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Distance from the edge of forest fragments influence the abundance of aphidophagous hoverflies (Diptera: Syrphidae) in wheat fields

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ABSTRACT. This study aimed to evaluate the influence of the distance from the edge of native forests on the abundance of aphidophagous hoverflies in wheat fields. The study was conducted in four commercial fields in the North of Paraná State, Brazil, during the wheat crop season of 2009. Two transects were surveyed parallel to the edge of the forest at two distances: 25 ("near") and 525 meters ("far") from the edge. The abundance of hoverflies was compared using a χ^2 test ($p \leq 0.05$). In total, 1,845 hoverflies adults were collected, which represented 15 species and three genera. The most abundant species was *Allograpta exotica* (60.43%), followed by *Toxomerus dispar* (17.78%) and *Toxomerus watsoni* (7.26%) (Diptera: Syrphidae). An important inference was that all fields showed a higher abundance of aphidophagous hoverflies closer to the edge of the forest (25 m) during the wheat tillering stage. The initial abundance of aphidophagous hoverflies in wheat fields is likely greater near the edge because of the availability of resources in the surrounding forest that enhance hoverfly survival during periods of low aphid infestation.

Keywords: conservative biological control, predators, wheat pests, landscape preservation, refuge area.

A distância da borda de fragmentos florestais infuencia a abundância de sirfídeos afidófagos (Diptera: Syrphidae) em lavouras de trigo

RESUMO. O objetivo desta pesquisa foi avaliar a influência da distância do fragmento de mata nativa sobre a abundância de sirfídeos afidófagos em lavoura de trigo. O experimento foi conduzido em quatro lavouras comerciais, localizadas no Norte do estado do Paraná, durante a safra 2009. Para isto, foram estabelecidos dois transectos paralelos à borda da mata, nas distâncias de 25 ("perto") e 525 metros ("longe") da borda. A abundância de sirfídeos foi comparada empregando-se o teste χ^2 ($p \leq 0,05$). No total, foram capturados 1845 sirfídeos adultos, representados por 15 espécies e três gêneros. A maior abundância de sirfídeos afidófagos foi registrada para espécie *Allograpta exotica* (60,43%), seguida por *Toxomerus dispar* (17,78%) e *Toxomerus watsoni* (7,26%) (Diptera: Syrphidae). Uma inferência de destaque foi que durante o estádio de perfilhamento do trigo, todas as lavouras apresentaram maior abundância de sirfídeos afidófagos próximo à borda da mata (25m). A abundância inicial da população de sirfídeos afidófagos na lavoura de trigo é maior na proximidade da borda da mata, provavelmente devido os recursos disponíveis para sobreviverem durante a baixa infestação de presas na lavoura.

Palavras-chave: controle biológico por conservação, predadores, pragas de trigo, preservação de paisagem, áreas de refúgio.

Introduction

Hoverflies (Diptera: Syrphidae) are notably important insects because they act as pollinators (Jun, Yibo, Jin, Fazhi, & Zhenhai, 2009; Blaauw & Isaacs, 2014) and biological control agents (Irshad, 2014). In wheat crops (*Triticum aestivum* L.), the agronomic importance is at the larval stage, where aphid predators (Schmidt et al., 2003; Bugg, Colfer, Chaney, Smith, & Cannon, 2008) can consume up to 2,000 aphids (Dib, Simon, Sauphanor, & Capowiez, 2010; Hogg, Bugg, & Daane, 2011). Meanwhile, adult hoverflies feed on nectar and pollen, whose energy (Van Rijn, Kooijman, & Wackers, 2013) increases the reproductive rate (Laubertie, Wratten, & Hemptinne, 2012) and longevity (Pinheiro, Torres, Raimundo, & Santos, 2015). Because of the importance of floral resources to hoverflies, many studies have been conducted to promote the action of this natural enemy in crop fields using landscape management (Hickman & Wratten, 1996; Bokina, 2012; Amaral et al., 2013; Gontijo, Beers, & Snyder, 2013; Martínez-Uña, Martín, Fernández-Quintanilla, & Dorado, 2013; Haenke et al., 2014).

Moreover, the remaining forest fragment may act as an area of refuge to natural enemies during little abundance of pests in crop fields (Koh & Holland, 2015). In Brazil, although several studies have shown that natural enemies are highly efficient in suppressing aphid infestation in wheat crops (Salvadori & Salles, 2002; Alves, Prestes, Zanini, Dalmolin, & Menezes Jr., 2005; Bortolotto, Menezes Jr., Sampaio, & Hoshino, 2012; Bortolotto, Menezes Jr., & Hoshino, 2015), have no investigation about the influence of non-crop fields on these natural enemies. Among the conservative management strategies, the maintenance of non-crop habitats has been studied to understand the importance of natural enemies (Barbosa, 1998; Walton & Isaacs, 2011; Letourneau, Bothwell, & Stireman, 2012; Fahrig et al., 2015). However, it is important to consider that most studies were developed in temperate regions. Hence, the importance of the remaining forest fragment near crop fields and its contribution to natural enemies are unavailable for the Neotropical agroecosystem. In adittion, some investigations were reported a devastation of native forest fragments in Brazil reducing non-crop areas (Fearnside, 2001; Nassar, 2009), and this practice caused impact on biodiversity (Vieira, Toledo, Silva, & Higuchi, 2008). In this sense, it is important to develop research to increase understanding about the importance of remaining forest fragments for natural biological control, and to encourage growers to maintain refuge areas in their farms. Thus, this study investigates the effect of the distance from the edge of a forest fragment on aphidophagous hoverflies in wheat fields.

Material and methods

Study site

The study was performed in four commercial wheat crops in northern Paraná State, Brazil, during the 2009 crop season (usually in approximately April/May to August/September). The sites located in the municipalities of Ibiporã-Santo Antônio Farm (SAF) (23° 14' 34" S 51° 27' 07" W), Ibiporã-Bonsucesso Farm (BF) (23° 12' 26' S 51° 03' 51" W), Rolândia (Gioconda Farm) (23° 23' 59" S 5° 19' 01" W), and Londrina (23° 19' 49" S 51° 08' 12" W) (Table 1).

In all of the studied fields, wheat was sown in succession to soybean [*Glycine max* (Merrill) L.] in no-tillering soil. The fields were sown on April 29 (Rolândia-GF), May 6 (Ibiporã-FBS), May 8 (Ibiporã-SAF), and May 11 (Londrina). In general, the landscape complex around each farm (with an approximately 2 km radius) was primarily composed of wheat crops (32 to 47%), followed by non-crop area [Atlantic forest fragment (compound majority by *Aspidosperma polyneuronand*; *Ficus* spp.; *Euterpe edulis*; Orchidaceae and grasses) and pasture] (26.2 to 39%), maize (7 to 26.5%) and cofee crops (2.9 to 20.5%). Expeptionally in Ibiporã-SAF oleraceous, fruits and fallow areas (predominantly infested with wild radish) were reported.

Hoverfly survey

Hoverflies were assessed in two transects (90 m in length) that demarcated each field (adapted from Murta, Ker, Costa, Espírito-Santo, & Faria, 2008). The transects were set up immediately after the emergence (phenological stage V1) of wheat crops in all fields except Londrina, which was demarcated one day after sowing. In this sense, the assessment of hoverflies began on the same day that the transect was demarcated. To compare the "edge effect", one transect was demarcated at 25 m from the edge (near), and the other was at 525 m from the forest edge (far).

The hoverfly abundance was monitored using Malaise traps (Petanidou, Vuji, & Ellis, 2011), which were placed at the center of each transect (n = two traps field^{-1}). The traps were made of a synthetic material and shaped like a tent, with an opening at the bottom that intercepted the insects during flight after they collided with one of the trap's septa. The traps were installed and positioned to face north, where the most sunlight was received. Each trap was approximately 1.80 m high × 1.80 m long. The collecting bottle contained 70% alcohol, which was changed weekly on the day that the number of aphids was counted. In the laboratory, the collected material was screened, and the hoverflies were identified using a stereoscope microscope according to an identification guide (Marinoni, Morales, & Spaler, 2007; Borges & Couri, 2009; Mengual, Ruiz, Rojo, Stahl, & Thompson, 2009).

Table 1. Farm description and climatic data during the study. Paraná State, crop season (May to September of 2009).

Description	Farms			
	Ibiporã (SAF)	Ibiporã (BF)	Rolândia (GF)	Londrina
Wheat field (size)	2.3 ha	16.2 ha	20.9 ha	11.4 ha
Forest fragment (size)	45 ha	24.5 ha	380 ha	25 ha
Rapid Ecological Assessment[1]	34	28	48	50
Ecological Integrity[1]	Medium	Poor	Good	Excellent
Climatic data	-	-	-	-
Temperature average (°C)	20.54	20.54	17	17.5
Rainfall total (mm)	461.00	461.00	351.7	585.9

[1]Methodology and classification according to Medeiros and Torezan (2013).

Aphids survey

Aphid assessment was made for both distances (25 and 525 m from the edge of the forest). Each transect contained 10 evaluation points, where 20 tillers at each point were randomly evaluated (n = 400 tillers assessment in each field). All aphids were quantified and identified to the species level. To reduce interference, insecticides were not applied to a distance of 5 m from the evaluation points.

Similar to the hoverfly assessment, the aphis infestation survey began on the same day that the transect was demarcated, except in Londrina (seven days after the transect was demarcated). The assessments were performed on a weekly basis, and the aphid species were identified using a guide developed by Salvadori and Tonet (2001).

Statistical analysis

The aphid means were subjected to exploratory analyses to assess the assumptions of the normality of residuals, homogeneity of variance of the treatments, and additivity of the model to allow for parametric tests. The aphid abundance near (25 m) and far (525 m) the edge of the forest was compared using Student's *t*-test.

To compare the hoverfly abundance, the specimens were summed at each growth stage (except Rolândia-GF because of low abundance) and compared using a χ^2 (Chi-square) test. In adittion, the relationship between aphid and hoverfly abundance (density-dependence) was estimated using a quadratic regression model. The difference was considered significant only when the significance level was $p \leq 0.05$.

Results and discussion

In total, 1,845 adult hoverflies were captured, which represented 15 species and three genera (Table 2). The most abundant aphidophagous hoverfly species were *Allograpta exotica* (60.43%), *Toxomerus dispar* (17.78%) and *Toxomerus watsoni* (26.7%) (Diptera: Syrphidae). The reported major abundance of *Allograpta* and *Toxomerus* genus in the present study is consistent with that obtained in a previous report in the Neotropical region (Thompson, 1999), which indicates the adaptation of these hoverflies.

Interestingly, during the wheat tillering stage, consistently higher hoverfly abundance was reported near (25 m) the forest edge than far (525 m) from the edge of the forest (Figure 1). In this period, the predominant species was *A. exotica* (58%), which was followed by *Pseudodorus clavatus* (12%) (Diptera: Syrphidae). In Rolândia-GF farm, a low hoverfly abundance was captured (n total = 74), which did not allow us to perform a statistical test at each growth stage. However, the total abundance was higher near the forest edge (25 m) than far (525 m) from the edge of the forest fragment (Figure 1).

Table 2. Hoverflies (Diptera: Syrphidae) captured in Malaise trap during the crop season of 2009 (May to September) in the Northest of Paraná State.

Syrphidae species	Farms				Total	
	Ibiporã (SAF)	Ibiporã (BF)	Rolândia (GF)	Londrina	Absolute	Relative
Allograpta annulipes	3	0	0	0	3	0.16%
Allograpta exotica	794	169	40	112	1,115	60.43%
Allograpta falcata	3	0	0	0	3	0.16%
Allograpta hastata	3	10	0	0	13	0.70%
Allograpta neotropica	3	0	0	0	3	0.16%
Allograpta obliqua	0	0	3	3	6	0.33%
Pseudodorus clavatus	6	0	13	18	37	2.01%
Ocyptamus dimidiatus	3	0	0	9	12	0.65%
Ocyptamus gastrostactus	0	9	0	0	9	0.49%
Ocyptamus sp.1	3	0	0	0	3	0.16%
Ocyptamus sp.2	0	0	0	3	3	0.16%
Ocyptamus sp.3	0	0	0	3	3	0.16%
Syrphus phaeostigma	3	0	6	3	12	0.65%
Toxomerus dispar	258	15	0	55	328	17.78%
Toxomerus floralis	0	0	3	12	15	0.81%
Toxomerus lacrymosus	3	0	0	0	3	0.16%
Toxomerus politus	0	3	9	6	18	0.98%
Toxomerus sp.	52	22	0	48	122	6.61%
Toxomerus watsoni	134	0	0	0	134	7.26%
Trichopsomyia sp.	3	0	0	0	3	0.16%
Absolute abundance	1,271	228	74	272	1,845	100%
Relative abundance	68.89%	12.36%	4.01%	14.74%	-	100%
Richness	14	6	6	11	-	-

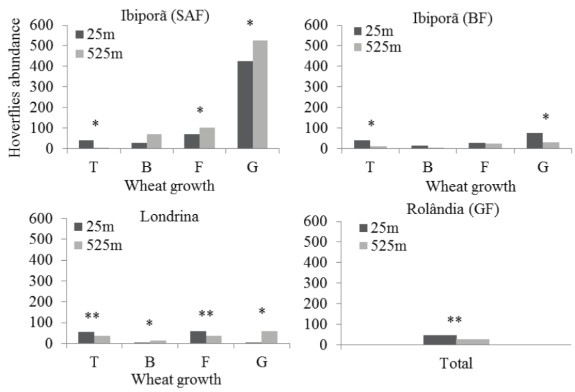

Figure 1. Hoverflies (Diptera: Syrphidae) captured in Malaise traps near (25 m) and far (525 m) from the edge of the forest fragments in different wheat growth stages (T = tillering; B = boot; F = flowering; G = grain). Parana State, wheat season (May to September) 2009. (*$p < 0.05$; **$p < 0.01$; χ^2 test).

The highest abundance of *A. exotica* indicates a nice stablishment of this specie in wheat crop. In a study developed by Greco (1995) the authors reported *A. exotica* strongly associated with the aphid abundance in wheat fields, reforceing the importance of this specie for aphid supression. In the current study, the aphids were represented by only two species: *Sitobion avenae*, which exibited greater abundance (85%) (Hemiptera: Aphididae), and *Rhopalosiphum padi* (15%) (Hemiptera: Aphididae). The highest aphid abundance was reported during the wheat grain stage (Figure 2), which can be explained by the largest occurrence of *S. avenae*.

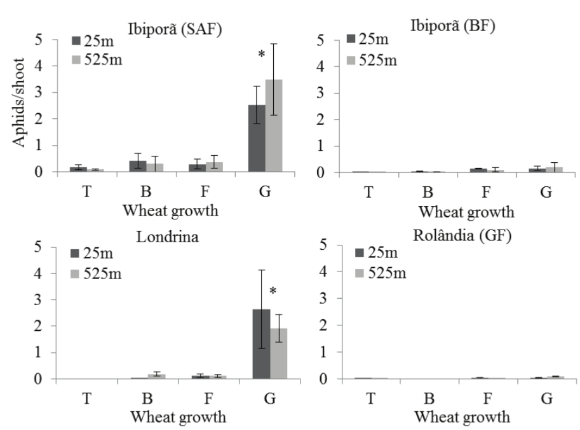

Figure 2. Aphids (mean ± SE) abundance in wheat fields near (25 m) and far (525 m) from the edge of the forest fragments in different wheat growth stages (T = tillering; B = boot; F = flowering; G = grain). Parana State, crop season (May to September) 2009. (*$p < 0.05$, Student's *t* test).

Unlike the present study, Alves et al. (2005) reported highest aphid infestation before the reproductive growth of wheat. However, in that case, *R. padi* was the predominant species. Therefore, the higher infestation of *S. avenae* in the present study is probably associated with decreased abundance of *R. padi* related to wheat growth. This promotes competition among the species, favouring *S. avenae* development during grain stage of wheat (Gianoli, 2000).

In general, the infestation of aphids was not associated with the distance from the forest fragmente and varies according to the study site. For example, differences were observed only in the grain stage, and in Ibiporã (SAF), a higher abundance of aphids was recorded far (525 m) from the edge of the forest, whereas in Londrina, a higher infestation of the pest was reported near (25 m) to the edge of the forest (Figure 2). This fact indicates that aphids are not dependent of refuge area, as opposed of the initial abundance of hoverflies reported in this study.

Is important to emphasize that both aphid species present in wheat fields, *R. padi* and *S. avenae* are prey to *A. exotica* (Rojo, Gilbert, Marcos-García, Nieto, & Durante, 2003; Bokina, 2012), which can contribute to highest abundance of this hoverfly specie in wheat fields (Table 1). In addition, some studies have reported that the hoverflies *T. watsoni* and *T. dispar* usually occur less frequently than *A. exotica* in open fields (Greco, 1995; Arcaya, Mengual, Bañon-Pérez, & Rojo, 2013), and that this species are probably less adapted to agroecosystems. One important factor that needs attention is that *A. exotica* has been reported in the Brazilian agroecosystem to prey on many aphids in oleraceuous and fruit gardens (Resende et al., 2006; Sturza, Dorfey, Poncio, Dequech, & Bolzan, 2011) and to have other prey, such as mites, thrips and newly hatched caterpillars (Rojo et al., 2003). Thus, we believe that the wide spectrum of preys of *A. exotica* is likely the main reason for its widespread occurrence in all areas and its adaptability to local agroecosystems because of food availability during the larval and adult stages. Secondly, it is necessary to consider the influence of climatic factors on hoverflies, because the microclimate in wheat fields can favour *A. exotica* in relation to other hoverflies species. However, there is very little information about the bioecology of these aphid predators and additional studies are necessary to verify this hypothesis.

Although flowers cultivated efficiently increases aphidophagous hoverflies around crop fields (Amaral et al., 2013; Gontijo et al., 2013; Martínez-Uña et al., 2013; Haenke et al., 2014), in the present work, is important to emphasize that we did not sow strip flowers; thus, our data strongly indicate the relevance of preserving native forest fragments to the survival of aphidophagous hoverflies during low aphid infestation in wheat crops. This report is supported by another study in Paraná State, which was developed by Marinoni, Miranda, and Thompson (2004). Their study found a larger abundance of *Allograpta* and *Toxomerus* in hedge forest than open fields (pasture), which indicates the availability of benefical resources to aphidophagous hoverflies.

The other factor is probably the presence of alternative prey for hoverfly larvae near the hedge. In this sense, this relation was previously reported by Koh and Holland (2015), which showed that Anthocoridae predators were in soybean crops before aphid infestation and survived because of the presence of alternative prey and floral resources or weeds. In the present study, during wheat tillering in Londrina, for example, only four aphids were quantified in the wheat fields, which indicates that the larvae of aphidophagous hoverflies can survive by feeding on other insects such as other aphid species and catepillars, in some cases, according to other studies (Rojo et al., 2003; Sturza et al., 2011). This fact reinforces the hypothesis of the importance of forest fragments to increase or mantain hoverfly abundance near the hedge during low aphid infestation in the fields.

Furthermore, the beneficial efect of forest fragments or refuge areas can vary according to the studied taxa or the local climate. In this sense, Raymond et al. (2015) reported a higher abundance of non-aphidophagous hoverflies in the hedge forest, whereas aphidophagous hoverflies were more abundant in crops, which are associated with a high availability of prey. However, in this study, we found a prevalence of aphidophagous predators in general, which was associated with the aphid abundance, but they were initially more abundant near the hedge forest fragment. Thus, the hedge "effect" on hoverflies was reported only in wheat tillering, and the distribution varied among the fields after this wheat growth stage, likely because of the expected relation with aphid infestation (Table 3). The exception was found near (25 m) the edge in one field (Londrina) (Table 3). Although this result is not clear, we hypothesized that another wheat field, which was sown later than the assessed field at approximately a distance far (525 m) from the edge, affected the hoverfly behavior and likely contained better-quality available aphids for consumption.

The importance of hoverflies in wheat fields can be atribute due female hoverflies strongly respond to aphid infestation and can locate even small colonies of the pest (Almohamad, Verheggen, & Haubruge, 2009). In this sense, several studies have shown that hoverflies are highly affected by the presence of infochemicals. For example, Leroy et al. (2014) found that the *honeydew* excreted by *Acyrtosiphum pisum* (Hemiptera: Aphididae) increased the oviposition of *Epysirphus balteatus* (Diptera: Syrphidae). In addition, other studies have shown that even in the absence of *honeydew*, the presence of aphids stimulates hoverfly oviposition and cairomone emission from the infested plants (Francis, Martin, Lognay, & Haubruge., 2005; Harmel et al., 2007; Verheggen, Arnaud, Bartram, Gohy, & Haubruge, 2008). Thus, although forest fragments can aid in hoverfly survival during low aphid infestation in the field, our data indicate that when the aphid infestation increases in wheat fields, these infochemical signals stimulate aphidophagous hoverflies to forage preys and those floral resources can be less important at this time.

Table 3. Relationship between aphid abundance and hoverflies near and far from the forest edge. Regression polinomial quadratic test. Paraná, wheat season (May to September of 2009).

Farm	Distance from edge					
	Near (25 m)			Far (525 m)		
	F	p	R^2	F	p	R^2
Ibiporã (SAF)	4.39	< 0.01	0.36	5.38	< 0.01	0.42
Londrina	0.56	n.s	0.08	6.24	< 0.01	0.48
Ibiporã (BF)	2.26	0.03	0.20	2.51	0.03	0.25

*Rolândia (GF) was not possible for a statistical analysis because of the low aphid and hoverfly abundances.

Is important to consider that many natural enemies are present in agroecossystem and contribute with aphid suppression. Although the present study showed hoverflies associated with aphid abundance (Table 3), other biological control agents acted against aphid infestation also. In Brazil, after implementation of biological control of aphids of wheat (BCAW) program, parasitoids are mainly responsible for reducing aphid infestation (Salvadori & Salles, 2002; Bortolotto et al., 2012). In the present work, we report an average parasitism between 6.8 and 16.9% among the fields. Another natural enemy associated with reduced aphid abundance was the predator Dolichopodidae (R^2 = 0.37 to 0.56; $p \leq 0.05$), supporting the importance of natural biological control against this pest in wheat fields. So, these natural enemies reported in this study can justify the weak influence of hoverflies on aphid abundance.

Although this subject is not the main objective of the study, the forest fragment quality was not associated with the abundance and richness of hoverflies. This result was observed in Ibiporã (SAF), which had the largest number of individuals and the largest richness, although it contained a forest section with intermediate biotic quality

(Table 1). Our data indicate that the abundance can be explained by the fact that this area also had the highest infestation of aphids, which suggests a density-dependent relationship. However, the hoverfly richeness must be linked to other factors that were not measured in the study, such as the diversity of plants on site in the agroecosystem, environmental complexity on a regional scale (Fahrig et al., 2015) and historical management of crops (input of pesticides) (Bokina, 2012). Thus, these factors must be investigated in other studies to better understand the relation between hoverflies and the environment.

Finally, this study reports for first time the importance of preserving areas of forest fragments as a refuge and likely source of supplies for aphidophagous hoverflies in Brazilian agroecosystems. There is currently a great necessity for similar studies in developing tropical regions because of the lack of such information. Thus, other aspects should be considered for further studies, such as identifying the weeds in the vicinity of the crop to select potential plants to be grown to attract these natural enemies in regions with poor natural biodiversity.

Conclusion

Hoverfly abundances are initially higher near the edge of the forest fragment. After the aphid abundance in wheat fields increases, the hoverfly population depends on the prey infestation.

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