Seasonal dynamics of a drosophilid (Diptera) assemblage and its potencial as bioindicator in open environments

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ABSTRACT. *Drosophila* Fallen, 1823 (Diptera, Drosophilidae) is for long a well-established model organism for genetics and evolutionary research. The ecology of these flies, however, has only recently been better studied. Recent papers show that *Drosophila* assemblies can be used as bioindicators of forested environment degradation. In this work the bioindicator potential of drosophilids was evaluated in a naturally opened environment, a coastal strand-forest (*restinga*). Data from nine consecutive seasonal collections revealed strong temporal fluctuation pattern of the majority of *Drosophila* species groups. *Drosophila willistoni* group was more abundant at autumns, whereas *D. cardini* and *D. tripunctata* groups were, respectively, expressive at winters and springs, and *D. repleta* group at both seasons. The exotic species *D. simulans* Sturtevant, 1919 (from *D. melanogaster* group) and *Zaprionus indianus* Gupta, 1970 were most abundant at summers. Overall, the assemblage structure did not show the same characteristics of forested or urban environments, but was similar to the forests at winters and to cities at summers. This raises the question that this locality may already been under urbanization impact. Also, this can be interpreted as an easily invaded site for exotic species, what might lead to biotic homogenization and therefore can put in check the usage of drosophilid assemblages as bioindicators at open environments.

KEYWORDS. *Drosophila*, seasonality, bioindicators, *restinga*, Brazil.

RESUMO. Dinâmica sazonal de uma assembléia de drosofilídeos (Diptera) e seu potencial como bioindicadora em ambientes abertos. *Drosophila* Fallen, 1823 (Diptera, Drosophilidae) é, há muito tempo, um organismo modelo em pesquisas de genética e evolução. A ecologia destas moscas, no entanto, apenas recentemente foi melhor estudada. Trabalhos recentes apontam que as assembléias de *Drosophila* podem ser utilizadas como bioindicadoras de degradação de ambientes florestais. Neste trabalho, foi avaliado o potencial bioindicador dos drosofilídeos em um ambiente de restinga, naturalmente aberto. Dados de nove coletas sazonais consecutivas revelaram um forte padrão de flutuação temporal na maioria dos grupos de espécies de *Drosophila*. O grupo *D. willistoni* foi mais abundante nos outonos, enquanto os grupos *D. cardini* e *D. tripunctata* foram, respectivamente, expressivos nos invernos e primaveras, e o grupo *D. repleta* em ambas as estações. As espécies exóticas *D. simulans* Sturtevant, 1919 (do grupo *D. melanogaster*) e *Zaprionus indianus* Gupta, 1970 foram mais abundantes nos verões. Em geral, a estrutura desta assembléia não mostrou as mesmas características de ambientes florestais ou urbanos, mas mostrou-se similar às florestas nos invernos e aos urbanizados nos verões. Isto demonstra que esta localidade já pode estar sofrendo impacto da urbanização. Também, este pode ser interpretado como um local facilmente invadido por espécies exóticas, o que pode levar à homogeneização biótica e, portanto, pode por em cheque o uso de assembléias de drosofilídeos como bioindicadores em ambientes abertos.

PALAVRAS-CHAVE. *Drosophila*, sazonalidade, bioindicadores, restinga, Brasil.

Drosophila Fallen, 1823 (Diptera, Drosophilidae) is for long a model organism in genetics and evolution. Community ecology studies with these flies are still scarce, but provided significant improvements in the area of species competition (review in Hartley & Shorrocks, 2002). The richness of this genus, though, is still poorly known, especially in the Neotropical region, where Medeiros & Klazcko (2004) and Döge *et al*. (2008) estimated that nearly 40% of the brazilian *Drosophila* species are still undescribed. Even the geographical distribution of many species is still not well established (Döge *et al*., 2006, 2007; Mata *et al*., 2008a).

The American invasion of the African drosophilid *Zaprionus indianus* Gupta, 1970 instigated studies of its impact on the assemblies' structure and on the temporal dynamics of native species. Collections were performed at many ecosystems, like the Atlantic Rain Forest (Mateus *et al*., 2006; Torres & Madi-Ravazzi, 2006; De Toni *et al*., 2007), mangroves (Schmitz *et al*., 2007), *cerrado lato sensu* (the Brazilian savanna) (Tidon *et al*., 2003; Tidon, 2006; Mata *et al*., 2008b), and even urban environments (Goñi *et al*., 1997; Ferreira & Tidon, 2005; Silva *et al*., 2005b; Gottschalk *et al*., 2007). These and other studies also demonstrated the possible use of drosophilids as bioindicators of forest degradation (Parsons, 1991; Martins, 2001; Avondet *et al*., 2003; Ferreira & Tidon, 2005; Silva *et al*., 2005b).

Among the Brazilian coastal ecosystems, mangroves and *restingas* (strand forest) are the most extensive. The *restingas* are distributed along almost 80% of the Brazilian shore and comprises an herbaceous to arboreal vegetational complex, usually not very dense, that is situated between the beach sand dunes and other ecosystems, like the Atlantic Rain Forest *stricto sensu*. Schmitz *et al*. (2007) made extensive collections on mangroves at Florianópolis (state of Santa Catarina, southern Brazil) and found somewhat different assemblies' structure when compared to urban and forested ecosystems of the same city (Gottschalk *et al*., 2007). Bizzo & Sene (1982) made the sole survey of drosophilids at a *restinga* site and found a similar structure to the Atlantic Rain Forest nearby.

As MATA *et al*. (2008b) pointed out, species richness and precedence (*i.e.* exotic or naturally endemic), as well as assemblage structure across habitats offer a good picture of the assemblage disturbance. Thus, the present work aims to analyze the temporal dynamics of a drosophilid assemblage in a coastal ecosystem, discussing the usage of these flies as bioindicators in open environments.

MATERIAL AND METHODS

Collections were performed in a well preserved arboreal strand forest (*restinga*) fragment in a shrub to grassland strand forest matrix at Praia da Joaquina, Florianópolis (27°38'21''S; 48°27'49''W), state of Santa Catarina, southern Brazil. The site is 350 m far from a low density residential area and, in the same direction, 650 m far from a chain of mountains called Morro da Lagoa da Conceição. In this region, the climate is classified as Cfa by KÖPPEN (1948), that is, subtropical with the coldest month average temperature inferior to 18°C and superior to 22°C in the hottest month. Rain is concentrated in summer but there is no defined dry season.

Between May 2002 (autumn) and May 2004, nine consecutive collections were performed, one per season. In each collection, 50 banana-baited traps (TIDON & SENE, 1988) were hung to trees at 1.5 m high and left in field for four days. Traps were distributed two to four meters far from each other, covering an area of about 200 m^2.

Captured flies were identified to species level utilizing keys, descriptions and male terminalia dissection, which followed WHEELER & KAMBYSELLIS' (1966) technique, modified by KANESHIRO (1969). Only individuals identified to species or sub-group were used in further analysis. Voucher specimens are deposited at Laboratório de Drosofilídeos, Universidade Federal de Santa Catarina.

The analyzed parameters were: number of individuals (N) and species collected (S), and its relative abundance (p_i = number of individuals of species i / total number of individual per collection). Were also calculated the diversity index of Simpson in its inverse form, $l = 1/D$, where $D = \Sigma\, [n_i.(n_i-1)]/[N.(N-1)]$ and n_i is the number of individuals from species i in the collection, and the Shannon-Wiener index, $H' = -\Sigma\, [p_i.\ln(p_i)] - [(S-1)/2.N]$ (KREBS, 1999). While the Simpson index is more influenced by dominance, the Shannon-Wiener index is more biased towards species richness (MAGURRAN, 2003). We opted to use both because they have good performance and are widely used in the ecological literature, what permits future comparisons.

The sample effort and richness of the collections were estimated through rarefaction (S_{RAR}) (KREBS, 1999), what makes possible to compare samples with very different N.

Similarity between collections was estimated using Morisita similarity index, with clustering through UPGMA algorithm (KREBS, 1999). All analyses were performed in program PAST 1.56 (HAMMER *et al.*, 2001).

RESULTS

A total of 11,787 individuals of 49 Drosophilidae species from seven genera were collected (Tab. I). Besides *Drosophila*, *Zaprionus* Coquillett, 1901 was the only genus widely collected. Five *Drosophila* species, one *Amiota* Loew, 1862 and one *Mycodrosophila* Oldenberg, 1914 could not be identified and summed up to 427 individuals (less than 4% of the total sample). Nine species are exotic or cosmopolitan (identified with double asterisks on table I), and corresponded to 38% of the specimens collected.

All surveyed parameters presented great oscillation (Tab. II) and almost always in a clear pattern. Number of individuals was much higher in summers and autumns. Winters and the spring of 2003 (Spr2003), however, were proportionally richer and more diverse, as showed by S_{RAR} and the diversity indexes. Although there is much overlapping among standard deviations in rarefaction analysis, summer samples are clearly poorer (Fig. 1).

Community structure at autumns and springs were also very characteristic: the first joined a separate cluster and the latter were extremely similar (Fig. 2); summer and winter collections, on the other hand, were less related. These similarities in richness and community structure are a byproduct of drosophilid population dynamics, and here species groups' dynamics represents much of the assemblage variation.

Almost all species groups of *Drosophila* as well as *Z. indianus* presented evident seasonal patterns (Fig. 3). *Drosophila willistoni* group was dominant at autumns; *D. melanogaster* group was always very common but

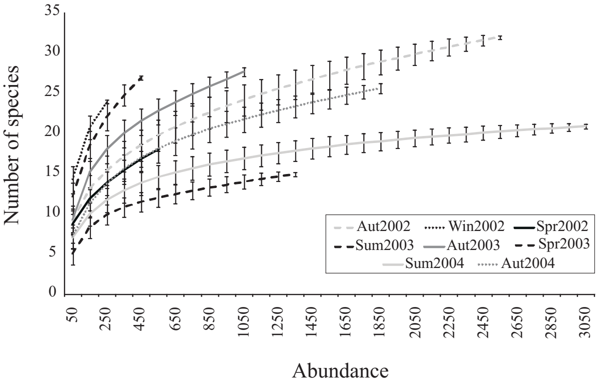

Figure 1. Rarefaction curves of the seasonal collections. Vertical bars indicate standard errors (Aut, autumn; Spr, spring; Sum, summer; Win, winter).

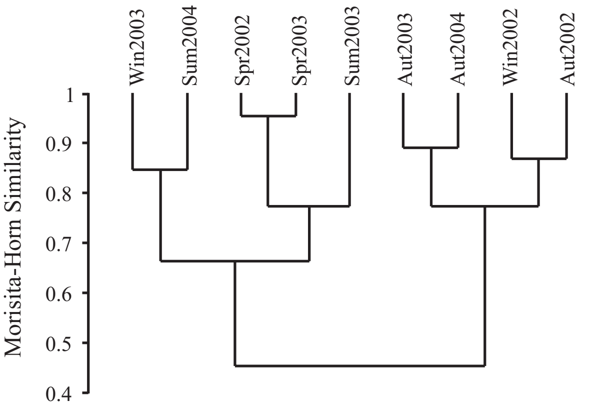

Figure 2. Morisita similarity index dendrogram, with clustering though UPGMA (Aut, autumn; Spr, spring; Sum, summer; Win, winter).

Table I. Drosophilid species identified and their abundances in each seasonal collection (*ni*, is the absolute abundance of the species on the sample; *pi*, its respective relative abundance; asterisks represents *pi*<0,01). Exotic species are marked with double asterisks (Aut, autumn; Spr, spring; Sum, summer; Win, winter).

Genera/ Subgenera/ species group	Species	Aut 2002	Win 2002	Spr 2002	Sum 2003	Aut 2003	Win 2003	Spr 2003	Sum 2004	Aut 2004	*ni* (*pi*)
Genus *Drosophila*											
Subgenus *Dorsilopha*											
D. busckii group	*D. busckii* Coquillett, 1901**	0	1	0	0	0	0	0	0	1	2 (*)
Subgenus *Drosophila*											
D. annulimana group	*D. annulimana* Duda, 1927	0	2	1	0	1	0	4	1	0	9 (*)
	D. ararama Pavan & Cunha, 1947	0	0	0	0	0	0	0	1	0	1 (*)
	D. schineri Pereira & Vilela, 1987	1	0	1	0	1	0	1	0	0	4 (*)
D. bromeliae group	*D. bromelioides* Pavan & Cunha, 1947	8	0	0	0	13	0	0	30	0	51 (*)
D. calloptera group	*D. atrata* Burla & Pavan, 1953	0	0	0	0	0	0	0	1	0	1 (*)
	D. calloptera Schiner, 1868	3	0	0	0	0	0	0	0	0	3 (*)
	D. quadrum (Weidemann, 1830)	0	0	0	0	1	0	0	0	0	1 (*)
	D. schildi Malloch, 1924	0	0	0	0	1	0	0	0	0	1 (*)
	unidentified	0	0	0	0	1	0	0	0	0	1 (*)
D. caponei group	*D. caponei* Pavan & Cunha, 1947	0	0	6	1	18	0	0	14	5	44 (*)
D. cardini group	*D. cardini* Sturtevant, 1916	2	0	0	3	0	0	0	0	0	5 (*)
	D. cardinoides Dobzhansky & Pavan, 1943	45	1	0	1	5	0	1	0	1	54 (*)
	D. neocardini Streisinger, 1946	3	0	16	0	0	0	8	5	1	33 (*)
	D. polymorpha Dobzhansky & Pavan, 1943	67	9	40	18	17	4	25	63	11	254 (0.02)
D. guarani group	*D. ornatifrons* Duda, 1927	5	1	0	0	0	0	2	0	0	8 (*)
	D. griseolineata Duda, 1927	10	1	1	0	3	1	1	3	2	22 (*)
	D. maculifrons Duda, 1927	0	0	0	0	0	0	0	0	1	1 (*)
	unidentified	0	2	3	0	0	0	0	5	6	16 (*)
D. immigrans group	*D. immigrans* Sturtevant, 1921**	0	0	0	0	0	2	0	0	0	2 (*)
D. pallidipennis group	*D. pallidipennis* Dobzhansky & Pavan, 1943	0	3	0	2	4	1	0	3	1	14 (*)
D. repleta group	*D. fascioloides* Dobzhansky & Pavan, 1943	0	2	0	0	0	0	0	0	0	2 (*)
	D. onca Dobzhansky & Pavan, 1943	1	3	0	0	0	0	2	0	0	6 (*)
	D. hydei Sturtevant, 1921	0	0	0	1	0	0	1	0	0	2 (*)
	D. mercatorum Patterson & Wheeler, 1942	14	4	51	14	20	10	68	14	8	203 (0.02)
	D. serido Vilela & Sene, 1977	1	0	0	0	0	0	0	0	0	1 (*)
	D. zottii Vilela, 1983	0	4	0	0	0	4	0	0	0	8 (*)
	unidentified	5	13	0	10	7	1	0	8	3	47 (*)
D. tripunctata group	*D. cuaso* Bächli, Vilela & Ratcov, 2000	0	0	0	0	0	0	0	0	7	7 (*)
	D. mediopunctata Dobzhansky & Pavan, 1943	5	12	1	0	5	5	7	0	0	35 (*)
	D. paraguayensis Duda, 1927	12	14	2	0	10	2	3	1	7	51 (*)
	D. roehrae Pipkin & Heed, 1964	1	1	1	0	7	0	0	2	0	12 (*)
	D. bandeirantorum Dobzhansky & Pavan, 1943	2	0	0	0	0	2	1	0	0	5 (*)

Table I (cont.)

	D. mediopicta Frota-Pessoa, 1954	2	0	0	0	0	0	1	0	0	3 (*)
	D. mediostriata Duda, 1925	0	0	0	0	0	0	0	0	2	2 (*)
	unidentified	40	82	8	0	7	5	1	2	17	162 (0.01)
Subgenus *Sophophora*											
D. melanogaster group	*D. ananassae* Doleschall, 1858**	0	0	0	8	0	0	0	0	3	11 (*)
	D. malerkotliana Parshad & Paika, 1964**	94	11	2	12	0	0	2	17	37	175 (0.01)
	D. melanogaster Meigen, 1830**	103	16	0	0	0	0	12	0	0	131 (0.01)
	D. simulans Sturtevant, 1919**	203	27	267	1192	64	28	171	737	111	2800 (0.24)
	D. kikkawai Burla, 1954**	12	0	0	0	0	0	0	0	0	12 (*)
D. saltans group	*D. prosaltans* Duda, 1927	1	2	1	0	5	0	13	0	1	23 (*)
	D. saltans Sturtevant, 1916	1	0	0	0	0	0	3	0	0	4 (*)
	D. sturtevanti Duda, 1927	32	2	9	12	28	0	3	5	8	99 (0.01)
	unidentified	39	11	6	6	4	0	7	6	9	88 (0.01)
D. willistoni group	*D. bocainensis* Pavan & Cunha, 1947	0	0	0	0	1	1	0	0	0	2 (*)
	D. capricorni Dobzhansky & Pavan, 1943	1	0	0	0	25	1	0	0	15	42 (*)
	D. fumipennis Duda, 1925	831	31	21	9	246	7	1	5	7	1158 (0.10)
	D. nebulosa Sturtevant, 1916	1	0	0	0	1	0	10	587	43	642 (0.05)
	willistoni subgroup	844	81	71	74	591	31	58	735	1299	3784 (0.32)
unidentified species	*Drosophila* sp. 1	1	0	0	0	0	0	0	0	0	1 (*)
	Drosophila sp. 2	2	0	2	0	4	1	21	82	307	419 (0.04)
	Drosophila sp. 3	0	0	0	0	1	0	1	0	1	3 (*)
	Drosophila sp. 4	0	0	0	0	1	0	0	0	0	1 (*)
	Drosophila sp. 5	0	0	0	0	0	0	0	0	1	1 (*)
Genus *Amiota*	*Amiota* sp.1	0	0	0	0	0	0	0	0	1	1 (*)
Genus *Chymomyza*	*C. pectinifemur* Duda, 1927	0	0	0	0	0	1	0	0	0	1 (*)
Genus *Mycodrosophila*	*Mycodrosophila* sp.1	1	0	0	0	0	0	0	0	0	1 (*)
Genus *Scaptodrosophila*	*S. latifasciaeformis* (Duda, 1940)**	1	1	0	1	1	0	1	14	6	25 (*)
Genus *Zaprionus*	*Z. indianus* Gupta, 1970**	256	15	59	24	13	20	32	802	60	1281 (0.11)
Genus *Zygothrica*	*Z. orbitalis* Grimaldi, 1987	0	8	0	0	1	0	0	0	0	9 (*)
Total		2650	360	569	1388	1107	127	461	3143	1982	11787 (1.00)

Table II. For each seasonal collection is given the number of species (S) and individuals (N) collected, rarefied S for N = 121 (S_{RAR}), and the diversity indices of Shannon-Wiener (H') and Simpson (*l*) (Aut, autumn; Spr, spring; Sum, summer; Win, winter).

	S	N	S_{RAR}	H'	*l*
Aut2002	32	2650	12.24	1.84	4.28
Win2002	24	360	19.38	2.40	6.75
Spr2002	18	569	11.13	1.74	3.59
Sum2003	15	1388	7.63	0.65	1.32
Aut2003	28	1107	13.90	1.59	2.83
Win2003	18	127	18	2.15	6.28
Spr2003	27	461	17.05	2.16	5.14
Sum2004	21	3143	9.34	1.72	4.68
Aut2004	26	1982	10.36	1.26	2.11
Sample	49	11787		2.07	5.08

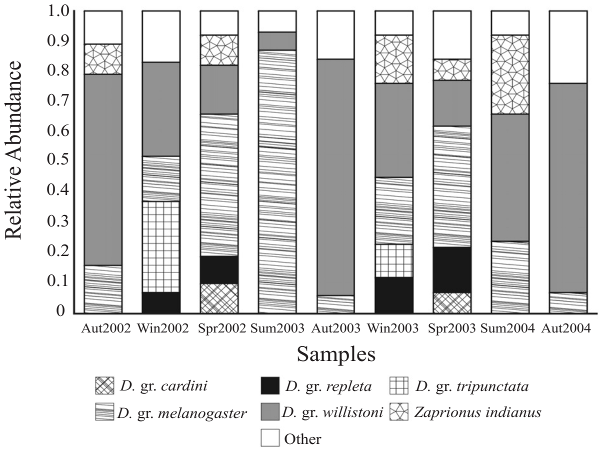

Figure 3. Relative abundance of the main representative *Drosophila* groups and *Zaprionus indianus* Gupta, 1970 in each seasonal collection (Aut, autumn; Spr, spring; Sum, summer; Win, winter).

was less represented in autumns and winters, increasing at springs and particularly dominant at summer of 2003 (Sum2003). The *D. tripunctata* group was more represented at winters and less at summers (Tab. I); the same happened to the *D. cardini* group at springs and winters, respectively. In these last two seasons, the *D. repleta* group increased its abundance, and *Z. indianus* was more abundant at summer of 2004 (Sum2004).

DISCUSSION

All exotic species of Drosophilidae registered in Brazil were collected at this site (Gottschalk *et al*., 2007), and were usually more abundant in hot seasons. Bizzo & Sene (1982) found less exotic species but a similar seasonality, an observation that, together with data from breeding sites, might corroborate the observations that *Z. indianus* is not excluding other species through competition (Leão & Tidon, 2004; Silva *et al*., 2005a; Valiati *et al*., 2005).

As a general rule, the analyzed parameters presented a clear seasonal pattern, in agreement with other studies. The small N in winters, the coldest and driest period, was registered on other Brazilian localities too, together with the higher species diversity in this season (Saavedra *et al*., 1995; Tidon, 2006; De Toni *et al*., 2007), irrespectively of N. Thus, this seems to be a common feature of drosophilid assemblies.

In the rarefaction analysis, however, the species richness of winters seems to be super estimated, a bias of small samples. Nevertheless, the technique was robust in detecting the lower richness of summers.

Among the native species groups, the increased presence of the *D. tripunctata* group in winters is well documented, as well as from the *D. willistoni* group in autumns and summers (Dobzhansky & Pavan, 1950; Frank & Valente, 1985).

Only the *D. melanogaster* group showed an unexpected seasonal dynamics, being more abundant in springs and in the first summer. Other works report autumns or summers as seasons of increased N (Franck & Valente, 1985; Benado & Brncic, 1994; Tidon, 2006; Schmitz *et al*., 2007). *Zaprionus indianus* was more abundant in the summer, the hottest and wettest period, what corroborates several previous studies (Castro & Valente, 2001; Tidon *et al*., 2003; Silva *et al*., 2005b; De Toni *et al*., 2007).

In the majority of papers that dealt with drosophilid seasonality, only one or two taxa present a temporal pattern, while others differed between years (*e.g.* Bonorino & Valente, 1989; Castro & Valente, 2001; Silva *et al*., 2005a). The lack of patterns is expected, because changes in the environmental conditions and resource availability are common between years and can modify the structure of drosophilid assemblages (Dobzhansky & Pavan, 1950; Pipkin, 1953), what is ultimately part of the evolutionary process (Tidon-Sklorz & Sene, 1992). The diversity of resources and the consequently ecological complexity that results certainly contributes to the unpredictability of species fluctuation.

Here, surprisingly, the majority of taxa presented a clear seasonal dynamics. This could be expected to be found within mature assemblies in stable environments (Worm & Duffy, 2003), but it is difficult to explain this pattern in this assemblage, with different dominant species between seasons and in this harsh and unpredictable ecosystem.

The coastal strand forest vegetation has less species diversity than its native surroundings (the Atlantic Rain Forest *sensu strictu*) and is subject to higher insolation, winds, drought and daily temperature amplitude. This contributes to the determination of resources' availability time, besides the own capacity of the flies to survive and persist at this oscillating environment. Overall, these complex interactions seem to be modeling the assemblage structure, which changes abruptly within seasons.

When compared to other environments, the *restinga* assemblage did not present a characteristic structure, as the ones of forested or urban sites. At the Atlantic Rain Forest, the *D. willistoni* subgroup and *D. saltans* group are usually dominant and there are dozens of rare native species (Pavan, 1959; Medeiros & Klaczko, 2004; De Toni *et al*., 2007). The urban sites, on the other hand, are strongly dominated by exotic species, usually *D. simulans* Sturtevant, 1919 or *D. malerkotliana* Parshad & Paika, 1964 (*D. melanogaster* group) (Bonorino & Valente, 1989; Goñi *et al*., 1997) and, more recently, by *Z. indianus* (Ferreira & Tidon, 2005; Silva *et al*., 2005b; Gottschalk *et al*., 2007).

At summers, less species were collected and *D. simulans* and *Z. indianus* were dominant, what resembles this structure to an urban environment. This suggests that, although not closer to the city then other studied forest sites (De Toni & Hofmann, 1995; De Toni *et al*., 2007; Gottschalk *et al*., 2007), this *restinga* fragment is already under human impact.

In contrast, autumns' assemblage structures were more similar to the forest ones, with higher S, dominance of the *D. willistoni* group and presence of characteristic native groups, such as *tripunctata*. The small representativeness from *D. saltans* group can be related to the low humidity of the site, since they seem to prefer humid places (Jonas S. Döge, pers. comm.).

In sum, because of not possessing a characteristic drosophilid assemblage structure and being an opened environment, the strand forest is apparently more suitable for the invasion of exotic species; there may be even seasonal invasions. In fact, biotic homogenization is a major impact of urbanization (McKinney, 2006; Rooney *et al*., 2007) and has been seen in other insect assemblages, including *Drosophila* (*e.g.* Ferreira & Tidon, 2005; Gottschalk *et al*., 2007).

Although in this particular case the assemblage might not be a good bioindicator of environment degradation, the use of *Drosophila* is still a growing field. There have been propositions of indicator species by Saavedra *et al*. (1995), Martins (2001), Ferreira & Tidon (2005) and Mata *et al*. (2008b) but few examined the assemblage as a whole.

Our observation also raises questions about the ecological processes that protect forests from invasions of exotic species. Thus, future studies that show how populations interact and maintain in natural ecosystems are extremely important to untangle the assemblies' dynamics and the possible use of this knowledge in the management and conservation of areas of ecological interest.

Acknowledgments. We are indebted to Dr. Hermes J. Schmitz, Msc. Jonas S. Döge, Msc. Sabrina C. F. Oliveira and Hugo B. Mozerle for assistance in field collections and fly identification, and to PET/SESu and CNPq for financial support. Jonas S. Döge and Dr. Tânia T. Castellani kindly read an early version of the manuscript. Dr. Vera L. S. Valente and an anonymous reviewer made important suggestions and improvements, for which we are also grateful.

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Recebido em junho de 2008. Aceito em julho de 2009. ISSN 0073-4721
Artigo disponível em: www.scielo.br/isz