Necrophagous species of Diptera and Coleoptera in northeastern Brazil: state of the art and challenges for the Forensic Entomologist

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ABSTRACT. Necrophagous species of Diptera and Coleoptera in northeastern Brazil: state of the art and challenges for the Forensic Entomologist. Inventories on necrophagous insects carried out in Brazil encompass mostly species from the southeastern and central-western regions of the country. This review aims to produce the first checklist of necrophagous Diptera and Coleoptera species of forensic relevance in northeastern Brazil, an area that concentrates high rates of homicides. We performed a literature survey on scientific articles, theses and dissertations regarding necrophagous insect species in the region, and contacted scientists who develop research on forensic entomology. Fifty-two species of Diptera belonging to eight families with previous record of necrophagy were reported in the region: Sarcophagidae, Calliphoridae, Muscidae, Fanniidae, Piophilidae, Phoridae, Anthomyiidae and Stratiomyidae. Coleopteran species from six families of forensic relevance were registered, although taxonomical identification remained superficial. Bait traps were the most frequent methodology used, followed by collection on animal carcasses. Seven Dipteran species from two families were registered on human cadavers. All species had been previously reported in other Brazilian states and/or other countries, although none has been effectively used in legal procedures in the region. The status of research on forensic entomology in northeastern Brazil is incipient, and the checklist produced here contributes to the knowledge on the local diversity of necrophagous insects.

KEYWORDS. Biodiversity; blowflies; flesh flies, forensic entomology; legal medicine.

RESUMO. Espécies necrófagas de Diptera e Coleoptera na Região Nordeste do Brasil: estado da arte e desafios para o Entomologista Forense. Inventários de insetos necrófagos no Brasil abordam em sua maioria espécies das regiões Sudeste e Centro-Oeste do país. Esta revisão visa apresentar um *checklist* de espécies necrófagas de Diptera e Coleoptera de importância forense no Nordeste brasileiro, uma área que concentra elevadas taxas de homicídio. Nós conduzimos uma revisão bibliográfica consultando artigos, teses e dissertações sobre espécies necrófagas na região, e contatamos cientistas que desenvolvem pesquisa em entomologia forense. Cinquenta e duas espécies de Diptera pertencentes a oito famílias com registro prévio de necrofagia foram registrados na região: Sarcophagidae, Calliphoridae, Muscidae, Fanniidae, Piophilidae, Phoridae, Anthomyiidae e Stratiomyidae. Espécies de Coleoptera de seis famílias de importância forense foram listadas, embora a identificação taxonômica tenha sido superficial. Armadilhas contendo iscas foram o método de coleta mais frequente, seguidas de coleta sobre carcaças animais. Sete espécies de Diptera pertencentes a duas famílias foram registradas sobre cadáveres humanos. Todas as espécies haviam sido previamente registradas em outros estados brasileiros e/ou em outros países, embora nenhuma tenha sido efetivamente utilizada em procedimentos legais na região. O status da pesquisa em entomologia forense no Nordeste do Brasil é incipiente, e o *checklist* apresentado neste trabalho contribui para sistematizar o conhecimento sobre a diversidade local de insetos necrófagos.

PALAVRAS-CHAVE. Biodiversidade; califorídeos; entomologia forense, medicina legal, sarcofagídeos.

The rate of homicides in Brazil is extremely high – and has increased 259% between 1980 and 2010, reaching an average rate of 26.2/100,000 inhabitants (Waiselfisz 2011). Homicides are far more frequent in the nine states that comprise the Northeast region, which is partially a reflex of the region's lower social and economic development compared to the rest the country. Of the eight state capitals with the highest rate of homicides, five are located in the Northeastern region: Maceió, João Pessoa, Salvador, Recife and São Luís, all of which have homicides rates above 46,6/100,000 inhabitants (Waiselfisz 2011).

The vast majority of homicides in Northeastern Brazil is unsolved, partly due to convoluted mechanisms in the Brazilian legal system and to the deficient investment in intelligence procedures for the police *modus operandi*. In this context, recent advances in applied biology have prompted the need to incorporate genetic, molecular, ecological and entomological tools in the forensic scientist's routine. The consolidation of forensic entomology research in Brazil has occurred in the last two decades, and a major body of theoretical and practical work starts to become available (see Pujol-Luz *et al.* 2008 for a review). Such advance, however, has been limited to the capital, Brasilia and to South-Southern states. Ironically, cities that suffer from the highest rates of violence have been neglected in field inventories of forensically important species.

A variety of necrophagous insect species occurs on or around a cadaver and, depending on their preference for a given stage of decomposition, a certain chronological sequence of colonization is supposed to take place (Byrd &

Castner 2010). Species from the orders Diptera (*e.g.*, Calliphoridae, Muscidae, Sarcophagidae, Stratiomyidae) and Coleoptera (*e.g.*, Dermestidae, Cleridae, Silphidae) have been associated with criminal investigations that extrapolate their use in estimating the post-mortem interval (or period of insect activity, as suggested by Tomberlin *et al.* 2011). Nowadays, entomological evidence in medico-legal procedures can be used in studies of postmortal transfer, entomotoxicology, neglect of living people, association of a suspect with a victim by detection of human DNA in insects and even sexual crimes (Byrd & Castner 2010; Tomberlin *et al.* 2011). None of this utility can be validated without proper knowledge on insects' bionomics, behaviour and geographical distribution.

Studies on the diversity of forensically important species have been performed by several research groups in Brazil so that an overview of native and invasive species is being compiled. The northeast region, with an area of 1,558,296 km^2 and population of 55 million people still remains a major challenge for entomologists. This review aims to provide a state of the art on the occurrence of necrophagous species of Diptera and Coleoptera in the Northeast region of Brazil, according to their potential use in forensic investigations. Specifically, we aimed to: *i)* perform an updated literature survey, listing the most frequent species and the types of environments in which they occur; *ii)* examine the methodologies used in field surveys, *iii)* identify species that have been previously associated with medico-legal practices and *iv)* draw perspectives on the status of the scientific research and on the potential of forensic entomology as a routine procedure in the region.

MATERIAL AND METHODS

This review is based on a thorough bibliographical survey performed between July/2009 and September/2010 on databases from Web of Science®, PubMed, Google Scholar, Periodicos Capes (a Brazilian catalogue that provides access to articles from over 15,000 scientific journals and 130 databases) and the Scientific Electronic Library Online (SciELO), which covers Latin American scientific journals, with emphasis on Natural Sciences. We also scrutinized theses and dissertations from Brazilian universities through the Ministry of Education database. Key words used in this search included general terms and scientific names related to forensic entomology (*e.g.*, post-mortem interval, *Necrobia*, *Chrysomya,* Calliphoridae), adding geographical references to Northeastern Brazil.

Additionally, we searched for scientists who work on forensic entomology in the region, by browsing the *Curriculo Lattes* database, maintained by the Ministry of Science and Technology, which comprises virtually all personnel involved in scientific research in Brazil. This search retrieved the names of 36 scientists who were contacted by e-mail and asked to send their publications related to necrophagous insects.

Nine sources of data, which comprised scientific articles and M.Sc. dissertations were used, as they were available in printed or electronic version. The scientific production regarding necrophagous insect species was analyzed under the following criteria: insect taxonomical position, substrate involved (baits, animal carcasses, human cadavers) and type of environment (urban zone, forest, etc.).

RESULTS AND DISCUSSION

Overall number of families and species. Diptera species belonging to 22 families were registered. From these, species from the families Asillidae, Dixidae, Drosophilidae, Micropezidae, Tabanidae, Chloropidae, Neriidae, Milichiidae, Ropalomeridae and Tachinidae were considered to be of minor or no medico-legal importance and are not listed here. Three families (Ulidiidae, Syrphidae and Sepsidae) that, depending on the literature, can be regarded as forensically important were reported but since only one unidentified species of each family was registered, they were also excluded.

Fifty-two species from eight families of medico-legal relevance identified at least on genus level are listed in Table I. Clearly, Sarcophagidae (flesh flies), Muscidae and Calliphoridae (blowflies) comprise the highest number of species, which is a reflex of their high richness and their frequent use of decomposing animal matter as a site for feeding, mating and egg-laying (Byrd & Castner 2010). Muscidae is a diverse family with around 5,000 species distributed throughout the world, particularly in the Neotropics, and an intimate evolutionary association with necrophagy has been established (de Carvalho *et al.* 2005). Calliphoridae has 190 genera and over 1,300 species described worldwide; their feeding habits include variations on parasitism, necrophagy and saprophagy (Zumpt 1965). Sarcophagidae comprises *ca.* 2,600 species distributed in all geographical regions, especially in areas with tropical climate; Neotropical sarcophagids include over 800 species (Shewell 1987; Pape 1996). Several species act as ectoparasites and their forensic importance derives from their habit of colonizing vertebrate carcasses, including man (Byrd & Castner 2010).

When data from all surveys are combined, Coleoptera species belonging to 22 families were reported. Species from families of minor or null medico-legal importance such as Bostrichidae, Bruchidae, Chrysomelidae, Cerambycidae, Coccinellidae, Curculionidae, Elateridae and Tenebrionidae are not listed (Table II). Species from six families associated with cadavers were identified at least at genus level, from which Scarabaeidae and Histeridae were the richest families, with ten and eight species each, respectively.

The superficial taxonomical identification of Coleoptera hinders inferences about their feeding habits but it is known that species from the six families listed here (Table II) are regarded, to some extent, as forensically important even if their representatives are not obligatory necrophagous. Only ten species of necrophagous or copronecrophagous Coleoptera were fully identified: *Ateuchus carbonarius* (Harold, 1868)*, Coprophanaeus ensifer* (Germar, 1824), *C. jasius* (Olivier, 1789), *C. pertyi* (d'Olsoufieff, 1924), *Dichotomius*

Table I. Species of Diptera collected in field surveys of necrophagous insects in northeastern Brazil, according to the type of environment. U = urban area; L = littoral; F = forest; P = sugarcane plantation.

Species	Environment			
	U	L	F	P
Sarcophagidae				
Hystricocnema plinthopyga (Wiedemann, 1830)	–	–	X	–
Oxysarcodexia avuncula (Lopes, 1933)	–	–	X	–
Oxysarcodexia fluminensis Lopes, 1946	–	–	X	–
Oxysarcodexia intona (Curran & Walley, 1934)	–	–	X	–
Oxysarcodexia modesta Lopes, 1946	X	–	X	–
Oxysarcodexia riograndensis Lopes, 1946	X	–	X	–
Oxysarcodexia simplicoides Lopes, 1933	X	–	–	–
Oxysarcodexia thornax (Wiedemann, 1830)	X	–	–	–
Oxyvinia excisa (Lopes, 1950)	–	–	X	–
Peckia (*Peckia*) *chrysostoma* (Wiedemann, 1830)	–	X	–	–
Peckia (*Pattonella*) *intermutans* (Walker, 1861)	X	–	X	–
Peckia (*Squamatodes*) *ingens* (Walker, 1849)	X	X	X	–
Ravinia belforti (Prado & Fonseca, 1932)	X	–	X	X
Sarcodexia lambens (Wiedemann, 1830)	X	–	–	–
Tricharaea (*Sarcophagula*) *occidua* (Fabricius, 1794)	–	X	–	–
Tricharaea sp.	X	X	X	X
Muscidae				
Atherigona orientalis Schiner, 1868	X	X	X	X
Biopyrellia bipuncta (Wiedemann, 1830)	X	–	–	–
Brontaea delecta (Wulp, 1896)	X	–	–	–
Brontaea normata (Bigot, 1885)	X	–	X	–
Cariocamyia maculosa Snyder, 1951	X	–	X	–
Cyrtoneuropsis rescita (Walker, 1861)	–	X	–	–
Graphomya analis (Macquart, 1851)	X	–	–	–
Graphomya maculata (Scopoli, 1763)	–	–	X	–
Hydrotaea nicholsoni Curran, 1939	X	–	–	–
Morellia humeralis (Stein, 1898)	–	–	X	–
Musca domestica Linnaeus, 1758	X	X	X	X
Ophyra aenescens (Wiedemann, 1830)	X	–	–	–
Ophyra chalcogaster (Wiedemann, 1824)	X	X	X	–
Parapyrellia maculipennis (Macquart, 1846)	–	–	X	–
Synthesiomyia nudiseta (Wulp, 1883)	X	X	–	X
Calliphoridae				
Cochliomyia macellaria (Fabricius, 1775)	X	X	X	X
Chloroprocta idioidea (Robineau-Desvoidy, 1830)	–	–	X	-
Chrysomya albiceps (Wiedemann, 1819)	X	X	X	X
Chrysomya megacephala (Fabricius, 1794)	X	X	X	X
Chrysomya putoria (Wiedemann, 1819)	X	X	X	X
Hemilucilia segmentaria (Fabricius, 1805)	X	–	X	–
Hemilucilia semidiaphana (Rondani, 1850)	–	–	X	–
Lucilia cuprina (Wiedemann, 1830)	X	–	–	–
Lucilia eximia (Wiedemann, 1819)	X	X	X	X
Lucilia sericata (Meigen, 1826)	–	–	X	–
Mesembrinella bellardiana (Séguy, 1925)	–	–	X	–
Fanniidae				
Fannia canicularis (Linnaeus, 1761)	X	X	X	–
Fannia obscurinervis (Stein, 1900)	–	–	X	–
Fannia pusio (Wiedemann, 1830)	X	X	X	X
Anthomyiidae				
Anthomyia aurifacies (Albuquerque, 1952)	–	–	X	–
Anthomyia plurinervis (Albuquerque, 1958)	–	–	X	–
Anthomyia punctipennis (Wiedemann, 1830)	–	–	X	–
Piophilidae				
Piophila casei (Linnaeus, 1758)	X	X	X	X
Piophila sp.	–	–	X	–
Phoridae				
Megaselia scalaris (Loew, 1866)	X	X	X	X
Stratiomyidae				
Hermetia illucens (Linnaeus, 1758)	X	–	X	–

Continue

Table I. Continued.

Additional sources: Andrade *et al.* (2005); Nilo (2007); Couri *et al.* (2008); Cruz (2008); Oliveira & Vasconcelos (2010); A. R. B. Santos (pers. comm.).

risus Olivier, 1789, *Digitonthophagus gazella* (Fabricius, 1787), *Omalodes bifoveolatus* Marseul, 1853, *Dermestes maculatus* (De Geer, 1774), *Xanthopygus bicolor* (LaPorte, 1835) and *Necrobia rufipes* (De Geer, 1775) (Table II).

Table II. Species of Coleoptera of forensic importance collected in field experiments in northeastern Brazil, according to the environment (U = urban area; L = littoral; F = forest; C = caatinga).

Species	Environment			
	U	L	F	C
Scarabaeidae				
Ateuchus carbonarius (Harold, 1868)	–	–	X	X
Canthon sp.	–	–	X	–
Coprophanaeus ensifer (Germar,1824)	–	–	X	–
Coprophanaeus jasius (Olivier, 1789)	–	–	–	X
Coprophanaeus pertyi (d'Olsoufieff, 1924)	–	–	–	X
Coprophanaeus sp.	–	–	X	–
Delthochilum sp.	X	X	X	–
Dichotomius nisus Olivier, 1789	–	–	X	X
Dichotomius sp.	–	–	X	–
Digitonthophagus gazella (Fabricius, 1787)	–	–	X	X
Histeridae				
Euspilotus sp.	–	–	X	–
Hister sp.	X	X	X	–
Holepta sp.	–	–	X	–
Phelister sp.	–	–	X	–
Omalodes bifoveolatus Marseul, 1853	–	–	X	–
Omalodes sp.	X	X	X	–
Saprinus sp.	–	–	X	–
Xestipyge sp.	–	–	X	–
Dermestidae				
Dermestes maculatus (De Geer, 1774)	X	X	X	X
Staphylinidae				
Aleochara sp.	–	–	X	–
Atheta sp.	–	–	X	X
Belonchus sp.	–	–	X	–
Philonthus sp.	–	–	X	–
Xanthopygus bicolor (LaPorte, 1835)	–	–	X	–
Trogidae				
Omorgus sp.	–	–	X	–
Cleridae				
Necrobia rufipes (De Geer,1775)	X	X	X	X

Additional sources: Endres *et al.* (2005); Cruz & Vasconcelos (2006); Cruz (2008); Mayer (2009); C. L. Bicho (pers. comm.).

Diversity of collection techniques. Several methods of capture and types of substrate have been used in field inventories in the region, ranging from short-term collection using meat baits and pitfall traps to non-replicated experiments

using animal carcasses and collections on human corpses (Tables III and IV). The most frequent method was a modification of the trap designed by Ferreira (1978), which is a portable, inexpensive and effective technique that collects mainly Dipteran adults. Although suspended bait traps have been successfully used to collect necrophagous species in Brazil and abroad, their drawbacks include their non-selective nature and the rapid decomposition of animal tissues used as baits so that collection favours early colonizers and is little effective for capture of late colonizers and non-flying necrophagous beetles.

Field studies performed in Northeastern Brazil have used animal tissues as varied as fish, pork and, especially because of the high number of species collected, chicken liver. Bait traps were associated with the collection of 16 species of Sarcophagidae, seven Calliphoridae and also species of scuttle flies (Phoridae), Lesser houseflies (Fanniidae) and skipper flies (Piophilidae).

Pitfall traps scattered around animal carcasses (Mayer 2009) or containing decomposing meat and human faeces as attractants (Endres *et al.* 2005) were used for the collection of soil copronecrophagous coleopterans. These heterogeneous methods make it difficult to differentiate accidental species (*e.g*. Curculionidae, Cerambycidae) from the true necrophagous, since feeding habits can vary within one Coleoptera genus or even within different stages of development of the same species (Arnett Jr. *et al.* 2002). Also, the non-discriminate nature of pitfall traps cause the collection of several non-necrophagous species, which can be affected by factors as diverse as trap quantity, size and spacing, time of exposure and type of bait (Ward *et al.* 2001).

Carcasses varied from pigs and dogs to hamsters, rats and rabbits. Domestic pigs have been successfully used as models in forensic entomology for decades, as there are similarities with the dermal composition, gut flora and rates of tissue decomposition when compared to humans (Catts & Goff 1992). The higher number of dipteran and coleopteran species associated with pig carcasses (43 spp.) reflects the reliability of this model which is, in turn, used more frequently than other vertebrates.

Insect collection on carcasses involved mostly flight interception traps for dipterans (*e.g*., Cruz 2008), direct collection of larvae and adults on the carcass (especially for Coleoptera) and the placement of trays containing sawdust under the carcass to collect immature and adult coleopterans and also dipteran larvae at the post-feeding stage.

In the region, only two studies (Andrade *et al.* 2005; Oliveira & Vasconcelos 2010) analysed insect fauna from corpses, increasing the applicability of the data. Combined data from those studies totalled seven species from two families: *Oxysarcodexia riograndensis* Lopes, 1943, *Ravinia belforti* (Prado & Fonseca, 1932) (Sarcophagidae), *Chrysomya albiceps* (Wiedemann, 1819), *C. megacephala* (Fabricius, 1794), *Cochliomyia macellaria* (Fabricius, 1775), *Lucilia cuprina* (Wiedemann, 1830) and *L. eximia* (Wiedemann, 1819) (Calliphoridae) (Table III).

Table III. Species of Diptera collected in field experiments on forensic entomology in northeastern Brazil, according to the type of substrate: bait (C = chicken liver; S = sardine, P = pork), carcass (Pi = pig; D = dog; R = rodent; Rb = rabbit) or cadaver.

Species	Bait			Carcass				Cadaver
	C	S	P	Pi	D	R	Rb	
Sarcophagidae								
Hystricocnema plinthopyga	X	–	–	X	–	X	–	–
Oxysarcodexia avuncula	–	–	–	X	–	–	–	–
Oxysarcodexia fluminensis	–	–	–	X	–	–	–	–
Oxysarcodexia intona	–	–	–	X	–	–	–	–
Oxysarcodexia modesta	X	–	–	X	–	–	–	–
Oxysarcodexia riograndensis	X	–	–	X	–	–	X	X
Oxysarcodexia simplicoides	–	–	–	–	–	X	–	–
Oxysarcodexia thornax	–	–	–	–	–	X	–	–
Oxyvinia excisa	–	–	–	X	–	–	–	–
Peckia(*Peckia*) *chrysostoma*	X	X	–	X	–	–	–	–
Peckia (*Pattonella*) *intermutans*	X	–	–	–	–	X	–	–
Peckia (*Squamatodes*) *ingens*	X	–	–	X	–	X	X	–
Ravinia belforti	X	X	X	–	–	–	X	X
Sarcodexia lambens	X	X	–	–	–	–	X	–
Tricharaea (*Sarcophagula*) *occidua*	X	–	–	–	–	–	–	–
Tricharaea sp.	X	X	X	X	–	–	–	–
Muscidae								
Atherigona orientalis	X	X	X	X	–	–	–	–
Biopyrellia bipuncta	X	–	–	X	–	–	–	–
Brontaea delecta	X	–	–	–	–	X	–	–
Brontaea normata	X	–	–	X	–	–	–	–
Cariocamyia maculosa	X	X	–	–	–	–	–	–
Cyrtoneuropsis rescita	X	–	–	–	–	–	–	–
Graphomya analis	X	X	–	–	–	–	–	–
Graphomya maculate	–	–	–	–	X	–	–	–
Hydrotaea nicholsoni	X	–	–	X	–	–	–	–
Musca domestica	X	X	X	X	–	X	–	–
Morellia humeralis	–	–	–	X	–	–	–	–
Ophyra aenescens	X	X	–	–	–	–	–	–
Ophyra chalcogaster	X	X	–	X	–	X	–	–
Parapyrellia maculipennis	–	–	–	X	–	–	–	–
Synthesiomyia nudiseta	X	X	X	X	–	–	–	–
Calliphoridae								
Cochliomyia macellaria	–	X	X	X	–	X	–	X
Chloroprocta idioidea	–	–	X	X	–	–	–	–
Chrysomya albiceps	X	X	X	X	X	X	X	X
Chrysomya megacephala	X	X	X	X	X	X	X	X
Chrysomya putoria	X	X	X	X	X	X	X	–
Hemilucilia segmentaria	X	–	–	X	X	X	–	–
Hemilucilia semidiaphana		–	–	X	–	–	–	–
Lucilia cuprina	–	–	–	–	X	–	–	X
Lucilia eximia	X	X	X	X	X	X	–	X
Lucilia sericata	–	–	–	–	X	–	–	–
Mesembrinella bellardiana	–	X	X	X	–	–	–	–
Fanniidae								
Fannia canicularis	X	–	–	–	–	X	–	–
Fannia obscurinervis	–	–	–	X	–	–	–	–
Fannia pusio	X	X	X	–	–	–	–	–
Anthomyiidae								
Anthomyia aureficies	–	–	–	X	–	–	–	–
Anthomyia plurinervis	–	–	–	X	–	–	–	–
Anthomyia punctipennis	–	–	–	X	–	–	–	–
Piophilidae								
Piophila casei	X	X	X	X	X	X	–	–
Piophila sp.	–	–	–	X	–	–	–	–

Continue

Table III. Continued.

Species	Bait			Carcass				Cadaver
	C	S	P	Pi	D	R	Rb	
Phoridae								
Megaselia scalaris	X	X	X	X	X	–	–	–
Stratiomyidae								
Hermetia illucens	X	–	–	X	X	X	–	–

Additional sources: Andrade *et al.* (2005); Nilo (2007); Couri *et al.* (2008); Cruz (2008); Oliveira & Vasconcelos (2010); A. R. B. Santos (pers. comm.).

Table IV. Species of Coleoptera collected in field experiments on forensic entomology in Northeastern Brazil, according to the type of carcass (P = pig; D = dog; R = rodent, Rb = rabbit) and previous report of forensic importance for the family in the literature.

Species	Forensic importance	Type of carcass			
		P	D	R	Rb
Histeridae	a, b, c, d, e				
Euspilotus sp.		X	X	–	X
Hister sp.		–	X	X	X
Holepta sp.		–	X	–	–
Omolodes bifoveolatus		–	–	–	X
Omalodes sp.		X	X	X	–
Phelister sp.		–	–	–	X
Saprinus sp.		–	–	–	X
Xestipyge sp.		X	–	–	–
Scarabaeidae	a, b, c, d, e				
*Ateuchus carbonarius**		–	–	–	–
Canthon sp.		X	–	–	–
*Coprophanaeus ensifer**		–	–	–	–
*Coprophanaeus jasius**		–	–	–	–
*Coprophanaeus pertyi**		–	–	–	–
Coprophanaeus sp.		X	–	–	–
Delthochilum sp.*		–	–	–	–
*Dichotomius nisus**		–	–	–	–
Dichotomius sp.*		X	–	–	–
*Digitonthophagus gazella**		–	–	–	–
Dermestidae	a, b, c, d, e, f, g, i				
Dermestes maculatus		X	–	X	–
Staphylinidae	a, b, c, d, e, h				
Aleochara sp.		–	–	–	X
Atheta sp.*		–	–	–	–
Belonchus sp.		–	–	–	X
Philonthus sp.		–	–	–	X
Xanthopygus bicolour		–	–	–	X
Trogidae	a, b, e				
Omorgus sp.		X	–	–	–
Cleridae	a, b, c, d, e, f, g				
Necrobia rufipes		X	–	X	–

* Species found exclusively on baited pitfall traps. Sources: a = Byrd & Castner (2010); b = Oliveira–Costa (2011); c = Smith (1986); d = Carvalho *et al.* (2000); e = Almeida & Mise (2009); f = Schroeder *et al.* (2002); g = Kulshrestha & Satpathy (2001); h = Marquez–Luna (2001); i = Sukontason *et al.* (2007).

Regardless of their abundance, insect collection on animal carcasses does not necessarily mean necrophagy: because carcasses are ephemeral resources rapidly colonized by thousands of immature and adult individuals, they are a suitable feeding site for predators and parasitoids in search of hosts. For example, from the 32 dipteran species collected flying over a pig carcass in a forest remnant in Recife, Pernambuco, only five effectively used the resource to complete their life cycle (Vasconcelos, S. D., *unpublished data*). The high diversity of Histeridae (Table II), a predatory coleopteran family, reinforces the ubiquity of non-necrophagous species associated with decomposing bodies.

Geographical distribution and types of environment. The variety of biomes, ecosystems and environment has been only superficially explored in the inventories. The northeast region encompasses rain forests, a long coastline (*ca.* 3,300 km), dunes, canyons, mangroves, *caatinga* (a type of dry forest endemic to Brazilian territory), diversified agroecosystems, large cities, among others, and such variety should be reflected in the diversity of necrophagous species. Forest remnants have been the commonest environment used for inventories, not only for its ecological importance as habitats for a wide variety of species, but also because urban enclaves of rainforests are the most frequent repositories for cadavers resulting from homicides in large cities in the region. Thirteen species of sarcophagids, nine species of calliphorids and three of muscids were registered in forest fragments in cities such as Recife (Pernambuco State) and Salvador (Bahia State) (Table I). Necrophagous species reported exclusively in forest remnants in the region so far include *Hystriocnema plinthopyga* (Wiedemann, 1830), *Oxysacordexia avuncular* (Lopes, 1933), *O. fluminensis* Lopes, 1946, *O. intona* (Curran & Walley, 1934), *O. modesta* Lopes, 1946, *Oxyvinia excisa* (Lopes, 1950) (Sarcophagidae), *Chloroprocta idioidea* ((Robineau-Desvoidy, 1830)), *Hemilucilia segmentaria* (Fabricius, 1805), *H. semidiaphana* (Randoni, 1850) and *Lucilia sericata* (Meigen, 1826) (Calliphoridae) all of which have been previously regarded as having forensic relevance (Carvalho *et al.* 2004). Coleopteran species found exclusively on forest fragments so far included *Euspilotus* sp., *Holepta* sp., *Xestipyge* sp., *Omalodes bifoveolatus* Marseul, 1853*, Sapinus* sp. (Histeridae), *Coprophaneous ensifer*, *Coprophanaeus* sp., *Canthon* sp., *Dichotomius* sp. (Scarabaeidae) and *Omorgus* sp. (Trogidae).

Data on necrophagous fauna in the littoral is incipient: so far, necrophagous species reported in coastal zones included four sarcophagids, four calliphorids and four muscids (Table I). Couri *et al.* (2008), working on material collected in the 1970's in the archipelago of Fernando de Noronha, 550 km from Pernambuco coastline, listed eight dipteran families, including Calliphoridae, Sarcophagidae and Muscidae. *Tricharaea* (*Sarcophagula*) *occidua* (Fabricius, 1794) (Sarcophagidae) was reported only in beach ecosystems (Couri *et al.* 2008; Oliveira 2009), similarly to what was observed in Argentina (Mariluis *et al.* 2007). No necrophagous coleopteran species were found to be exclusive to coastal zone according to the reviewed literature.

Urban areas have been sampled more frequently than other ecosystems, mainly due to their easy access and to the frequency of homicides. Most cases of actual use of entomological evidence (*e.g.*, *C. albiceps*, *C. megacephala*, *C. putoria* and *L. eximia*) for estimating the PMI in other countries occurred in urban areas (Table V) and the location of

institutes of legal medicine in state capitals increases the importance of collecting data on synanthropic species. Dipteran species with strong association with urban environments in Northeastern Brazil include: *O. simplicoides* Lopes, 1933, *O. thornax* (Walker, 1849), *Sarcodexia lambens* (Wiedmann, 1830) (Sarcophagidae), *Biopyrellia bipuncta* (Wiedemann, 1830), *Brontaea delecta* (Wulp, 1896), *Hydrotaea nicholsoni* Curran, 1939, *Ophyra aenescens* (Wiedemann, 1830) (Muscidae) and *L. cuprina* (Calliphoridae). No necrophagous coleopteran species were found exclusively in urban zones.

A few species were reported throughout several ecosystems, such as *C. megacephala*, *C. albiceps*, *C. macellaria*, *L. eximia* (Calliphoridae), *Megaselia scalaris* (Loew, 1866) (Phoridae), *M. domestica* Linnaeus, 1758 and *Atherigona orientalis* Schiner, 1868 (Muscidae). Naturally, this is a dynamic situation: for example, the introduction of *Chrysomya* species in the 1970's is believed to have dislocated native species from their habitats due mainly to predatory behaviour and larval competition (Wells & Greenberg 1992) so that a widespread occurrence of *Chrysomya* species may be reported in near future.

Table V. Species of Diptera with previous register of necrophagy collected in field experiments in northeastern Brazil, according to occurrence on human cadavers and register of actual use in forensic entomology cases. Forensic importance was also based on de Carvalho & Mello-Patiu (2008).

Species	Human cadaver	Forensic Entomology
Calliphoridae		
Chrysomya albiceps	k, l, m, n, o	n, o
Chrysomya megacephala	k, l, m, n, p, q, r	n
Chrysomya putoria	m	–
Cochliomyia macellaria	k, l, m, r	–
Hemilucilia segmentaria	m	z
Hemilucilia semidiaphana	m	–
Lucilia cuprina	l, n, r	–
Lucilia eximia	l, m	–
Sarcophagidae		
Oxysarcodexia riograndensis	k	–
Peckia (*Pattonella*) *intermutans*	m	–
Ravinia belforti	k	–
Muscidae		
Musca domestica	n, q	–
Ophyra chalcogaster	m	–
Synthesiomyia nudiseta	n, r, s	–
Fanniidae		
Fannia canicularis	v, n	v
Piophilidae		
Piophila casei	m, t, r	t
Phoridae		
Megaselia scalaris	m, r, y	w
Stratiomyidae		
Hermetia illucens	x, m, n, u	x, u

Sources: k = Oliveira & Vasconcelos (2010); l = Andrade *et al.* (2005); m = Carvalho *et al.* (2000); n = Velázquez *et al.* (2010); o = Grassberger *et al.* (2003); p = Oliveira –Costa & Mello-Patiu (2004); q = Barreto *et al.* (2002); r = Sukontason *et al.* (2007); s = Shewell (1987); t = Benecke (1998); u = Lord *et al.* (1994); v = Benecke & Lessig (2001); w = Greenberg & Wells (1998); x = Pujol-Luz *et al*. (2006); y = Disney (2008); z = Kosmann *et al.* (2011).

The status of research on forensic entomology in the region. References on necrophagous insect species originated from six out of the nine states in the region: Pernambuco, Rio Grande do Norte, Paraiba, Bahia, Maranhao and Alagoas. All species registered in the region have been previously reported for other Brazilian states and many of them were also registered in other countries. Is it possible that further taxonomical identification may demonstrate the occurrence of new species, or first records. Most species were listed for Pernambuco, which does not necessarily imply a higher diversity but reflects the fact that forensic research has been more firmly established in that state. From the ongoing projects on the ecology of necrophagous Diptera and Coleoptera in other states, it is expected that updated lists of necrophagous species will be available in the next few years.

Research on forensic entomology is incipient in Northeastern Brazil and appears to be limited to public universities, despite the alarming rates of unsolved homicides. Contact with local scientists reinforces the notion that forensic entomology is, until now, a secondary line of investigation. The studies performed so far are isolated initiatives with limited financial support and rarely as part of national/international cooperation projects. This diverges from the entomological research in the region, which holds eminent teaching and research centres and post-graduate courses on applied (*e.g*., medical and agricultural) entomology.

There is no published data from the actual experience of local forensic scientists in elucidating murder cases. The intricate police system in Brazil, aggravated by the insufficient number of professionals in the region, does not entitle scientific research as a priority for forensic experts, which explains the scarcity of criminal experts involved in ongoing cooperation projects with local universities. Most data on necrophagous species are limited to abstracts from local congresses and dissertations from undergraduate and post-graduate courses, which hampers the validation of the main findings. Publication in international journals is scant so far.

The restricted visibility and limited impact of data generated in the region may reflect not only the recent initiatives on this topic, but also limitations in the scope of the studies, such as: non-innovative design, lack of replication and statistical analysis, short-term field collection, among others. Legal, bureaucratic and ethical restraints limit the use of human cadavers in entomological surveys. The availability of bodies is highly irregular and procedures related to medico-legal practices (*e.g*., washing and disinfecting the cadavers) eliminate entomological evidence. Access to cadavers is limited to authorized personnel and authorization for external scientists requires a tremendous degree of bureaucracy. This fact compromises the reliability of data collected in broader inventories. To illustrate that, when dipteran species are analysed according to previous register on human cadavers, the diversity of dipterans is significantly reduced (Table V), and only a few had been actually used as valid evidence in criminal investigations, according to specialized literature.

Most critical of all is the superficial taxonomic identifi-

cation, especially for Coleoptera and for dipteran families that need more complex examinations such as the morphological analysis of the male genitalia, as it is the case of Sarcophagidae. It is not impossible that inaccuracies in the identification may be manifested in the data presented here. The lack of experts on systematics hinders significant contributions that field surveys may attempt at, since the identification for most cases reported here is insufficient to establish the medico-legal importance of the species. Molecular tools devised to facilitate insect identification have not yet been employed in practical research in the region.

CONCLUSIONS

The establishment of forensic entomology as a reliable tool in the routine of forensic scientists in Northeastern Brazil faces challenges common to many developing countries exposed to high indices of violence. Yet, it could be significantly improved if standardized methods were addressed, based on sound knowledge on insects' systematics, bionomics and ecology. This methodological standardization should guarantee that entomological evidence is reliable and repeatable – especially when biological variations are inherent to such diversity of environments and resources.

Inventories of necrophagous species are not valuable unless data on other variables (environmental, to start with) that influence insect colonisation are also quantified. Furthermore, the lack of molecular and genetic studies is of special concern, since this type of information is essential to understand variations in development, colonization and survival – all of which influence PMI estimates (Tomberlin *et al.* 2011). Given the initial stage of the research on forensic entomology in Northeastern Brazil, it is expected that a substantial amount of time will elapse before entomological evidence is incorporated in the practice of the forensic investigator. The lack of cooperation between local entomologists, scientific police and lawyers is a major obstacle. Cases of entomological evidence playing a key role in legal processes have not been publicized in the nine states of the region – unlike increasing number of cases elsewhere in Brazil (Oliveira-Costa & Mello-Patiu 2004; Pujol-Luz *et al.* 2006; Kosmann *et al.* 2011). Multidisciplinary studies involving aspects of bionomics, genetics, behaviour and molecular biology of necrophagous species start to be developed at local universities. Through this integration, it is expected that a more comprehensive overview of the actual diversity of necrophagous species in Northeastern Brazil, and their relevance for medico-legal investigations, will begin to emerge.

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