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Source: Florida Entomologist, 102(3) : 562-570

Published By: Florida Entomological Society

URL: <https://doi.org/10.1653/024.102.0333>

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Diversity of fruit flies (Diptera: Tephritoidea) and their host plants in a conservation unit from midwestern Brazil

Luciano Brasil Martins de Almeida^{1,*}, João B. Coelho¹, Manoel A. Uchoa¹, and Laura J. Gislotti¹

Abstract

Fruit flies (Diptera: Tephritidae and Lonchaeidae) are among the principal phytophagous insects of fruit and vegetables. Their larvae feed on the pulp or seeds of fruits to complete their development, which favors the entry of pathogens and early fall of the fruits, damaging fruit production. The objectives of this research were to determine the richness of fruit fly species and their associations with their host fruits in the Serra da Bodoquena National Park (Mato Grosso do Sul State, Brazil) and surrounding areas. To obtain the fruit fly species from their hosts, monthly collections of fruits were made. Leaf samples were prepared and identified by botanists. The collected fruits were transported to the Laboratório de Insetos Frugívoros, where they were counted and weighed. The species of fruit flies were identified, and their trophic interactions with their hosts analyzed. Thirty-nine plant species from 29 plant families were collected. Twelve fruit species were hosts to fruit fly larvae. The survey resulted in the recovery of 1,476 larvae and 968 adult fruit flies. Among the adults, 878 were Tephritidae and 90 Lonchaeidae. Nine species from the genus *Anastrepha* (Diptera: Tephritidae) and 3 from *Neosilba* (Diptera: Lonchaeidae) were obtained. These are the first reports for *Anastrepha serpentina* (Wiedemann), *Anastrepha fraterculus* (Wiedemann), and *Anastrepha obliqua* (Macquart) (all Diptera: Tephritidae) infesting fruits of *Eugenia myrcianthes* Nied (Myrtaceae); *Anastrepha striata* Schiner (Diptera: Tephritidae) infesting *Jacaratia spinosa* Aubl. (Caricaceae); *Anastrepha zenildae* Zucchi (Diptera: Tephritidae) infesting *Campomanesia guazumifolia* (Cambess) O. Berg. (Myrtaceae); *Neosilba glaberrima* (Wiedemann) and *Neosilba zadolicha* McAlpine & Steyskal are recorded for the first time infesting *Persea americana* Miller (Lauraceae), and *Neosilba certa* (Walker) (all Diptera: Lonchaeidae) infesting *Chrysophyllum gonocarpum* (Mart. & Eichler) Engl. (Sapotaceae), *Anastrepha barbiellinii* Lima (Diptera: Tephritidae) is recorded for the first time infesting *Pereskia aculeata* Miller (Cactaceae) in Mato Grosso do Sul State.

Key Words: *Anastrepha* spp.; host fruits; trophic interactions; *Neosilba* spp.; infestation

Resumo

As moscas das frutas (Diptera: Tephritidae e Lonchaeidae), estão entre os principais insetos fitófagos em frutíferas e hortícolas. Suas larvas, ao se alimentarem da polpa ou das sementes dos frutos para completar o desenvolvimento, podem favorecer a entrada de patógenos ou queda precoce dos frutos, prejudicando a produção. Os objetivos desta pesquisa foram conhecer a riqueza em espécies de moscas das frutas e suas associações com seus frutos hospedeiros no Parque Nacional da Serra da Bodoquena (Mato Grosso do Sul, Brasil) e arredores. Para a obtenção das moscas das frutas a partir dos seus hospedeiros foram realizadas expedições mensais para amostragem de frutos. Foram preparadas exsiccatas das frutíferas amostradas, que foram identificadas por botânicos. Os frutos coletados foram transportados ao Laboratório de Insetos Frugívoros, onde foram contados e pesados. As espécies de moscas das frutas foram identificadas e suas interações tróficas com seus hospedeiros analisadas. Foram coletadas 39 espécies frutíferas pertencentes a 29 famílias. Doze espécies frutíferas foram hospedeiras de larvas de moscas das frutas, sendo obtidas 1.476 larvas de moscas das frutas, com 968 adultos: 878 de Tephritidae e 90 de Lonchaeidae. Nove espécies do gênero *Anastrepha* (Diptera: Tephritidae) e 3 de *Neosilba* (Diptera: Lonchaeidae) foram obtidas. Estes são os primeiros relatos de: *Anastrepha serpentina* (Wiedemann), *Anastrepha fraterculus* (Wiedemann) e *Anastrepha obliqua* (Macquart) (todos Diptera: Tephritidae) infestando frutos de *Eugenia myrcianthes* Nied (Myrtaceae); *Anastrepha striata* Schiner (Diptera: Tephritidae) em *Jacaratia spinosa* Aubl. (Caricaceae), *Anastrepha zenildae* Zucchi (Diptera: Tephritidae) em *Campomanesia guazumifolia* (Cambess) O. Berg. (Myrtaceae), *Neosilba glaberrima* (Wiedemann) e *Neosilba zadolicha* McAlpine & Steyskal são reportadas pela primeira vez infestando *Persea americana* Miller (Lauraceae) e *Neosilba certa* (Walker) (todos Diptera: Lonchaeidae) infestando *Chrysophyllum gonocarpum* (Mart. & Eichler) Engl. (Sapotaceae), *Anastrepha barbiellinii* Lima (Diptera: Tephritidae) é registrada pela primeira vez infestando *Pereskia aculeata* Miller (Cactaceae) em Mato Grosso do Sul.

Palavras Chave: *Anastrepha* spp.; frutos hospedeiros; interações tróficas; *Neosilba* spp.; infestação

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In Brazil, fruticulture is one of the most important elements of the agricultural economy. Of the 5.7 million ha devoted to agricultural crops, fruit trees occupy 27.3% (Vitti 2009). According to FAO (2019), in 2016 Brazil was the third largest fruit producer in the world, after China and India, with 42.3 million metric tons.

The fruit and fruit byproducts sector is considered the largest generator of jobs in Brazil, occupying 40% of the Brazilian agribusiness labor force. Farms with fruit and vegetable cultivations are characterized by being from small to medium-sized (10–50 ha). To each R \$20,000 invested in horticulture, 3 to 5 jobs are generated along the production chain (Vitti 2009).

Despite being the third largest fruit producer in the world, Brazil occupies the twenty-third place in the ranking of exporting countries (Anuário Brasileiro de Fruticultura 2018). One of the principal problems faced by export of fruits and vegetables in the country is the occurrence of a great diversity of fruit fly species. Such species cause constant concern to importing countries, which often are free from these pests. These nations invest heavily in their agriculture, and impose severe quarantine restrictions on imports of fresh goods from countries where fruit fly pest species occur. In order to meet the sanitary requirements imposed by importing countries, producer nations are obliged to take several preventive measures, such as thermal treatment for some species of fruit, such as mango (*Mangifera indica* L.) (Anacardiaceae). They also require the demarcation of fruit fly-free areas or areas with low prevalence of fruit flies in order to get export permits (Uchoa 2012).

Fruit flies herein considered are frugivorous species from the families Tephritidae and Lonchaeidae (sensu Uchoa 2012). The most important tephritid genera are *Anastrepha* Schiner, *Bactrocera* Macquart, *Ceratitis* Macleay, *Dacus* Fabricius, and *Rhagoletis* Loew (Tephritidae). In the family Lonchaeidae, the most important genera are *Dasiops* Rondani and *Neosilba* McAlpine (Uchoa 2012).

Management of fruit flies is challenging because the eggs are inserted into the fruit, and the larvae that feed inside the fruit leave the fruit to pupate in the soil. Thus, they may escape contact with insecticides (Heve et al. 2016).

In the Neotropical region, more than 300 species of *Anastrepha* have been described (Norrbon et al. 1999, 2012, 2015) based on adult morphological studies. Recently, the genus *Toxotrypana* Gerstaecker was combined with *Anastrepha*, increasing the number of valid species in this taxon (Norrbon et al. 2018). These flies cause about US \$120 to 200 million annual losses to Brazilian horticulture (Felix et al. 2009).

The family Lonchaeidae, with 587 species described worldwide, is subdivided into 2 subfamilies: Dasiopinae and Lonchaeinae. Dasiopinae has 128 described species in a single genus: *Dasiops* Rondani, followed by Lonchaeinae, with 8 genera: *Protearomyia* McAlpine (12), *Chaetolonchaea* McAlpine (Steyskall & Henning) (8), *Earomyia* Macquart (22), *Lamprolonchaea* Czerni (17), *Fulgenta* MacGowan (15), *Lonchaea* Fallen (232), *Silba* Rondani (113), and *Neosilba* Steyskall (40) (MacGowan 2018).

Most research on tephritoids focuses on the economic importance of several species associated with agriculture (Lemos et al. 2015), whereas studies in native areas (Uramoto et al. 2008; Uchoa & Nicácio 2010) are scarce. Protected natural areas, such as conservation units, represent one of the best strategies to conserve local biodiversity. Such areas play an important role in the conservation of regional biodiversity, as well as in the ecological processes that occur in these environments. In the case of fruit flies, it is very important to conserve their alternative hosts, and the monophagous and stenophagous tephritoid species (Aluja & Mangan 2008), because juvenile and adult non-pest species can persist in preserved environments, and natural enemies can proliferate and be studied for use in programs of biological control of fruit fly pest species in orchards and vegetable gardens.

Knowledge about the biodiversity of fruit flies in conservation units allows us to obtain essential information for management techniques, besides providing additional data on fauna potentially affecting fruit crops (Bomfim et al. 2007). In this context, the purpose of this study was to determine the richness of fruit fly species and their associations with host plants in the Parque Nacional da Serra da Bodoquena and surrounding areas.

Material and Methods

STUDY AREA

The fruit collections were carried out in the Parque Nacional da Serra da Bodoquena (at 20.341000°S, 56.513900°W) and farms along the access road to the park, which integrate the buffer zone. This park is located in the Cerrado biome, but the proximity to other biomes and the distance from the Cerrado nuclear region suggest influences of the Pantanal and Atlantic forest. The total area of the park is 76,481 ha. It consists of 2 large geomorphological blocks with distinct characteristics: 1 to the north with an area of 27,793 ha, and the other to the south with 48,688 ha (PNSB 2013). The park consists mostly of submontane deciduous seasonal forest (about 70,000 ha), followed by areas of savannah (3,564 ha), floodplains (379 ha), and anthropized areas (2,576 ha) (PNSB 2013).

Fruit sampling was carried out on 3 trails that had been pre-established by the Instituto Chico Mendes de Conservação da Biodiversidade for the periodic monitoring of flora and fauna in the park. These trails start at the end of the buffer zone leading to the interior of the park. The trails are designated Marambaia, Santa Fé, and Catamarca.

Marambaia Trail (20.580700°S, 56.422300°W)

The predominant vegetation is shrubs and large trees (between 3 and 30 m in height), with characteristics of semideciduous submontane forest. This area is close to domestic orchards at the headquarters of the surrounding farms, and displays great species richness, including cultivated fruits, such as passion fruit (*Passiflora* spp.) (Passifloraceae), mango (*Mangifera indica* L.) (Anacardiaceae), red-mobim (*Spondias purpurea* L.) (Anacardiaceae), and avocado (*Persea americana*) (Miller) (Lauraceae), among others.

Santa Fé Trail (21.302600°S, 56.450500°W)

The Santa Fé trail is characterized by a mountainous region, with shallow soil and many rocky outcrops (soil surface with large blocks of rocks), making it difficult to establish large trees. This area is close to farms with annual grain crops, alternating soybean (spring to summer) and corn (late summer to winter) plantations.

Catamarca Trail (21.616000°S, 56.432800°W)

This area is characterized by open cerrado (arboreal savanna) and ciliary forest, with typical vegetation of semideciduous submontane tropical forest. The area along this trail displays human impact, with interspersed pastures in the cerrado vegetation, including farming activities (cattle breeding), intense deforestation, and artificial diversion of the Perdido River in some stretches, which interrupts the natural ecology.

FRUIT SAMPLING FOR TEPHRITOIDEA

Fruits were sampled monthly from Jan 2017 to Feb 2018. The fruit fly species were obtained from native wild fruits, or from naturally oc-

curing cultivated fruit such as avocado, guava L. (Myrtaceae), and cajá (*Spondias mombim* L.) (Anacardiaceae).

In order to inventory the fruit flies, fruits of different plant taxa were sampled along the trails (Marambaia, Santa Fé, and Catamarca). About 2,500 m of trail length were sampled for each trail, and the fruits were sampled at a distance of approximately 2.5 m from each side of the trail, totaling a sampled area of about 37,500 m² (12,500 m² on each trail). The collected fruits were taken directly from the trees and also from the ground if they were freshly fallen.

The leaf samples taken from the trees were identified by Zefa Valdivina Pereira, Faculdade de Ciências Biológicas e Ambientais, Universidade Federal da Grande Dourados, Dourados, Mato Grosso do Sul, Brazil, and Ângela Sartori, Departamento de Biologia, Universidade Federal de Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil.

The collected fruits were placed in cotton bags and transported to the laboratory, where later they were transferred to wooden pallets inserted in trays containing a shallow layer of water (± 1 cm) to collect the last instar larvae of fruit flies. Larvae were collected daily every 12 h from the trays, and inserted into transparent acrylic pots with sterilized sand, where they remained until adult emergence.

Identification of adult Tephritidae was performed by M. A. Uchoa based on body and wing color patterns of adults and examination of female genital morphology, using a stereomicroscope (Zeiss, Discovery V-8, Dourados, Mato Grosso do Sul State, Brazil) and taxonomic identification keys (Stone 1942; Steyskal 1977; Zucchi 2000). Identification of *Anastrepha* species is based principally on morphometric characteristics of females.

The Lonchaeidae were identified by L. J. Gistloti based on morphological examination of the genitalia of males using identification keys (Korytowsky & Ojeda 1971; McAlpine & Steyskal 1982; Galeano-Olaya et al. 2012). In Lonchaeidae, identification is based only on male genital characters.

DATA ANALYSIS

The analysis of the patterns of fruit fly infestation in their hosts plants was based on Uchoa et al. (2003). The parameters calculated were: (1) viability of third instar larvae (percentage of unparasitized larvae) was calculated as the number of emerged fruit flies per fruit \times 100 divided per total number of third instar larvae in each fruit-number of non-emerged parasitoids; (2) species richness was calculated as the total number of fruit fly species collected in each plant community. These communities were represented by each of the trails sampled: Marambaia, Santa Fé, and Catamarca; (3) the rates of fruit fly infestation were calculated according to Uchoa et al. (2003) using the following parameters: (3a) dividing the total number of third instar fly larvae (L3) by the number of fruits in the sample (L3 per fruit), and (3b) dividing the total number of third instar larvae by the total mass (g) of sample (L3 per g).

Results

A total of 7,389 fruits from 39 fruit species of 29 plant families were collected, totaling 32,242 g of fruits (Table 1). Twelve species of fruit from 8 plant families were hosts to fruit fly larvae: *Spondias mombim* (Anacardiaceae), *Pereskia aculeata* Miller (Cactaceae), *Jacaratia spinosa* (Aubl.) ADC (Caricaceae), *Eugenia myrcianthes* Nied. (Myrtaceae), *Psidium guajava* L. (Myrtaceae), *Campomanesia guazumifolia* (Cambess.) O. Berg (Myrtaceae), *Psidium guineense* (Swartz) (Myrtaceae), *Passiflora alata* Curtis (Passifloraceae), *Passiflora gibertii* N. E.

Br. (Passifloraceae), *Persea americana* Mill. (Lauraceae), *Randia ferox* (Cham. & Schldt.) DC (Rubiaceae), and *Chrysophyllum gonocarpum* (Mart. & Eichler) Engl. (Sapotaceae) (Table 1).

Among the 8 host plant families of fruit flies, 7 fruit species were infested by Tephritidae: cajá (*S. mombim*), ora pro nobis (*P. aculeata*), guava (*P. guajava*), sweet passion fruit (*P. alata*), jacaratiá (*J. spinosa*), sete-capotes (*C. guazumifolia*), araçá (*P. guineense*), and 3 by Lonchaeidae: avocado (*P. americana*), espinho cruz (*R. ferox*), and wild silver passion fruit (*P. gibertii*). Two species, ubajai (*E. myrcianthes*) and aguai (*C. gonocarpum*), were infested by both families of Tephritoidea (Table 1).

From the host fruits, 1,476 larvae of fruit flies were obtained, which produced 968 adults consisting of 878 tephritids and 90 lonchaeids (Table 1). Twelve species of fruit flies were recovered, including 9 species of *Anastrepha* (Tephritidae), and 3 of *Neosilba* (Lonchaeidae): *Anastrepha sororcula* Zucchi, *Anastrepha striata* Schiner, *Anastrepha pseudoparallela* (Loew), *Anastrepha barbiellinii* Costa Lima, *Anastrepha obliqua* (Macquart), *Anastrepha fraterculus* (Wiedemann), *Anastrepha serpentina* (Wiedemann), *Anastrepha elegans* Blanchard, *Anastrepha zenildae* Zucchi (all Tephritidae), *Neosilba certa* Walker, *Neosilba glaberrima* (Wiedemann), and *Neosilba zadolicha* McAlpine & Steyskal (all Lonchaeidae) (Table 1).

Chrysophyllum gonocarpum was the host with the highest frugivorous tephritoid species richness (6), and was infested by 246 adults: *A. elegans* (1 adult), *A. fraterculus* (2), and *A. serpentina* (234). The last 2 associations are new records between species of fruit flies and host fruit. The following *Neosilba* species (Lonchaeidae) also were recovered from this host: *N. certa* (1 adult), *N. glaberrima* (1), *N. zadolicha* (4), and *Neosilba* sp. (3).

Other hosts also were infested by multiple species of fruit flies. *Eugenia myrcianthes* was second in terms of species richness of fruit flies infesting their fruits: *A. sororcula* (9), *A. serpentina* (1), *A. fraterculus* (45), *A. obliqua* (4), and *Neosilba* sp. (6).

Campomanesia guazumifolia was infested by 4 species: *A. fraterculus* (4), *A. zenildae* (3), *A. sororcula* (4), and *A. obliqua* (1), followed by *P. guineense* with 3 frugivorous species: *A. sororcula* (151), *A. fraterculus* (25), and *A. zenildae* (1). *Psidium guajava* was infested by 3 species: *A. sororcula* (71), *A. striata* (3), and *A. fraterculus* (1); *S. mombim* by *A. striata* (1), and *A. obliqua* (2); *P. alata* by *A. pseudoparallela* (10); *P. gibertii* by *Neosilba* spp. (6 ♀ ♀); *P. aculeata* by *A. barbiellinii* (28); *J. spinosa* by *A. striata* (1); *R. ferox* was infested by 3 ♀ ♀ of *Neosilba* spp.; and *P. americana* was infested by 2 species of Lonchaeidae: *N. glaberrima* (30) and *N. zadolicha* (8) (Table 1).

ABUNDANCE

Anastrepha sororcula was the most abundant species ($n = 235$), followed by *A. serpentina* ($n = 234$), *A. fraterculus* ($n = 45$), *A. barbiellinii* ($n = 28$), *A. pseudoparallela* ($n = 10$), *A. striata* ($n = 5$), *A. obliqua* ($n = 4$), and *A. elegans* ($n = 1$).

The most abundant species of Lonchaeidae were *Neosilba zadolicha* ($n = 30$), *N. glaberrima* ($n = 8$), and *Neosilba* sp. (1) (Table 1).

SPECIES RICHNESS

The highest species richness of tephritids ($n = 8$) was recorded along the Marambaia Trail (Bonito, Mato Grosso do Sul, Brazil), where the following species were recovered: *A. striata* and *A. obliqua* from *S. mombim*; *A. barbiellinii* from *P. aculeata*; *A. zenildae* from *P. guineense* and *C. guazumifolia*; *A. sororcula* and *A. fraterculus* from *P. guineense*; and *A. striata* from *J. spinosa*. *Neosilba glaberrima*, *N. zadolicha*, and *Neosilba* sp. were obtained from *P. americana*; *A. fraterculus*, *A. obli-*

Table 1. Fruit flies emerging from fruit sampled from host or non-host plants collected at Parque Nacional da Serra da Bodoquena and surrounding areas (Bonito and Jardim, Mato Grosso do Sul), Brazil, from Jan 2017 to Feb 2018.

Plant family	Plant species	Fruit (g)	Fruits (n)	Larvae (n)	Adults (n)	Fruit fly species (n)
Anacardiaceae	<i>Spondias mombin</i>	1,047	67	3	3	<i>Anastrepha obliqua</i> (2) <i>Anastrepha striata</i> (1)
Annonaceae	<i>Unonopsis guatterioides</i>	90	185	0	0	
Araceae	<i>Anthurium</i> sp.	163	432	0	0	
Arecaceae	<i>Allagoptera caudescens</i>	1,695	683	0	0	
	<i>Attalea speciosa</i>	506	321	0	0	
Boragnaceae	<i>Cordia sellowiana</i>	214	228	0	0	
Bromeliaceae	<i>Ananas ananassoides</i>	2,949	26	0	0	
Bignoniaceae	<i>Fridericia florida</i>	20	5	0	0	
Cactaceae	<i>Opuntia stricta</i>	40	5	0	0	
	<i>Pereskia aculeata</i>	300	112	51	28	<i>Anastrepha barbiellini</i> <i>Neosilba</i> sp.
				2	1	
Caricaceae	<i>Jacaratia spinosa</i>	1,632	31	2	2	<i>Anastrepha striata</i> (1) <i>Anastrepha</i> sp. (1)
Combretaceae	<i>Terminalia triflora</i>	18	27	0	0	
Curcubitaceae	<i>Melothria pendula</i>	97	140	0	0	
Euphorbiaceae	<i>Sebastiania</i> sp.	80	183	0	0	
Lauraceae	<i>Persea americana</i>	7,823	8	110	75	<i>Neosilba zadolicha</i> (30) <i>Neosilba glaberrima</i> (8) <i>Neosilba</i> spp. (33)
Lecythidaceae	<i>Cariniana</i> sp.	647	51	0	0	
Fabaceae	<i>Peltophorum dubium</i>	192	255	1	0	
Myrtaceae	<i>Psidium guajava</i>	1,038	65	191	80	<i>Anastrepha sororcula</i> (71) <i>Anastrepha striata</i> (3) <i>Anastrepha fraterculus</i> (1) <i>Anastrepha</i> spp. (5)
	<i>Campomanesia guazumifolia</i>	489	74	30	19	<i>Anastrepha fraterculus</i> (4) <i>Anastrepha zenildae</i> (3) <i>Anastrepha sororcula</i> (4) <i>Anastrepha obliqua</i> (1) <i>Anastrepha</i> sp. (7)
	<i>Psidium guineense</i>	1,047	75	576	356	<i>Anastrepha sororcula</i> (151) <i>Anastrepha fraterculus</i> (25) <i>Anastrepha zenildae</i> (1) <i>Anastrepha</i> spp. (179)
	<i>Eugenia myrcianthes</i>	779	133	197	145	<i>Anastrepha fraterculus</i> (45) <i>Anastrepha sororcula</i> (9) <i>Anastrepha obliqua</i> (4) <i>Anastrepha serpentina</i> (1) <i>Anastrepha</i> spp. (85) <i>Neosilba</i> sp. (6)
Myrsinaceae	<i>Myrsine guianensis</i>	12	60	0	0	
Myctoginaceae	<i>Guapira opposita</i>	1,061	403	0	0	
Moraceae	<i>Maclura tinctoria</i>	141	89	0	0	
Passifloraceae	<i>Passiflora alata</i>	1,649	10	30	10	<i>Anastrepha pseudoparallela</i> <i>Neosilba</i> sp.
	<i>Passiflora gibertii</i>	257	17	5	5	
Phyllanthaceae	<i>Margarita nobilis</i>	489	118	0	0	
Primulaceae	<i>Clavija</i> sp.	45	20	0	0	
Rhamnaceae	<i>Rhamnidium elaeocarpum</i>	464	598	0	0	

Table 1. (Continued) Fruit flies emerging from fruit sampled from host or non-host plants collected at Parque Nacional da Serra da Bodoquena and surrounding areas (Bonito and Jardim, Mato Grosso do Sul), Brazil, from Jan 2017 to Feb 2018.

Plant family	Plant species	Fruit (g)	Fruits (n)	Larvae (n)	Adults (n)	Fruit fly species (n)
Rubiaceae	<i>Alibertia edulis</i>	1,491	523	0	0	
	<i>Psychotria carthagenensis</i>	163	1,540	0	0	
	<i>Randia ferox</i>	498	260	3	3	<i>Neosilba</i> sp.
Rutaceae	<i>Citrus aurantium</i>	4,083	40	0	0	
	<i>Zanthoxylum</i> sp.	12	60	0	0	
Sapindaceae	<i>Matayba elaeagnoides</i>	5	35	0	0	
Sapotaceae	<i>Chrysophyllum gonocarpum</i>	157	235	279	246	<i>Anastrepha elegans</i> (1) <i>Anastrepha fraterculus</i> (2) <i>Anastrepha serpentina</i> (234) <i>Neosilba certa</i> (1) <i>Neosilba glaberrima</i> (1) <i>Neosilba zadolicha</i> (4) <i>Neosilba</i> sp. (3)
Vitaceae	<i>Cissus verticillata</i>	92	394	0	0	
Volchrysiaceae	<i>Qualea grandiflora</i>	325	12	0	0	
Total		32,242	7,389	1,476	968	

qua, *A. sororcula*, *A. serpentina*, and *Neosilba* sp. from *E. myrcianthes*; and *A. serpentina* from *C. gonocarpum*.

Along the Santa Fé trail (Jardim, Mato Grosso do Sul, Brazil), only 3 species were recovered: *A. sororcula* and *A. striata* from *P. guajava*; and *A. barbiellinii* from *P. aculeata* (Table 2).

Along the Catamarca trail (Bonito, Mato Grosso do Sul, Brazil), a single species was obtained: *A. serpentina*, in the fruits of *E. myrcianthes* (Table 2).

The highest rates of fruit fly infestation occurred in fruit samples from the Marambaia and Santa Fé trails. In some cases only 1 species of tephritid or lonchaeid per host was recovered (Table 2).

VIABILITY AND INFESTATION INDICES

The viability indices (% flies not infested by parasitoids) per fruit fly species were *R. ferox* with 100% viability, *P. gibertii* (100%), *J. spinosa*

Table 2. Viability indices (unparasitized) of fruit flies (Diptera: Tephritidae and Lonchaeidae) and their association with host fruits in the interior of Parque Nacional da Serra da Bodoquena and surrounding areas (Bonito and Jardim, Mato Grosso do Sul), Brazil, from Jan 2017 to Feb 2018.

Host fruits (family, species)	Location	Third instar larvae (n)	Adults (n)	Viability (% unparasitized)
Anacardiaceae			Tephritidae	
<i>Spondias mombin</i>	Marambaia Trail	3	2	66.6
Cactaceae			Tephritidae	
<i>Pereskia aculeata</i>	Santa Fé Trail	51	28	55
Caricaceae	Marambaia Trail	1	1	100
<i>Jacaratia spinosa</i>		2	2	100
Lauraceae			Lonchaeidae	
<i>Persea americana</i>	Marambaia Trail	110	75	68
Myrtaceae			Tephritidae	
<i>Eugenia myrcianthes</i>	Marambaia Trail	197	145	73.6
<i>Psidium guajava</i>	Santa Fé Trail	191	80	42
<i>Psidium guineense</i>	Marambaia Trail	576	356	61.8
<i>Campomanesia guazumifolia</i>	Marambaia Trail	30	19	63.3
		21	8	38
Passifloraceae			Tephritidae	
<i>Passiflora alata</i>	Marambaia Trail	30	10	33.3
			Lonchaeidae	
<i>Passiflora gibertii</i>	Marambaia Trail	5	5	100
Rubiaceae			Lonchaeidae	
<i>Randia ferox</i>	Catamarca Trail	3	3	100
Sapotaceae			Tephritidae	
<i>Chrysophyllum gonocarpum</i>	Marambaia Trail	279	246	88.1

(100%), followed by *C. gonocarpum* (88.1%), *E. myrcianthes* (73.6%), *P. americana* (68%), *S. mombin* (66.6%), *C. guazumifolia* (63.3%), *P. guineense* (61.8%), *P. aculeata* (55%), and *P. alata* (33.3%). The viability index of Tephritidae was 90.7% and for Lonchaeidae it was 9.3% (Table 2).

The fruit trees with the highest fruit infestation rates (number of larvae per fruit) were *P. americana* (13.75), *P. guineense* (7.6), *P. alata* (3), *P. guajava* (2.9), *C. guazumifolia* (2.4), *E. myrcianthes* (1.48), *C. gonocarpum* (1.18), *P. aculeata* (0.45), *P. gibertii* (0.29), *P. alata* (0.3), *J. spinosa* (0.06), *R. ferox* (0.006), and *S. mombin* (0.02) (Table 3). In relation to the indices of infestation of fruit fly larvae per mass of fruit, the highest indices were found in *C. gonocarpum* (1.77), *P. guineense* (0.40), *E. myrcianthes* (0.25), *P. guajava* (0.18), *P. aculeata* (0.17), *P. gibertii* (0.019), *P. alata* (0.018), *P. americana* (0.014), *R. ferox* (0.011), *C. guazumifolia* (0.006), and *J. spinosa* (0.001) (Table 3).

Discussion

TEPHRITIDAE

Anastrepha sororcula was the most abundant species in *P. guajava*, *C. guazumifolia*, and *P. guineense*. This species is commonly obtained from Myrtaceae, both wild and cultivated, in several studies (Bomfim et al. 2007; Marsaro Junior et al. 2013). In Mato Grosso do Sul, *A. sororcula* is the most abundant species in guava, as shown by Uchoa et al. (2002) and Uchoa and Nicácio (2010), results that are consistent with this research.

Anastrepha serpentina was recovered from fruits of Myrtaceae and Sapotaceae. This species attacks a wide diversity of fruits, and it has been recorded that it infested 7 families and 22 species (Zucchi & Moraes 2008), including sweet orange (*Citrus sinensis* L.) and tangerine (*Citrus reticulata* Blanco) (Rutaceae) (Lemos et al. 2011). Among the 22 hosts in which this species is recorded, 12 are Sapotaceae (Zucchi & Moraes 2008), indicating this family of plants as their preferred hosts. This explains the high abundance of *A. serpentina* in *C. gonocarpum*.

Anastrepha fraterculus was obtained from 4 host species in 2 families: *E. myrcianthes*, *P. guineense*, *C. guazumifolia* (all Myrtaceae), and *C. gonocarpum* (Sapotaceae) in descending order of abundance. This is the most polyphagous species of the genus *Anastrepha*, attacking 116 species of fruits from 27 families of plants (Zucchi & Moraes 2008). The

discovery of *A. fraterculus* infesting *E. myrcianthes* emphasizes the importance of research on trophic interactions between tephritid species and fruit trees in conservation units. *Eugenia myrcianthes* is phylogenetically close to other co-generic species of genus *Eugenia*. In addition, *A. fraterculus* already had been reported in *Eugenia schomburgkii* Benth (Raga et al. 2005), *Eugenia desynerica* DC (Silva et al. 2010), and *Eugenia uniflora* L. (Veloso et al. 2012).

Anastrepha barbiellinii is considered monophagous because *P. aculeata* is its only known host (Zucchi & Moraes 2008). This species was reported in a few inventories in other Brazilian states: São Paulo (Uramoto et al. 2004), Santa Catarina (Garcia & Norrbom 2011), and Rio de Janeiro (Ferrara et al. 2004). This species has the potential to be included in the list of fruit fly pests because at least 2 species of Cactaceae, which may be potential hosts, have been economically exploited in Brazil: pitahaya, *Hylocereus undatus* (Haw.) Britton & Rose, from Colombia, and the fig of India, *Opuntia ficus-indica* (L.) Miller (both Cactaceae). This last species already had been reported as being infested by *A. fraterculus* (Junqueira et al. 2002; Torres et al. 2009; Leite et al. 2017).

Anastrepha pseudoparallela herein was recovered only from *P. alata*. This species is reported attacking 6 host fruits: 4 species of passion fruit (*P. alata*, *P. edulis*, *P. quadrangularis*, *P. elegans* Mast.), *M. indica*, and the Neotropical Myrtaceae *P. guajava* (Uramoto et al. 2004; Garcia & Norrbom 2011; Marsaro Junior 2014), suggesting a probable preference of this fruit fly species for Passifloraceae. In research on trophic associations between fruit flies and their host plants, *A. pseudoparallela* has been recovered only from fruits of the genus *Passiflora* (Garcia & Norrbom 2011; Araújo et al. 2018).

Anastrepha striata was recovered from 3 hosts: *P. guajava*, *S. mombin*, and *J. spinosa*. This species usually is abundant in fruits of Myrtaceae, such as *P. guajava* and *P. guineense* (Marsaro Junior 2011; Marsaro Junior et al. 2013), but in this study its infestation in guava was considered low, probably due to the competition with *A. sororcula*, which was quite abundant.

In an earlier study, there were reports of 2 species of *Anastrepha* (*A. fraterculus* and *Anastrepha turpiniae* Stone) (Diptera: Tephritidae) infesting Caricaceae in Brazil (Martins et al. 1993). *Anastrepha striata* is reported here as an additional species that can infest Caricaceae. *Anastrepha striata* is polyphagous, with a wide range of hosts already reported, including cashew (*Anacardium occidentale* L.) (Anacardiaceae) (Jesus-Barros et al. 2012) and araçá (*Psidium cattleianum* Sabine) (Myrtaceae) (Uchoa & Nicácio 2010).

Table 3. Infestation of larvae per number of fruit and flies per fruits from fruit tree species infested by frugivorous flies (Tephritidae and Lonchaeidae) in the interior of Parque Nacional da Serra da Bodoquena and surrounding areas (Bonito and Jardim, Mato Grosso do Sul), Brazil, from Jan 2017 to Feb 2018.

Plant family	Fruit tree species	Third instar larvae (n)	Fruits (n)	Fruits weight (g)	Relative infestation (n per mass [g] of fruits)	Relative infestation (flies per fruits)
Anacardiaceae	<i>Spondias mombin</i>	2	67	1,047	0.001	0.02
Cactaceae	<i>Pereskia aculeata</i>	51	112	300	0.17	0.45
Caricaceae	<i>Jacaratia spinosa</i>	2	31	1,632	0.001	0.06
Lauraceae	<i>Persea americana</i>	110	8	7,832	0.014	13.75
Myrtaceae	<i>Psidium guajava</i>	191	65	1,038	0.18	2.9
	<i>Campomanesia guazumifolia</i>	30	74	489	0.06	2.4
	<i>Psidium guineense</i>	576	75	1,417	0.40	7.6
	<i>Eugenia myrcianthes</i>	197	133	779	0.25	1.48
Passifloraceae	<i>Passiflora alata</i>	30	10	1,649	0.018	3
	<i>Passiflora gibertii</i>	5	17	257	0.019	0.29
Rubiaceae	<i>Randia ferox</i>	3	498	160	0.018	0.006
Sapotaceae	<i>Chrysophyllum gonocarpum</i>	279	235	157	1.77	1.18

The low level of abundance of *A. striata* in this study may result from the absence of its favorite hosts in the park, as well as local competition with other *Anastrepha* species. In native forests, where there is a tendency for more effective parasitism, this pest species may be disfavored. In addition, most of the hosts reported for *A. striata* are fruits with a large proportion of endocarp, such as guava (Uchoa et al. 2002), sour passion fruit (*Passiflora edulis* Sims) (Passifloraceae), and jackfruit (*Artocarpus heterophyllus* Lam.) (Moraceae) (Zucchi & Moraes 2008). These species are less common in natural environments (Uchoa et al. 2002; Bomfim et al. 2007, 2014).

Anastrepha obliqua was recovered from *S. mombin*, *C. guazumifolia*, and *E. myrcianthes*. *Anastrepha obliqua* was reported previously in 50 hosts (Zucchi & Moraes 2008). Here, for the first time, *A. obliqua* is associated with *E. myrcianthes*. This is the second most polyphagous species of the genus *Anastrepha*, being reported in several countries of South and Central America (Ovruski et al. 2009; Uchoa 2012; Sosa-Armenta et al. 2015). The low level of abundance of this species in the evaluated conservation unit may be related to the absence of its preferred hosts, such as cultivated species of Myrtaceae, Anacardiaceae, and Oxiladeaceae. *Anastrepha obliqua* has been reported as one of the most abundant species in guava, cashew, and star fruit (Uchoa 2012).

Anastrepha elegans was recovered from fruits of *C. gonocarpum*, its only known host. This association has been reported already by Garcia et al. (2008). There are few records of *A. elegans* in Brazil: Mato Grosso do Sul (Canesin & Uchoa 2007); São Paulo (Uramoto et al. 2004), Santa Catarina (Garcia et al. 2003), Paraná (Garcia 2003), and Rio Grande do Sul (Garcia et al. 2002). The low level of abundance of this species likely derives from its food habit (monophagy). It is believed that there are few individuals of *C. gonocarpum* in the park because it is a forest environment where fruit species are randomly distributed.

Anastrepha zenildae was recovered from 2 hosts: *C. guazumifolia* and *P. guineense*. It is considered a polyphagous species of great economic importance (Uchoa 2012). *Anastrepha zenildae* is reported infesting a wide range of hosts, including guava (Uchoa 2012), juá (*Ziziphus joazeiro* Mart.) (Rhamnaceae) (Canal et al. 1998), and guavira (*Campomanesia sessiflora* (O. Berg) Mattos) (Myrtaceae) (Uchoa et al. 2002).

In this study, the infestation by *A. zenildae* was considered low ($n = 4$), similar to the results of other inventories carried out in natural environments (Bomfim et al. 2007; Uchoa & Nicácio 2010). In native forests, such as conservation units, the abundance of available host fruits is lower than in commercial orchards, where they are found in great abundance and with uniform spatial distribution (Araújo et al. 2013). In addition, the same fruit tree may be host to several species of fruit flies, especially for the polyphagous species, such as *A. fraterculus* and *A. sororcula*, both found in great abundance in this study. In this study, the diversity of the tephritid species is directly related to the abundance of fruits in the samples: the fruit species with the highest species number of fruit flies were those with greater abundance and biomass of fruit in the sample (e.g., *C. gonocarpum*, *P. guineense*, and *E. myrcianthes*).

Anastrepha barbiellinii was observed for the first time infesting *P. aculeata* in Mato Grosso do Sul. We also observed for the first time *A. serpentina*, *A. fraterculus*, and *A. obliqua* infesting fruits of *E. myrcianthes* and *A. striata* in *J. spinosa*, and *A. zenildae* in *C. guazumifolia*.

LONCHAEIDAE

Lonchaeid species are as important as the tephritids in the infestation of many fruit species of economic interest. In certain plant taxa, such as *Citrus* spp. (Rutaceae) and several other native species, some species of *Neosilba* are primary invaders (Uchoa et al. 2002). More-

over, they also are indirectly responsible for the process of putrefaction of host fruits (Uchoa 2012).

Several species of the genus *Neosilba* are considered polyphagous, infesting a wide diversity of host plants in the Neotropical region. The 5 species considered the most important of this genus are *N. zadolicha*, *Neosilba pendula* (Bezzi), *N. glaberrima*, *Neosilba perezii* (Romero & Ruppell), and *Neosilba inesperata* Strikis & Prado (all Diptera: Lonchaeidae) (Uchoa 2012).

Neosilba zadolicha can be considered a primary pest in many fruit species in several regions of the country. Among its hosts are coffee, *Coffea arabica* L. (Rubiaceae) (Strikis & Prado 2005); araticum, *Annona rugulosa* (Schltdl.) H. Rainer (Annonaceae); araçá, *Psidium cattleianum* Sabine (Myrtaceae); and peach, *Prunus persica* (L.) Batsch. (Rosaceae) (Garcia & Norrbom 2011).

In this study, *N. zadolicha* was found infesting *P. americana* and *C. gonocarpum*. In the latter, it co-occurred with *A. serpentina*. No species of *Anastrepha* was recovered in *P. americana* in the present study, although *A. striata* has been reported already from avocado fruits (Uchoa et al. 2002). The results obtained here point out that some species of lonchaeids, such as *N. glaberrima* and *N. zadolicha*, apparently can be primary pests of avocado, in contrast to some reports (Araújo & Zucchi 2002; Souza-Filho et al. 2003) in which the lonchaeids were considered secondary or opportunistic pests, colonizing only fruits previously punctured by tephritids.

Recent research has associated *N. certa* with 15 hosts (Uchoa 2012 [11 hosts]; Gisloti et al. 2017 [2]; Santos et al. 2017 [2]). However, in this study, it was recovered only from *C. gonocarpum*. The low level of abundance of *N. certa* is possibly related to the interspecific competition with *A. serpentina* individuals ($n = 234$), which was more abundant in this host fruit.

Neosilba glaberrima is reported to infest 21 hosts (Uchoa 2012; Gisloti et al. 2017; Santos et al. 2017). In this research, this species was recovered only from *C. gonocarpum* and *P. americana*; both are new records. However, *N. zadolicha*, *N. certa*, *N. glaberrima*, *N. pendula*, and *Neosilba parva* (Hennig) (Diptera: Lonchaeidae) have been reported from *P. americana* (Raga et al. 2015). *Neosilba* species have been found in greater abundance and frequency in avocado than tephritids (Aluja et al. 2004; Raga et al. 2011). Until this study, only *A. striata* was obtained from *P. americana* (Uchoa et al. 2002; Uchoa 2012), indicating this host fruit as preferred for *N. glaberrima*.

More research on lonchaeids and their host fruits in natural environments are needed, because knowledge about their biology and trophic associations with host plants and natural enemies are scarce in the Neotropical region. In this research we provide the first reports of *N. glaberrima* and *N. zadolicha* infesting *P. americana*, and *N. certa* infesting *C. gonocarpum*.

Acknowledgments

We would like to thank the Instituto Chico Mendes de Conservação da Biodiversidade for its authorization for this research in the Parque Nacional da Serra da Bodoquena and for the logistic support and facilities to the research team.

To Zefa Valdivina Pereira, Faculdade de Ciências Biológicas e Ambientais, Universidade Federal da Grande Dourados and Ângela Sartori, Departamento de Biologia da Universidade Federal de Mato Grosso do Sul, for identifying the species of sampled plants; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior for the award of scholarship to the first (L. B. M. A.) and third (J. B. C.) authors.

Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul, and Coordenação de Aper-

feijão de Pessôal de Nível Superior: FUNDECT-CAPES-PAPOS-MS 44/2014, and FUNDECT-CAPES 12/2015-BIOTA-MS-Ciência e Biodiversidade for financial support. Also, Universidade Federal da Grande Dourados for financial support.

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