



Early-season crop colonization by parasitoids is associated with native vegetation, but is spatially and temporally erratic



F.J.J.A. Bianchi^{a,b,c,*}, B.J. Walters^{a,b}, A.L.T. ten Hove^c, S.A. Cunningham^{b,e},
W. van der Werf^d, J.C. Douma^d, N.A. Schellhorn^{a,b}

^a CSIRO Agriculture Flagship, P.O. Box 2583, Brisbane, QLD 4001, Australia

^b Cotton Catchment Communities CRC, Australian Cotton Research Institute, Narrabri, NSW 2390, Australia

^c Farming Systems Ecology, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands

^d Crop and Weed Ecology Group, Centre for Crop Systems Analysis, P.O. Box 430, 6700 AK Wageningen, The Netherlands

^e CSIRO Agriculture Flagship, P.O. Box 1700, Canberra, ACT 2601, Australia

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ABSTRACT

Semi-natural habitats in agricultural landscapes may support parasitoid populations that provide biocontrol services by suppressing populations of crop pests, but little is known about the spatial pattern and variability of these services at different levels of scale. Here we investigate the rarely studied phenomenon of early-season crop colonization by parasitoids and the relationship with the surrounding landscape. We assessed parasitism of whiteflies by placing whitefly infested cotton seedlings in remnant vegetation, arable land 25–125 m from remnant vegetation, and arable land further than 400 m from remnant vegetation. Twelve to twenty sentinel plants were exposed in a 25 × 25 m grid pattern in plots in each habitat. The experiment was conducted at 18 locations across two landscapes and repeated three times in a 2-week period in 2007 and 2008. Parasitism was observed during the first three days after the introduction of the whitefly infested seedlings and was in all cases caused by *Encarsia* spp. The mean number of parasitized whitefly per plant was 0.106 ± 0.025 and was highest on cotton plants placed in remnant vegetation, declining with increasing distance from remnant vegetation. A regression model with land use and meteorological variables received more statistical support from the data than models with only landscape and time period as factors. Parasitism levels were influenced by the proportion of remnant vegetation, grassland, as well as wind, temperature, dew point temperature and year. Early-season colonization of whitefly infested seedlings by parasitoids was erratic and characterized by large spatial (inter-plant and inter-plot) and temporal variation. Our study confirms that remnant vegetation function as reservoirs for parasitoids and that parasitoids can penetrate arable fields beyond 125 m within 3 days. However, variation in the occurrence of parasitism makes it difficult to predict parasitoid colonization at a specific place and time. Therefore, field-based scouting for pests and parasitoids is necessary, even in landscapes with a high biocontrol potential.

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1. Introduction

With increasing concern that biocontrol services are declining at a world-wide scale (Millennium Ecosystem Assessment, 2005) there is growing interest in habitat management to restore functional biodiversity in agricultural landscapes and strengthen natural biocontrol potential (Gurr et al., 2012). Despite growing consensus that landscape heterogeneity can support arthropod

mediated biocontrol services in crops (Bianchi et al., 2006; Chaplin-Kramer et al., 2011), there are many questions regarding the spatial pattern of these ecosystem services around resource habitats of the natural enemies, and the distances over which these services extend into crops (Kremen, 2005; Schellhorn et al., 2008). Identifying the appropriate management scales for conservation biological control requires understanding of how landscape heterogeneity influences the processes underlying natural pest control, including the frequency and spatial extent of dispersal of biological control agents from source habitats to crops and the associated variability in time and space. While the importance of native perennial vegetation for sustaining parasitoid populations and crop colonization has been demonstrated (Landis and Haas,

* Corresponding author at: Wageningen University, Farming Systems Ecology, P. O. Box 430, 6700 AK Wageningen, The Netherlands. Tel.: +31 317 81197.
E-mail address: felix.bianchi@wur.nl (F.J.J.A. Bianchi).

1992; Dyer and Landis, 1997; Bianchi et al., 2008; Thomson and Hoffmann, 2009; Letourneau et al., 2012; Macfadyen and Muller, 2013), the spatial and temporal variation associated with the crop colonization process and how this is influenced by the surrounding landscape has largely been overlooked. Information on the predictability of the crop colonization process by natural enemies is essential to inform effective conservation biological control programs that aim to strengthen biocontrol services by habitat management.

Despite growing concerns about the sustainability of pest management strategies based on the use of synthetic insecticides, these chemicals provide short term pest control that is highly predictable, which makes them attractive pest management option for conventional farmers (Ekström and Ekbohm, 2011) even where there is a longer term risk of pest resistance. The predictability of natural biocontrol differs fundamentally from that of synthetic insecticides as it depends on the colonization of natural enemies from habitats outside the field into the target crop (Wissinger, 1997; Schellhorn et al., 2014). This process depends on the frequency and timing of the colonization events and the number of colonizers, which in turn can be influenced by the quality and spatial distribution of source habitats in the surrounding landscape from which natural enemies are recruited and weather conditions favoring or discouraging dispersal. The dispersal-driven colonization process is therefore a variability generating process, and underlies the intrinsically stochastic nature of biocontrol as compared to the use of synthetic insecticides.

The predictability of benefits from non-crop habitats could be improved when biocontrol agents have large dispersal capacity and if different habitat patches have overlapping areas of influence, providing spatial insurance in the case that a particular habitat patch would not provide natural enemies (Loreau et al., 2003). While the dispersal capacity of marked parasitoids are typically assessed at spatial scales less than 100 m (Schellhorn et al., 2014), one of the few studies that quantified parasitoid dispersal over larger distances indicates that the emergent spatial pattern is erratic (Kristensen et al., 2013). Estimates of the dispersal capacity of parasitoids can also be derived from spatially-indexed regression approaches, which suggest that crop colonization from source habitats can take place over distances of 1–1.5 km and further (Thies et al., 2003; Bianchi et al., 2008), but these studies do not always differentiate between the colonization process and local reproduction at target sites (e.g., Thies et al., 2003). There is a need for further studies to underpin our understanding of the initial crop colonization by parasitoids that capture the appropriate spatial and temporal scales and provide information on the biotic and abiotic factors influencing the colonization process.

Australia hosts many indigenous whitefly species (Martin, 1999; De Barro et al., 2000; Sequeira et al., 2009), but these are typically not considered agricultural pests. In 1994, the major pest *Bemisia tabaci* (Middle East-Asia Minor 1 (MEAM1)) arrived in Australia (De Barro et al., 2011), which now causes economic damage to melons, cotton, and soybean. Whiteflies are attacked by indigenous and exotic aphelinid parasitoids (De Barro et al., 2000). In cotton, parasitism of *B. tabaci* MEAM1 nymphs by *Eretmocerus* and *Encarsia* spp. is highly variable, and can be as high as 80% depending on time of year, pest management, and host density (Sequeira et al., 2009).

The 2-year study reported here focuses on the colonization of whitefly parasitoids early in the growing season as this period is considered critical for effective suppression of pest populations that have potential for exponential increase (Schellhorn et al., 2014). The aim of the study is twofold. Firstly, to assess the factors that best explain the colonization of parasitoids for plots in, near to and further than 400 m from remnant vegetation. Secondly, to assess the variability of biocontrol services associated with remnant vegetation by comparing the colonization in plots of

remnant vegetation and plots in arable fields near and further away from remnant vegetation. Variability is assessed at two spatial scales (plant and plot level) and between time periods.

2. Materials and methods

2.1. Study sites

The study was conducted at 18 locations spread among two 5 km radius landscape sectors in an arable production area west of the Great Dividing Range, near Dalby, Queensland, Australia. The areas were 50 km apart, with the centers located at 151° 6' 2.28" E; 26° 51' 31.52" S (North landscape) and 151° 5' 47.83" E; 27° 17' 43.43" S (South landscape). The landscapes consisted of agricultural fields, including sorghum (*Sorghum bicolor* L. Moench), barley (*Hordeum vulgare* L.), canary (*Phalaris canariensis* L.), chick pea (*Cicer arietinum* L.), mungbean (*Vigna radiata* L.), oat (*Avena sativa* L.), wheat (*Triticum aestivum* L.) and cotton (*Gossypium hirsutum* L.), as well as grassland, and remnant native vegetation in various forms (linear strips of trees, patches of remnant vegetation and remnant vegetation along creeks). The plant species composition of the remnant vegetation was similar in both landscapes. Remnant vegetation was dominated by *Eucalyptus populnea* (F. Muell.), *Acacia salicina* (Lindl.) and *Acacia harpophylla* (F. Muell.) in the tree and shrub layer, and several chenopodiaceous species in the understory (Bianchi et al., 2012).

2.2. Experimental setup and data collection

Experiments were conducted in the spring (October) of 2007 and 2008, around the time at which the first cotton is sown and colonization by cotton herbivores and their natural enemies begins. In each landscape, 3 plots (75 m × 50 m) were laid out in patches of remnant vegetation, 3 plots (75 m × 100 m), within in arable fields at 25 m from the edge of the remnant vegetation plots, and 3 plots (75 m × 100 m) in arable fields with the nearest edge at least 400 m from remnant vegetation, for a total of 18 plots (2 landscapes × 9 plots) in each year (Fig. 1). We refer to the location of the plots (i.e., within, near and far from remnant vegetation) as “treatment”. In 2007, all arable fields were fallow, containing sorghum or cereal stubble, whereas in 2008, which was wetter than 2007, most fallow fields were planted and therefore plots were established in newly planted sorghum fields. At the start of the experiment sorghum plants were 13.6 ± 1.56 cm high (mean ± SEM). Twelve sentinel cotton plants (3 × 4) were placed in a 25 × 25 m grid pattern in each remnant vegetation plot (plot size 50 × 75 m), while twenty sentinels (5 × 4) were placed in each of the arable plots (near and far; plot size 100 × 75 m) (Fig. 1). By placing these cotton seedlings in fallow (2007) or newly sown fields (2008) we mimicked an emerging cotton crop, and avoided potential confounding effects of parasitism from within the field vs. the surrounding landscape. In both years, seedlings were set out and recollected three times in each plot within a time window of approximately two weeks coinciding with the time of emergence of the cotton. In each landscape we took half-hourly records of temperature, precipitation, wind, and dewpoint temperature, using a Davis Vantage Pro2 weather station (South Windsor, Australia). In summary, the design included 108 plots with 1872 plants: 3 treatments (within + near + far = 12 + 20 + 20 = 52 plants) × 3 spatial replicates × 2 landscapes × 3 periods × 2 years.

Sentinel cotton seedlings were grown in pots (8 cm diameter, 7 cm high) and brought into the field when they were five weeks old (height 6–10 cm, 2–4 leaf stage). The seedlings were infested with silverleaf whitefly eggs two weeks prior to exposure to ensure that nymphs were in the second/third instar during exposure,

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