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Frugivorous flies (Diptera: Tephritidae, Lonchaeidae) associated with fruit production on Ilha de Santana, Brazilian Amazon

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Abstract

We conducted a survey of the species of frugivorous flies (Tephritidae and Lonchaeidae), their hosts, and their parasitoids found on Ilha de Santana, Amapá State, Brazilian Amazon. We also assessed host plant use by Bactrocera carambolae Drew & Hancock. Fruits were collected from various plant species, at 30 d intervals, from Jan to Jul 2015. In total, 149 fruit samples were collected (3,142 fruits, 76.3 kg), belonging to 20 plant species (9 native and 11 introduced) in 13 botanical families. Infestation by fruit flies was observed in 86 samples (11 species in 8 botanical families). Specimens of 5 species of Tephritidae and 4 species of Lonchaeidae fruit flies were obtained, as well as 3 species of braconid parasitoids. The most important fruit fly species on Ilha de Santana are: B. carambolae, for being a species of quarantine importance; and Anastrepha obliqua (Macquart) and Anastrepha striata Schiner, for infesting plant species of local socioeconomic importance. Averrhoa carambola (Oxalidaceae), Eugenia uniflora (Myrtaceae), Malpighia emarginata (Moc. & Sesse) ex DC. (Malpighiaceae), and Psidium guajava (Myrtaceae) are the host plants responsible for sustaining the population of B. carambolae.

Key Words: Bactrocera carambolae; Anastrepha; Neosilba; Doryctobracon

Resumo

Este trabalho teve por objetivo identificar as espécies de moscas frugívoras (Tephritidae e Lonchaeidae), seus hospedeiros e parasitóides na Ilha de Santana, estado do Amapá, Amazônia brasileira. Adicionalmente, objetivou estudar a exploração hospedeira por Bactrocera carambolae Drew & Hancock. Foram realizadas coletas de frutos de diversas espécies vegetais, a cada 30 dias, no período de janeiro a julho de 2015. Foram coletadas 149 amostras de frutos (3.142 frutos, 76.3 Kg), pertencentes a 20 espécies vegetais (9 nativas e 11 introduzidas) de 13 famílias botânicas. Houve infestação por moscas frugívoras em 86 amostras (11 espécies de 8 famílias botânicas). Foram obtidos espécimes de cinco espécies de Tephritidae, quatro de Lonchaeidae e três de parasitóides Braconidae. As espécies de moscas frugívoras mais importantes na Ilha de Santana são: B. carambolae, devido sua expressão quarentenária; e Anastrepha obliqua (Macquart) e Anastrepha striata Schiner, pelo fato de infestarem espécies vegetais de importância socioeconômica local. Os hospedeiros Averrhoa carambola (Oxalidaceae), Eugenia uniflora (Myrtaceae), Malpighia emarginata (Malpighiaceae) e Psidium guajava (Myrtaceae) são responsáveis pela manutenção da população de B. carambolae.

Palavras Chave: Bactrocera carambolae; Anastrepha; Neosilba; Doryctobracon

Tephritidae and Lonchaeidae are the principal families of Diptera whose larvae use the flesh of fruits or parts of plants as substrates for their development. Tephritidae are among the major groups of phytophagous insects of worldwide economic importance (Aluja 1994). Their larvae develop on fruits of various species of fruit-bearing trees, making them unsuitable for sale and consumption (Aluja & Mangan 2008). In addition, some species can make export impossible due to quarantine restrictions imposed by importing countries where a specific pest is not already present (Malavasi 2000).

Tephritidae that have economic importance are most frequently studied (Aluja & Norrbom 2000). Anastrepha Schiner is viewed as the genus of highest economic importance to the Americas (UCHÔA & NICÁCIO 2010). In Brazil, 6 species are particularly important: Anastrepha striata Schiner, Anastrepha obliqua (Macquart), Anastrepha fraterculus (Wiedemann), Anastrepha grandis (Macquart), Anastrepha pseudoparallela (Loew), and Anastrepha zenildae Zucchi (ZUCCHI & ZUCCHI 2009). Two exotic introduced species also occur in the country: Ceratitis capitata (Wiedemann), known as the Mediterranean fruit fly,
and Bactrocera carambolae Drew & Hancock, the carambola fruit fly (Zucchi 2001).

Bactrocera carambolae is considered a quarantine pest present in Brazil, and though limited to the states of Amapá and Roraima (Brazil 2013), it is subject to rigorous official control (Lemos et al. 2014). Bactrocera carambolae is the biggest phytosanitary barrier to Brazilian fruit agribusiness exports, because the main buyers of Brazilian fruit establish restrictions against acquiring products from countries where the pest is present. The Brazilian government, through its Ministry of Agriculture, Livestock and Food Supply, established a National Program for Eradication of the Carambola Fruit Fly, aiming to eliminate the pest from the states of Amapá and Roraima and maintain the “B. carambolae-free” status of other Brazilian states (Godoy et al. 2011).

As frugivorous dipterans whose larvae can damage fruit and vegetables, Lonchaeidae have been reported as primary pests of various crops in Brazil, with species of economic importance being found in the genera Dasiops Rondani and Neosilba McAlpine (Uchôa 2012). Some recent studies on Lonchaeidae have been conducted in Brazil, driven by advances in taxonomic knowledge about Brazilian lonchaeids (Lemos et al. 2015). However, the scarcity of studies on lonchaeid taxonomy, biology, and ecology has been hindering the development of strategies to manage these insects (Strikis et al. 2011).

In the state of Amapá, located in the Brazilian Amazon, studies on frugivorous flies and their natural enemies were started only recently. However, especially in the past 10 yr, knowledge about species that occur in Amapá, their hosts, and their parasitoids has grown significantly. On the other hand, some localities within the state remain poorly studied, including Ilha de Santana. The island belongs to the municipality of Santana and is characterized by small rural properties where fruit trees are grown, mainly for the production of fruit concentrates. The only existing survey of fruit flies on Ilha de Santana was conducted between Jan and Jul 2005 (Silva et al. 2007). The authors collected 44 samples of 13 plant species (4,177 fruits, 78.7 kg) and obtained specimens of A. obliqua on fruits of Spondias mombin Jacq. (Anacardiaceae), A. striata on fruits of Psidium guajava L. (Myrtaceae), and Anastrepha leptozona Hendel on fruits of Pouteria caimito (Ruiz & Pav.) Radlk. (Sapotaceae).

Three species of parasitoids were also obtained: Doryctobracon aroloatus (Szépligeti), Opius bellus Gahan, and Asobara anastrephae (Muesebeck) (Hymenoptera: Braconidae).

We conducted research to expand our knowledge of the frugivorous flies (Tephritidae and Lonchaeidae), their hosts, and their parasitoids found on Ilha de Santana, Amapá State, Brazilian Amazon. We also assessed host plant use by B. carambolae.

**Materials and Methods**

**SITE CHARACTERISTICS**

The study was conducted on Ilha de Santana, municipality of Santana, state of Amapá, Brazil (Fig. 1). The island occupies an area of approximately 2,005 ha and is situated on the banks of the Norte Canal, facing the city of Santana, between the geographic coordinates 00.0666667°S and 00.1000000°S, and 00.0666667°W and 51.2083333°W (Valente et al. 1998).

The predominant climate in the area is Am’w under the Köppen classification system, characterized as a tropical wet climate with a well-defined dry season, with mean temperatures never dropping below 18 °C and annual fluctuations seldom exceeding 5 °C. Annual precipitation ranges from 1,300 to 1,900 mm, with well-defined rainy and dry seasons (Dec to Mar and Aug to Nov, respectively). The predominant soils are Yellow Latosol and Haplic Gleysol. Yellow Acrisol, Fluvic Neosol, and Indiscriminate Hydromorphic Soils are also present (Valente et al. 1998).

The island is located 600 to 800 m from the Port of Santana. Access is obtained using small boats. The predominant activity on the island is small-scale family agriculture, with fruit growing as the most representative activity. Products are sold once a week, mainly in the form of fruit concentrate, in public farmers’ markets in the municipalities of Macapá and Santana.

**SAMPLING PROCEDURES**

Monthly sampling of fleshy fruits from various plant species was performed from Jan to Jul 2015, a period in which there is high availability of fruiting plants in the region. To quantify the rate of infestation by fruit flies and the percentage of parasitism, we applied the grouped samples method described by Silva et al. (2011a).

As the availability of fruits is small-scale family agriculture, with fruit growing as the most representative activity, products are sold once a week, mainly in the form of fruit concentrate, in public farmers’ markets in the municipalities of Macapá and Santana.

**ACQUISITION OF PUPARIA AND ADULT INSECTS**

In the laboratory, the fruits were weighed and transferred to plastic trays containing a thin layer of sterilized, moistened vermiculite. The trays were covered with organza fabric fastened in place with rubber bands. The material on the trays was examined every 3 d. Recovered puparia were removed and transferred to transparent plastic jars (8 cm diameter) containing a thin layer of moistened vermiculite. The bottles were covered with organza fastened in place with a vented lid, then placed in climate-controlled chambers under controlled temperature (27 ± 0.5 °C), relative humidity (70 ± 10%) and photoperiod (12:12 h L:D). They were checked daily for puparia. Adult insects that emerged (fruit flies and parasitoids) were killed and stored in glass vials containing 70% ethanol, duly tagged for subsequent identification.

**IDENTIFICATION OF INSECTS**

Specimens of Anastrepha were identified using the illustrated identification key published by Zucchi et al. (2011). Only females were used for identification, which was performed by examination of everted aculi, using a stereomicroscope and optical microscope (40×). Other characteristics were also observed, including wing pattern, mesonota, metatergite, and scutellum. Confirmation of B. carambolae identity was based on the identification key published by Drew & Hancock (1994). To identify parasitoids (Hymenoptera: Braconidae), we used the work of Canal & Zucchi (2000) and Marinho et al. (2011). Neosilba specimens were identified according to McAlpine & Steyskal (1982) and Strikis (2011).

**IDENTIFICATION OF BOTANICAL MATERIAL**

To identify the forest plant species, we collected branches containing their reproductive structures (flowers and fruits), which were later processed into herbarium specimens using the mounting and preserv-
vation techniques described by Fidalgo & Bononi (1984). The plant species were identified using identification keys and specialized literature, as well as comparison with specimens available at the Herbário Amapaense (HAMAB), the herbarium at the Amapá Institute for Scientific and Technological Research (IEPA) in Macapá, Amapá, Brazil.

DATA ANALYSES

The following data were calculated: 1) infestation index = number of puparia obtained/weight (kg) of fruit collected; 2) emergence = (number of emerged flies + number of emerged parasitoids)/total number of puparia × 100; and 3) percentage of parasitism = (number of parasitoids emerged/number of puparia) × 100.

Results

In total, 149 fruit samples were collected (3,142 fruits, 76.3 kg), belonging to 20 plant species (9 native and 11 introduced) in 13 botanical families. Infestation by fruit flies was observed in 86 samples (11 species in 8 botanical families). The sampled host plants were: Averrhoa carambola L. (Oxalidaceae), Capsicum baccatum L. (Solanaceae), Eugenia uniflora L. (Myrtaceae), Inga edulis Mart. (Fabaceae), Licania sp. (Chrysobalanaceae), Malpighia emarginata (Moc. & Sesse) ex DC. (Malpighiaceae), Mangifera indica L. (Anacardiaceae), Passiflora sp. (Passifloraceae), P. guajava, Spondias mombin Jacq. (Anacardiaceae), and Syzygium cumini (L.) Skeels (Myrtaceae) (Table 1).

We obtained 4,046 puparia, from which emerged specimens of Tephritidae (5 species), Lonchaeidae (4 species), and Braconidae (3 species). Emergence ranged from 14.3% (on P. indica) to 100% (on Passiflora sp.), and was higher than 50% on 8 plant species. The highest infestation rates were obtained on S. mombin (174.1 puparia per kg of fruit), S. cumini (106.4), P. guajava (142.0), and E. uniflora (125.6). The host plants infested by the largest numbers of fruit flies were M. emarginata and S. mombin (Tables 1 and 2).

TEPHRITIDAE

The species of Tephritidae obtained were: A. striata, A. obliqua, A. fraterculus, Anastrepha antunesi Lima, and B. carambolae (Table 1). Anastrepha striata occurred on 2 hosts (M. emarginata and P. guajava) and A. obliqua occurred on 3 (S. mombin, M. emarginata, and S. cumini). Anastrepha antunesi and A. fraterculus occurred exclusively on S. mombin (Table 2). Bactrocera carambolae occurred on 8 of the 11 plant species infested by fruit flies: A. carambola, E. uniflora, Licania sp., M. emarginata, M. indica, P. guajava, S. mombin, and S. cumini (Tables 1, 2, and 3).

Fig. 1. Sampling sites of fruits on Ilha de Santana, state of Amapá, Brazil (Jan to Jul 2015).
Table 1. Rates of infestation of various plant species by fruit flies on Ilha de Santana, Amapá, Brazil (Jan to Jul 2015).

| Families              | Scientific names [Portuguese] | Common names          | Origin | Samples | Fruits (n) | Mass (kg) | Infestation | Emergence (%) | Tephritidae (n) | Lonchaeidae (n) | Hymenoptera (n) | %P |
|----------------------|------------------------------|-----------------------|--------|---------|------------|-----------|-------------|---------------|----------------|----------------|----------------|----------------|-----|
| Anacardiaceae        | Spondias mombin L.           | Taperebá              | N      | 11/11   | 387        | 4.9       | 853         | 174.1         | 67.9           | A(99♂), A(2♀), Aa(1♀), 108♂ + Bc(1) |     | Da(327), Ob(37), Ua(4) | 43.1 |
|                      | Spondias purpurea L.         | Seriguela              | I      | 1/0     | 20         | 0.2       | —           | —             | —              | —              | —              | —              |     |
|                      | Mangifera indica L.          | Manga                 | I      | 11/1    | 80         | 14.4      | 7           | 0.5           | 14.3           | Bc(1)          | —              | —              |     |
| Apocynaceae          | Hancornia speciosa Gomes     | Mangaba               | N      | 1/0     | 20         | 0.5       | —           | —             | —              | —              | —              | —              |     |
|                      | Chrysobalanaceae             | Licania sp.            | N      | 3/2     | 81         | 0.9       | 7           | 7.8           | 71.4           | Bc(2)          | —              | Da(2), nl(1) | 42.8 |
| Fabaceae             | Inga edulis Mart.            | Ingá—cipó             | N      | 1/1     | 11         | 0.7       | 2           | 2.9           | 50.0           | —              | Nz(1♂)         | —              |     |
| Lauraceae            | Persea americana Mill.       | Abacate                | I      | 3/0     | 11         | 2.0       | —           | —             | —              | —              | —              | —              |     |
| Malpighiaceae        | Malpighia emarginata D.C     | Acerola                | I      | 27/22   | 1,205      | 5.5       | 293         | 53.3          | 58.0           | Ao(6♂), As(1♀), 5♂ + Bc(144) | Npd(5♂, 2♀), Npz(2♂, 3♀), Nz(1♂) | Da(1) | 0.3  |
| Apocynaceae          | Byrsonima crassifolia (L.)   | Muruci                 | N      | 4/0     | 98         | 0.2       | —           | —             | —              | —              | —              | —              |     |
| Melastomataceae      | Bellucia grossularioides (L.)| Triana Goiaba—de—anta | N      | 1/0     | 33         | 0.3       | —           | —             | —              | —              | —              | —              |     |
| Myrtaceae            | Syzygium cuminii (L.) Skeels | Ameixa roxa            | I      | 3/3     | 147        | 1.1       | 117         | 106.4         | 21.4           | Ao(3♂), 2♂ + Bc(10) | —             | Da(10) | 8.5   |
| Passifloraceae       | Passiflora sp.               | Maracujá              | N      | 13/1    | 55         | 8.1       | 1           | 0.1           | 100            | —              | Ng(1♂)         | —              |     |
| Rubiaceae            | Morinda citrifolia L.        | None                  | I      | 8/0     | 80         | 6.6       | —           | —             | —              | —              | —              | —              |     |

N: native; I: introduced; C: collected; n: number; PP: puparia; %P: percentage of parasitism; Aa: Anastrepha antunesi; Ao: Anastrepha obliqua; Af: Anastrepha fraterculus; As: Anastrepha striata; Bc: Bactrocera carambolae (♀, ♂); Nz: Neosilba glaberrima; Npd: Neosilba pendula; Npz: Neosilba pseudozadolicha; Ns: Neosilba zadolicha; Da: Doryctobracon areolatus (♀, ♂); Ob: Opius bellus (♀, ♂); Ua: Utetes anastrephae (♀, ♂); ni: not identified.
Table 1. Rates of infestation of various plant species by fruit flies on Ilha de Santana, Amapá, Brazil (Jan to Jul 2015).

| Families | Origin | Samples | Fruits | Mass (kg) | Puparia (n) | Infestation (PP/kg) | Parasitoids (n) |
|----------|--------|---------|--------|-----------|-------------|---------------------|-----------------|
| Tephritidae | Lonchaeidae | Hymenoptera | Rutaceae | Orange | Citrus aurantium | 1 | 5/0 | 45 | 5.5 | 4,046 | — | — | — | — |
| | | | Citrus limon | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus maxima | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
| | | | Citrus paradisi | | | | | | | | | | | | |
| | | | Citrus unshiu | | | | | | | | | | | | |
| | | | Citrus sinensis | | | | | | | | | | | | |
Table 2. Fruit flies obtained from host plants sampled in each month of sampling on Ilha de Santana, Amapá, Brazil (Jan to Jul 2015).

| Hosts                  | Sampling months¹ |  |  |  |  |  |  |  |
|------------------------|------------------|---|---|---|---|---|---|---|
|                        | Jan              | Feb | Mar | Apr | May | Jun | Jul |
| Averrhoa carambola     | B. carambola     | B. carambola | B. carambola | N. zadolicha³ | N. glaberrima³ | N. zadolicha |
| Capsicum baccatum      |                 | B. carambola | N. zadolicha | B. carambola | B. carambola | B. carambola |
| Eugenia uniflora¹      |                 | B. carambola | N. zadolicha | B. carambola | B. carambola | B. carambola |
| Inga edulis            |                 |                 |                 |                 |                 |                 |
| Licania sp.¹           |                 |                 |                 |                 |                 |                 |
| Malpighia emarginata   | B. carambola     | B. carambola | B. carambola | N. pseudozadolicha³ | N. pseudozadolicha³ | N. pseudozadolicha³ | B. carambola |
| Mangifera indica       |                 |                 |                 |                 | B. carambola |                 |                 |
| Passiflora sp.¹        | N. glaberrima³   |                 |                 |                 |                 |                 |                 |
| Psidium guajava        | A. striata       | A. striata     | B. carambola | A. striata | B. carambola | B. carambola | B. carambola |
| Spondias mombin        | A. obliqua       | A. obliqua     | A. obliqua    | A. obliqua   | A. obliqua   | A. obliqua   |                 |
| Syzygium cumini³       |                 |                 |                 |                 |                 |                 |                 |

¹ Area in gray indicates that the plant species was collected in the corresponding month.
² New host for Bactrocera carambola in Brazil.
³ New association between host plant and Neosilba species in the Brazilian Amazon.
⁴ New association between host plant and Neosilba species in the state of Amapá.
at many localities in South America, including the Brazilian Amazon (Aluja 1994; Silva et al. 2011b; Marsaro Júnior et al. 2013). In addition, A. stria is the most abundant and widely distributed tephritid species in the state of Amapá, and is also the most polyphagous (infesting 25 host plants in 16 botanical families) (Silva et al. 2011c; Jesus-Barrós et al. 2012).

Anastrepha obliqua has been particularly associated with S. mombin. In surveys conducted in the state of Amapá, A. obliqua was predominant on this host (Silva et al. 2007, 2011d; Deus et al. 2009, 2013). In this work, the mean infestation index was 173.2 puparia per kg, lower than the highest index reported for this host in the state of Amapá, i.e., 385.1 puparia per kg in samples obtained at Serra do Navio (Deus et al. 2013). These results show the importance of A. obliqua as a pest of S. mombin in the state of Amapá (Silva & Ronchi-Teles 2000; Deus & Adaime 2013; Deus et al. 2016), especially as the fruit is very well-liked by the local population, who purchase it as concentrate to be made into juice.

This is the first report of A. obliqua associated with S. cumini in Brazil. On the other hand, A. obliqua has already been associated with M. emarginata in the states of Amapá, Pará, and Roraima (Ohashi et al. 1997; Amorim et al. 2004; Marsaro Júnior et al. 2011; Lemos 2014). Anastrepha antunesi and A. fraterculus had already been associated with S. mombin in the state of Amapá (Deus & Adaime 2013).

Bactrocera carambola was obtained from 8 plant species, with E. uniflora, S. cumini, and Licania sp. representing new reports of host plants for the species in Brazil. The other plant species had already been reported to be hosts of B. carambola in Amapá (Silva et al. 2004; Lemos et al. 2010, 2014).

LONCHAEIDAE

All Lonchaeidae obtained in this study are first reports for Ilha de Santana. Neosilba glaberrima and N. zadolicha infested the highest number of hosts (Tables 1 and 3), confirming the results obtained by Strikis et al. (2011) and Lemos et al. (2015), which indicated that these are the most polyphagous species of Lonchaeidae in the Amazon region. They are also among the species of highest economic importance for South America (Uchôa 2012).

In the Brazilian Amazon, N. pendula had already been reported on M. emarginata in the states of Pará and Roraima (Perreira & Adaime 2016). Araújo & Zucchi (2002) reported the species as an important primary invader of M. emarginata fruits in the state of Rio Grande do Norte.

No specimens of Lonchaeidae were obtained from S. mombin. This result was repeated during the sampling performed by Lemos et al. (2015) in 3 municipalities of Amapá (14 samples, containing 210 fruits in total).

Five samples of 4 plant species were infested exclusively by species of Neosilba: N. glaberrima on P. edulis (1 sample), N. pendula on M. emarginata (1 sample), N. zadolicha on I. edulis (1 sample), and N. zadolicha and N. glaberrima on C. baccatum (2 samples). This finding may indicate that these lonchaeid species are primary pests of the plant species in question. In addition, Uchôa (2012) mentioned that for some plant species of economic importance in South America, lonchaeids may be more abundant and important as pests than tephritids.

This work makes new associations between species of Neosilba and host plants in the Brazilian Amazon: N. glaberrima on Passiflora sp. and C. baccatum; N. pseudozadolicha on M. emarginata; and N. zadolicha on M. emarginata and C. baccatum (Table 2).

PARASITOIDS

This work adds 1 species of parasitoid (U. anastrephae) not reported by Silva et al. (2007) on Ilha de Santana. Therefore, to date, 4 species of parasitoids have been reported at this locality: A. anastrephae, D. areolatus, O. bellus, and U. anastrephae.

The higher abundance of D. areolatus found in this work is consistent with the notion that this is the most abundant and disseminated species of native parasitoid of Anastrepha in Latin America, including in Brazil (López et al. 1999; Ovruski et al. 2005; Marinho et al. 2011). The longer ovipositor of D. areolatus (3.8 mm) allows it to infest larvae of fruit flies in fruits of various sizes, enabling it to outperform other parasitoids (Aluja et al. 2013).

The highest percentages of parasitism were observed on S. mombin (43.1%) and Licania sp. (42.6%), which are native plants in the sampled region (Table 1). Overall, native plants in the wild harbor significantly more parasitoids per fruit than cultivated plants (López et al. 1999; Aluja et al. 2003).

All 3 species of parasitoids obtained in this work were present on S. mombin. This plant species has been reported as an important reservoir of parasitoids in the state of Amapá (Sousa 2015). Considering that 11 samples of S. mombin were collected (4.9 kg of fruits) and that 368 specimens of parasitoids were obtained from these samples, this means that 75.1 parasitoids were obtained per kilogram of fruit. The greatest number of parasitoids obtained to date from S. mombin in the Brazilian Amazon was 165 parasitoids per kg of fruit, in the state of Para (Sousa 2015).
of Roraima (Marsaro Júnior et al. 2011). However, these are low values if compared with those reported by López et al. (1999) in Mexico (207 parasitoids per kg of fruit).

Two of the 3 samples of *Licania* sp. fruits were infested by fruit flies (presence of puparia). Four puparia were obtained from 1 sample, from which emerged 2 specimens of *B. carambolae*. Only parasitoids emerged from the other sample (2 specimens of *D. areolatus* and 1 unknown specimen). This finding merits special attention, as it suggests that at least 1 parasitoid species may be infesting larvae of *B. carambolae*. However, this cannot yet be positively affirmed. Should this be confirmed by an additional study, it will be the first report of a natural parasitoid of *B. carambolae* in Brazil, given that, up to the present time, no native parasitoid has been reported for this species (Adaime et al. 2014a). Lemos (2014) individually observed 1,262 puparia of *B. carambolae* in Amapá, originating from 9 plant species, without obtaining any parasitoid specimens. In Suriname and French Guyana, there is no record of parasitoid specimens. In Suriname and French Guyana, there is no record of parasitoid specimens.

| Location | Hosts | Jan | Feb | Mar | Apr | May | Jun | Jul | Total | % |
|----------|-------|-----|-----|-----|-----|-----|-----|-----|-------|---|
| E₁       | Averrhoa carambola | 1/1 | 1/1 | 1/1 | 0/0 | —   | —   | —   | 4/3   | 75.0|
|          | Citrus aurantium    | 1/0 | —   | —   | —   | 1/1 | 1/1 | 7/1 | 2/1   | 7.5 |
|          | Eugenia uniflora    | —   | 1/0 | 1/0 | 0/0 | 1/1 | 1/1 | 7/1 | 2/1   | 71.4|
|          | Malpighia emarginata| 2/2 | 2/2 | —   | 1/1 | 1/1 | 1/1 | 1/1 | 8/7   | 87.5|
|          | Mangifera indica    | 1/0 | 1/0 | 1/0 | —   | —   | —   | —   | 3/0   | 0   |
|          | Psidium guajava     | 1/0 | 2/0 | 1/1 | 2/1 | 1/0 | 1/1 | —   | 8/3   | 37.5|
|          | Spondias mombin     | 1/0 | 1/0 | —   | —   | —   | —   | —   | 2/0   | 0   |
| Subtotal |       | 7/3 | 8/4 | 4/2 | 5/3 | 3/2 | 4/2 | 3/2 | 34/18 | 52.9|
| E₂       | Byrsonima crassifolia| 1/0 | 1/0 | 1/0 | —   | —   | —   | —   | 4/0   | 0   |
|          | Citrus limon        | 1/0 | 1/0 | 1/0 | —   | —   | —   | —   | 2/0   | 0   |
|          | Eugenia uniflora    | —   | 1/0 | —   | —   | —   | —   | —   | 2/0   | 0   |
|          | Malpighia emarginata| 2/1 | 2/2 | 2/2 | —   | 1/0 | 1/0 | 7/7 | 77.7  | 0   |
|          | Passiflora sp.      | 1/0 | 1/0 | 1/0 | —   | —   | —   | —   | 4/0   | 0   |
|          | Psidium guajava     | 2/0 | 2/0 | 3/2 | 2/1 | 1/0 | 1/0 | 2/0 | 13/3  | 23.1 |
|          | Spondias mombin     | —   | 1/0 | 1/0 | —   | —   | —   | —   | 1/0   | 0   |
| Subtotal |       | 6/1 | 9/2 | 8/4 | 1/1 | 1/1 | 1/1 | 4/1 | 35/10 | 31.0|
| E₃       | Averrhoa bilimbi    | —   | 1/0 | 1/0 | —   | —   | —   | —   | 2/1   | 50.0|
|          | Citrus aurantium    | 1/0 | 1/0 | 1/0 | —   | —   | —   | —   | 3/0   | 0   |
|          | Citrus limon        | —   | —   | —   | 1/0 | —   | 1/0 | 1/0 | 3/0   | 0   |
|          | Inga edulis         | —   | —   | 1/0 | —   | —   | —   | —   | 2/0   | 0   |
|          | Malpighia emarginata| 1/0 | 1/0 | —   | —   | —   | —   | —   | 4/2   | 50.0|
|          | Mangifera indica    | —   | 1/0 | 2/0 | 2/1 | 1/1 | 1/1 | —   | 5/1   | 20.0|
|          | Morinda citrifolia  | —   | 1/0 | 1/0 | 1/0 | —   | —   | —   | 3/0   | 0   |
|          | Passiflora sp.      | —   | 1/0 | 1/0 | 1/0 | —   | —   | —   | 5/0   | 0   |
|          | Psidium guajava     | 1/0 | 1/0 | 1/1 | 2/1 | 1/0 | 1/0 | 9/5 | 55.6  | 0   |
|          | Spondias mombin     | 1/0 | 1/0 | 1/1 | —   | —   | —   | —   | 3/1   | 33.3|
| Subtotal |       | 3/1 | 7/1 | 9/2 | 7/2 | 2/2 | 4/1 | 4/1 | 36/10 | 27.8|
| E₄       | Malpighia emarginata| —   | —   | —   | —   | —   | —   | —   | 1/0   | 0   |
|          | Psidium guajava     | —   | —   | —   | —   | —   | —   | —   | 1/0   | 0   |
|          | Syzygium cumini     | —   | —   | —   | —   | —   | —   | —   | 1/0   | 0   |
| Subtotal |       | 5/0 | 8/0 | 7/0 | 8/3 | 3/1 | 3/0 | —   | 34/4  | 11.8|
| P₁       | Licania sp.         | —   | —   | —   | 1/1 | 1/0 | —   | —   | 1/1   | 100 |
|          | Bellucia grossularioides| —   | —   | —   | 1/1 | 1/0 | —   | —   | 1/1   | 100 |
|          | P₂       | —   | —   | —   | 3/3 | —   | —   | —   | 3/3   | 100 |
| P₃       | Hanckornia speciosa | —   | —   | —   | —   | —   | —   | —   | 1/0   | 0   |
| Overall  |       | 21  | 32  | 28  | 22  | 18  | 14  | 14  | 149/48 | 32.2|

* E = Rural establishment = E₁ to E₄, P = Isolated collection point = P₁ to P₃.

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Table 4. Occurrence of *Bactrocera carambolae* (samples collected/samples infested) on plant species sampled on Ilha de Santana, Amapá, Brazil (Jan to Jul 2015).
also no indication of native parasitoids specifically attacking larvae of *B. carambolae* (Sauers-Müller 2005; Vassilier et al. 2013). However, Vassilier et al. (2013) considered the hypothesis that parasitoids do attack immatures of *Bactrocera*, but do not successfully develop due to poor adaptation to this host or the immune response of its larvae. According to their observations, the only species of parasitoid to emerge from pupae of *B. carambolae* was *Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae), which was introduced to the region in the year 2000.

We did not detect any parasitoids in Lonchaeidae in this work, although species of Eucolinae (Figitidae) have already been reported in association with frugivorous larvae of *Neosilba* in Brazil (Uchôa 2012).

**HOST PLANT USE BY *B. CARAMBOLAE***

Among the 8 plant species identified as hosts of *B. carambolae* in this study, 5 (*S. mombin, M. indica, M. emarginata, P. guajava, and A. carambola*) were also sampled on Ilha de Santana by Silva et al. (2007), without being infested by the pest. The authors collected 5 samples of *A. carambola* (416 fruits, 9.2 kg) and 9 samples of *M. emarginata* (2,741 fruits, 14.4 kg) but did not obtain any puparia. This suggests that the composition of fruit fly species at this locality has changed in the 10 yr interval between the 2 surveys.

*Bactrocera carambolae* infested 70.4% of the samples of *M. emarginata* (19 out of 27 samples), 66.7% of the samples of *A. carambola* (4 out of 6 samples), 55.5% of the samples of *E. uniflora* (5 out of 9 samples), and 41.2% of the samples of *P. guajava* (14 out of 34 samples) (Table 3).

Analyzing the percentages of occurrence of *B. carambolae* when compared with other fruit flies (Table 3), we can assume the pest to prefer hosts that are not infested by other species. This is clearly illustrated by noting that *B. carambolae* was the only species to infest *A. carambola, E. uniflora, Licania sp.* and *M. indica* in this study. In conclusion, when *B. carambolae* infests hosts that are strongly associated with a given species of fruit fly, such as *S. mombin* with *A. obliqua*, or *P. guajava* with *A. striata*, its percentage of occurrence is very low.

*Averrhoa carambola, E. uniflora, M. emarginata, and P. guajava* are responsible for sustaining the population of *B. carambolae* in the sampled areas (Tables 2 and 4). In the case of *A. carambola*, the availability of fruits and consequent infestation occurred in the initial months of the year. In the case of the other plant species mentioned, particularly *M. emarginata*, fruits were available throughout the sampling period.

*Bactrocera carambolae* was found at all 5 sampled rural establishments and at 1 of the 3 isolated collection points (Table 4). The percentage of samples infested by *B. carambolae* at each establishment or isolated collection point ranged from 11.8% (E.) to 100% (E.). The number of samples infested by the pest varied according to sampling month, peaking in Apr and May, with 10 and 11 samples infested, respectively (Table 4).

On *M. indica* (unidentified genetic material, not grafted), although 11 samples were collected (80 fruits, 14.4 kg), only 7 puparia were obtained, originating from a single sample collected in Apr in establishment E, (Table 4) and from which emerged only a single specimen of *B. carambolae*. Lemos (2014) also sampled fruits of *M. indica* (50 fruits, unidentified genetic material, not grafted) in 3 municipalities in Amapá without observing any infestation. On the other hand, Lemos et al. (2014) obtained 22 puparia and 19 adults of *B. carambolae* from a single fruit of *M. indica* (Tommy Atkins cultivar), reporting an infestation rate of 28.5 puparia per kg. This relationship merits further investigation, as the origins of the genetic materials cultivated in the region are unknown, as is their potential resistance to *B. carambolae*. The low rate of tephritid infestation on *M. indica* can be at least partly explained by the density of laticiferous ducts present on the epicarp and mesocarp of the fruit, which has a toxic effect on eggs and larvae, as shown by Joel (1980, 1981) for *C. capitata* and by Adaime et al. (2014b) for *A. obliqua* and *Anastrepha ludens* (Loew). These topics should therefore be studied further, especially considering that *M. indica* is widely used for urban landscaping in Macapá and Santana, municipalities that contain over 70% of the population of the state of Amapá. If their genetic materials are susceptible to infestation by the carambola fruit fly, these trees used in urban landscaping could be responsible for sustaining elevated populations of the pest.

Finally, it should be noted that *B. carambolae* seems to be adapting to infest native hosts in the Amazon, such as *Licania* sp. Lemos et al. (2014) highlighted this same fact, mentioning infestations on *Eugenia stipitata* McVaugh (Myrtaceae) and *Pouteria macrophylla* (Lam.) Eyma ( Sapotaceae) in the state of Amapá. In both reports, although *B. carambolae* infested native plants, the fact that they were not located in completely unaltered environments should be taken into account.

In conclusion, the most important species of fruit flies on Ilha de Santana are: *B. carambolae*, for being a species of quarantine importance; and *A. obliqua* and *A. striata*, for infesting plant species of local socioeconomic importance (*S. mombin* and *P. guajava*, respectively). Species of *Neosilba*, though potential pests, are not abundant at the sampled locality. In addition, we can conclude that *A. carambola, E. uniflora, M. emarginata, and P. guajava* are responsible for sustaining the population of *B. carambolae* in the sampled areas.

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