**Drosophilidae (Diptera) associated to fungi: differential use of resources in anthropic and Atlantic Rain Forest areas**

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**ABSTRACT.** This study investigates the Drosophilidae species associated to fruiting bodies of fungi in forested and anthropized environments of the Atlantic Rain Forest Biome, in south and southeastern Brazil. We collected samples of imagos flying over and emerging from fruiting bodies of species of five fungi families, in six collection sites. We obtained 18 samples, from which emerged 910 drosophilids of 31 species from the genera *Drosophila* Fallen, 1823, *Hirtodrosophila* Duda, 1923, *Leucophenga* Mik, 1886, *Mycodrosophila* Oldenberg, 1914, *Scaptomyza* Hardy, 1849, *Zaprionus* Coquillett, 1901 and *Zygothrica* Wiedemann, 1830. The *Drosophila* species collected on fungi, as well as *Zaprionus indicus* Gupta, 1970, had previously been recorded colonizing fruits, demonstrating their versatility in resource use. Most of these species belong to the *immigrans-tripunctata* radiation of *Drosophila*. Our records expands the mycophagous habit (feeding or breeding on fungi) to almost all species groups of this radiation in the Neotropical region, even those supposed to be exclusively frugivorous. Assemblages associated to fungi of forested areas were more heterogeneous in terms of species composition, while those associated to fungi of anthropized areas were more homogeneous. The drosophilids from anthropized areas were also more versatile in resource use.

**KEYWORDS.** *Drosophila*, mycophagous insects, feeding sites, breeding sites.


**PALAVRAS-CHAVE.** *Drosophila*, insetos micófagos, sítios de alimentação, sítios de oviposição.
species of the genus oviposit in fungi, while some use them as courtship site. VAL & KANESHIRO (1988) carried out a survey in the Atlantic Rain Forest with commercial fungi and banana baits, and Zygothrica was the most abundant genus after Drosophila, with almost 50 species identified. Recently, ROQUE et al. (2006) collected drosophilids flying over and emerging from fruiting bodies of Pleurotus sp. (Tricholomataceae, Agaricales) and another undetermined fungus at the Cerrado Biome, Central Brazil, where 20 species from five genera of Drosophilidae were collected, and Drosophila was the most abundant.

Although there have been important studies on the ecology of mycophagous drosophilids, they were conducted in temperate zones, where the diversity of Drosophilidae are lower than those found inhabiting other regions. Therefore, it becomes necessary to discover whether the processes and patterns found in temperate zones are applicable in tropical zones. In this context, the aim of the present study is to contribute to the understanding of the processes driving the colonizing patterns of mycophagous drosophilids, by analyzing and comparing the drosophilid assemblage associated to fruiting bodies of fungi in the Atlantic Rain Forest stricto sensu and anthropic areas, in south and southeastern Brazil.

MATERIAL AND METHODS

Drosophilids and fungi were collected in six sites in south (States of Rio Grande do Sul and Santa Catarina) and southeast regions of Brazil (State of São Paulo) (Fig. 1). Samplings were conducted at three environments of the Atlantic Rain Forest stricto sensu and three anthropic areas, near buildings or gardens (Tab. I).

To evaluate the probable feeding sites of mycophagous Drosophilidae species, adult flies flying over fructification bodies of fungi were captured in the field by sweeping with an entomological net or with an entomological aspirator. To assess the breeding sites of Drosophilidae species, fructification bodies of fungi were collected, brought to the laboratory and kept in glass vials with sterilized sand. Vials were maintained in controlled temperature at 24 ± 1°C. Water was added whenever necessary to prevent dehydration. Emerged adults were aspirated daily.

Drosophilid identification was based on external morphology and on male genitalia (prepared according to WHEELER & KAMBSSELLIS, 1966, modified by KANESHIRO, 1969). Voucher specimens were deposited at the Museu de Ciências Naturais, Fundação Zoobotânica do Rio Grande do Sul (MCN/FZB), and Museu de Zoologia, Universidade de São Paulo (MZSP). Fungi identification was conducted using a dichotomic key (GUERRERO & HOMRICH, 1999).

To test the association between drosophilid species and feeding sites, we conducted a Detrended Correspondence Analysis (DCA) (HILL & GAUCH, 1980), where the drosophilid species that flew over the fruiting bodies were the descriptors and fungi taxa were the objects. Another DCA was used to test an association between drosophilid species and breeding sites (fungi taxa), where the former were the descriptors and the latter the objects. DCA is an ordination analysis and, similarly to the Correspondence Analysis, it has been proposed as a way to analyze two-way contingency tables. However, DCA removes the arch effect found in most ordination analysis. DCA was conducted on the software R 2.5.0 (R DEVELOPMENT CORE TEAM, 2007), with the VEGAN package 1.8-8 (OKSANEN et al., 2007), and it was based on 26 segments, as recommended by HILL & GAUCH (1980).

RESULTS

A total of 910 individuals belonging to 31 Drosophilidae species were collected (Tabs. I, II). Among the drosophilid genera collected, Drosophila was the richest (17 species) and the most abundant in all environments sampled, even when compared to other exclusively mycophagous species, like Hirtodrosophila (five species), Leucophenga (two species) and Mycodrosophila (two species).
Considering all sites sampled, 90 individuals were collected flying over fructification bodies, totaling 21 fly species, of which 14 belonged to the genus Drosophila (Table III). At least four fungi species (probably used as feeding sites) were identified: Coprinus comatus (Agaricaceae), Phallus sp. (Phallaceae, Agaricales) and one species of Agaricales sampled in anthropic areas; one member of the Polyporaceae family and a group of several undetermined fungi species sampled in forest areas. In the DCA conducted for the specimens collected flying over fructification bodies, the components 1 and 2 accounted for 40.9% of data variation. Our analysis distinguished between generalist and specialist fly species (Fig. 2).

Table I. Sampling sites of the Drosophilidae species associated to fruiting bodies of fungi, co-ordinates, and their respective environment types.

<table>
<thead>
<tr>
<th>Sampled Sites</th>
<th>Co-ordinates</th>
<th>Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Campus of Universidade Federal do Rio Grande do Sul, Porto Alegre, RS</td>
<td>30°04'16.1''S; 51°07'13.7''W</td>
<td>anthropic area</td>
</tr>
<tr>
<td>B Campus of Universidade de São Paulo, Ribeirão Preto, SP</td>
<td>21°10'11.7''S; 47°51'33.4''W</td>
<td>anthropic area</td>
</tr>
<tr>
<td>C Campus of Universidade Federal de Santa Catarina, Florianópolis, SC</td>
<td>27°36’12.9”S; 48°31’21.9”W</td>
<td>anthropic area</td>
</tr>
<tr>
<td>D Morro da Lagoa da Conceição, Florianópolis, SC</td>
<td>27°35’26.8”S; 48°28’32.9”W</td>
<td>Atlantic Rain Forest</td>
</tr>
<tr>
<td>E Biguaçu, SC</td>
<td>27°29’09.8”S; 48°39’17.7”W</td>
<td>Atlantic Rain Forest</td>
</tr>
<tr>
<td>F Piraí, Joinville, SC</td>
<td>26°17’37.9”S; 49°00’56.4”W</td>
<td>Atlantic Rain Forest</td>
</tr>
</tbody>
</table>

Table II. Fungi taxa, dates of collections, sampled sites (A, Campus of Universidade Federal do Rio Grande do Sul, Porto Alegre, RS; B, Campus of Universidade de São Paulo, Ribeirão Preto, SP; C, Campus of Universidade Federal de Santa Catarina, Florianópolis, SC; D, Morro da Lagoa da Conceição, Florianópolis, SC; E, Biguaçu, SC; F, Piraí, Joinville, SC) and size (number of fruiting bodies) of each sample.

<table>
<thead>
<tr>
<th>Code</th>
<th>Collected fungi species</th>
<th>Date</th>
<th>Site</th>
<th>Methods of collection</th>
<th>Sample size</th>
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<td>A</td>
<td>Feeding sites</td>
<td>-</td>
</tr>
<tr>
<td>F2</td>
<td>Coprinus comatus (Agaricaceae)</td>
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<td>A</td>
<td>Feeding sites</td>
<td>-</td>
</tr>
<tr>
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<td>Phallus sp. (Phallaceae)</td>
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<td>B</td>
<td>Feeding sites</td>
<td>-</td>
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<tr>
<td>F4</td>
<td>Agaricales sensu lato</td>
<td>22.I.2005</td>
<td>B</td>
<td>Feeding sites</td>
<td>-</td>
</tr>
<tr>
<td>F5</td>
<td>Polyporaceae</td>
<td>07.IV.2005</td>
<td>D</td>
<td>Feeding sites</td>
<td>-</td>
</tr>
<tr>
<td>F6</td>
<td>Group of several undetermined fungi species</td>
<td>07.IV.2005</td>
<td>D</td>
<td>Feeding sites</td>
<td>-</td>
</tr>
<tr>
<td>B1</td>
<td>Macrolepiota sp. (Agaricaceae)</td>
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<td>C</td>
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<tr>
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<td>Marasmius sp. (Marasmiaceae)</td>
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<td>Polyporaceae</td>
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<td>24.V.2005</td>
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<td>A</td>
<td>Breeding sites</td>
<td>17 fruiting bodies</td>
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</table>

Table III. Drosophilidae species collected flying over fungi fruiting bodies in different sites in Brazil (F1, Coprinus comatus, anthropic area; F2, C. comatus, anthropic area; F3, Phallus sp., anthropic area; F4, Agaricales sensu lato, anthropic area; F5, Polyporaceae, Atlantic Rain Forest area; F6, Group of several undetermined fungi species, Atlantic Rain Forest area). *Same species introduced by Gottschalk et al. (2007).

<table>
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<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
<th>Total</th>
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<td>cardini</td>
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<td>12</td>
<td>13</td>
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</table>
Generalist Drosophilidae species generated dots closer to the point of origin of axes, and occurred mainly in association with *C. comatus* samples, that was found in the anthropized environments and which had also more homogeneous assemblages. The dots of the more specialist drosophilids are farther away from the point of origin, just as the dots representing more heterogeneous assemblages associated to feeding sites.

Specimens of four fungi families (Agaricaceae, Auriculariaceae, Marasmiaceae and Polyporaceae) were collected and brought to the laboratory, of which 820 drosophilids emerged (Tab. IV). *Drosophila* was once again the richest and most abundant genus, with ten species and 273 individuals. In the DCA for species that emerged from the fructification bodies (breeding sites) (Fig. 3), the components 1 and 2 accounted for 14.8% of data variation. Exactly as observed in feeding sites, the composition of breeding Drosophilidae from fungi of anthropized areas (*C. comatus*, *Macrolepiota* sp., *Marasmius* sp. and *Agaricales lato sensu*) was more homogeneous. Similar situation was observed regarding the presence of more generalist species. This is highlighted by the clustering of dots next to the point of origin of the chart’s axes. The fauna emerged from Polyporacea, that was found mainly in the forest areas, was typical and distinct from that of other fungi, including specialized Drosophilidae genera, as *Hirtodrosophila*, *Mycodrosophila* and *Zygothrica*. The Atlantic Rain Forest samples were likewise more heterogeneous regarding composition of colonizing species (evidenced by respective dots distant from the point of origin), and the species that colonized fungi from the woods were observed exclusively in these samples.

![Detrended Correspondence Analysis results for feeding sites data](image)

Figure 2. Detrended Correspondence Analysis results for feeding sites data. DCA1, component 1; DCA2, component 2; circles, Drosophilidae species; cross and underlined text: fungi species collected in anthropized environment; cross and underlined text in bold: fungi species collected in Atlantic Rain Forest.
Table IV. Drosophilidae species emerged from fungi fruiting bodies in different sites in Brazil (B1, *Macrolepiota* sp., Atlantic Rain Forest area; B2, *Marasmius* sp., Atlantic Rain Forest area; B3, Polyporaceae, Atlantic Rain Forest area; B4, Polyporaceae, Atlantic Rain Forest area; B5, Polyporaceae, anthropic area; B6, Polyporaceae, Atlantic Rain Forest area; B7, Agaricales sensu lato, anthropic area; B8, *Auricularia* sp., Atlantic Rain Forest area; B9, *Auricularia* sp., Atlantic Rain Forest area; B10, *Coprinus comatus*, anthropic area; B11, *C. comatus*, anthropic area; B12, *C. comatus*, anthropic area). *Same species introduced by Gottschalk et al. (2007).*

<table>
<thead>
<tr>
<th>Genus Group</th>
<th>Species</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
<th>B6</th>
<th>B7</th>
<th>B8</th>
<th>B9</th>
<th>B10</th>
<th>B11</th>
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<td>28</td>
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<td><em>D. cardinoides</em> Dobzhansky &amp; Pavan, 1943</td>
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<td>7</td>
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<td></td>
<td><em>D. cuaso</em> Bächli, Vilela &amp; Ratcov, 2000</td>
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<td><em>D. mediosticta</em> Frota-Pessoa, 1954</td>
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<td><em>hiricornis</em></td>
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<td><em>Z. hirsuta</em> (cf.) Wheeler, 1949</td>
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**Total** | 34 | 176 | 35 | 24 | 2 | 13 | 38 | 14 | 200 | 87 | 117 | 80 | 820 |

Figure 3. Detrended Correspondence Analysis results for breeding sites data. DCA1, component 1; DCA2, component 2; circles, Drosophilidae species; cross and underlined text: fungi species collected in anthropized environment; cross and underlined text in bold: fungi species collected in Atlantic Rain Forest.
DISCUSSION

As a whole, our results indicate that mycophagy is far more common than previously thought, since the present records expands the mycophagous habit (feeding or breeding on fungi) to almost all species groups of *immigrans-tripunctata* in the Neotropical region, even those supposed to be exclusively frugivorous. The species of *calloptera*, *cardini*, *guarani* and *tripunctata* species groups of *Drosophila*, all belonging to the *immigrans-tripunctata* radiation (*REMSEN & O'GRADY*, 2002; *MARKOW & O'GRADY*, 2005), were frequent in our samples (except for Polyporaceae). The same had been previously observed in a study conducted in central Brazil by *Roque et al.* (2006). Most of the species belonging to the *testacea* and *quinaria* species groups of *Drosophila*, which also belong to the *immigrans-tripunctata* radiation, are obligatory mycophagous flies. The characteristics related to the use of fungi by species of the *immigrans-tripunctata* radiation may thus be synapomorphic, since all its species groups, with the exception of *palildipennis*, were recorded colonizing fungi. However, the homoplasys hypothesis cannot be rejected.

The occurrence of *Hirtodrosophila*, *Leucophenga*, *Mycodrosophila*, *Scaptomyza* and *Zygorthica* in fungi lends more consistency to the existing literature records (*GRIMALDI, 1987; VAL & KANESHIRO, 1988; COURTNEY et al.*, 1990). Nevertheless, the presence of *Zaprionus* Coquillet, 1901 in our samples attracted our interest, as the only species observed in the Neotropics, *Z. indians*, is considered to be frugivorous. Adult specimens of *Z. indians* were collected over fruiting bodies of *Phallus* sp. (Phallaceae, Phallales) in anthropized areas of Ribeirão Preto (São Paulo, Brazil), and two individuals emerged from fungi collected by *Roque et al.* (2006). Taken together, these data demonstrate the versatility of this species, which recently invaded the American continent and is considered a pest for fruit production (*VALELA et al.*, 2000).

*Drosophilid* assemblages associated to Polyporaceae were distinct from that associated to fungi of other families, considering both breeding and feeding sites. The dominance of *Hirtodrosophila*, *Mycodrosophila* and *Zygorthica* species may be linked to higher frequencies of this fungus family in Atlantic Rain Forest areas, since it is possible that the richness of these drosophilids genera is higher in forests, as suggested by *SPEITH* (1987) and *COURTNEY et al.* (1990). In these forested areas, the assemblages were more heterogeneous regarding their composition. In contrast, the fauna emerging from the Agaricaceae, Auriculariaceae, Marasmiaceae and Phallaceae families, more abundant at anthropized areas, was far more homogeneous, with dominance of *Drosophila* species.

In the present study, the *cardini* species group of *Drosophila* (*D. cardini* Sturtevant, 1916, *D. cardinoides* Dobzhansky & Pavan, 1943 and *D. neocardini* Streisinger, 1946) was restricted to the anthropized environments, since these species were observed only in fungi collected in these areas. The low abundance of such species in forested areas, in contrast with the high abundance observed in anthropic ones, was also recorded by *Gottschalk et al.* (2007), though using banana baits. Similarly, the *calloptera* group, in spite of the low abundance observed, was restricted to forest areas, what have also been observed in banana-baited collections (*De Toni et al.*, 2007). On the other hand, species of the *tripunctata* and *guarani* species groups were observed in fungi collected in both forested and anthropized environments.

In the present study, 31 *Drosophilidae* species were collected associated to fungi fruiting bodies in the Atlantic Rain Forest and urbanized areas. Of these species, those belonging to the *Drosophila* and *Zaprionus* genera were also collected associated to fruits in other studies (*CARSON, 1971; SILVA et al., 2005; GARCIA et al., 2008*), demonstrating their versatility in resource use. The use of fungi as a trophic resource has probably played a more significant role, in comparison to previous notions, in the evolutive success of Neotropical species belonging to the *immigrans-tripunctata* radiation of *Drosophila*. Assemblages associated to fungi of forested areas were more heterogeneous in terms of species composition, while those associated to fungi of anthropized areas were more homogeneous at species level. The species of the *cardini* groups of *Drosophila* was restricted to anthropized areas, while the *calloptera* species group was restricted to forested areas. The drosophilids from anthropized areas were also more versatile in resource use, since they were collected in several samples of feeding and breeding sites.

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**REFERENCES**


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**References**


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