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Abstract: In Mediterranean regions, colonization of protected horticultural crops by native predatory mirid bugs is frequent, but these processes remain highly heterogeneous among crops. Our study aimed at assessing the effects of crop management practices and local landscape heterogeneity (landscape composition and configuration within 300m buffers around crops) on populations of *Macrolophus* and *Dicyphus* mirids in protected tomato crops in southern France. We found significant effects of landscape heterogeneity on mirid populations, but effects were similar for landscape composition and configuration. Tomato crops were colonized the most by *Macrolophus* mirids in landscapes with fallow, that seemed to act as source of mirids for crops. In contrast, crop colonization was reduced by nearby orchard, which reflected either sink or dilution effects. Mirid popuations were also reduced in crops with intensive management practices. Maintaining large areas of fallow is important to enhance native beneficial fauna, but adopting integrated plant management practices remains the most promising strategy to enhance mirid populations in protected horticultural crops.

Key words: conservation biological control, tomato colonization, landscape context, Miridae, *Macrolophus* spp., Dicyphus *spp.*

Introduction

In protected horticultural systems, actual crop protection strategies rely on the use of chemical treatments or on periodical release of commercialized biological control agents. However, these methods have important limits regarding socio-technical, economic, health and environmental aspects. In Mediterranean systems, protected crops are open structures that can be colonized by indigenous natural enemies of pests from surrounding agro-ecosystems (Gabarra et al., 2004). Among this native beneficial fauna, polyphagous predatory mirid bugs (Heteroptera: Miridae) of the genera *Macrolophus* and *Dicyphus* are considered major biological control agents against various Solanaceous crop pests (Perdikis et al., 2008). Success of crop colonization and mirid population establishment in crops remains, however, highly variable from one crop to another. This variability has been partly explained by the intensity of crop management practices (Bonato and Ridray, 2007; Arno and Gabarra, 2011) and by the proximity of source and refuge host-plants of mirids in the close surroundings of crops (75m) (Alomar et al., 2002). However, the effects of host-plant availability and more generally of landscape heterogeneity on crop colonization remain unexplored at larger scales.

The goal of our study was to assess the variability in crop colonization by mirid bugs related to local crop management practices and surrounding landscape heterogeneity (described within 300m buffers around crops). We focused on tomato crops under organic or conventional farming, in the French Mediterranean region.

Material and methods

Study area and field selection

We sampled 34 tomato crops (26 under organic management and eight crops under conventional management) in 2010 and 2011 located in the Roussillon plain, in southern France. Studied landscapes are mosaics of annual (cereal, horticultural) and perennial (orchard and vineyard) crops, semi-natural elements (hedges, herbaceous elements, fallow), and urban areas. Tomato crops were planted from mid-March to mid-April in tunnels or plastic greenhouses without insect-proof nets, in soil.

Biological sampling

Abundance of *Macrolophus* spp. and *Dicyphus* spp. was estimated in crops by non-destructive weekly sampling from early March just after tomato planting until late July (during 12 to 17 weeks depending on the planting date). Adult mirids were counted on 6 leaves of 24 tomato plants in each crop. Abundances of the main pests of tomato crops (aphids, whiteflies, leafminers, and mites) were also assessed on the same leaves according to three classes: none to a few, medium, or high numbers of individuals or galleries. Occurrences of medium to high infestation classes were summed for all pests, leaves, plants, and weeks to estimate total pest infestation levels.

Description of crop landscape context

Land-covers were digitized in a buffer area with a width of 300m around the border of each sampled crop, using aerial ortho-photographs and field surveys. Eight land-cover types were mapped: fallow, woodland, grassland, protected (vegetable) crop, open field (vegetable) crop, grassy orchard, other grassy perennial crop (vineyard and olive grove), perennial crops with bare soil, water, and urban area. Landscape heterogeneity was described in 50m, 100m, 200m, and 300m buffers around crops by the percent cover of land-covers and land-cover diversity (compositional heterogeneity) and by land-cover connectivity (index from Hanski and Thomas, 1994) (configurational heterogeneity).

Description of crop management practices

Observations in crops and interviews of farmers were realized to describe the type of farming system (organic, conventional), greenhouse type and state, tomato management practices, and crop protection practices. Multiple correspondence analysis (MCA) was done on variables to build synthetic descriptors of crop management practices (crop coordinates along MCA axes). The three first axes (AG1, AG2 and AG3) described: (1) a gradient of crop protection strategies, from preventive and organic (release of biological control agents, *Bt* treatments) to curative and conventional ones (pesticides), (2) a gradient distinguishing specific cultural interventions and greenhouse condition, and (3) a gradient of increasing frequency of cultural interventions (crop protection and plant management) associated to greenhouse type (tunnel *vs*. plastic) and plantation date.

Statistical analysis

Random forests were used to pre-select important, uncorrelated landscape metrics. Generalized Linear Models (GLM) were used to analyze the effects of crop characteristics (pest infestation levels and agricultural gradients) and landscape metrics on mirid abundance. Separate analyses were conducted for each buffer size and class of landscape metrics (composition, configuration). Multi-model inference and model averaging were used to test all possible models and to determine the average of relevant models (with ΔAICc < 2).

Results and discussion

Effects of landscape heterogeneity on mirid abundances at different spatial scales

Landscape heterogeneity affected the abundance of both mirid groups. Models integrating composition or configuration metrics had similar effects on mirid abundance, as illustrated by the similar averaged AICc from GLMs (Figure 1). *Macrolophus* mirids responded the most to landscape heterogeneity at large scales (lowest averaged AICc within 200m and 300m buffers), whereas *Dicyphus* mirids responded the most at smaller scales (lowest averaged AICc within 100m buffers) (Figure 1). Until now, these two mirid groups were assumed to disperse over short distances (up to 100m) similarly to other mirid bugs (Alomar et al., 2002). Our results suggest that *Macrolophus* species might disperse beyond these expected distances.

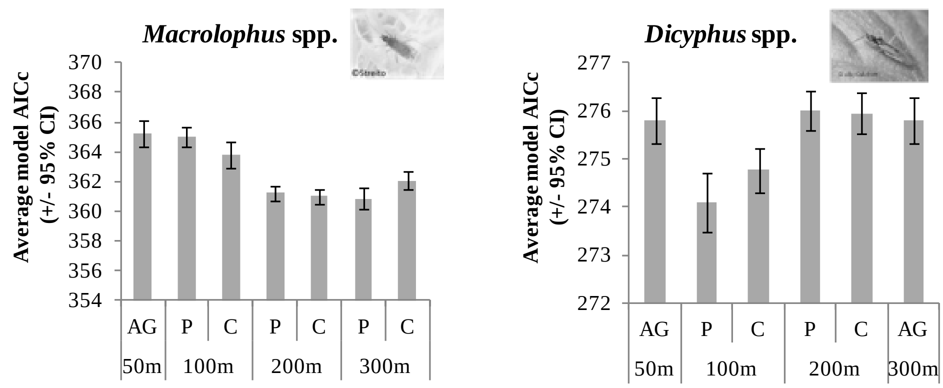

Figure 1. Mean AICc averaged over similar relevant models (ΔAICc < 2) for *Macrolophus* spp. and *Dicyphu*s spp. for each spatial scale (50m, 100m, 200m, 300 m). AG: models with local agricultural practices. P/C: models with local agricultural variables and landscape (percent cover P or configuration C) metrics.

Relative effects of local crop characteristics and landscape heterogeneity

We collected 3010 and 696 individuals of *Macrolophus* spp. and *Dicyphus* spp. respectively. During the study, the average occurrence (over sampled plants on the same crop) of pests at medium or high infestation levels was 89 times ± 124 times.

Table 1 gives an overview of significant variables and their relative importance value (RIV) in the average GLMs. It shows that tomato crops were colonized the most by *Macrolophus* mirids in landscapes with fallow (100m). This positive effect might be explained by the presence in fallow of host-plant species known to act as refuges in winter and as sources of mirids during their active period (Alomar et al., 2002). In contrast, crop colonization by mirids was reduced by large areas of orchard (in 100m, 200m or 300m buffers depending on mirid group). This negative effect might either reflect a sink effect for orchards that can be intensively managed, or, on the contrary, a dilution effect if the herbaceous strata of orchards contain attractive host-plants.

Overall, the effects of landscape heterogeneity on mirid abundance were lower than those of local crop management practices (lower RIV, Table 1). Mirid abundance decreased from organic to conventional crop protection strategies (AG1). *Macrolophus* abundance further decreased with the intensification of cultural interventions on crops (AG3, in both organic and conventional systems). *Dicyphus* abundance was also positively related to pest infestation levels in crops.

Table 1. Overview of variables having a significant effect on mirid abundance and their relative importance values (from 0 to 1) in average GLMs. (+) or (-): positive or negative effect; *ns*: not significant. AG: agricultural gradients. P: percent cover, C: connectivity.

Variables	***Macrolophus* spp.**				***Dicyphus* spp.**			
	50 m	**100 m**	**200 m**	**300 m**	**50 m**	**100 m**	**200 m**	**300 m**
AG1	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	*ns*	*ns*	*ns*	*ns*
AG2	*ns*	*ns*	0.49 (+)	*ns*	*ns*	*ns*	*ns*	*ns*
AG3	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	0.86 (-)	1.00 (-)	0.87 (-)	0.86 (-)
Pest infest.	*ns*	*ns*	*ns*	0.14 (+)	0.70 (+)	0.86 (+)	0.73 (+)	0.70 (+)
P_fallow	*ns*	0.55 (+)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
C_fallow	*ns*	0.79 (+)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
P_Orchard	*ns*	*ns*	0.89 (-)	1.00 (-)	*ns*	0.87 (-)	*ns*	*ns*
C_Orchard	*ns*	*ns*	0.89 (-)	1.00 (-)	*ns*	*ns*	*ns*	*ns*

Our study suggests that converting farms from conventional to organic production systems and adopting integrated plant management practices remain the most promising strategies to enhance mirid populations in protected horticultural crops. However, maintaining large areas of fallow seems also to be important to ensure colonization of protected crops by mirids. Specific field surveys are however needed to explain the negative impact of orchard on mirids.

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