



Identification key for drosophilid species (Diptera, Drosophilidae) exotic to the Neotropical Region and occurring in Brazil

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ABSTRACT

Thirteen species of drosophilid exotic to the Neotropical Region are recorded in Brazil, and some of them are highly invasive and threaten significantly fruit cultures. We provide an illustrated key for identifying these species, and briefly discuss their taxonomic status, distribution, and occurrence in the Neotropics. The key should not only support newcomers to the study of *Drosophila* but also facilitate their identification by those interested in insects associated with cultivated areas.

Introduction

The Taxonomic Catalog of the Brazilian Fauna (TCBF) records 305 drosophilid species in this country (Tidon et al., 2019). Most are neotropical and ecologically restricted to a particular type of vegetation. Thirteen of these species, however, are exotic to the Neotropical Region and widely distributed in the world. Some (e.g., *Drosophila melanogaster* Meigen and *D. simulans* Sturtevant) possibly arrived in Brazil in the 16th century, transported by slave ships from Africa. Others reached the country later, throughout trade ships and airplanes. From the late 20th century, four new arrivals in the Neotropics were accurately recorded in the earlier stages of invasion: *D. malerkotliana* Parshad and Paika (Val and Sene, 1980), *Zaprionus indianus* Gupta (Vilela, 1999), *D. nasuta* Lamb (Vilela and Goñi, 2015) and *D. sukuii* Matsumura (Deprá et al., 2014).

The impacts of biological invasions have been widely recognized since the seminal book *The ecology of invasions by animals and plants* (Elton, 1958). Ecological interactions between invasive and native species, like predation and competition, often affect the population dynamics (births, deaths, migration) of native species and bring severe negative

consequences for biodiversity (Millennium Ecosystem Assessment, 2005). Moreover, invasive species can also cause economic troubles. In Brazil, annual losses to major crops caused by alien species are estimated to about US\$1.6 billion (ca. 16% caused by dipterans), and for USA and India this value is even higher (Oliveira et al., 2013). Therefore, it is crucial to understand the biology and distribution of exotic species (Sakai et al., 2001).

In Brazil, drosophilid communities have been studied by several independent research groups, covering the Amazonian and Atlantic forests (Medeiros and Klaczko, 2004; Penariol and Madi-Ravazzi, 2013; Coutinho-Silva et al., 2017; Santa-Brígida et al., 2017), the Cerrado biome (Tidon, 2006; Blauth and Gottschalk, 2007), Caatinga (Rohde et al., 2010; Garcia et al., 2014; Oliveira et al., 2016), araucarias (Cavasini et al., 2014), pampas (Poppe et al., 2016) and urban sites (Ferreira and Tidon, 2005; Gottschalk et al., 2007). Exotic species are recorded in all drosophilid assemblages, and their relative abundance depends on many factors, as vegetation type, the season of the year, and disturbance (Mata et al., 2015).

Taxonomic identification based on morphological characters is an effective way of determining many drosophilid species, especially the non-natives in a particular region. However, there is a lack of

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identification resources that can be easily used by non-specialists. The primary dichotomous key for drosophilids in Brazil (Freire-Maia and Pavan, 1949) attended several generations of researchers, and certainly contributed for spreading the study of these flies in the country. However, it does not include the recently introduced species and needs to be taxonomically upgraded (e.g. *Drosophila mirim* was synonymized as *Scaptodrosophila latifasciaeformis*). Here, we provide an illustrated identification key for 13 exotic drosophilid species recorded in Brazil and briefly discuss their taxonomic status, distribution, and occurrence in the Neotropics.

Material and Methods

We analyzed specimens of 11 among the 13 non-neotropical drosophilids occurring in Brazil and collected data of *Drosophila virilis* and *Scaptodrosophila lebanonensis* from the literature (Table 1). The illustrations were hand-made utilizing a *camera lucida* coupled to a Leica MZ75 stereoscope and followed traditional China ink scientific illustration methods reassembling those from Bächli et al. (2004). The morphological terms used in the dichotomous key are also based mainly on Bächli et al. (op cit.).

The dichotomous key does not consider the degree of phylogenetic correlation, but rather the difficulty of identifying each specimen. Thus, the species with the most striking morphological characteristics (*Z. indianus* with their bright stripes and *D. busckii* with their mesonotum patterns) were placed at the first steps of the key. Those specimens that required the rigorous analysis of bristles or sex combs (*Scaptodrosophila* genus and *melanogaster* species group) were left for the end section of the key.

The characters addressed here to identify females of *D. melanogaster* and *D. simulans* are useful for lab routine or identifying flies in the field, but insufficient for a taxonomic study because the black pigmentation on each tergite is highly variable according to genotype and grow temperature (Moreteau et al., 1995). For more accurate techniques such as egg-shape inspection or wing and thorax size ratio see Moreteau et al. (op cit.).

Identification key for non-neotropical drosophilid species occurring in Brazil

1. Presence of stripes on mesonotum.....2
 - Absence of stripes on mesonotum.....3
2. Yellowish fly, with two silvery-white stripes bordered by black across the head (Fig. 1A). Four stripes across the mesonotum and two in the scutellum (Fig. 1B). Two reduced prescutellar setae. Profemur with a row of strong setae, each one arising from a small tubercle with another setula (Fig. 1C). Costal index

- about 2.6. Subapical setae on fourth and fifth abdominal tergites arising from blackish spots..... *Zaprionus indianus*
- Yellowish fly with three dark-brown stripes across the mesonotum, median one forked in posterior half (Fig. 1D). Pleura with two horizontal stripes (Fig. 1E). Costal index about 3.1. Abdomen with dark bands interrupted in the middle and narrowed at the sides (Fig. 1F)..... *Drosophila busckii*
- 3. Dark brown fly. Carina longitudinally grooved (Fig. 1G). Basal scutellar setae divergent (Fig. 1H). Wing crossveins slightly shaded (Fig. 1I). Costal index about 3.0. Abdominal tergites 2-6 completely dark*Drosophila virilis*
 - Basal scutellar setae convergent (Fig. 1J)4
- 4. Presence of cuneiform setae on the inner side of profemur (Fig. 2A)5
 - Absence of cuneiform setae on the inner side of profemur6
- 5. Face region with a silvery-shining pigmentation (Fig. 2B), this area is more easily visualized in dry preserved males. Pleura with a wide, slightly brownish stripe (Fig 2C). Costal index about 3.1*Drosophila nasuta*
 - Male protarsomeres 1 and 2 with a dense brush of long hairy setae (Fig. 2D). Wings with crossveins and tips of longitudinal veins slightly shaded (Fig. 2E), costal index about 4.4. Abdominal bands medially interrupted with triangular marginal bands (Fig. 2F)*Drosophila immigrans*
- 6. Presence of prescutellar setae on mesonotum (Fig. 2G). Light hyaline wings. Sex combs absent (*Scaptodrosophila* genus).....7
 - Absence of prescutellar setae on mesonotum. Males with sex combs on protarsus (*melanogaster* species group)8
- 7. Light yellow fly. Costal index about 1.5. Abdomen deep dark (Fig. 2H)*Scaptodrosophila latifasciaeformis*
 - Dark brown fly. Costal index about 2.1 Large brown abdominal bands*Scaptodrosophila lebanonensis*
- 8. Male protarsus with two small rows of 3-4 peg-like setae forming a sex comb (Fig. 2I). Male wings with a large subdistal black spot (Fig. 3A), costal index about 3.5. Females with a large serrated oviscapt (Fig 3B)*Drosophila suzukii*
 - Male protarsus with a single row of peg-like setae forming a sex comb (Fig. 3C). Costal index 2.4. Male epandrial posterior lobe small and nearly triangular (Fig. 3D). Female abdomen with

Table 1
Non-neotropical species of Drosophilidae recorded in Brazil.

Genus	Subgenus	Species	Source	
<i>Drosophila</i>	<i>Dorsilopha</i>	<i>D. busckii</i> Coquillett	collection	
		<i>D. immigrans</i> Sturtevant	collection	
	<i>Drosophila</i>	<i>D. nasuta</i> Lamb	lab strain	
		<i>D. virilis</i> Sturtevant	literature*	
		<i>Sophophora</i>	<i>D. ananassae</i> Doleschall	lab strain
			<i>D. kikkawai</i> Burla	collection
			<i>D. malerkotiana</i> Parshad and Paika	lab strain
			<i>D. melanogaster</i> Meigen	lab strain
			<i>D. simulans</i> Sturtevant	lab strain
			<i>D. suzukii</i> Matsumura	collection
			<i>S. lebanonensis</i> Wheeler	literature**
	<i>S. latifasciaeformis</i> Duda	collection		
	<i>Zaprionus</i>	<i>Z. indianus</i> Gupta	collection	

* description and Miller et al. (2017) ** description and Bächli et al. (2005).

its large dark bands on the sixth tergite running to its ventral margin (Fig. 3E).....*Drosophila melanogaster*

- Male protarsus with a single row of peg-like setae, forming a sex comb (Fig. 3C). Costal index 2.3. Male epandrial posterior lobe very large and roundish with an amber like color (Fig. 3F). Female abdomen pigmentation border line making an angle with the sixth tergite margin (Fig. 3G)
.....*Drosophila simulans*

- Male protarsus with several transverse rows of short setae on the ventral surface, forming an indistinct sex comb (Fig. 3H). Costal index 1.5*Drosophila ananassae*
- Male protarsus with three small rows of 2-3 peg-like setae, forming a sex comb (Fig. 3I). Costal index 1.7.....
.....*Drosophila malerkotliana*
- Male protarsus with two rows of peg-like setae, forming a sex comb (Fig. 3J). Costal index 1.9.....
.....*Drosophila kikkawai*

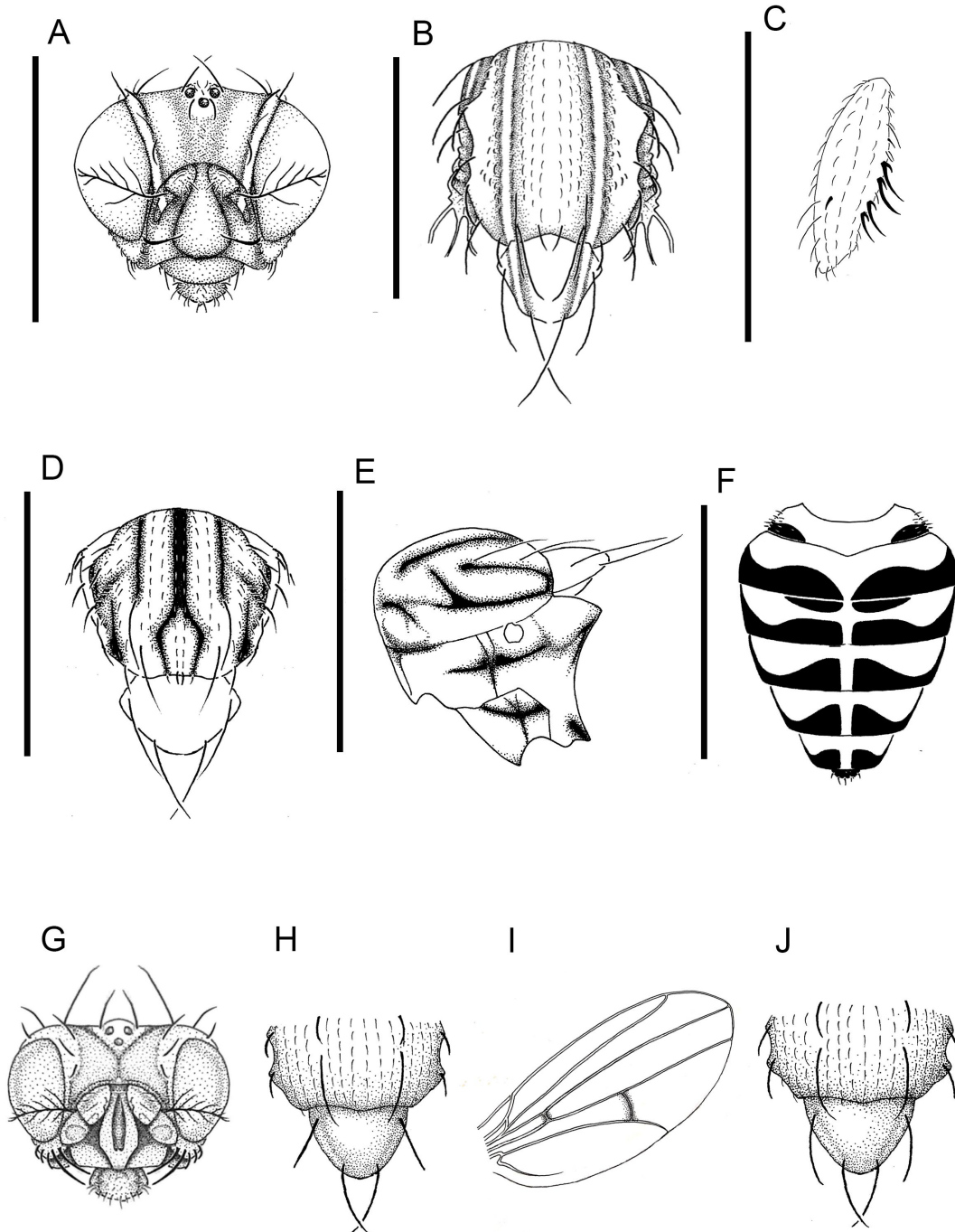


Figure 1. *Zaprionus indianus*, *Drosophila busckii* and *D. virilis*. A. Head of *Z. indianus* in frontal view, showing the two silvery stripes bordered by black. B. Thorax of *Z. indianus* in dorsal view, showing the four silvery stripes bordered by black. C. Profemur of *Z. indianus*, showing the row of characteristic strong setae. D. Thorax of *D. busckii* in dorsal view, showing its characteristic dark stripes, the middle one bifurcating at the base. E. Thorax of *D. busckii* in lateral view with its characteristic dark stripes. F. Abdomen of *D. busckii*, showing the bands interrupted in the middle. G. Head of *D. virilis* in frontal view, showing its carina with a longitudinal groove at midline. H. Divergent basal scutellar setae. I. *D. virilis* wing, showing the shaded crossveins. J. Convergent basal scutellar setae. Bar = 1mm. Illustrations of *D. virilis* were based on published images without scale (Miller et al., 2017).

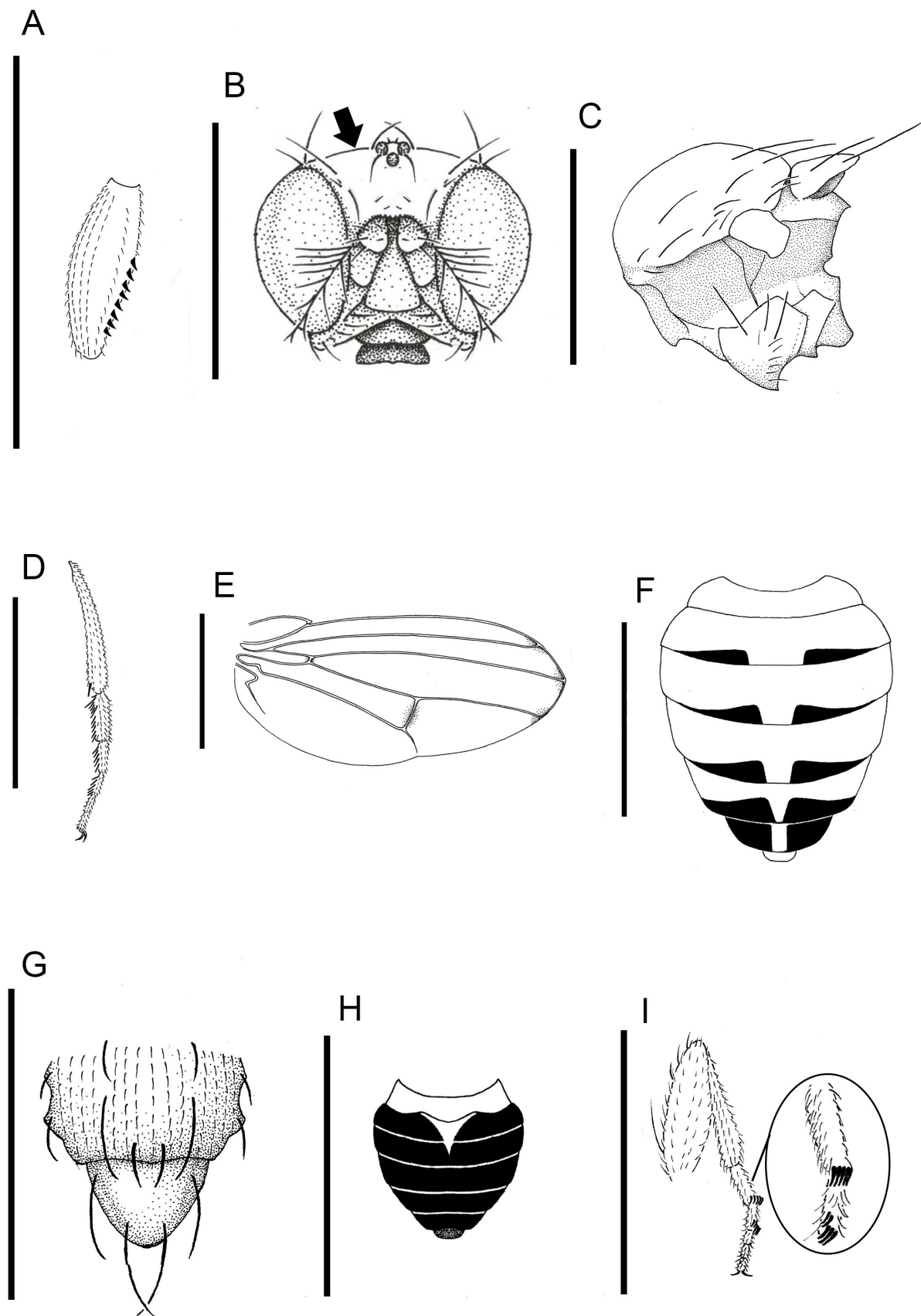


Figure 2. *Drosophila nasuta*, *D. immigrans*, *Scaptodrosophila latifasciaeformis*, and *D. suzukii*. A. Profemur with a row of cuneiform setae. B. Head of *D. nasuta* in frontal view, showing the characteristic silvery pigmentation in the face region. C. Thorax of *D. nasuta* in lateral view, showing the large brownish stripe on half dorsal area of pleura. D. *D. immigrans* protarsomer, showing the brush like thin setae. E. *D. immigrans* wing, showing the shaded cross veins and ends of longitudinal veins. F. *D. immigrans* abdomen, showing the bands interrupted in the middle. G. Prescutellar setae. H. *S. latifasciaeformis* dark abdomen. I. *D. suzukii* protarsus with sex combs. Bar = 1mm.

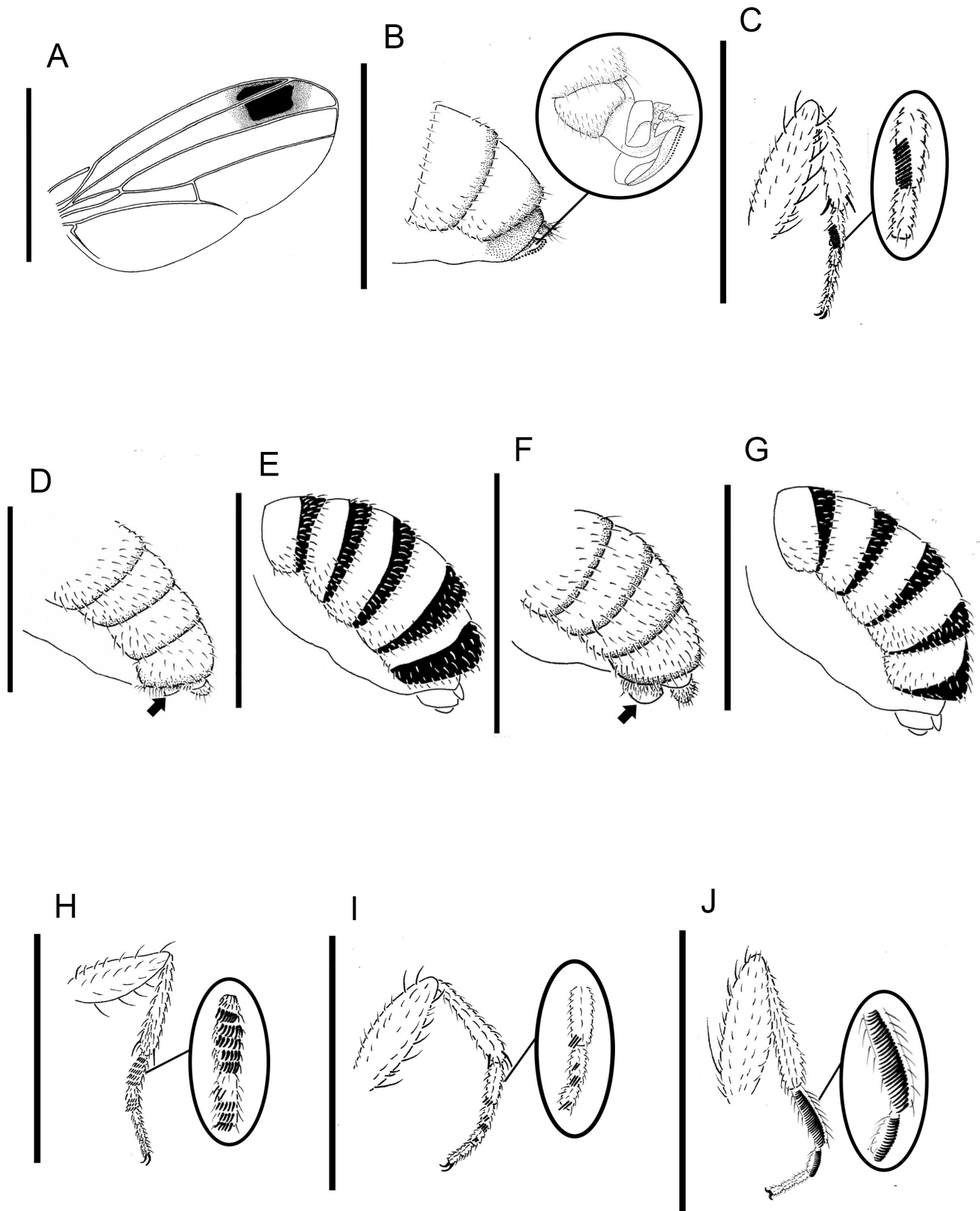


Figure 3. *Drosophila suzukii*, *D. melanogaster*, *D. simulans*, *D. ananassae*, *D. malerkotliana* and *D. kikkawai*. A. *D. suzukii* male spotted wing. B. *D. suzukii* female abdomen, showing the serrated oviscapt. C. *D. melanogaster* and *D. simulans* protarsus sex comb. D. *D. melanogaster* male epandrial posterior lobe. E. *D. melanogaster* female abdomen in lateral view, showing the large dark bands on the sixth tergite running to its ventral margin. F. *D. simulans* male epandrial posterior lobe. G. *D. simulans* female abdomen in lateral view, showing the pigmentation border line making an angle with the sixth tergite margin. H. *D. ananassae* protarsus sex combs. I. *D. malerkotliana* protarsus sex combs. J. *D. kikkawai* protarsus sex combs. Bar = 1mm.

Discussion

Potentially colonizer drosophilids had attracted the attention of researchers for over five decades (Dobzhansky, 1965; Lewontin, 1965; David and Tsacas, 1981; Parsons, 1983), and it is well established that these flies can be used as models in studies of biological invasions (Gibert et al., 2016). The species registered here are widely distributed not only in South America but also in other regions of the world (Bächli, 2019). The section below provides information about the origin (David and Tsacas, 1981), distribution (Brake and Bächli, 2008; Bächli, 2019), and general characteristics of each species.

Genus *Drosophila* Fällén

The genus *Drosophila* includes approximately half of the 4,000 species in the family Drosophilidae. Its members have adapted to and radiated in a variety of niches (Markow and O'Grady, 2008), and currently divided into nine subgenera (O'Grady and DeSalle, 2018).

Subgenus *Dorsilopa* Sturtevant

This subgenus of oriental origin (Toda, 1986) consists of only four species, including the cosmopolitan *Drosophila busckii*. While many common drosophilids prefer decaying fruit, *D. busckii* larvae seem to have a broader niche (Atkinson and Shorrocks, 1977) and were recorded feeding on many different vegetables (Valadão et al., 2019), animal excrement and meat (Sturtevant, 1921). This species is very abundant in temperate places, where its competitive ability is apparently higher (David and Tsacas, 1981). In Brazil, *D. busckii* is rare in natural habitats but can be found in disturbed areas (Sene et al., 1980).

Subgenus *Drosophila* Fällén

This is the largest subgenus of *Drosophila*, supporting about 80% of its ca. 2000 species. Therefore, this subgenus is organized in 47 species groups, which are an informal taxonomic rank (Sturtevant, 1942) that organize the diversity within large clades of drosophilids.

The *immigrans* species group, probably of oriental origin, currently contains about 100 nominal species and two of them are recorded in Brazil. The cosmopolitan *Drosophila immigrans* is abundant in the Palearctic and Nearctic Regions (David and Tsacas, 1981) and has been collected in Brazilian natural and modified environments since the pioneer studies of Pavan (1959). In this country, the abundance of *D. immigrans* seems to be low at warmer areas (Sene et al., 1980) but increases in the colder southern regions (Hochmüller et al., 2010). *Drosophila nasuta*, on the other hand, is widespread and abundant in the tropical parts of Africa (David and Tsacas, *op cit.*) and has been recently recorded in the Neotropics (Vilela and Goñi, 2015). In forest patches located in the Brazilian savanna, where *D. immigrans* remains rare (data not shown), *D. nasuta* can reach 20% relative abundance of drosophilids during Summer months (Leão et al., 2017). These findings support the hypothesis raised by David and Tsacas (*op cit.*) that *D. immigrans* is cold-adapted, whereas *D. nasuta* is a tropical species.

The *virilis* species group consists of about thirteen described species that are typically found in a boreal distribution (Markow and O'Grady, 2006). The group appears to have originated in Asia as a species of the temperate deciduous forest associated predominantly with riparian communities (Throckmorton, 1975). Only *Drosophila virilis* Sturtevant has been recorded worldwide in wine production areas as well as in breweries (Bächli et al., 2004).

Subgenus *Sophophora* Sturtevant

This subgenus currently contains 344 species organized in nine species groups. The *Drosophila melanogaster* species group, the largest of this subgenus, contains almost 200 species widely distributed in the Oriental Region and adjacent areas, but some lineages reached the African continent and radiated. Six species of this group are recorded in Brazil.

The sibling African species *Drosophila melanogaster* and *D. simulans* probably are the most studied examples of widespread drosophilids (Capy et al., 2004). *D. melanogaster* first colonized Eurasia (10,000- 15,000 years ago) and later spread to America and Australia. It is generally admitted that this human commensal species travel easily with fruit shipments, mostly as larvae or pupae on rotting material. *D. simulans* expanded worldwide more recently, probably a few centuries ago, establishing in natural and disturbed environments throughout the invaded areas. In Brazil, both species arrived probably as a result of the slave trade. Currently, *D. simulans* is a widespread species in all sorts of environments, whereas *D. melanogaster* is rare in natural habitats (Sene et al., 1980).

Drosophila ananassae, probably native of the Orient, is a peridomestic species occurring in tropical and subtropical areas of the world. In Brazil, it is rare in natural environments but can be found in open types of vegetation (Sene et al., 1980). We have been collecting this species in urban orchards, near Brasília.

The oriental species *D. kikkawai* supports a cosmopolitan status (Pinheiro and Valente, 1993), but it is not clear when it was introduced in South America and Africa and nor if this process was mediated by humans (Ashburner, 1989). In Brazil, this species is found in both natural (Sene et al., 1980) and urban environments (Costa et al., 2003), usually in low abundances (but see Cavasini et al., 2014).

Drosophila malerkotliana, also native of the Orient, was described from the Malerkotla region in India by Parshad and Paika, in 1964. Besides being widespread in the Orient, it also occurs in Africa and Americas, where it was introduced in recent decades (Val and Sene, 1980; Sene et al. 1980; David and Tsacas 1981; Castrezana et al., 2010). In Brazil, it occurs in both natural environments (Medeiros and Klaczko, 2004; Torres and Madi-Ravazzi, 2006; Tidon, 2006; Schmitz et al., 2010), and urbanized sites (Gottschalk et al., 2007).

Finally, a species that is currently meriting the status of cosmopolitan is *D. sukukii*, known as the spotted-wing *Drosophila* due to the dark spot on the male wings. Probably native of East Asia, this species has spread to western regions: it was found in Hawaii in the early 1980s and more recently in North America and Europe, where it has reached invasive pest status (Asplen et al., 2015). The female has a long and narrow ovipositor used to infest soft-skinned fruit crops and causing enormous economic damage on commercial plantations; hence, the spotted-wing *Drosophila* has become an agricultural pest in several countries worldwide (Walsh et al., 2011). In Brazil, this cold-adapted species was first detected in the southern region in February 2013 (Deprá et al., 2014). As conjectured by Vilela and Mori (2014), who recorded this species in Southeast Brazil, *D. sukukii* is probably expanding its territory to other South American areas through the trade of cultivated soft skin fruits and the use of small wild fruits as breeding sites. Although Southern Brazil is the most climatically favorable area for *D. sukukii* development (Benito et al., 2016), it has already been found in natural vegetations of the tropical Brazilian Savanna, at low abundances (Leão et al., 2017).

Genus *Scaptodrosophila* Duda

The genus *Scaptodrosophila*, initially described as a subgenus of *Drosophila*, was formally elevated to generic rank by Grimaldi (1990). Probably originated in tropical Asia, *Scaptodrosophila* currently includes

almost 300 species distributed in Asia, New Guinea, Australia, and Africa, with few species in the Americas and Europe. Two species of this genus have reached the Neotropical Region. *Scaptodrosophila latifasciaeformis* is a widespread species in tropical and subtropical areas of the world. In Brazil, it was described by Dobzhansky and Pavan (1943) as *Drosophila mirim* and has been collected in all types of vegetations (Sene et al., 1980), including mangroves in the southern region of the country (Schmitz et al., 2010). *S. lebanonensis*, later described as *Drosophila galloiby* by Lourenço and Mourão (1992) and synonymized by Bächli et al. (2005), was recorded in southern Neotropical region in 1960 and we have no notice of other records in the Neotropical region after then.

Genus *Zaprionus*

Zaprionus is an Afrotropical genus that extended its distribution to the Australian, Oriental and Palearctic regions. *Zaprionus indianus* constitutes one of the most successful colonizing species of this genus (Chassagnard and Tsacas, 1993), probably because of its broad niche-width characteristics: it utilizes diverse food resources and displays adaptation to variable climatic conditions (Parkash and Yadav, 1993). The first record of *Z. indianus* in Brazil was in São Paulo State (Vilela, 1999) and, after that, the species was found in many Brazilian regions (Galego and Carreto, 2010). In natural areas where environmental conditions are similar to those observed in its original area in Africa, *Z. indianus* dominates drosophilid assemblages during the wet season (Tidon et al., 2003). It also predominates in fig plantations: among 125,00 drosophilids captured in São Paulo State, 83,339 were identified as *Z. indianus* (Roque et al., 2017). This species is highly adaptable (Mata et al., 2010) and deserves to be monitored.

Final Remarks

Most drosophilids approached in this study are widely distributed thought natural populations in many Brazilian biomes, and two species in particular, *Drosophila suzukii* and *Zaprionus indianus*, can cause great impact on cultivated areas. The identification key provided here should not only support newcomers to the study of *Drosophila* but also the professional that will be dealing with the elimination of the pests affecting plantation, who generally will not be *Drosophila* experts.

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