Aphidophagous parasitoids, which are found in many regions of the world, help to regulate aphid populations in wheat crops (Adisu et al. 2002, Schmidt et al. 2003, Saether et al. 2011, Pléciasha et al. 2014, Elliott et al. 2014, Zhao et al. 2014). In temperate regions, common aphids sexually reproduce during severe winters, and the female aphids usually lay their eggs on primary (harboreus) host plants (Stary and Havelka 2008). Sexual reproduction is a winter survival strategy because the eggs can endure the winter conditions. However, when the temperature begins to rise, the nymphs eclose and the young aphids migrate to the wheat, usually from the flowering stage onward (Schmidt et al. 2003, Thies et al. 2005, Caballero-López et al. 2012). In temperate regions, natural enemies such as aphidophagous parasitoids can survive winter in two ways: by starting diapause or by migrating to warmer regions (Jones et al. 2008). However, both these processes mean that these natural enemies need a long time to colonize wheat crops, which hinders initial aphid suppression.

However, the warmer climate in tropical and subtropical regions is more favorable to aphid development, and aphid reproduction is often asexual (thelytokous parthenogenesis) (Simon et al. 2002). This implies that there is a different dynamic spatial and temporal relationship between aphids and their natural enemies in tropical and temperate zones. In Brazilian fields, most studies have investigated the occurrence of aphid parasitoids in a field by measuring the number of mummies. This method severely restricts the understanding of the behavior of these natural enemies in the field. Many studies conducted in Brazil have shown that parasitized aphids (mummies) appeared during the tillering stage (Alves et al. 2005, Machado and Santos 2013), usually parasitized by polyphagous parasitoids (Starý et al. 2007). So, it is possible that this earlier occurrence and the broad spectrum of hosts, was the main reason that biological control was quite successful.

Therefore, we believe that this natural enemy is present in the field immediately after aphid infestation. In this sense, to better understand it, this work aimed investigated when aphidophagous parasitoids colonizes wheat crops, in Parana State, Brazil. To confirm this hypothesis, we used traps that were designed to capture parasitoids, which allowed us to estimate the moment that aphid parasitoids appeared in wheat fields. This enabled us to evaluate the incidence and colonization of aphid parasitoids during the initial wheat development phase.

Materials and Methods

The study was carried out in four commercial wheat crops in northern Parana State, Brazil, during the 2009 season (usually around April/May to August/September). The sites were located in the municipalities of Ibiporã: San Antonio Farm (SAF, 23°14′34″S, 51°27′07″W), Ibiporã Bonsucesso Farm (BF, 23°12′26″S, 51°03′51″W), Rolândia-Giconda Farm (23°23′59″S, 5°19′01″W), and Londrina (23°19′49″S, 51°08′12″W), and the area of study (ha) was 2.63, 16.2, 20.9, and 11.4ha, respectively. According to Köppen’s classification, the regional climate where the experiment was conducted is characterized as humid subtropical (Cfa). During the study, the mean (day/night) temperature was 20.54°C ± 1.45°C. The data were collected over 24 h by the meteorological station at the Instituto Agronômico do Paraná (IAPAR).

In all the fields, wheat (Triticum aestivum L.) was sown in succession to soybean [Glycine max (Merrill) L.]. The crop was sown on April 29 (Rolândia), May 6 (Ibiporã-FBS), May 8 (Ibiporã-SAF), and May 11 (Londrina). The landscape complex around each farm is described in Table 1. To better support the work, the description was made considering the dispersal ratio of Aphidiinae parasitoids (2 km) (Thies et al. 2005). All fields wild radish (Raphanus raphanistrum L.) and black-jack (Bidens pilosa L.), however it was not quantified.

Aphid infestation was assessed by demarcating two transects (90 m in length) per field, which were spaced 500 m apart. The transects were set up immediately after emergence (stage V1) of the wheat crops in all fields, except in Londrina, which was demarcated 1 day after sowing. Each transect set up 10 evaluation points, where 20 tillers per point were randomly evaluated (n = 400 tillers/assessment in each field). All the aphids were quantified and identified to the species level. Aphidophagous parasitoid colonization was monitored using Malaise traps, which were placed in the center of each transect (n = two traps/field). The traps were made of a synthetic material and were shaped like...
Aphidius colemani parasitoids (Braconidae: Aphidiinae), and the major species were (Fabricius 1775) (12%) (Table 2). The Malaise traps captured 4,355

Results

positioned such that they faced north—where the most sunlight was re-

occurrence of parasitoids in wheat fields. The traps were installed and

in a collecting vessel (bottle). The traps allowed us to record the earliest

with one of the septa, they go to the raised end where they are trapped

is very efficient for capturing parasitoids, because after they collide

flight after they had collided with one of trap’s septa. This type of trap

a tent with an opening at the bottom that intercepted the insects during

flight after they had collided with one of the septa, they go to the raised end where they are trapped in a collecting vessel (bottle). The traps allowed us to record the earliest occurrence of parasitoids in wheat fields. The traps were installed and positioned such that they faced north—where the most sunlight was received. Each trap was ∼1.80 m high by 1.80 m long. The collecting bottle contained 70% alcohol, which was changed weekly on the day on which the number of aphids was counted. Is important consider that this trap allow to capture parasitoids during dispersal flight among the patches. In the laboratory, the material collected was screened, and the aphidophagous parasitoids were identified using a stereoscope microscope according to the method described by Kavallieratos et al. (2006) and Pereira and Salvadori (2005).

Infestation by aphids and colonization of their parasitoids began 7 days after the wheat was sown, except at Londrina where the assessment began 1 day after the wheat was sown. The assessments were carried out on a weekly basis, and aphid species were identified using a guide developed by Salvadori and Tonet (2001). To reduce interference, insecticides were not applied up to a distance of 5 m from the evaluation points.

Finally, the data were descriptively analyzed and illustrated to depict the seasonal dynamics of aphids and aphid parasitoids.

Results

In total, 197 aphids were quantified in four areas. The major species were Rhopalosiphum padi (Linnaeus 1758) (68%) and Sitobion avenae (Fabricius 1775) (12%) (Table 2). The Malaise traps captured 4,355 parasitoids (Braconidae: Aphidiinae), and the major species were Aphidius colemani (Viereck 1912), Lysiphlebus testaceipes (Cresson 1880), and Diaeretiella rapae (McIntosh 1855) (Table 3). These aphid parasitoids were found at all sites examined and at each assessment (Fig. 1).

In general, aphid parasitoids occurred even in low aphid infestation (Fig. 1). Unexpectedly, the Malaise traps captured 34 parasitoids before wheat emergence in Londrina. The species captured were L. testaceipes (n = 26) and D. rapae (n = 8). Larger numbers of parasitoids were captured at Ibiporã-BF (n = 3,418), although only 22 aphids were reported.

Discussion

Our results showed that aphid parasitoids can forage wheat fields even in a low aphid infestation, and sometimes in absence of aphids. This observation helps us to understand the biodynamics of aphidophagous parasitoids and can be explained by two hypotheses. First, the tropical climate in northern Parana State probably means that the parasitoids can survive actively (parasitizing) for a longer period. For example, the temperature during the assessments (around 20.54°C ± 1.45°C) was optimal for the development of aphidophagous parasitoids (Jones et al. 2003, Rodrigues et al. 2004, Sampaio et al. 2005). Thus, the tropical climate in northern Parana allows aphidophagous parasitoids to appear in crops immediately after wheat emergence. Second, their polyphagous habit probably plays an important role in the maintenance of these parasitoids in fields because they can survive by attacking aphids from other plants such as weeds or other crops cultivated near wheat fields.

The parasitoids captured in this study (L. testaceipes, A. colemani, and D. rapae) can parasitize a range of aphids, which occur in a several cultivated plants and weeds (Starý et al. 2007, Tepa-Yotto et al. 2013, Macedo et al. 2010, Hollingbery et al. 2012). Therefore, although aphid infestation in the fields was low, these parasitoids survived because of the presence of alternative aphid hosts. These included weeds such as wild radish (Raphanus raphanistrum) present in all areas as well as maize fields (Table 1) cultivated around the fields studied. These plants can favor the presence of aphid parasitoids due the presence of aphids hosts, which facilitates the migration of aphid parasitoids to wheat hosts. So, although the neighbor plants were not investigated, this hypothesis can explain the recordings at Londrina, where D. rapae and L. testaceipes were captured before wheat emergence.

Other important factor is that the L. testaceipes parasitoid species, in particular, showed a low capacity to locate the host, since it has a
limited response to volatiles released by the plants (Lo Pinto et al. 2004, Fauvergue et al., 2006). Therefore, this species in a plant with no wheat aphids may be captured owing to theirs disorientation or during transit, while they searched for hosts in other crops. In contrast, *D. rapae* responds strongly to volatiles emitted by brassica plants, even in the absence of hosts (Blande et al. 2007), which suggests that their natural occurrence is related to the presence of wild radish, inside the wheat fields.

The ‘early’ reports of aphidophagous parasitoids in this study are very important for biological control, and it explains the high efficiency of these natural enemies in the regulation of aphid abundance. Finally, this exploratory investigation suggests that these natural enemies are well established in local agroecosystems owing to the large number of alternative hosts that are available during the growing season. Further studies into the behavior of these natural enemies in different climate and regions around the world are needed for efficient conservation of these agents of biological control.

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Table 3. Abundance total and relative (%) of aphidophagous parasitoids (Braconidae: Aphidiinae) captured in Malaise traps located in four wheat fields in northern Parana, from May to June 2009. N = number of collections during the study

| Aphid parasitoids | Ibiporã (N = 7) | Santo Antônio (N = 7) | Rolândia (N = 7) | Londrina* (N = 7) | Total |
|-------------------|----------------|-----------------------|-----------------|------------------|-------|
| *Lysiphlebus testaceipes* | 616 (18%) | 278 (53%) | 112 (80%) | 208 (78%) | 1,214 (27.9%) |
| *Diaeretiella rapae* | 205 (6%) | 248 (46.3%) | 7 (5%) | 46 (17%) | 506 (11.6%) |
| *Aphidius colemani* | 2,597 (76%) | 4 (0.7%) | 21 (15%) | 13 (5%) | 2,635 (60.5%) |
| Total | 3,418 | 530 | 140 | 267 | 4,355 |

*, farm without a name.

Fig. 1. Seasonal abundance of aphids and aphid parasitoids (Braconidae: Aphidiinae) (Log₁₀ scale) in wheat fields located in northern Parana, Brazil, between May and June 2009. Black arrow indicates wheat emergence timing.

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