	Vairo et al. (2015b)[a]
		Paralucilia pseudolyrcea	Moura et al. (2005), Silveira (2007)	First record[c]
		Sarconesia chlorogaster	Moura et al. (1997, 2005), Silveira (2007)	Vairo et al. (2015b, 2017)[a]
	Muscidae	*Musca domestica*	Silveira (2007)	Oliveira-Costa et al. (2001)[b], Oliveira and Vasconcelos (2010)[b]
		Ophyra aenensis	Moura et al. (2005), Silveira (2007)	Oliveira-Costa et al. (2001)[b]
	Piophilidae	*Piophila casei*		Carvalho et al. (2000)[b]
	Sarcophagidae	*Microcerella halli*	Moura et al. (2005), Vairo et al. (2011)	Vairo et al. (2017)[a]
		Peckia (Pattonella) resona	Moura et al. (1997, 2005), Vairo et al. (2011)	First record[c]

[a] Brazilian case report.
[b] ILM collection.
[c] First recorded instance in Brazilian death scenes.

M. halli larvae and pupae were collected from an indoor urban scene (Case 17), and *P. resona* adults (Case 11) and eggs and larvae (Case 19) were collected at rural scenes.

Conclusion

The present study is currently the biggest compendium of insect species associated with death scenes in Brazil. We identified 23 species, eleven of which have not been previously noted on human corpses. Despite substantial literature regarding regional fauna, we observed five species that have not been reported in earlier carrion studies. Collaborating with the scientific police provided us with a better picture of which species were less understood and guided the focus of our investigation. Due to the reoccurring presence of certain species across the cases, biology studies for *S. chlorogaster* (Lecheta et al., 2015), *E. azureus* (Caneparo et al., 2017), *O. discicolle* and *O. erythrurum* (Caneparo, 2017), *A. pseudochrysorrhoa* (Rothe et al., unpublished data) and the description of the immature stages of *Paralucilia pseudolyrcea* (Silva et al., 2018) were published or in pre-publication. Producing literature on the biology of forensically relevant species is an important aspect of forensic entomology; as more species become relevant to forensics, references for biological data are necessary to utilize the information these species can provide in an investigation.

As any science, forensic entomology needs background information to be as precise and reliable as possible. Familiarizing oneself with local fauna before investigating a death scene is a simple yet underestimated procedure. For this reason, we strongly advise that forensic entomology groups do not rush into case studies. To this end, we suggest consulting Pujol-Luz et al.'s (2008b) directives for Brazilian forensic entomology, which advises conducting studies in taxonomy, biology, and succession. In addition to these measures, exhaustive surveys in different regions of the country can enable investigators or scientists to make more accurate estimations with greater specificity. It is our intention that the data presented in this study can guide new studies in forensic entomology and encourage partnership between scientific academia and law enforcement agencies.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.rbe.2019.05.009.

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