Anastrepha Species (Diptera: Tephritidae): Patterns of Spatial Distribution, Abundance, and Relationship with Weather in Three Environments of Midwestern Brazil

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Anastrepha species (Diptera: Tephritidae): patterns of spatial distribution, abundance, and relationship with weather in three environments of midwestern Brazil

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Abstract

Fruit flies (Diptera: Tephritidae) are a major problem in the global production of fruits and vegetables. Thus, information about spatial distribution and population dynamics of pest species is important for horticulture. The objectives of this study were to evaluate quantitatively the occurrence of *Anastrepha* Schiner species captured in McPhail traps throughout the year in a native forest, a backyard orchard, and a commercial orchard; to describe the spatial distribution type of *Anastrepha* species in those environments; and to investigate the relationship between *Anastrepha* species abundance and weather. *Anastrepha* species adults were sampled weekly, but the data were pooled by mo before analysis of all environments, and for each environment separately. We found a relationship between abundance of *Anastrepha* species and the seasons. In general, winter was the season with greatest abundance and species richness. Among the environments, we found greatest abundance and species richness in the backyard orchard, followed by the native forest, and the commercial orchard. In the latter environment, we found a higher abundance of *Anastrepha* species in summer, and greater species richness in the spring. *Anastrepha* species adults showed an aggregated spatial distribution. Relative humidity and wind speed influenced the number of *Anastrepha* species caught in the traps.

Key Words: aggregation index; fruit fly; native forest; orchard; species richness

Resumen

Las moscas de la fruta (Diptera: Tephritidae) son un problema importante en la producción de frutas y verduras a nivel mundial. Por lo tanto, la información sobre su distribución espacial y dinámica poblacional de las especies son importantes para la fruticultura/horticultura. Los objetivos de esta investigación son: Evaluar cuantitativamente la presencia de especies de *Anastrepha* Schiner capturadas en trampas McPhail durante las estaciones en: bosque nativo, huerto de patio y huerta comercial; conocer el tipo de distribución espacial de la especie *Anastrepha* en esos ambientes y buscar alguna relación entre las poblaciones de las especies de *Anastrepha* y el clima. Los adultos de las especies de *Anastrepha* se muestrearon semanalmente, pero los datos se agruparon por mes, antes del análisis: general y para cada ambiente. Hubo una relación positiva entre las poblaciones de especies de *Anastrepha* y las estaciones. En general, el invierno es la estación con mayor abundancia y mayor riqueza de especies. Entre los ambientes, hubo mayor abundancia y riqueza de especies en el huerto de patio, seguido por el bosque nativo y el huerto comercial. En este último, hubo mayor abundancia en verano y mayor riqueza de especies en la primavera. Los adultos de las especies de *Anastrepha* muestran distribución espacial agregada. Hay influencias de la humedad relativa y la velocidad del viento en la abundancia de especies de *Anastrepha* capturadas en las trampas.

Palabras Clave: índice de agregación; moscas de la fruta; bosque nativo; huertos; riqueza de especies

The international trade of tropical fruit generates billions of dollars annually, and Latin America and the Caribbean are the largest exporters (FAO 2010). Brazil produces around 43 million metric tons of fruit and is the third largest producer in the world, after China and India (INCT 2009).

Pests are one of the principal problems faced by fruit and vegetables farmers throughout the world. Among them are frugivorous dipterans, especially some species of Tephritidae. The larvae of these insects feed on fruit pulp, and have significant impacts on fruit production (Gonçalves et al. 2006; Garcia & Norrbom 2011). Some Tephritidae larvae may feed on other plant parts, such as flower buds, leaves, and seeds (Uchoa 2012). Hence, due to their high damage potential, studies on their biology, behavior, monitoring, and management strategies have been carried out throughout the world, in Papua New Guinea, Turkey, Tanzania, Mexico, and Spain (Novotny et al. 2005; Genç 2008; Mwatawala et al. 2009; Quintero Fong et al. 2009; Urbaneja et al. 2009).

In Brazil, species of *Anastrepha* Schiner, *Ceratitis capitata* (Wiedemann), and *Bactrocera carambolae* Drew & Hancock are considered to be the most important fruit crop pests. In Brazil, 14 *Anastrepha* species and *Ceratitis capitata* are known for their ability to feed on a large number of host plants (Uchoa 2012). Economic losses to fruit production may reach up to US $200 million annually, which includes the costs of insecticide application (Felix et al. 2009), and costs caused by commercial restrictions imposed by countries that import Brazilian fruit (Paranhos et al. 2007).

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For optimal insect pest management, it is important to know the spatial distribution of the pests, as well as their relationship with weather (Barbosa 1992). There are no studies on the spatial distribution patterns of fruit flies in Mato Grosso do Sul State (midwestern Brazil). Hence, the objectives of this study were (i) to quantitatively assess the occurrence of *Anastrepha* species captured in McPhail traps through 2 yr in a native forest, in backyard and commercial orchards, both with several fruit crops; (ii) to describe the population patterns of *Anastrepha* species spatial distribution in 3 environments (i.e., native forest, backyard orchard, and commercial orchard); and (iii) to test for a possible influence of weather on this guild of *Anastrepha* fruit flies in the 3 environments.

Materials and Methods

STUDY AREA

We sampled *Anastrepha* species with McPhail traps in a 43.0 ha native forest (22.2000000°S, 54.9166667°W), a 0.5 ha diversified backyard orchard (22.2000000°S, 54.9166667°W), and a 2.5 ha diversified commercial orchard (22.2166667°S, 54.7166667°W), with 11 fruit trees species (*Prunus persica* (L.) Batsch [Rosaceae], *Bactris gasipaes* K. [Areaceae], *Diospyrus kaki* L.f. [Ebenaceae], *Ficus carica* L. [Moraceae], *Psidium guajava* L. [Myrtaceae], *Annona muricata* L. [Annonaceae], atemoya (*Annona squamosa* L. × *Annona cherimoya* Mill.) [Annonaceae], *Mangifera indica* L. [Anacardiaceae], *Vitis vinifera* L. [Vitaceae], *Cocos nucifera* L. [Aracaceae], and *Musa* spp. [Musaceae]), in Dourados, Mato Grosso do Sul State, midwestern Brazil, weekly from Jun 2005 to Jun 2007. The altitude in the 3 environments was approximately 430 masl.

The regional climate is tropical semi-humid, and in some areas high-altitude tropical, with dry winters and rainy summers. Due to the longitudinal position of South America, the atmospheric dynamics of this region are subject to inter-tropical and extra-positive centers of action, with highly negative and subtropical pressures, represented by the Amazon and Chaco depressions (Peel et al. 2007).

SAMPLING

We distributed McPhail traps randomly on different plant species, at 1.80 m aboveground, in the 3 areas: a native forest (8 traps), a backyard orchard (8 traps), and a commercial orchard (10 traps). The fruit flies were collected from the traps weekly in all areas. The distances between the traps were 30 m in the orchards and 100 m in the native forest.

We used hydrolyzed corn protein (BioAnastrepha™, BioControle Métodos de Controle de Pragas Ltda., Indaiatuba, São Paulo, Brazil) at 5% as food bait, which was replaced weekly. The flies captured in traps were collected weekly, placed in vials with 85% ethanol, and sent to the Laboratório de Insetos Frugívoros at the Universidade Federal da Grande Dourados, Dourados, Mato Grosso do Sul, Brazil. Mean monthly data on abiotic factors (e.g., rainfall, temperature, wind speed, and relative humidity) were provided by the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) Meteorological Station at Centro de Pesquisa Agropecuária Oeste (CPAO), Dourados, Mato Grosso do Sul, Brazil.

STATISTICAL ANALYSIS

We used the Kruskal-Wallis test to determine if there were differences in fly numbers attributable to cropping environments, and then compared the environments with the Dunn-Bonferroni bilateral test ($P < 0.01$).

To calculate the faunal indices, we used the ANAFAU program by Moraes et al. (2003). This program takes into account only dominant and predominant species, and uses the indices of diversity and equity, Shannon-Weaver (H') and Hill Equitability, respectively.

To investigate the dispersion pattern of the *Anastrepha* species (aggregate, random, or uniform) collected in the traps in the 3 environments separately, the Morisita index, Mean Variance, and k Exponent methods were used, as recommended by Southwood (1978) and Elliot (1979).

To estimate theoretical frequency distributions, observed frequency of fruit fly species, we used the following models: negative binomial, positive binomial, and Poisson (Young & Young 1998). The peculiarity of the commercial orchard was applications of insecticides during the observational experiment. However, 1 of the data sets from the commercial orchard was excluded.

Fruit fly abundance was calculated using an index of fruit flies per trap per d (FFTD). So, FFTD = N/T × D, where N = number of fruit flies caught, T = number of traps evaluated, and D = interval in d between the collections, as suggested by Salas and Chavez (1981). However, for the d factor (D) in the analysis, we used 30 d.

For correlation analyses between the fruit flies per trap per d index and weather events (rainfall, temperature, wind speed, and relative humidity), we used the Spearman non-parametric correlation ($\alpha < 0.05$) (Dawson & Trapp 2003). Insecticide applications for control of fruit flies occurred in the commercial orchard. However, this environment was excluded from the second correlation analysis to verify the influence of the weather on the fruit flies per trap per d index.

The assumptions were for the selection of samples and variables in the regression analysis for H0 and H1 hypotheses tested for multicollinearity, normality, homogeneity, and independence of errors. For multicollinearity, H0 was accepted with the Index of Variation Interaction Factor (VIF) as the assumption of the regression analysis in more than 1 independent variable, with a value below 10 with a degree of tolerance above 76%, according to Field (2009).

Normality was evaluated with the Kolmogorov-Smirnov test and homogeneity by the Levene test. The test of independence was validated with the Durbin-Watson statistic ($d = 1.79$), as described by Maroco (2007). To evaluate the effect of the independent variables RH and WS upon the dependent variable (fruit flies per trap per d), we conducted a variance analysis (ANOVA-regression) (Ayres et al. 2007).

Results

OCCURRENCE AND POPULATION PATTERNS IN 3 ENVIRONMENTS

We captured 3,507 adult *Anastrepha* spp. in the 3 sampled areas during the weekly evaluations over a 24 mo period. The samples ranged from 0 to 362 individuals, totaling 301 adult *Anastrepha* in the native forest, a total of 2,940 in the backyard orchard, and 266 in the commercial orchard (Table 1).

The population patterns of *Anastrepha* species differed statistically within each environment, and between the 3 environments. In the native forest, the number of *A. sororcula* Zucchi caught in traps during the study differed from all other species ($U = 64.70$; $P < 0.001$; df = 8). In the native forest, *A. sororcula* and *A. montei* Lima were abundant species. In the backyard orchard, *A. fraterculus* (Wiedemann), *A. obliqua* (Macquart), *A. sororcula*, and *A. montei* were the most abundant. However, *A. obliqua* differed significantly ($U = 920.03$; $P < 0.001$; df = 10) in relation to the total number caught, compared with *A. sororcula* and *A. fraterculus*. In the commercial orchard, *A. sororcula* was abundant, differing significantly ($U = 89.18$; $P = 0.000$; df = 8) in the number

Table 1. Composition of *Anastrepha* species (Diptera: Tephritidae) caught in McPhail traps throughout the yr in 3 environments of the Dourados region, Mato Grosso do Sul State, midwestern Brazil, Jun 2005 to Jun 2007.

	Native forest				Subtotal	Backyard orchard				Subtotal	Commercial orchard				Subtotal	All environments				Total
Species (♀♀)	Su	Au	Wi	Sp	by species	Su	Au	Wi	Sp	by species	Su	Au	Wi	Sp	by species	Su	Au	Wi	Sp	by species
Anastrepha amita	0	0	2	0	2 a	—	—	—	—	0 n	—	—	—	—	0 n	0	0	2	0	2
A. barnesi	0	0	6	0	6 a	—	—	—	—	0 n	—	—	—	—	0 n	0	0	6	0	6 a
A. daciformis	0	0	1	6	7 a	0	0	1	3	4 n	0	0	0	3	3 a	0	0	2	12	14 a
A. dissimilis	—	—	—	—	0 n	0	0	1	0	1 n	—	—	—	—	0 n	0	0	1	0	1 n
A. elegans	0	1	2	4	7 a	—	—	—	—	0 n	—	—	—	—	0 n	0	1	2	4	7 a
**A.fraterculus*	0	5	13	1	19 bd	4	15	145	68	*232 a	3	5	2	1	11 a	7	25	160	70	*262 b
A. montei	0	17	7	2	*26 bc	0	6	114	9	129 b	0	0	3	0	3 a	0	23	124	11	158 c
**A. striata*	—	—	—	—	0 n	0	0	11	3	14 c	0	0	1	1	2 a	0	0	12	4	16 a
**A. serpentina*	—	—	—	—	0 n	0	0	1	0	1 n	—	—	—	—	0 n	0	0	1	0	1 n
**A. obliqua*	1	0	1	0	2 a	83	109	362	108	*662 d	0	2	1	0	3 a	84	11	364	108	*567 d
**A. sororcula*	0	4	25	10	*39 c	25	8	102	261	*396 a	72	23	0	5	*100 b	97	35	127	276	*535 d
**A. pseudoparallela*	1	3	8	12	24 d	0	3	39	11	53 bc	1	0	0	23	24 a	2	6	47	46	101 c
**A. turpiniae*	—	—	—	—	0 n	0	0	1	1	2 n	3	0	0	1	4 a	3	0	1	2	6 n
**A. zenildae*	—	—	—	—	0 n	0	0	4	0	4 n	3	0	0	0	3 a	3	0	4	0	7 n
No. ♀♀	2	30	65	35	132	112	141	781	464	1,498	82	30	7	34	153	196 a	201 ab	853 c	533 b	1,783
No. ♂♂	5	42	81	41	169	177	87	650	528	1,442	48	47	4	14	113	230	176	735	583	1,724
Total Number	7 a	72 b	146 c	76 b	301 A	289 abc	228 abc	1431 b	992 c	2,940 B	130 a	77 ab	11 b	48 ab	266 A	426 a	377 a	1,588 b	1,116 b	3,507

*Species considered pests; summer (Su); autumn (Au); winter (Wi), and spring (Sp); ♀♀ = female, ♂♂ = male; numbers followed by the same lowercase letters in a row or column do not differ significantly by Dunn-Bonferroni test ($P < 0.001$); numbers followed by the same uppercase letters in a row do not differ significantly; n = are not included in the evaluation because they were not dominant.

- Comparison of the number of *Anastrepha* by species within each environment (lowercase letter in subtotal columns): Native Forest = Kruskal-Wallis $U = 64.70$; $P < 0.001$; df = 8; $n = 15.264$; Backyard Orchard = Kruskal-Wallis $U = 920.03$; $P = 0.005$; df = 10; $n = 4.664$, and Commercial Orchard = Kruskal-Wallis $U = 89.18$; $P < 0.001$; df = 8; $n = 8{,}586$.

- Comparison of the total number of *Anastrepha* within each environment between seasons (lowercase letters in the total number line): Native Forest = Kruskal-Wallis $U = 57.86$; $P = 0.01$; df = 3; $n = 1{,}696$; Backyard Orchard = Kruskal-Wallis $U = 124.96$; $P < 0{,}001$; (df = 3); $n = 424$; Commercial Orchard = Kruskal-Wallis $U = 9.51$; $P = 0.02$; df = 3; $n = 954$.

- Comparison of the total number of *Anastrepha* between 3 environments (capital letters in the row of the total number in the columns of subtotal by species): Kruskal-Wallis $U = 1{,}019.01$; $P < 0.001$; df = 2; $n = 3{,}074$.

- Comparison of the total number of *Anastrepha* by species in all environments (lowercase letters in the column of Total by species): Kruskal-Wallis $U = 595.46$; $P = 0.02$; df = 13; $n = 28{,}514$.

- Comparison of the total number of *Anastrepha* between the seasons (lowercase letters in the line Total Number in All Environments column): Kruskal-Wallis $U = 41.708$; $P = 0.03$; df = 3; $n = 3{,}074$.

caught during the study from all the other co-occurring species. The analysis of the data pooled for the 3 environments showed that among the abundant species, *A. obliqua* and *A. sororcula* differed significantly (U = 595.46; P = 0.002; df = 13) in the total number caught compared with *A. fraterculus* (Table 1).

FRUIT FLIES BY SEASON

In the native forest, the highest capture of *Anastrepha* species occurred in winter (146 adults) (21 Jun–20 Sep), with summer (21 Dec–20 Mar) being the season with lowest abundance (7 adults). In the backyard orchard, the highest capture of fruit flies also occurred in winter (1,431), differing significantly from the second highest capture, in spring (21 Sep–20 Dec) (992). Both seasons differed significantly (P < 0.01) from summer (289) and autumn (228) (21 Mar–20 Jun), which had the lowest captures. On the other hand, in the commercial orchard, the highest capture of *Anastrepha* species occurred in summer (130), with winter (11) being the season with the lowest abundance of fruit flies. The backyard orchard differed statistically compared with the other environments in the number of *Anastrepha* females captured, totaling 2,940 individuals (Table 1).

Considering the seasonal abundance of different species, abundance of fruit flies in winter (1,588) differed significantly (P < 0.01) from abundance in spring (1,116) and autumn (377). The species *A. obliqua* and *A. sororcula* were more abundant in winter and spring than the other seasons, whereas *A. fraterculus* and *A. montei* had higher populations in winter compared with other seasons (Table 1).

INDICES OF FRUIT FLIES BY ENVIRONMENT

Of the sampled species of *Anastrepha* considered to be fruit pests, *A. fraterculus*, *A. sororcula*, and *A. pseudoparallela* (Loew) were dominant species in the native forest, with *A. montei* and *A. sororcula* considered to be indicators of that environment. In the backyard orchard, *A. fraterculus*, *A. obliqua*, *A. sororcula*, *A. pseudoparallela*, and *A. montei* occurred as super dominant. In this environment, *A. obliqua*, *A. sororcula*, and *A. fraterculus* were considered to be indicators. In the commercial orchard, *A. sororcula* was super dominant, and an indicator of that environment (Table 2).

In general, the dominant species varied among the environments. In the native forest, *A. sororcula* and *A. montei* were highly abundant, very frequent, constant, and dominant. In the backyard orchard, *A. obliqua*, *A. sororcula*, and *A. fraterculus* were super abundant, super dominant, super frequent, and constant. In the commercial orchard, *A. sororcula* was super abundant, super dominant, super frequent, and constant (Table 2).

PATTERN OF SPATIAL DISTRIBUTION

The variance-to-mean ratio (I), commonly known as the index of dispersion, indicated nonrandom dispersion patterns (values above 1.0) in the 3 environments (i.e., native forest, backyard orchard, and commercial orchard). The exponent k of the negative binomial calculated for the number of *Anastrepha* species adults caught in traps, in all the evaluated environments presented positive and significant values, above zero, except in the commercial orchard, with 2 negative values. When we applied the theoretical frequency distributions (i.e., Poisson, negative binomial, and positive binomial) during the seasons, we observed that in the spring and autumn *Anastrepha* species presented a strongly aggregated distribution pattern (Tables 3, 4). There was no definite spatial distribution pattern of *Anastrepha* species in the winter (Tables 4, 5).

Table 2. Faunistic analysis of the *Anastrepha* species (Diptera: Tephritidae) caught in 3 environments of the Dourados region, Mato Grosso do Sul State, midwestern Brazil, Jun 2005 to Jun 2007.

	Native forest						Backyard orchard						Commercial orchard						Total					
Species	NI	NS	Do[a]	Ab[b]	Fr[c]	Co[d]	NI	NS	Do[a]	Ab[b]	Fr[c]	Co[d]	NI	NS	Do[a]	Ab[b]	Fr[c]	Co[d]	NI	NS	Do[a]	Ab[b]	Fr[c]	Co[d]
A. amita	4	3	ND	R	FF	Z	0	0	NA	NA	NA	NA	0	0	NA	NA	NA	NA	2	2	ND	R	FF	Z
A. barnesi	12	5	D	D	FF	Z	0	0	NA	NA	NA	NA	0	0	NA	NA	NA	NA	6	6	D	C	F	Z
A. daciformis	14	4	D	C	F	Z	4	3	ND	C	F	Z	6	2	D	C	F	Y	14	10	D	VA	VF	Z
A. dissimilis	0	0	NA	NA	NA	NA	1	1	ND	C	F	Z	0	0	NA	NA	NA	NA	1	1	ND	R	FF	Z
A. elegans	14	8	D	C	F	Y	0	0	NA	NA	NA	NA	0	0	NA	NA	NA	NA	7	7	D	C	F	Z
A. fraterculus	38	17	D	C	F	W	*232	31	SD	SA	SF	W	11	9	D	C	F	W	*262	126	SD	SA	SF	W
A. montei	*52	16	D	VA	VF	W	129	17	SD	SA	SF	Y	3	2	ND	C	F	Y	158	72	SD	SA	SF	Y
A. striata	0	0	NA	NA	NA	NA	14	7	D	VA	VF	Y	2	2	ND	C	F	Y	16	14	D	VA	VF	Y
A. serpentina	0	0	NA	NA	NA	NA	1	1	ND	C	F	Z	0	0	NA	NA	NA	NA	1	1	ND	R	FF	Z
A. obliqua	4	3	ND	R	FF	Z	*662	47	SD	SA	SF	W	3	3	ND	C	F	Y	*667	189	SD	SA	SF	W
A. sororcula	*78	19	D	VA	VF	W	*396	38	SD	SA	SF	W	*100	17	SD	SA	SF	W	*535	174	SD	SA	SF	W
A. pseudoparallela	48	15	D	A	VF	W	53	18	SD	SA	SF	Y	24	4	D	VA	VF	Y	101	68	SD	SA	SF	Y
A. turpiniae	0	0	NA	NA	NA	NA	2	2	ND	C	F	Z	4	3	ND	C	F	Y	6	5	D	C	F	Z
A. zenildae	0	0	NA	NA	NA	NA	4	3	ND	C	F	Z	3	3	ND	C	F	Y	7	7	D	C	F	Z

NI = number of individuals; NS = number of samples with the species; Do = dominance: Ab = abundance; Fr = frequence, and Co = constance; [a]Dominance: ND = not dominant (0–1/3 = 33% of the species present); D = dominant (2/3 of the species present); SD = super dominant (1/1 of the species present); NA = not applicable as no individuals collected. [b]Abundance: R = rare (about 0.00–16.67%); D = dispersed (about 16.67–33.34%); C = common (about 33.34–50.00%); A = abundant (about 50.00–66.68%); VA = very abundant (about 66.68–83.35%); SA = super abundant (about 83.35–100.00%); NA = not applicable as no individuals collected. [c]Frequency: FF = infrequent (0–25%); F = frequent (25–50%); VF = very frequent (50–75%); SF = super frequent (75–100%); NA = not applicable as no individuals collected. [d]Constancy: Z = accidental (0–33% or 1/3), species present in less than 25% of the samples; Y = accessory (34–66% or 2/3), species present in 25 to 50% of the samples; W = constant (67–100% or 1/1–3/3), species present in 50% or more of the samples; NA = not applicable as no individuals collected; * = indicator of the environment.

Table 3. Average number of fruit flies in the genus *Anastrepha* (Diptera: Tephritidae) captured in 8 McPhail traps with food bait in a native forest (Dourados, Mato Grosso do Sul State, midwestern Brazil, Jun 2005 to Jun 2007): dispersion index mean variance *I*, factor *K*, and theoretical frequency distributions.

		Descriptive analysis		Dispersion indices		Theoretical frequency distribution					
Season	Month	NFF	Average	*I*	*K*	PD	Df	NBD	Df	PBD	Df
Summer	Jan	2	0.038	3.53 Ag	0.015 Ag	0.23 u	0	0.54 u	−1	0.23 u	−1
Summer	Feb	3	0.057	5.30 Ag	0.013 Ag	0.61 u	0	3.81 Ag	1	1.41 u	−1
Summer	Mar	9	0.170	15.90 Ag	0.011 Ag	13.51**	1	2.83 Ag	1	13.55 u	0
Autumn	Apr	17	0.321	30.03 Ag	0.011 Ag	63.85*	2	1.04 Ag	1	30.38 u	0
Autumn	May	33	0.500	72.6 Ag	0.007 Ag	63.19*	2	5.05 u	0	63.58**	1
Autumn	Jun	18	0.283	26.71 Ag	0.011 Ag	26.34*	1	3.50 Ag	1	69.01**	1
Winter	Jul	28	0.528	49.47 Ag	0.011 Ag	69.53*	2	5.68*	1	69.94**	1
Winter	Aug	165	1.887	196.64 Ag	0.010 Ag	504.67**	5	12.62**	2	504.56**	4
Winter	Sep	41	0.641	60.47 Ag	0.011 Ag	86.48**	2	2.31 Ag	2	87.10**	1
Spring	Oct	20	0.340	31.95 Ag	0.011 Ag	34.36**	1	0.50 Ag	1	115.30**	1
Spring	Nov	24	0.453	42.40 Ag	0.011 Ag	57.76**	2	4.32 Ag	2	56.61**	1
Spring	Dec	21	0.340	31.91 Ag	0.011 Ag	29.79**	1	1.57 Ag	1	30.01 u	0

NFF = number of fruit flies; *I* = variance-to-mean ratio index; *K* = exponent of the negative binomial distribution; PD = Poisson distribution; df = degrees of freedom of the χ^2 distribution; NBD = negative binomial distribution; PBD = positive binomial distribution; Ag = aggregated; u = undetermined; **highly significant ($P < 0.01$), *significant ($P < 0.05$).

Table 4. Average number of fruit flies in the genus *Anastrepha* (Diptera: Tephritidae), captured in 8 McPhail traps with food bait in a backyard orchard in Dourados, Mato Grosso do Sul State, midwestern Brazil, Jun 2005 to Jun 2007: dispersion index mean variance *I*, factor *K*, and theoretical frequency distributions (i.e., Poisson, negative binomial, and positive binomial).

		Descriptive analysis		Dispersion indices		Theoretical frequency distribution					
Season	Month	NFF	Average	*I*	*K*	PD	df	NBD	Df	PBD	Df
Summer	Jan	89	1.679	21.34 Ag	0.082 Ag	175.56**	4	9.20 Ag	6	198.15**	3
Summer	Feb	76	1.434	18.52 Ag	0.082 Ag	163.42**	3	14.77*	5	146.32**	2
Summer	Mar	264	4.981	80.63 Ag	0.062 Ag	6,397.63**	9	11.39 Ag	7	1,217.26**	7
Autumn	Apr	116	2.189	36.22 Ag	0.062 Ag	347.48**	5	8.88 Ag	5	367.49**	4
Autumn	May	78	1.472	24.67 Ag	0.062 Ag	142.36**	3	6.47 Ag	3	145.60**	2
Autumn	Jun	294	5.547	89.70 Ag	0.062 Ag	11,090.92**	10	11.41 Ag	7	15,209.13**	9
Winter	Jul	338	6.377	91.40 Ag	0.070 Ag	1,489.29**	2	18.49*	8	32,630.96**	10
Winter	Aug	517	9.755	102.24 Ag	0.096 Ag	1,181.03**	11	21.83*	8	1,651.12**	10
Winter	Sep	642	12.113	158.19 Ag	0.077 Ag	2,295.46**	13	23.85*	11	1,657.30**	11
Spring	Oct	352	6.641	181.48 Ag	0.037 Ag	1,168.50**	9	8.84 Ag	6	1,437.91**	8
Spring	Nov	345	6.509	132.70 Ag	0.049 Ag	949.01**	9	9.45 Ag	7	1,233.07**	8
Spring	Dec	205	3.868	63.10 Ag	0.062 Ag	2,121.29**	7	11.11 Ag	6	2,469.19**	6

NFF = number of fruit flies; *I* = variance-to-mean ratio index; *K* = exponent of the negative binomial distribution; PD = Poisson distribution; df = degrees of freedom of the χ^2 distribution; NBD = negative binomial distribution; PBD = positive binomial distribution; Ag = Aggregated; **highly significant ($P < 0.01$), *significant ($P < 0.05$).

Table 5. Average number of fruit flies in the genus *Anastrepha* (Diptera: Tephritidae), captured in 10 McPhail traps with food bait in a commercial orchard in Dourados, Mato Grosso do Sul State, midwestern Brazil, Jun 2005 to Jun 2007: dispersion index mean variance (*I*), factor *K*, and theoretical frequency distributions (i.e., Poisson, negative binomial, and positive binomial).

		Descriptive analysis		Dispersion indices		Theoretical frequency distribution					
Season	Month	NFF	Average	*I*	*K*	PD	Df	NBD	Df	PBD	Df
Summer	Jan	11	0.104	4.94 Ag	0.026 Ag	3.96 u	0	0.09 u	0	4.42 u	−1
Summer	Feb	3	0.028	0.98 Ag	−1.486 Un	0.00 u	0	0.01 u	0	0.00 u	−1
Summer	Mar	126	1.189	36.10 Ag	0.034 Ag	193.98**	3	5.95 Ag	6	196.36**	2
Autumn	Apr	100	0.943	37.51 Ag	0.026 Ag	146.8**	3	5.27 Ag	5	144.44**	1
Autumn	May	18	0.170	6.33 Ag	0.032 Ag	17.28**	1	2.96 Ag	2	17.04 u	0
Autumn	Jun	4	0.038	1.48 Ag	0.079 Ag	0.23 u	0	0.02 u	−1	0.23 u	−1
Winter	Jul	4	0.038	1.48 Ag	0.079 Ag	0.23 u	0	0.02 u	−1	0.23 u	−1
Winter	Aug	5	0.047	1.77 Ag	0.061 Ag	0.76 u	0	0.12 u	−1	0.76 u	−1
Winter	Sep	2	0.019	0.99 Ag	−1.981 Un	0.00 u	0	0.00 u	−1	0.00 u	−1
Spring	Oct	5	0.047	2.17 Ag	0.040 Ag	0.76 u	0	0.03 u	0	0.76 u	−1
Spring	Nov	5	0.047	1.36 Ag	0.130 Ag	0.13 u	0	0.01 u	−1	0.17 u	−1
Spring	Dec	107	1.009	55.64 Ag	0.018 Ag	172.98**	3	6.66 Ag	3	185.06**	2

NFF = number of fruit flies; *I* = variance-to-mean ratio index; *K* = exponent of the negative binomial distribution; PD = Poisson distribution; df = degrees of freedom of the χ^2 distribution; NBD = negative binomial distribution; PBD = positive binomial distribution; Ag = aggregated; Un = uniform; u = undetermined; **highly significant ($P < 0.01$).

The populations of *Anastrepha* species did not display a uniform spatial distribution pattern (i.e., positive binomial) or random spatial distribution (i.e., Poisson) in any of the evaluated environments. In fact, *Anastrepha* species adults presented a strongly aggregated spatial distribution in a natural environment (i.e., native forest) and in the backyard orchard, and they were characterized as moderately aggregated in the commercial orchard (Tables 3–5).

CORRELATION WITH WEATHER

The most important variables in the regression model were the air relative humidity (RH) and wind speed (WS), providing the equation: FFTD = 60.304 + 0.742RH−5.754WS. The adjusted model was highly significant for the effects of relative humidity and wind speed, and accounted for 93.1% of the total variability in the number of *Anastrepha* species adults caught in the traps per 30 d interval. This suggests that it was not necessary to add other variables in the model to verify and estimate the variation of the number of fruit flies by the McPhail trap during a 30 d interval (fruit flies per trap per d) (Table 6).

The model predicted 0.742 fruit flies per trap per 30 d interval for every 1% increase in relative humidity during this interval, considering constant wind speed. There was a reduction of 0.742 fruit flies for each m per s increase in wind speed when relative humidity remained constant (Table 6).

Discussion

FRUIT FLY SPECIES ABUNDANCE BY ENVIRONMENT

Fourteen species of *Anastrepha* were captured in the 3 environments, 9 in the native forest, 11 in the backyard orchard, and 9 in the commercial orchard. The species found exclusively in the native forest environment were *A. amita* Zucchi, *A. barnesi* Aldrich, and *A. elegans* Blanchard. *Anastrepha dissimilis* Stone and *A. serpentina* (Wiedemann) were found exclusively in the backyard orchard environment. Most of the species (9) were common for both backyard and commercial orchards (Table 1).

Anastrepha amita, *A. barnesi*, and *A. elegans* feed on native host fruit from Atlantic forests, such as *Citharexylum myrianthum* Cham. (Verbenaceae), *Pouteria torta* Mart. (Radlk; Sapotaceae), and *Chrysophyllum gonocarpum* (Mart. & Eichler) Engl. (Sapotaceae), respectively (Souza-Filho et al. 1999; Garcia et al. 2008). It is probable that these species occur in the native forest, a part of Fazenda Coqueiro, Dourados, a forest fragment with a phyto-physiognomy of the Atlantic forest.

All the species present in the backyard orchard and in the commercial orchard are associated with fruit crops, principally Passifloraceae, Myrtaceae, and Euphorbiaceae (Uchoa 2012). The abundance of fruit flies was highest in the backyard orchard. This result can be explained by the higher diversity of host fruit cultivated in this environment, and because the site was adjacent to a riparian forest, which provided an access corridor from several native forest fragments in the Dourados region.

INDICES OF FRUIT FLIES IN THE ENVIRONMENTS

In the native forest, no super dominant, super abundant, or super frequent species occurred. This is expected, due to the occurrence of fewer host plants, more predators, more parasitoids, and the fruit trees are spaced by chance. On the other hand, in backyard and commercial orchards, the most dominant, abundant, frequent, and constant species were *A. fraterculus*, *A. obliqua*, and *A. sororcula* (Table 2). This result was expected, because these 3 species are polyphagous and key pests on fruit crops in Brazil (Uchoa 2012).

PATTERN OF SPATIAL DISTRIBUTION

In the native forest (Table 3) and the backyard orchard (Table 4), the spatial distribution of *Anastrepha* species was aggregated (except in Jan, May, Jul, and Aug). In the commercial orchard (Table 5), the spatial distribution pattern was characterized as moderately aggregated. Population growth may occur due to the infestation of the fruits of plants that are used as mating sites by these tephritids, which lay eggs soon after on fruits.

The Poisson and binomial positive distributions do not fit our data because a large number of individuals of *Anastrepha* species was caught in a few traps, indicating a clustered (i.e., clumped) distribution. This finding is in agreement with Martella et al. (2012) for aggregated distributions. Martella et al. (2012) highlighted the common occurrence of high population densities of individuals in some areas and low densities in others.

We observed that the spatial distribution of fruit fly species was clustered not only in the native forest and backyard orchard, where the fruit trees were randomly arranged, but also in the commercial orchard, where the plants were arranged according to a pre-established density and distribution pattern. The fruit fly spatial distribution pattern remained clustered, even when traps were set at different distances. In this study, the traps were spaced more than 100 m away from each other in the forest and less than 50 m away from each other in the backyard and commercial orchards. Silva (2007) captured a higher number of *C. capitata* in traps at 25 and 50 m from the release site, in comparison with traps installed at greater distances. According to Silva (2007), the maximum limit of movement for this fruit fly species was 250 m from the release site.

The clustered distribution observed in this study also may be influenced by the mating behavior of the fruit fly species. In some *Anastrepha* species, the male performs courtship through a ritual dance, called lekking behavior, where several males come to a point and release a sex pheromone together to attract conspecific females (Facholi-Bendassolli & Uchoa 2006). According to Segura et al. (2007), for *A. fraterculus*, the most successful males are those grouped in the region

Table 6. Multiple regression of the number of fruit flies by species of the genus *Anastrepha* (Diptera: Tephritidae), captured in McPhail traps per day (FFTD), and its relationship with relative humidity and wind speed in 3 environments of the Dourados region, Mato Grosso do Sul State, midwestern Brazil (Jun 2005 to Jun 2007).

	Confidence Interval of 95% for B and R^2 values			
Variables	*B* (DE)	Lower	Upper	R^2
Constant (FFTD)	60.304 (5.770) **	48.290	72.319	0.931
Relative humidity (RH) (%)	0.742 (0.060) **	0.618	0.866	0.666
Wind speed (WS) (m/s)	−5.754 (1.484) **	−8.839	−2.669	−0.064

Legend: **highly significant ($P < 0.01$); FFTD = fruit flies per trap per 30 days; *B* = angular slope constant; DE = default error; ANOVA $F_{2,21}$ = 141.184; (FFTD) = 60,304 + 0.742RH − 5,754WS; *t* test ($P < 0.001$); m/s = meters per second.

of the tree with the highest luminous intensity in the early hours of the d. The calling behavior with release of the sex pheromone is positively associated with the copulatory success of males, which also correlates with some morphometric and behavioral traits.

RELATIONSHIP WITH WEATHER

The monthly averages of relative humidity, wind speed, and the number of fruit flies per season of the year showed an influence on the number of fruit flies caught in the traps. The number of fruit flies per trap per 30 d interval expressed an inverse and significant correlation with wind speed, and a direct correlation with relative humidity, holding the other variables constant. Chen and Ye (2007) found that air temperature, precipitation, hours of sunshine, and relative humidity were the principal weather factors correlated with changes in population size for *Bactrocera dorsalis* (Hendel).

In this study, the maximum temperature and the accumulated precipitation did not have a significant effect on the capture of fruit flies; that is, the correlations did not differ from zero. However, the abundance of *Anastrepha* spp. was significantly influenced by lower temperatures (captures increased) compared with higher temperatures (captures decreased).

The average maximum relative humidity was positively correlated with captures (fruit flies per trap per d), probably due to the effect of existing multicollinearity with other climatic variables. Possibly, the increase in fruit fly abundance in relation to relative humidity was due to the fact that during the sampling period the average relative humidity had a greater amplitude in relation to the minimum and maximum humidity, becoming more favorable to the development of fruit flies. According to Rodrigues (2004), the favorable range of relative humidity for insects is between 40 and 80%, which provides greater development speed, longevity, and fecundity.

When we analyzed the effect of the correlations individually, without eliminating the overlap effect, wind speed was the only weather variable that showed a negative and significant correlation with the number of fruit flies caught in the traps ($P < 0.05$). This finding is in agreement with Chen and Ye (2007), that highlighted that weather conditions, such as temperature, insolation, and wind speed, could affect the behavior of fruit flies.

This research found that in the native forest and the backyard orchard, we found positive correlations between the abundance of fruit flies and the seasons of the year, with higher abundance of fruit flies caught in the winter. In the commercial orchard, higher capture of *Anastrepha* species occurred in the summer. *Anastrepha* species presented a strongly aggregated spatial distribution in the native forest and the backyard orchard, whereas in the commercial orchard their populations were moderately aggregated. Relative air humidity and wind speed influenced the capture of *Anastrepha* species in the traps, with these 2 variables explaining more than 93% of the total variability in fruit fly species capture per trap per 30 d interval.

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