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Department of Agronomy, Food, Natural resources, Animals and Environment

Second Cycle Degree (MSc) in Sustainable Cropping Systems in Plant Health

Pest abundance and biocontrol in annual crops in contrasting landscapes

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Index

ABSTRACT

Wheat pests are expected to be influenced by the activity of their natural enemies and by landscape features (i.e., composition and configuration). Although numerous studies have been conducted to determine the effect of several landscape descriptors on pests and natural enemies' populations, the findings are very diverse and sometimes contradictory. The main objective of this study was to compare the effects of landscape composition and configuration on aphid, cereal leaf beetle (CLB) densities and biocontrol. To address this subject, two simultaneous analyses were carried out in wheat fields embedded in contrasting landscapes in the Veneto region, northeastern Italy. The results of the first analysis do not indicate that aphid occurrence is influenced by any of the landscape descriptors studied, suggesting that it may be determined by population dynamics variability and local factors. Parasitism was overall low (0%-20%) and was not affected by landscape complexity but showed to have a positive effect on aphid density. On the other hand, predation decreases by increasing the percentage of seminatural habitat at the 500 m scale. Cereal leaf beetle adult abundances were negatively correlated with the % of cereal crops, supported by the resource dilution hypothesis. The percentage of seminatural habitat and focal field size had a positive effect on the CLB larvae and predation rates showed to have a positive correlation with CLB adults abundance. The second analysis indicate that overall arthropod predation was enhanced by seminatural habitats. This study showed that the effects of the landscape over pests and their biocontrol may vary among regions, and long-term studies are needed to adjust and recommend landscape-scale management strategies.

1. Introduction

Wheat fields in Europe are dominated mainly by three aphid species, being the most predominant *Sitobion avenae* followed by *Metopolophium dirhodum* and *Rhopalosiphum padi*. These species of aphids are mostly abundant at flowering and milk ripening stage. Leaf-colonizing aphids *M. dirhodum* and *R. padi* are highly influenced by the content of nitrogen in the plant, therefore, they are found mainly colonizing intensified conventional wheat fields where high amounts of inorganic fertilizers are applied. Conversely, *S. avenae* is highly benefited from the proportion of grassland in complex landscapes, as they serve as hibernating sites. Several species of aphid primary parasitoids have been recorded, within which the genera *Aphidius*, *Ephedrus* and *Praon* are the most predominant and have been found in greater proportion at milk ripening stage. The primary parasitoid communities are also affected by the local management and landscape complexity, since *A. rhopalosiphi* is more common in highly intensified fields and it is associated with the aphids *M. dirhodum* and *R. padi*; on the other hand, species *E. plagiator* is commonly linked to *S. avenae* and it has been reported mainly in fields under low agricultural intensification regimes. The dominant hyperparasitoid species are *Asaphes suspensus* and *A. vulgaris* in conventionally managed fields, and *Dendrocerus carpenter* in low agricultural intensification fields. On the other hand, cereal leaf beetles are more abundant in landscapes diverse and rich flower resources (Al Hassan et al., 2013; Gagic et al., 2012; González et al., 2022; Hawro et al., 2015).

The responses of wheat pests and their biocontrol to local and landscape factors are variable and depends on the development stage of the crop. In general, landscapes with high edge densities and flowering woody plants support natural enemies of wheat pests, however, landscape effects and the effectiveness of landscape measures will vary in every region depending on the ranges of the descriptors (González et al., 2022). Some pests and their natural enemies require resources from surrounding habitats to complete their life cycles. In agricultural sceneries, seminatural habitats enhance pest and natural enemy populations by providing alternative or supplemental food resources, shelter, or overwintering refuges; and their populations are influenced by both direct (landscape effects on arthropods themselves) and indirect effects (landscape effects on the interaction between arthropods) (Yang et al., 2019).

The specific response of arthropod density and their function in the agroecosystems are determined by the interactions between landscape composition (% of arable land and % of seminatural habitat) and configuration (density of edges), and on their response traits; and it can be explained by three different patterns: 1) those influenced by edge density, such as flight (low ED) and ground dispersers (high ED) that overwinter outside crops, which also increase to a lesser extent by increasing % of SNH and decreasing % arable land; 2) those enemies benefited mainly by high % of SNH (flyers) and high % arable land (ground dispersers) that overwinter in crops and 3) those barely influenced by the landscape, such as wind dispersers, i.e. ballooning spiders and parasitoid wasps. Different patterns have also been identified in pests: landscape variables show scarce effects on pests overwintering in the crops, while ED negatively affect the abundance of pests that overwinter outside crops, regardless of composition. Nevertheless, some functional groups of arthropods may not reflect any of these patterns (Martin et al., 2019).

Aphid density, and parasitoid richness and effectiveness are affected positively by complex landscapes due to their ability to provide alternative hosts, shelters from agricultural disturbance, overwintering sites, and additional food sources. Configurational heterogeneity components differ in their impact, as field size does not influence aphid density or parasitism rates, but changes between wheat phenological phases seemed to be correlated. Nevertheless, edge variables such as field margin type and distance from the margin have shown some effects on wheat aphid abundance and parasitism. Consequently, the decrease in aphid populations is also determined by the increase in parasitism rates (Plećaš et al., 2014). Intensive agricultural management and landscape simplification induce fluctuations in aphid and natural enemies' communities at small and large scales, i.e. at field and regional levels. Thus, increasing arable land proportion in the landscape decrease vegetation-dwelling predators, wolf spiders and aphid parasitism rates (Gagic et al., 2017).

The effect of landscape heterogeneity on cereal leaf beetle abundance seems to be consistent among scales. Seminatural habitat has no effect on cereal leaf beetle populations. The proportion of major host such as wheat and barley in addition to minor host such as corn, oat and rye in the landscape impact positively the abundance and parasitism of cereal leaf beetle, while crop diversity decreases populations. Thus, crop diversification may be an important element to consider in the management of CLB densities at landscape scale (Kheirodin et al., 2020).

The importance of the seminatural habitats for pests and their biocontrol vary considerably depending on type of crop, pest, natural enemy, field management, and landscape structure (Tscharntke et al., 2016). In this study, the potential direct and indirect effects of landscape complexity on wheat pests were analysed among spatial scales.

This study was aimed to test the following hypotheses:

1) Landscape composition and configuration might affect aphid and cereal leaf beetle abundances and their natural enemies across different spatial scales.
2) Parasitism and predation rates might be positively related to pest abundances.
3) Predation rates might change along a gradient of seminatural.

2. Materials and methods

2.1. Study area

This study was conducted in the low Venetian plain in the Veneto Region, northwestern Italy. This area is embedded in the Po Plain and Upper Adriatic climatic zone, which is characterized by accentuated seasonal excursion, with high temperatures in summer (>30°C) and below zero temperatures in winter. Rainfall had its higher frequency in spring and autumn with 600 to 800 mm per year (Fratianni & Acquaotta, 2017). This area comprises mainly arable land where wheat, maize and soybean are predominantly cultivated under intensive agriculture regimens (Dainese et al., 2017).

2.2. Sampling design and site selection

Two simultaneous studies were carried out in the field to address the possible influence of landscape complexity on pest abundance and their biocontrol. In the first study, the effects of landscape composition and configuration on pest abundance and biocontrol were tested in twenty-five wheat fields within nine contrasting landscapes during the wheat flowering stage, from May 24th to June 1st, 2023.

The second study, the predation between cereal crop fields and seminatural habitats was investigated across 88 sites embedded in 8 landscapes (44 cereal crops and 44 seminatural areas). This experiment was performed twice, the first round was carried out from May 24th to June 1st, and the second round from June 25th to July 9th, 2023.

For landscape selection, a land cover map was produced in QGIS (v3.26; QGIS.org, 2022) by integrating the Land Cover Map of the Veneto Region (available at https://idt2.regione.veneto.it/) and the Regional crop map (available at https://www.avepa.it/paesc). For site selection, land cover features were classified into five classes: 1) "seminatural habitat", 2) "annual crop", 3) "perennial crop", 4) "urban", and 5) "water". Seminatural habitats consisted of various types of forest, as well as herbaceous-dominated cover types, including hedgerows, meadows, permanent grasslands, and shrublands.

We overlapped a grid (1 km side) and landscape composition was calculated each cell as the percentage of the landscape belonging to each class (PLAND), while the configuration of the landscape was calculated as the edge density in relation to the landscape area (ED). All metrics were calculated in R statistical software (v4.1.1; R Core Team, 2021) using the package ‘landscapemetrics’ (Hesselbarth et al., 2019).

Based on their degree of complexity, ten contrasting non-overlapping landscapes (1 km^2) were selected among all candidates (Figure 1). The landscape selection was aimed to include complex landscapes with a high proportion of semi-natural habitats, as well as landscapes with a high proportion of agricultural lands.

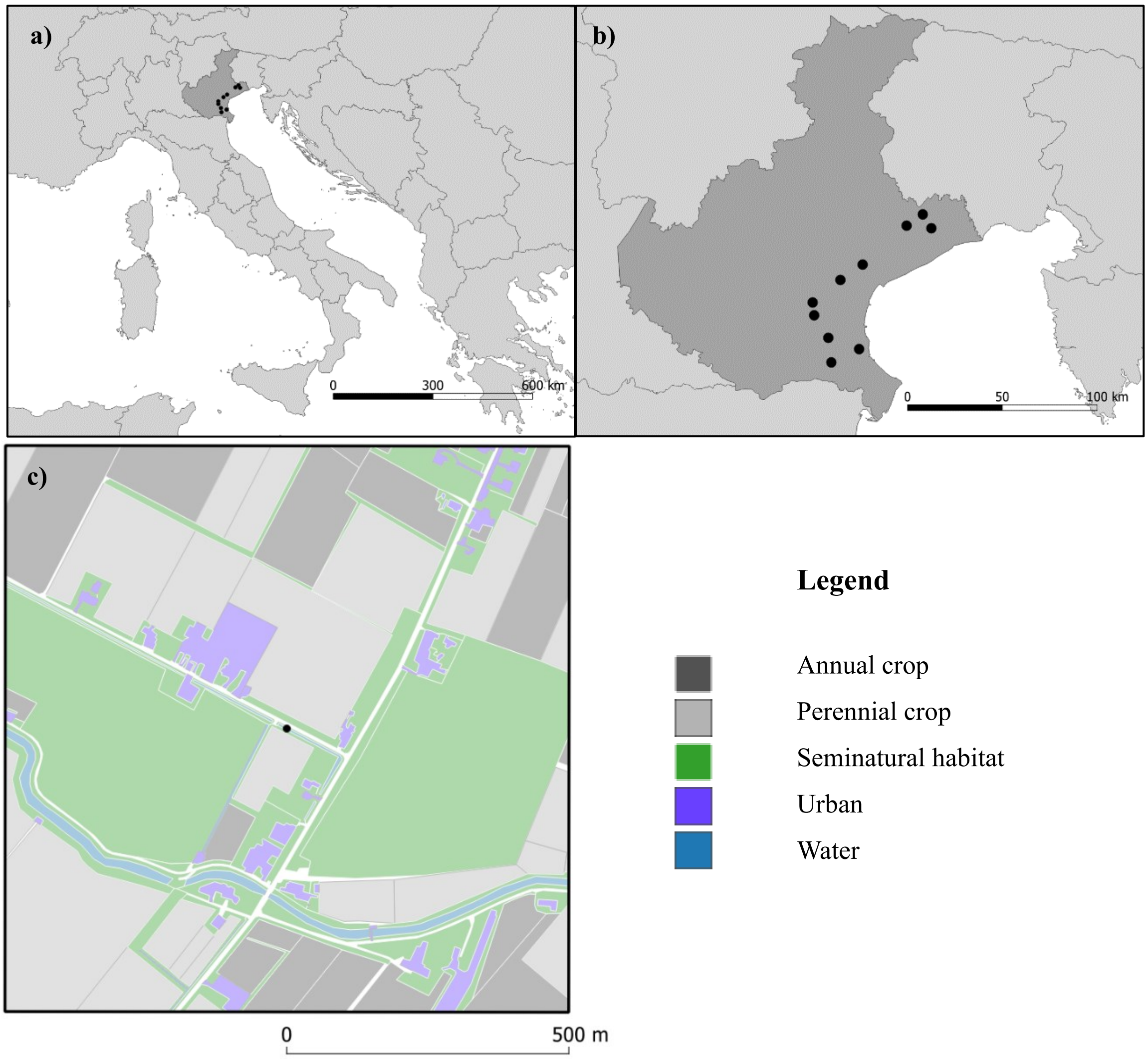

FIGURE 1. Study area: Veneto Region (shaded) (a); spatial distribution of the 10 selected landscapes (black points) (b); example of landscape landcover in 1 km^2 buffer (c).

2.3. Data collection

For the first study, pest abundance was assessed in each wheat field within the nine landscapes between flowering and milk ripening stages by direct count on 100 plants. For this purpose, 25 plants were randomly chosen at each of five different transects (Gagic et al., 2012; Hawro et al., 2015). Plants were inspected visually for aphids, mummified aphids, and larvae and adults of cereal leaf beetle (Figure 2). Parasitism rates were calculated as the ratio of mummified aphids to total aphids (Plećaš et al., 2014). Predation was assessed using artificial sentinel preys, which consisted of lepidopteran-shaped caterpillars made of light green plasticine (3x30 mm).

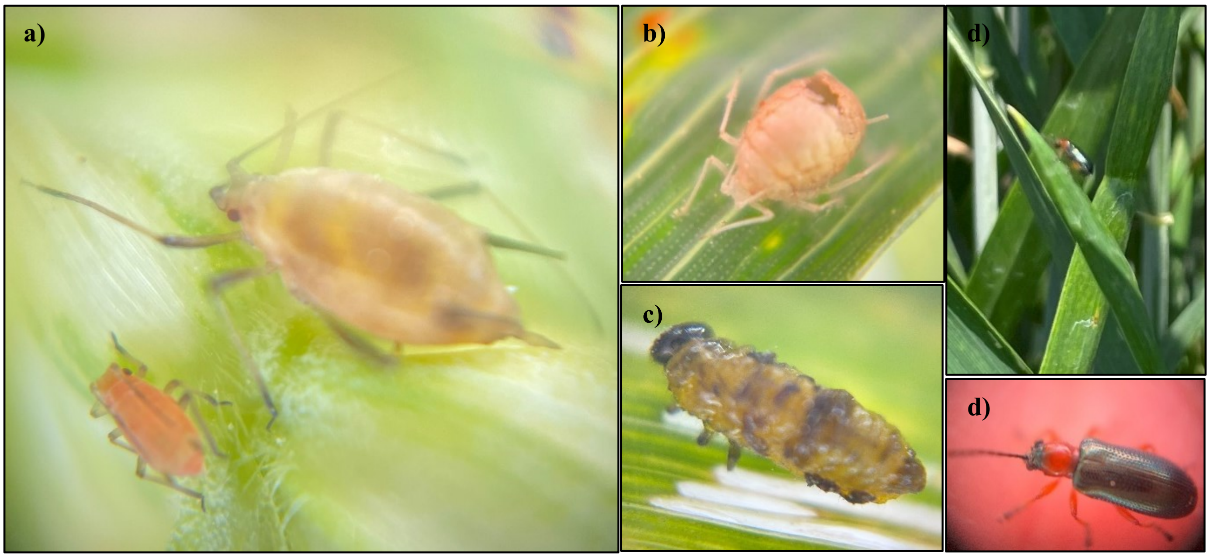

FIGURE 2. Aphids (a), mummified aphid (b), cereal leaf beetle larva (c) and adult (d) in wheat fields in Veneto, Italy.

For the second study, the comparative analysis of predation between cropland and seminatural habitats a total of 88 sampling sites were established, equally distributed in 8 landscapes. Of the total, 44 sites were in cereal fields (wheat and corn crops) and the remaining 44 sites were dispersed in different seminatural areas (grasslands and forests).

At each study site, eight artificial caterpillars were randomly placed at ground level every 50 cm (Figure 3). After 48 hours of exposure, the caterpillars were collected in polystyrene plates and labelled according to site ID.

In the laboratory, caterpillars were examined for predation signs under stereo microscope (OPTIKA SZM-LED1). Predation marks were classified into four categories: carabids, birds, mammals, and other arthropods (Figure 4). To estimate predation rates, the proportion of attacked caterpillars was calculated for every category.

FIGURE 3. Plasticine artificial sentinel preys.

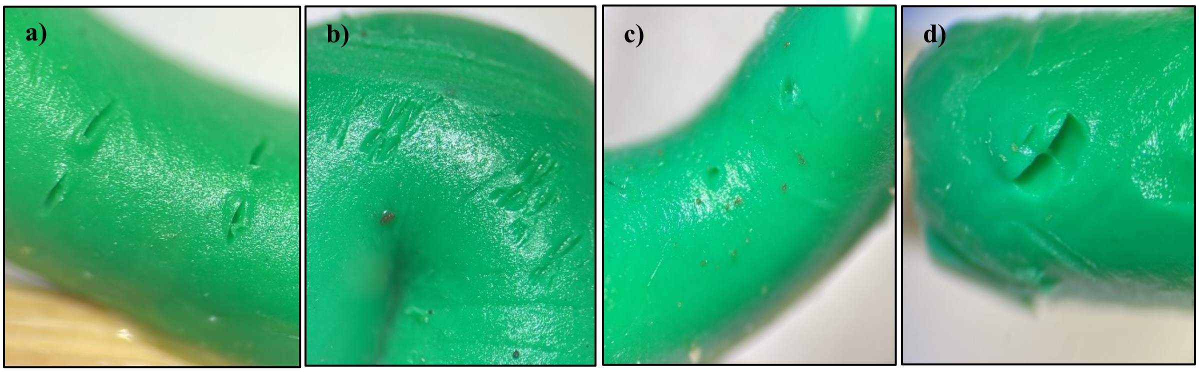

FIGURE 4. Predation marks by carabids (a) ants (b), spiders (c) and mammals (d).

2.4. Landscape descriptors

Land cover types were grouped into new classes based on their importance as pest hosts: 1) “seminatural habitat”, 2) “cereal crop”, and 3) “non-cereal crop”. In alternative models, “seminatural habitat” category was analysed into two classes (“forest” and “grassland”), and “wheat” was analysed as a separate variable from the category “cereal crop”.

For landscape metrics, composition was calculated as the proportion of landscape of each new class (PLAND), and configuration was calculated as edge density (ED, m/ha) based on a raster-format land cover map of 5 m resolution. All metrics were calculated for all study sites at three spatial scales: 250, 500, and 1000 m (radius) in R using the package ‘landscapemetrics’. In addition, the focal field size was estimated based on field boundaries.

2.5. Data analyses

2.5.1. Landscape effect on pest abundance and biocontrol at different spatial scales

The effects of landscape composition and configuration on pest abundance and biocontrol were analysed using linear models at each different spatial scale (250, 500, and 1000 m).

Model predictors were ‘mean focal field size’, ‘% of seminatural habitat’, ‘% of cereal crops’, and the ‘edge density’. Response variables were pest abundance (aphids, CLB adults and CLB larvae) and parasitism of aphids and caterpillar predation. Aphids, CLB adults and CLB larvae abundance were log transformed to meet model assumptions. Linear models were fitted using the lm() function of the stats package (R Core Team, 2021).

Pearson correlation tests between predictors were conducted at each spatial scale to find possible collinearity issues.

In the final models, multicollinearity between independent variables was checked using Variance Inflation Factor (VIF) through the function vif from the package “car” (Fox & Weisberg, 2019), using VIF>2 as threshold (Duflot et al., 2017). High VIF values indicates that two or more independent variables are highly correlated (Fein et al., 2022). Residuals were checked using the “DHARMa” package (Hartig, 2022). None of the models showed multicollinearity issues.

Final models were compared among different scales by calculating Akaike's ‘An Information Criterion’ (AIC) values, and the best-fitted models (lowest AIC value) were selected (Gagic et al., 2017; Kheirodin et al., 2020). Multiple comparison tests were performed and using α=0.05 as threshold, only models with statistically significant P values were reported. Plotting for data visualization was performed using the “effects” package (Fox, 2003).

2.5.2. Co-occurrence between pest abundance and biocontrol

The correlation between pests and their biocontrol was analysed by calculating the Pearson correlation coefficient (ρ) which determines the linear relationship between two variables. Pearson’s coefficient assumes a value from -1 to 1; where ρ= -1 indicates a perfect negative linear relationship between variables, ρ= 0 indicates no linear relationship, and ρ= 1 indicates a perfect positive linear relationship (Lane, 2023).

The degree of correlation between two variables was determined based on the ranges established by (Ratner, 2009).

2.5.3. Overall predation rates within cereal crops and seminatural habitats

The predation rates within cereal crops and seminatural habitats were analysed using a linear mixed-effects model using the function lmer() from the package lme4 (Bates et al., 2015). The predictor was ‘habitat’ (cereal crop and seminatural), with ‘site-ID’ nested in ‘Landscape-ID’ as random factors. All statistical tests were performed in R software.

3. Results

3.1. Correlation between landscape descriptors at different spatial scales

The analysis of the Pearson's correlation coefficients between the compositional and configurational variables of the landscape at each of the three scales was used to identify the landscape predictors for the model tested. There was a moderate and somehow expected negative correlation (ρ= -0.38) between the percentage of seminatural habitat and cereal crops at the smaller scale (250 m). At the intermediate scale (500 m) it was observed also a moderate negative correlation (ρ= -0.36) between the percentage of seminatural habitat and the size of the focal field. However, no significant correlations were observed at the highest scale (1000 m) (Table 1).

TABLE 1. Pearson's correlation coefficient (ρ) between landscape descriptors at 250, 500 and 1000 m scales.

	% Seminatural habitat	% Cereal crops	Edge density (m/ha)
scale 250 m			
Focal fields size (ha)	-0.2	-0.13	-0.33
% Seminatural habitat	-	**-0.38**	0.22
% Cereal crops	-	-	0.23
scale 500 m			
Focal fields size (ha)	**-0.36**	-0.11	-0.16
% Seminatural habitat	-	-0.27	0.0025
% Cereal crops	-	-	0.29
scale 1000 m			
Focal fields size (ha)	-0.21	0.0044	0.032
% Seminatural habitat	-	0.046	-0.069
% Cereal crops	-	-	0.072

3.2. Landscape effect on pest abundance and biocontrol at different spatial scales

The effects of landscape composition and configuration varied between pests and biocontrol indicators. Although scarce significances were obtained, the effects found were consistent among scales (250, 500 and 1000 m) (Table 2).

TABLE 2. Outputs of linear models testing the effects of landscape composition and configuration on wheat pests and their biocontrol across different scales (250, 500 and 1000 m). ED = edge density. P-values are bold when the descriptor was significant at '*' 0.05 and '.' 0.1. vif = Variance Inflation Factor, SE = standard error of the coefficient estimate, AIC = Akaike's 'An Information Criterion' values.

	vif	Estimate	SE	t-value	P-value	AIC	vif	Estimate	SE	t-value	P-value	AIC	vif	Estimate	SE	t-value	P-value	AIC
scale	**250**						**500**						**1000**					
a) Aphids																		
Intercept		2.9113	1.3129	2.22	0.0383			3.3743	1.5908	2.12	0.0466			3.6735	1.6953	2.17	0.0425	
Focal field size	1.23	-0.6192	0.4180	-1.48	0.1541		1.20	-0.6953	0.4094	-1.70	0.1050		1.13	-0.6764	0.3974	-1.70	0.1043	
% annual crop	1.32	0.0053	0.0223	0.24	0.8145		1.21	0.0063	0.0242	0.26	0.7976		1.02	0.0082	0.0276	0.30	0.7703	
% seminatural	1.36	-0.0386	0.0571	-0.68	0.5063		1.28	-0.0923	0.0974	-0.95	0.3543		1.13	-0.0665	0.0658	-1.01	0.3241	
ED	1.34	-0.0001	0.0044	-0.02	0.9816	106.67	1.12	-0.0009	0.0053	-0.18	0.8623	106.18	1.01	-0.0029	0.0059	-0.49	0.6323	106.18
d) Parasitism rate																		
Intercept		0.0165	0.0441	0.37	0.713			0.0136	0.0527	0.26	0.8			-0.0271	0.0553	-0.49	0.629	
Focal field size	1.23	-0.0061	0.0140	-0.43	0.67		1.20	-0.0119	0.0136	-0.87	0.393		1.13	-0.0149	0.0130	-1.15	0.265	
% annual crop	1.32	-0.0001	0.0007	-0.18	0.857		1.21	-0.0003	0.0008	-0.32	0.755		1.02	0.0006	0.0009	0.68	0.507	
% seminatural	1.36	-0.0025	0.0019	-1.32	0.202		1.28	-0.0042	0.0032	-1.30	0.21		1.13	-0.0026	0.0021	-1.23	0.232	
ED	1.34	0.0002	0.0001	1.22	0.237	-62.99	1.12	0.0003	0.0002	1.53	0.143	-64.18	1.01	0.0003	0.0002	1.63	0.12	-64.95
e) Carabids predation rate																		
Intercept		0.3801	0.1957	1.94	0.0699			0.4256	0.2269	1.88	0.0791			0.0102	0.2535	0.04	0.969	
Focal field size	1.30	0.0256	0.0689	0.37	0.7156		1.28	0.0004	0.0636	0.01	0.9954		1.19	0.0286	0.0625	0.46	0.653	
% annual crop	1.37	-0.0023	0.0034	-0.69	0.5031		1.20	-0.0029	0.0033	-0.86	0.4047		1.03	0.0005	0.0040	0.14	0.893	
% seminatural	1.42	0.0094	0.0084	-1.11	0.2825		1.35	-0.0273	0.0139	-1.97	**0.0665.**		1.17	-0.0098	0.0092	-1.06	0.303	
ED	1.42	0.0000	0.0007	-0.03	0.9781	8.70	1.38	0.0003	0.0007	0.47	0.6466	5.72	1.01	0.0012	0.0009	1.38	0.187	6.58
b) CLB adults																		
Intercept		0.6652	0.5179	1.29	0.2136			1.0162	0.6555	1.55	0.1368			0.3503	0.7070	0.50	0.6256	
Focal field size	1.23	0.0830	0.1649	0.50	0.6200		1.20	0.0012	0.1687	0.01	0.9943		1.13	0.1294	0.1657	0.78	0.4440	
% annual crop	1.32	-0.0219	0.0088	-2.49	**0.0217***		1.21	-0.0209	0.0100	-2.11	**0.0481***		1.02	-0.0210	0.0115	-1.83	**0.0824.**	
% seminatural	1.36	-0.0376	0.0225	-1.67	0.1100		1.28	-0.0545	0.0401	-1.36	0.1891		1.13	0.0154	0.0274	0.56	0.5807	
ED	1.34	0.0023	0.0017	1.32	0.2023	60.15	1.12	0.0017	0.0022	0.79	0.4371	61.85	1.01	0.0028	0.0024	1.13	0.2738	62.45
c) CLB larvae																		
Intercept		3.0601	1.1270	2.72	0.0133			2.8570	1.4265	2.00	0.0589			1.7875	1.3657	1.31	0.2054	
Focal field size	1.23	0.3339	0.3588	0.93	0.3631		1.20	0.4790	0.3671	1.31	0.2068		1.13	0.7695	0.3201	2.40	**0.0261***	
% annual crop	1.32	-0.0236	0.0192	-1.23	0.2317		1.21	-0.0058	0.0217	-0.27	0.7919		1.02	-0.0216	0.0222	-0.97	0.3421	
% seminatural	1.36	-0.0552	0.0490	-1.13	0.2728		1.28	0.0177	0.0873	0.20	0.8416		1.13	0.1233	0.0530	2.33	**0.0305***	
ED	1.34	-0.0011	0.0038	-0.28	0.7836	99.03	1.12	-0.0039	0.0047	-0.84	0.4138	100.73	1.01	-0.0005	0.0047	-0.11	0.9139	95.37

Aphid density was not significantly influenced by any of the landscape predictors considered in this study (Figure 5).

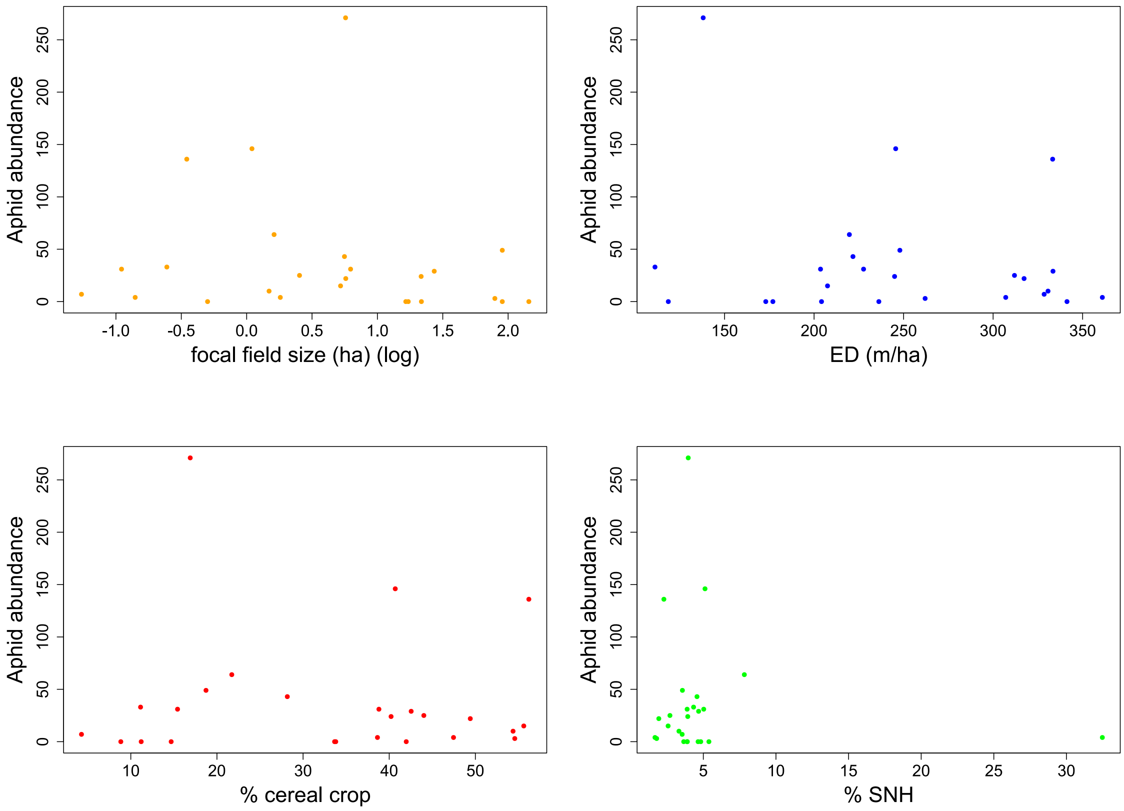

FIGURE 5. Aphid density across different gradients of focal field size, edge density (ED), % of cereal crop and % of seminatural habitat in the landscape at 500 m scale.

Parasitism rates were from 0% to 20% and were also not significantly influenced by landscape predictors (Figure 6).

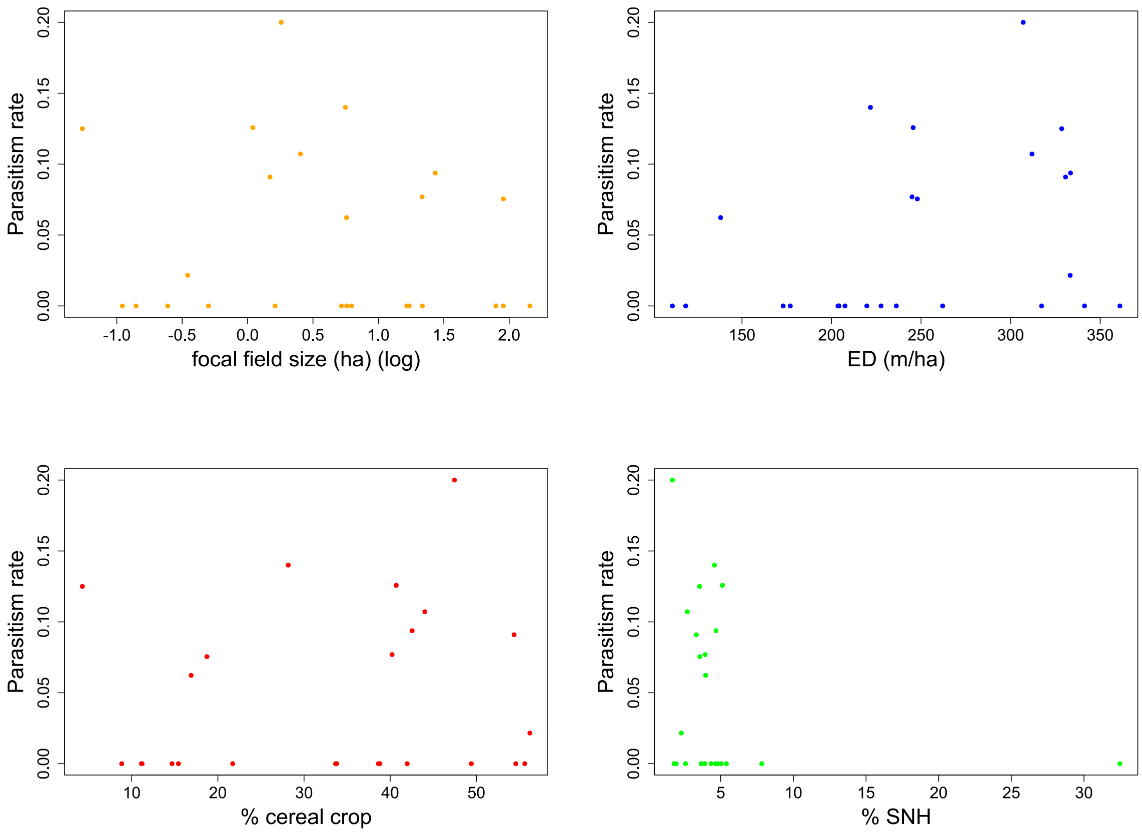

FIGURE 6. Parasitism rates across different gradients of focal field size, edge density (ED), % of cereal crop and % of seminatural habitat in the landscape at 500 m scale.

Predation rates were negatively correlated to the percentage of seminatural habitat at 500 m scale, no correlation was found at 250 and 100 m scales. The focal field size, edge density (ED) and percentage of cereal crops in the landscape had no significant effects on predation rates. (Figure 7).

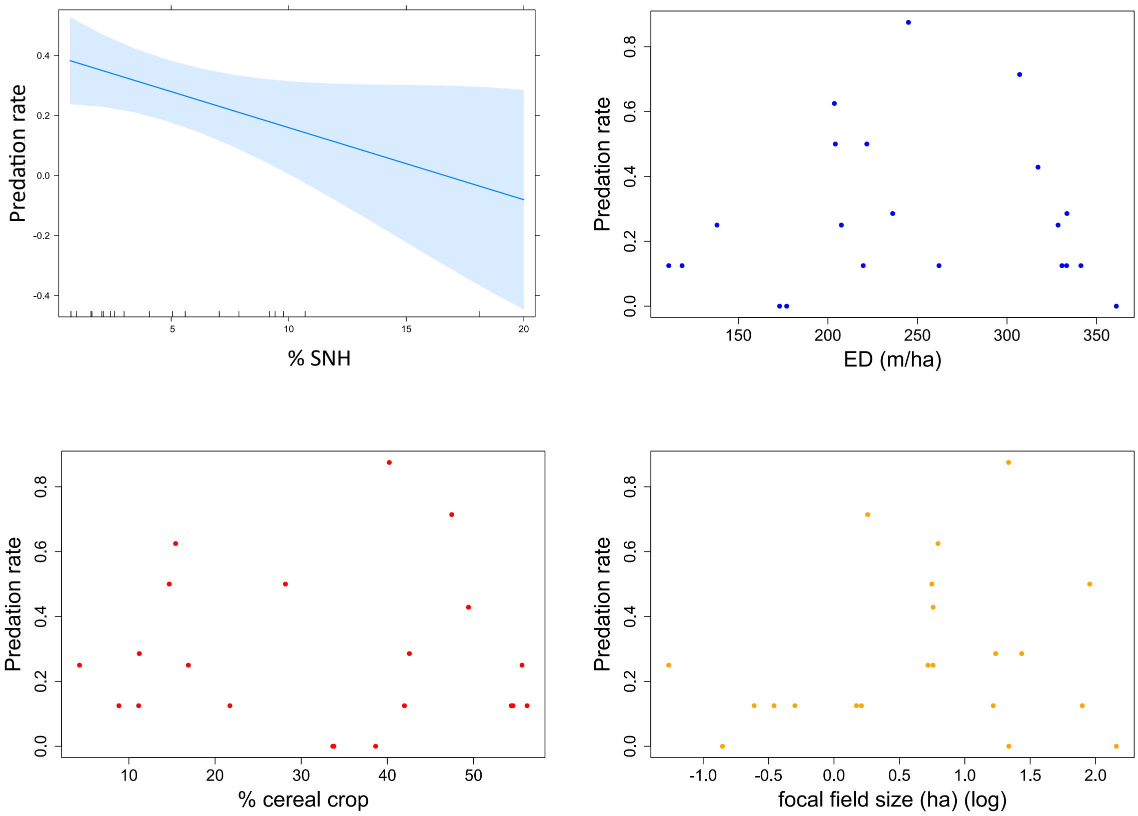

FIGURE 7. Effect of the % of seminatural habitat on predation rates at 500 m scale; and predation rates across different gradients of focal field size, edge density (ED) and % of cereal crop in the landscape.

Cereal leaf beetle (CLB) adults' abundance significantly decreased by increasing the percentage of cereal crops in the landscape at all scales. For this predictor, the model tested performed similarly between the 250 (AIC= 60.15), 500 (AIC= 61.85) and 1000 m (AIC= 62.45) scales (Table 2). The effects of focal field size, edge density (ED) and percentage of seminatural habitat were not affected significantly CLB adults' abundance (Figure 8).

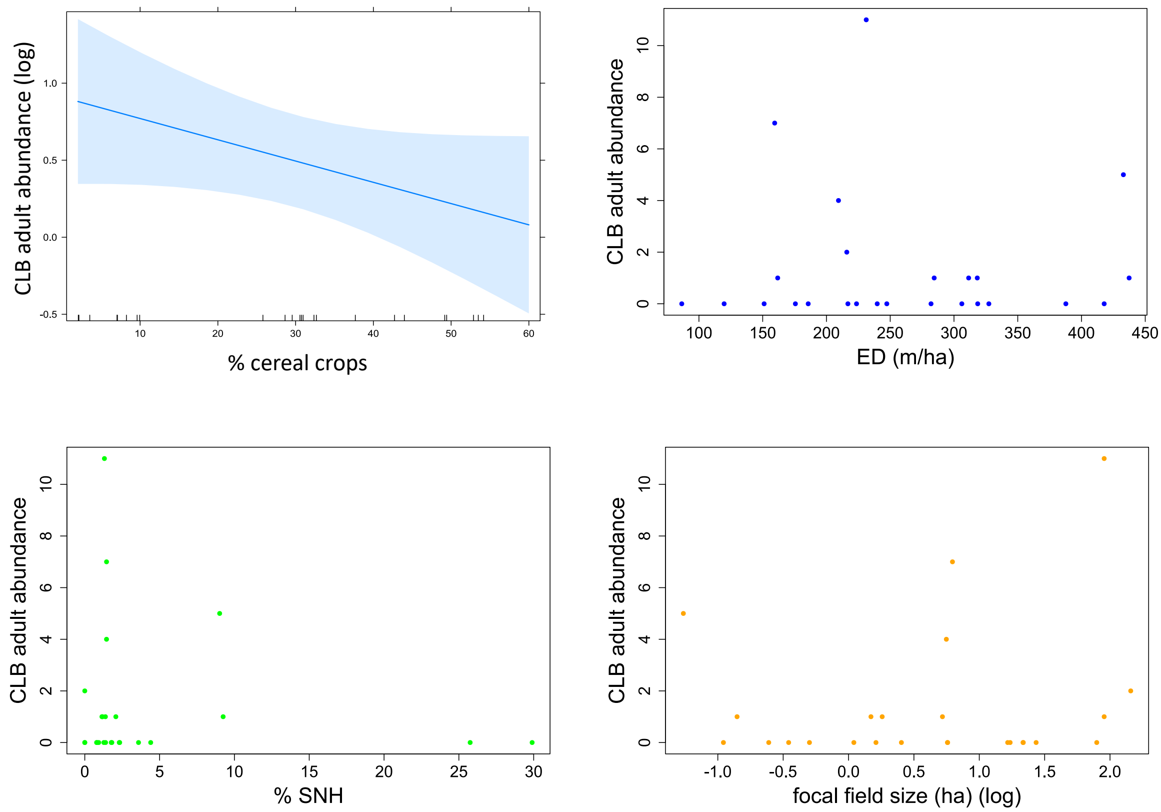

FIGURE 8. Effect of the % of cereal crops on CLB larvae abundance at 250 m scale; and cereal leaf beetle (CLB) adults abundance across different gradients of focal field size, edge density (ED) and % of seminatural habitat in the landscape.

Focal field size was positively correlated with CLB larva abundance at 1000 m scale. The percentage of seminatural habitat had a significant positive effect on CLB larvae abundance at 1000 m scale, no effect was found at 250 and 500 m scales. Conversely, the edge density (ED) and percentage of cereal crops in the landscape showed no significant effects on CLB larvae densities (Figure 9).

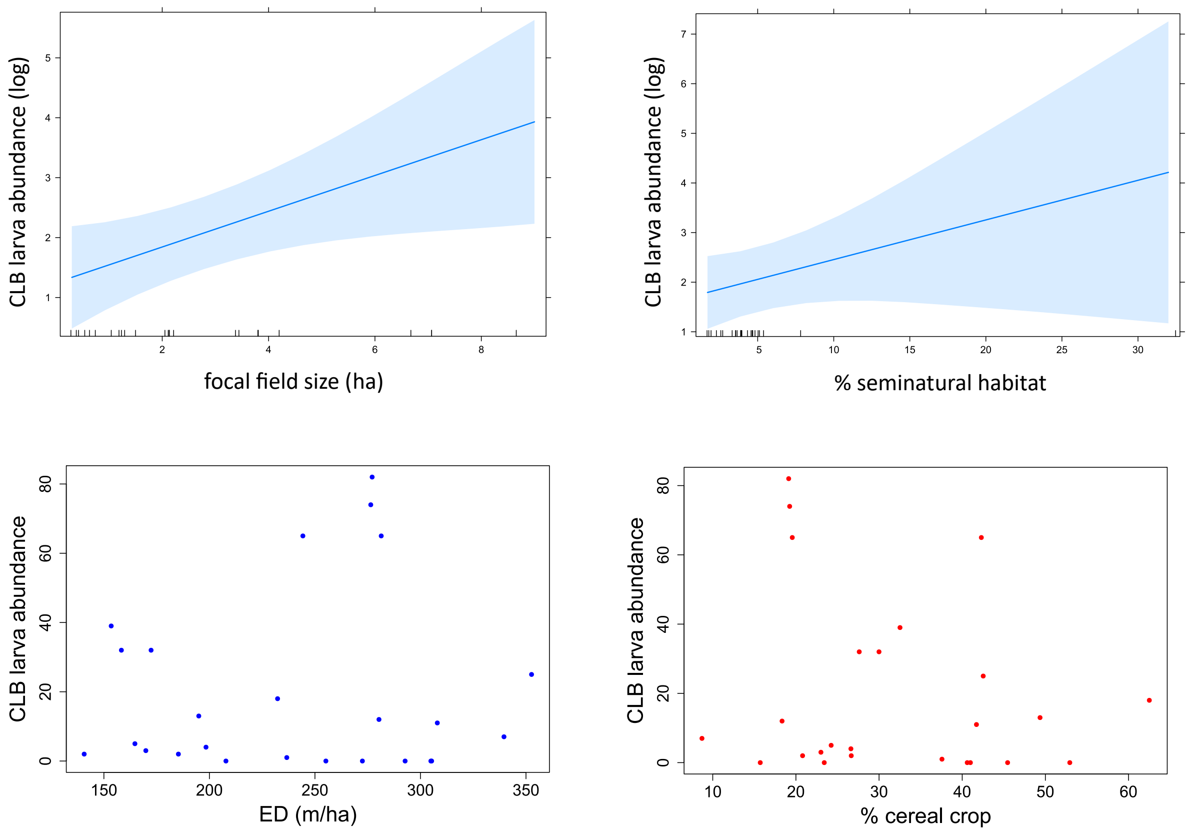

FIGURE 9. Effect of focal field size and % of seminatural habitat on CLB larvae abundance at 1000 m scale; and cereal leaf beetle (CLB) adults abundance across different gradients of edge density (ED) and % of cereal crop in the landscape.

3.3. Co-occurrence between pest abundance and biocontrol

Parasitism and predation by carabids were not substantially co-occurring with aphid populations. The Pearson's correlation coefficients obtained indicates a weak relationship between parasitism and aphid abundance (ρ = 0.17), as well as no relationship with predation by carabids (ρ = -0.02). Otherwise, both biocontrol indicators showed to be correlated (ρ = 0.49) (Table 3, Figure 10).

TABLE 3. Co-occurrence (Pearson's correlation coefficient = ρ) between pests and biocontrol indicators.

	CLB larvae	Parasitism	Predation
Aphids	-	0.17	-0.02
CLB adults	**0.51**	-	0.30
CLB larvae	-	-	-0.02
Parasitism	-	-	**0.49**

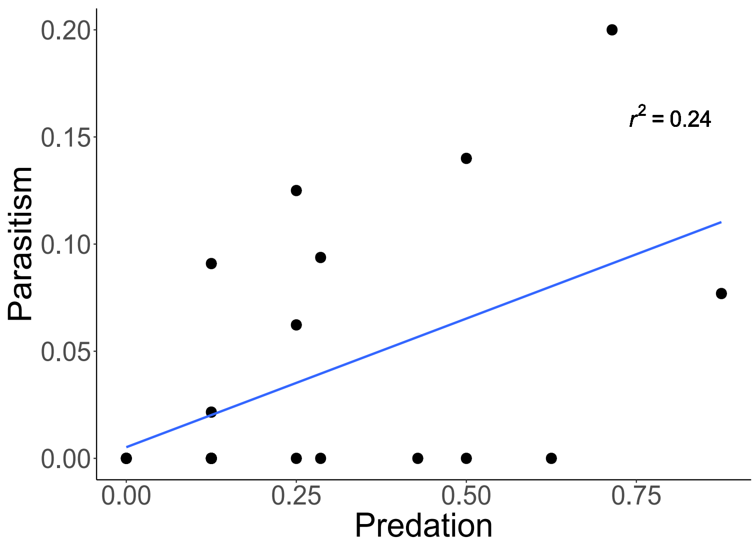

FIGURE 10. Co-occurrence between biocontrol indicators, parasitism and predation by carabids (ρ = 0.49).

Likewise, cereal leaf beetle (CLB) larvae populations were not co-occurring with predation (ρ = -0.02). However, the abundance of adults of CLB was in fact, co-occurring with predation by carabids (ρ = 0.30). Finally, as expected, CLB larvae and adult densities were highly correlated (ρ = 0.51) (Table 3, Figure 11).

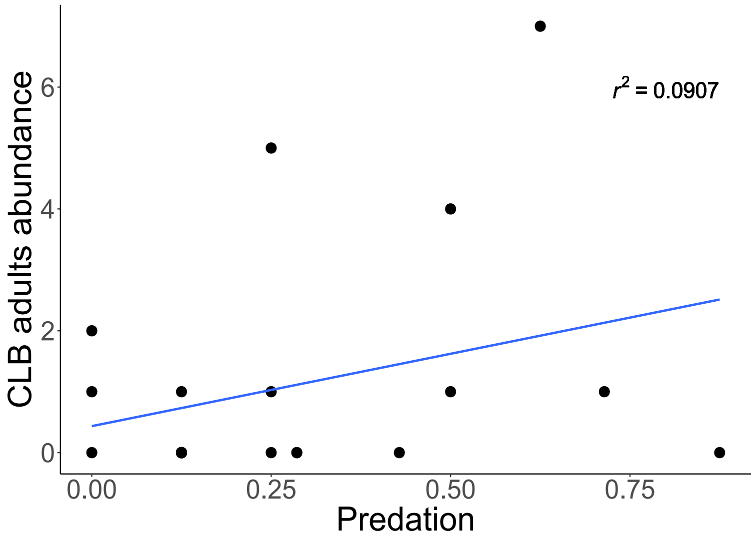

FIGURE 11. Co-occurrence between the abundance of cereal leaf beetle (CLB) adults and predation by carabids (ρ = 0.30).

3.4. Overall predation rates within cereal crops and seminatural habitats

In a simultaneous comparison analysis of predation rates between cereal crop fields and seminatural habitats, it was found a significantly higher overall arthropod predation rate in SNH in comparison with cereal crop fields (P=0.009) (Figure 12). In contrast, the predation rates by carabids only did not change significantly between habitat types (P=0.27)

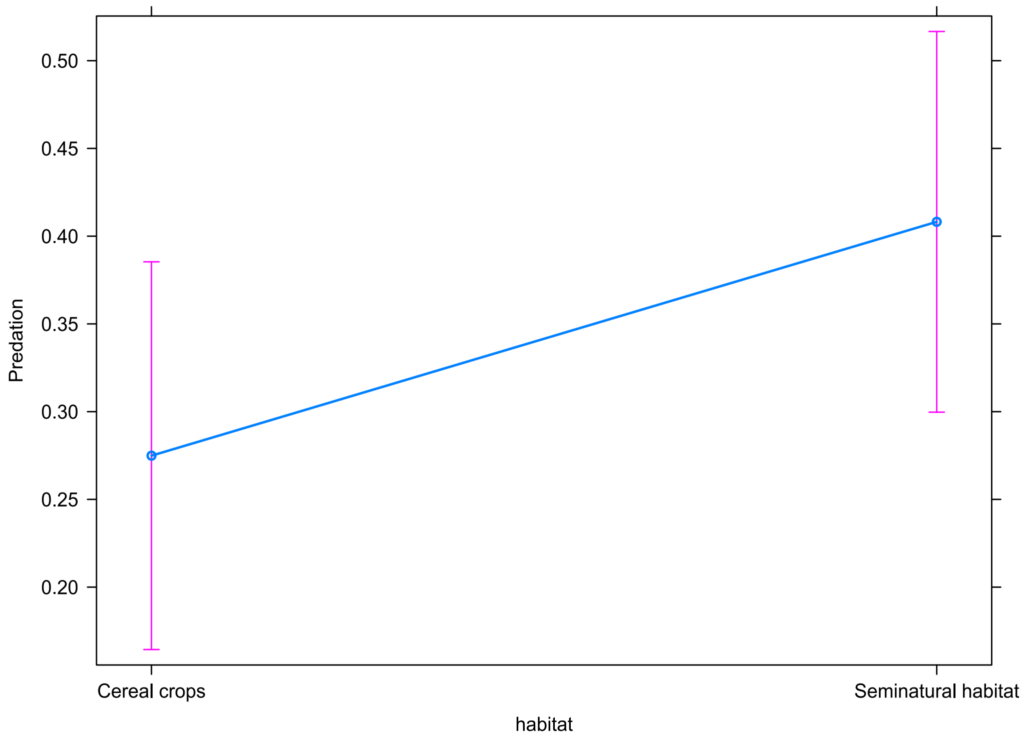

FIGURE 12. Overall arthropod predation rates in cereal crop fields and seminatural habitats.

4. Discussion

The landscape features (composition and configuration) analysed in this study affected aphid and cereal leaf beetle (CLB) densities and biocontrol (i. e. parasitism and predation) differently among spatial scales (250, 500 and 1000 m).

The results obtained in this study do not support the common hypothesis that aphid populations are influenced by landscape complexity, since any of the descriptors investigated had a significant impact on aphid abundance. Similarly, Hawro et al. (2015) found that landscape complexity and agricultural intensification has no effect on the total density of aphids, nevertheless they observed species-specific responses, since *S. avenae* was more abundant in in more complex landscapes and was negatively correlated with the proportion of arable land, while *M. dirhodum* populations were positively correlated with agricultural intensification. Several studies indicate that more complex landscapes with high proportion of seminatural habitat support higher wheat aphid densities (Al Hassan et al., 2013; Gagic et al., 2012; González et al., 2022; Plećaš et al., 2014; Thomine et al., 2023; Yang et al., 2019). However, contradictory results have also been reported, such as those found by Zhao et al. (2015) and McHugh et al. (2020), who evidenced that landscape simplification enhance aphid populations. These heterogeneous studies suggest that aphid abundance may be region-specific and could be related to the variability in population dynamics. It has also been suggested that the duration of the study or the period in which it is established may also impact the results. Plećaš et al. (2014) highlights that in short studies with a duration of less than two years, the expected trends and patterns are not always obtained and could be more difficult to analyse, while four-year long studies offer more realistic results.

Aphid parasitism rates in this study were low (from 0% to 20%) and were not significantly affected by landscape descriptors. This results are consistent with those obtained by Janković et al. (2017) who reported wheat aphid parasitism rates from 0 to 10%, and no correlation with any of the landscape variables, as well as by Hawro et al. (2015), who found that aphid parasitism on wheat fields is independent of landscape composition and agriculture intensification. In similar studies, parasitism rates were reported in a range from 0% to 36% and were significantly higher in fields embedded in structurally complex landscapes with more than 30% of seminatural habitat, probably because of their high availability of alternative resources. In addition, no effects on parasitism rates were attributed to crop-field size, but wheat phenological phase was positively correlated, with higher rates during the milk ripening phase. Moreover, although changes in primary parasitoids species were related to landscape complexity and agricultural intensification, the increase in parasitism rates was indeed positively correlated to parasitoid total abundance (Gagic et al., 2012; Plećaš et al., 2014).

Lower predation rates by carabids were significantly related to increasing proportion of seminatural habitat in the 500 m scale. A similar study found no relationship between carabids activity and % of seminatural area, and attributed negative effects to local management practices, such as insecticide application in neighbouring fields (Gagic et al., 2017). Zhao et al. (2015) reported that the abundance of ground-dwelling predators is significantly reduced by landscape simplification, while the abundance of leaf-dwelling predators in wheat fields is not significantly influenced. Conversely, Tschumi et al. (2018) reported that pest predation is lower in fields with adjacent seminatural grasslands. Moreover, *S. avenae* sentinel predation in wheat fields was positively correlated with herbaceous linear seminatural habitats at local scales and negatively correlated to the distance from the adjacent seminatural habitat (McHugh et al., 2020).

In this study, an increasing percentage of cereal crops in the landscape was correlated with a decrease in the density of cereal leaf beetles (CLB) at all scales. This result reflects a crowding effect of CLB on wheat fields within more diverse landscapes, supported by the resource dilution hypothesis, which suggests that greater densities of herbivores occur in host plants in high-diversity mixtures, i. e. in a resource-dense patch, there are more plants among which herbivores are distributed, leading to a lower load of pest on each plant in comparison with a resource-sparce area. These herbivore distribution patterns depend on diverse mechanisms such as herbivore dispersal mode, food requirements during its life cycle, mobile or rather immobile feeding stages, diet breadth, competition, and predation (Bognounou et al., 2017; Doublet et al., 2019; Hambäck et al., 2014; Moreira et al., 2016; Otway et al., 2005; Stephens & Myers, 2012). In addition, the proportion of seminatural habitat seemed to have a positive effect on the density of larvae of CLB only at the largest scale (1000 m), which is related to the fact that CLB adults overwinter in debris in or near wooded areas leading to enhance the spring migration of this pest to cereal fields (Lajos et al., 2020; Philips et al., 2011; Tscharntke et al., 2016) but contrary to the reported by Fusser et al. (2017), who reported that density of predatory carabids in wheat fields is not significantly affected by the amount of seminatural habitats in the landscape, whereas species richness of predatory carabids significantly increased. Focal field size was also positively correlated to CLB larvae abundance, which coincides with González et al. (2022), who found a weak positive relationship between mean field size and the abundance of CLB larvae. Kheirodin et al. (2020) found that crop diversity was a better predictor of CLB abundance than landscape diversity across multiple scales, reporting a positive correlation between the percentage of cereal crops in the landscape and the abundance of CLB in wheat fields the following year. In the same study, CLB density was not influenced by the percentage of seminatural habitats (grassland, woodland, and pasture) merged into one category, but when tested separately, it was found a positive correlation with the percentage of woodlands, which was explained by their importance as overwintering sites. Lajos et al. (2020) also reported that areal woody elements, i. e. plantations of poplar, pines, and black locust with a strong canopy closure, had significant negative effects on CLB herbivory suppression at multiple spatial scales. Contrasting results were reported by González et al. (2022), who found that the abundance of CLB larvae was negatively correlated with seminatural cover and edge density, and positively associated with flower diversity. Tschumi et al. (2015) found that landscape complexity (% of non-crop area) did not significantly influence CLB larvae or adult density but reported a notable decrease in CLB density in fields with flower strips in comparison with control fields.

Parasitism and predation showed to be correlated to aphid and cereal leaf beetle (CLB) abundances. A weak relationship between parasitism and aphid abundance ($\rho = 0.17$) was found, while no relationship with predation by carabids ($\rho = -0.02$) was observed in this study. Plećaš et al. (2014) found that parasitism rate was a good predictor of aphid population growth, and pointed out that parasitism rates above 22-24% led to aphid population decline. Jonsson et al. (2015) also reported that parasitism had a negative effect on aphid abundance. In addition, Gagic et al., (2017), reported that the carabid beetle activity-density was the only variable, unlike parasitism rate, positively related to the biocontrol of aphids in wheat fields. Yang et al. (2018) and Raymond et al. (2015) also reported that aphid population dynamics might be influenced by predation, since they observed a negative correlation between aphid population growth and abundance of coccinellid and carabid beetles. Otherwise, both parasitism and predation indicators showed to be correlated ($\rho = 0.49$).

Only the abundance of adults of CLB was significantly correlated with the predation by carabids ($\rho = 0.30$). On a molecular gut content analysis of six common predators of CLB collected in wheat fields, Kheirodin et al. (2019) found that *Hippodamia parenthesis*

(Coleoptera: Coccinellidae) had the highest incidence of CLB ADN positives in gut content, suggesting that it was the predominant predator among all species tested; other *Hippodamia* species had less than 25% of incidence of positives. A positive correlation between CLB abundance and predation positives also was reported. On a subsequent study, Kheirodin et al. (2022) also described a positive relationship between predator abundance and proportion of woodland at 0.5 km scale; in addition, they described a positive association between predators and CLB larvae abundance and crop diversity at 1 km scale.

Finally, predation rates were different among habitat types. The simultaneous comparative study on predation rates of ground-dwelling predators between cereal crop fields and seminatural habitats showed that seminatural habitats significantly enhance overall arthropod predation rates (P = 0.009), while predation by carabids was not significantly influenced by habitat type (P = 0.27). Similarly, in a study on seminatural grasslands using ladybird eggs as sentinel prey, it was found a higher predation in grasslands adjacent to forest in comparison to those neighbouring crop fields, suggesting that seminatural habitats provide antagonistic spillover effects (Schneider et al., 2013).

5. Conclusions

This study indicates that landscape features (composition and configuration) affect aphid and cereal leaf beetle (CLB) abundance and their natural enemies, i. e. parasitism and predation, differently among spatial scales (250, 500 and 1000 m). Aphid populations were not influenced by any of the landscape descriptors analysed in this study. On the other hand, cereal leaf beetle adult density decreased by increasing the percentage of cereal crops in the landscape, and larvae increased by increasing both size of focal field and percentage of seminatural habitat. Aphid parasitism rates were not affected for landscape complexity, meanwhile, predation by carabids was negatively correlated to percentage of seminatural habitat surrounding wheat fields. The patterns observed can be attributed to region-specific and local field management factors, such as insecticide spraying, weed management and inorganic fertilization, rather than landscape complexity.

Parasitism and predation also showed a different co-occurrence with aphids and cereal leaf beetle abundances. Parasitism and aphid density showed a weak correlation, while predation by carabids was not correlated. However, the abundance of adults of cereal leaf beetle was correlated to a greater extent to predation by carabids, which suggests that predation may be involved to some extent with the decrease of CLB populations. Both parasitism and predation indicators were also correlated between each other. Thus, understanding pest and natural enemies' dynamics is crucial to develop effective management strategies to enhance biological control. It has been shown that the influence of the landscape may vary among regions and crop stages, hence long-term studies are needed to avoid missing temporal changes and variability in population dynamics.

Comparatively, predation vary depending on the habitat type, as seminatural habitats supported more arthropod predation than cereal crop fields. However, the predation rates by carabids did not change significantly between habitats.

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