Pol. J. Environ. Stud. Vol. 31, No. 3 (2022), 2895-2903
DOI: 10.15244/pjoes/143764 ONLINE PUBLICATION DATE: 2022-02-28

Original Research

The Quantity and Quality Structure of Coccinellids (Coleoptera, Coccinellidae) in Apple Orchards with Integrated and Ecological Management and in Their Surroundings

Elżbieta Wojciechowicz-Żytko[1]*, Edyta Wilk[2]

[1]Agricultural University, Department of Botany, Physiology and Plant Protection,
31-422 Kraków, al. 29-Listopada 54, Poland
[2]Voivodeship Inspectorate of Plant Health and Seed Inspection, Rzeszów, Poland

Received: 9 September 2021
Accepted: 6 November 2021

Abstract

The observations were carried out in the south-eastern part of Poland in apple orchards with different management systems and their surroundings. During that period, 816 individuals of the Coccinellidae belonging to 10 species were collected in apple orchards and 670 specimens (8 species) in their neighbourhood.

In the orchards with IPM, more beetles were recorded in their surroundings than in the orchards; presumably, use of chemical treatments in the IPM orchards negatively affected the species richness and the number of coccinellids while in the surroundings the presence of varied vegetation (shrubs, trees and herbaceous plants) contributed to the increase in the species richness of the Coccinellidae. On the ecological site, however, more ladybird beetles were collected in the orchard than in its neighbourhood.

The species which dominated the coccinellid assemblages in the orchards and their surroundings were *Coccinella septempunctata* L. and *Harmonia axyridis* (Pall).

The research showed that in the case of coccinellids, the impact of the vegetation surrounding the orchards on the presence of ladybugs in the orchard was smaller than the management system.

Keywords: apple orchards, impact, ladybird beetles, management system, surroundings

Introduction

Orchards benefit from ecosystem services such as pollination and natural pest control. The surrounding landscape affects the species composition and abundance of insect communities, which in turn can lead to higher biocontrol rates and less crop damage [1, 2].

The landscape surrounding orchards may directly influence the biodiversity and richness of arthropods through its effects on their immigration or emigration. The neighbourhood vegetation may also indirectly

*e-mail: elzbieta.wojciechowicz@gmail.com

affect the abundance of predators by modifying their resources.

Predatory insects are usually found in large numbers in the vegetation adjacent to fields or orchards, which results in higher densities of those insects on crops. Higher numbers of beneficial insects along the borders with a proper plants species composition may increase the rates of predation inside orchards [3-5]. In orchards with integrated pest management (IPM), natural pest enemies may supplement the insecticide treatments for pest control [6].

Natural habitats can provide beneficial insects with food resources, shelter during disturbances in orchards, as well as an overwintering place, thus leading to a higher abundance, species richness and fecundity of those insects [2, 7-11].

The Coccinellidae are generalist predators of a variety of hemipterous species – an important group of pests of many crops causing serious economic losses [6, 12- 14]. Ladybird larvae and beetles help regulate the number of harmful species f.e. *Aphis pomi* DeGeer, *Dysaphis plantaginea* Pass occurring on apple trees, which results in providing environmental resistance to phytophagous insects, as well as larger crops, for this reason it's important to create the best conditions for their development [4, 10].

The abundance and diversity of predators highly depend on the crop management system. In apple orchards, intensive chemical pest control is applied and the side effects of the use of chemicals are higher mortality or lower fecundity of beneficial insects [12]. A positive effect of ecological management on the occurrence of arthropods were shown by many authors [15-17].

Proper arrangement of orchard surroundings can improve the rate of arrival of predatory coccinellids into orchards and in this way increase the efficacy of these natural pest enemies [2]. Few studies show the correlation between the features of the surrounding vegetation and pest control in orchards.

The aim of the study was to determine how the agricultural management system of apple orchards and their surrounding vegetation (trees, shrubs and herbaceous plants) affect the density and species composition of predatory coccinellids occurring in apple orchards.

The final objective was to improve predatory insect management in apple orchards through the use of appropriate plants in the surroundings to improve biological pest control through a conservation strategy of the best coccinellid species.

Materials and Methods

Research Sites

The study was conducted in the years 2011-2013 in the south-eastern part of Poland near Przemyśl (49.82°N, 22.79°E). Four apple orchard were investigated – in three of them, integrated pest management (IPM) was applied (sites 1-3, area of 9, 10, 8.5 ha, respectively), and the fourth one was an ecological apple orchard (site 4, 9 ha) (no chemicals such as pesticides or fertilizers were used in it), all of them with 'Szampion', 'Elise' and 'Elstar' cultivars. In the orchards apple trees grew 1.5 x 3 m apart, rows of trees were separated by sward.

The surroundings adjacent to the orchard were 7-8 m wide. The vegetation were determined by manually assigning and consisted of:

site 1 – woodlands (*Cerasus vulgaris* Mill., *Juglans regia* L., *Picea abies* (L.), *Prunus* L., *Rhus typhina* L.), shrubs (*Berberis vulgaris* L., *Corylus avellana* L., *Crataegus monogyna* Jacq., *Ligustrum vulgare* L., *Photinia melanocarpa* Michx., *Ribes uva-crispa* L., *Rosa canina* L., *Rubus* L., *Sambucus nigra* L., *Syringa vulgaris* L.) and herbaceous plants (*Achillea millefolium* L., *Aegopodium podagraria* L., *Artemisia absinthium* L.; *Capsella bursa-pastoris* L., *Daucus carota* L., *Galinsoga parviflora* Cav., *Galium aparine* L., *Lamium album* L., *Matricaria discoidea* DC., *Plantago lanceolata* L., *Ranunculus acris* L., *Rhamnus cathartica* L., *Rumex acetosa* L., *Stellaria media* (L.) Vill., *Solidago virgaurea* L., *Taraxacum officinale* Web., *Trifolium repens* L., *Urtica dioica* L., *Veronica chamaedrys* L.);

site 2 – a pear orchard (*Pyrus* L.) (also with IPM) and herbaceous plants (*Achillea millefolium* L., *Aegopodium podagraria* L., *Capsella bursa-pastoris* L., *Daucus carota* L., *Galinsoga parviflora* Cav., *Galium aparine* L., *Lamium album* L., *Matricaria discoidea* DC., *Plantago lanceolata* L., *Ranunculus acris* L., *Rumex acetosa* L., *Stellaria media* (L.) Vill., *Solidago virgaurea* L., *Taraxacum officinale* Web., *Trifolium repens* L., *Urtica dioica* L., *Veronica chamaedrys* L.);

site 3 – a pear orchard (also with IPM), woodlands with a predominance of *Cerasus vulgaris* Mill., *Picea abies* (L.), *Prunus* L., *Rhus typhina* L. *Berberis vulgaris* L. *Corylus avellana* L *Ligustrum vulgare* L and herbaceous plants (*Aegopodium podagraria* L., *Daucus carota* L., *Lamium album* L., *Plantago lanceolata* L., *Ranunculus acris* L., *Rhamnus cathartica* L;, *Stellaria media* (L.), *Taraxacum officinale* Web., *Trifolium repens* L., *Urtica dioica* L., *Veronica chamaedrys* L.);

site 4 – an ecological walnut orchard (*Juglans regia* L.) and herbaceous plants (*Aegopodium podagraria* L., *Matricaria discoidea* DC., *Plantago lanceolata* L., *Poa annua* L., *Stellaria media* (L.) Vill., *Solidago virgaurea* L., *Trifolium repens* L., *Urtica dioica* L., *Veronica chamaedrys* L.).

No chemical pesticides were used in the ecological orchard, as well as in surrounding walnut orchard while the plants in the IPM orchards were protected in accordance with the methodology of integrated production in the same terms against the diseases and pests in all the orchards. In each orchard, depends on year of study, 5-7 procedures against diseases and 6-7 against pests were performed.

Coccinellid Sampling

Coccinellidae adults were caught using the yellow Moericke traps – yellow plastic pans filled with water and glycol [18], 17 cm in diameter and 20 cm in deep. All traps were placed 1.5-2 m above the ground, 10 pans in each orchard and 10 pans in its surroundings. On each site, the traps were placed 10 m apart from each other in rows in the middle of the respective area - no traps were placed on the edge of the orchard and surroundings to avoid marginal effects. Coccinellid adults caught in the traps were counted, recorded, and removed every 2 weeks from the end of April to the end of September. Insects collected in one pan during 14 days constituted one sample. The identification of coccinellids was based on the Bielawski [19] key.

Statistical Analysis

The captured Coccinellidae individuals were analyzed with respect to the species composition, abundance, dominance structure frequency and species richness.

The similarity of coccinellid communities among the apple orchards and their neighbouring vegetation was estimated using Jaccard classic index [20] which is used for gauging the similarity and diversity of samples.

$$J_{clas} = A/A + B + C$$

J_{clas}- Jaccard similarity index, A- number of shared species, B - number of species unique to the first assemblage, C -number of species unique to the second assemblage.

The similarity was also studied using cluster analysis, and the results were presented as a dendrogram. The abundance of predatory species collected from each site was examined by applying principal components analysis (PCA) (Statistica 13.3).

Results

During the 3 years of observations, 816 Coccinellidae individuals belonging to 10 species were collected in the yellow Moericke traps in apple orchards with different management systems, and 670 specimens (8 species) in their neighbourhood. The total number of the collected ladybird beetles was 1486 specimens (Table 1).

There were differences in the number of beetles occurring on the various sites. In all the years of the experiment, the Coccinellidae were the most numerous (481 individuals) on site 4 (ecological orchard), where no chemical treatments were applied (Table 1).

Of the three IPM-orchards, the Coccinellidae most often occurred in orchard 2 (153 specimens) and the surroundings of orchard 1 with the most varied vegetation in the neighbourhood (374 individuals); however, the most species were collected on site 3 (Table 1). The presence of trees and shrubs with herbaceous vegetation provides an ideal living place for these beetles so could be a source of ladybugs which in IPM orchards had worse development conditions due to the use of chemicals.

Many species of aphids were observed on the vegetation surrounding the orchards, e.g. *Aphis grossulariae* Kalt., *Aphis podagrariae* Schrank, *Aphis sambuci* L., *Aphis urticata* Gmelin, *Dysaphis crataegi* Kalt., *Liosomaphis berberidis* Kalt., *Myzus cerasi* F., *Myzocallis coryli* Goetze, and *Myzus ligustri* Mosley. They attracted adult ladybirds and provided alternative food for the larvae and beetles. The lowest number of beetles (69 individuals) were recorded in the surroundings of orchard 4 – the place with the least diverse vegetation (walnut orchard and few species of herbaceous plants).

In all the orchards and their surroundings, two common ladybird species were found: *Coccinella septempunctata* L. and *Harmonia axyridis* Pallas. There were two species specific to the orchards: *Calvia quatuordecimguttata* (L.) and *Coccinella quinquepunctata* (L.), whereas no exclusive species were noted in the surroundings (Table 1).

In all the apple orchards and their surroundings, two eudominants were found: *C. septempunctata* with a share of 23.2-94.9% and *H. axyridis* (18.9-76.8%). Only in the edge vegetation of orchard 1 was *H. axyridis* a subdominant species (Table 1). These two species constituted 96.2% of all the collected ladybirds. *C. septempunctata* was the most numerous in the surroundings of orchard 1 (355 individuals – 23.9% of all the collected coccinellids); its frequency ranged from 19.4% to 66.7% (it was collected in 2/3 of the samples), whereas *H. axyridis* was the most common in orchard 4 (314 specimens – 21.1% of all the beetles recorded). Its frequency ranged from 25 to 58.3%, which means that it was found in ¼ to half of all the samples. Other species with high density were *Adalia bipunctata* (L.) and *Propylaea quatuordecimpunctata* (L.) (18 specimens each). The remaining species occurred sparsely, including *Calvia quatuordecimguttata* (L.) and *Coccinella quinquepunctata* (L.). They included mainly recedents and subrecedents (Table 1).

Having analyzed the number of species of the Coccinellidae in the orchards and their surroundings, the greatest richness of species was found in orchard 3 (3.1) and its surrounding (2.8), whereas the poorest species composition and the lowest richness in the surroundings of orchard 4 (richness – 0.5). Species richness in other sites was similar and ranged from 1.4 to 2.0.

The communities of coccinellid beetles collected in the apple orchards and their surroundings were compared in terms of quantity using Jaccard index [20] (Table 2). The communities of the particular sites were found to be mostly similar in over third of their species composition. The highest similarity between

Table 1. Species composition , domination and frequency of coccinellids collected to the yellow traps in orchards and their surroundings 2011-2013.

Species	Site 1						Site 2						Site 3						Site 4					
	Orchard			Surrounding			Orchard			Surrounding			Orchard			Surrounding			Orchard			Surrounding		
	no.	%	f	no.	%	f	no.	%	f	no.	%	f	no.	%	f	no.	%	f	no.	%	f	no.	%	f
Adalia bipunctata (L.)	2	1.9 R	2.8	1	0.3 Sr	2.8	1	0.7 Sr	2.8	5	4.8 Sd	11.1	3	3.9 Sd	5.6	6	5.0 Sd	16.7						
Adalia decempunctata (L.)				3	0.8 Sr	2.8							2	2.6 Sd	2.8	1	0.8 Sr	2.8						
Calvia decemguttata (L.)										1	0.9 Sr	2.8	1	1.3 R	2.8									
Calvia quatuordecimguttata(L.)													1	1.3 R	2.8									
Chilocorus renipustulatus (Scr.)							1	0.7 Sr	2.8							1	0.8 Sr	2.8						
Coccinula quatuordecimpustulata (L.)				3	0.8 Sr	5.6	2	1.3 R	2.8							2	1.7 R	2.8						
Coccinella quinquepunctata (L.)																			2	0.41 Sr	4.2			
Coccinella septempunctata (L.)	82	77.4 Eu	30.6	355	94.9 Eu	19.4	107	69.9 Eu	44.4	40	37.8 Eu	52.8	24	31.6 Eu	25.0	36	30.0 Eu	55.6	160	33.3 Eu	66.7	16	23.2 Eu	25.0
Harmonia axyridis (Pallas)	20	18.9 Eu	36.1	12	3.2 Sd	25.0	40	26.1 Eu	47.2	58	54.2 Eu	50.1	42	55.3 Eu	33.3	71	59.2 Eu	58.3	314	65.3 Eu	45.8	53	76.8 Eu	41.7
Propylaea quatuordecimpunctata (L.)	2	1.9 R	5.6				2	1.3 R	5.6	3	2.8 Sd	8.3	3	3.9 Sd	5.6	3	2.5 Sd	8.3	5	1.0 Sr	16.7			
Total	106			374			153			107			76			120			481			69		

no.- number, f- frequency, % percent; Eudominants (Eu)> 10%, Dominants (D) 5,1-10%, Subdominants (Sd) 2,1-5%, Recedents (R)1,1-2%, Subrecedents (Sr) <1%

Table 2. Similarity of coccinellid associations collected into yellow traps calculated from Jaccard classic index.

	Site 1 orchard	Site 1 surrounding	Site 2 orchard	Site 2 surrounding	Site 3 orchard	Site 3 surrounding	Site 4 orchard	Site 4 surrounding
Site 1 orchard	x	0.50	0.667	0.80	0.571	0.571	0.333	0.50
Site 1 surrounding	0.50	x	0.571	0.571	0.50	0.714	0.286	0.40
Site 2 orchard	0.667	0.571	x	0.571	0.444	0.857	0.50	0.333
Site 2 surrounding	0.80	0.571	0.571	x	0.714	0.625	0.50	0.333
Site 3 orchard	0.571	0.50	0.444	0.714	x	0.714	0.375	0.286
Site 3 surrounding	0.571	0.714	0.857	0.625	0.714	x	0.375	0.286
Site 4 orchard	0.333	0.286	0.50	0.50	0.375	0.375	x	0.50
Site 4 surrounding	0.50	0.40	0.333	0.333	0.286	0.286	0.50	x

the communities of coccinellid occurring in orchard and its surrounding was found on site 3 (0.714). In total habitats the assemblage of coccinellids in orchard 2 and in surroundings of orchard 3 were the most similar (0.857), whereas the lowest similarities were noted between the communities collected in ecological orchard 4 and surroundings 1 (with very diverse vegetation), surroundings 4 (walnut orchard) and orchard and surroundings 3 (very diverse vegetation – a pear orchard, woodlands and herbaceous plants). Those communities reached Jaccard index below 0.3 (Table 2). The coccinellid communities inhabiting the apple orchards and their surroundings were also compared in terms of quantity and quality using order grouping with the cluster method. The community of coccinellids found in the ecological orchard (site 4) differed markedly from other communities (Fig. 1).

The analysis of the similarities in the quantity and quality structures of the Coccinellidae communities found on the different sites was completed by comparing their structures using the principal component analysis method (PCA). The results showed similarities between the same communities as those determined with the cluster method and the different character of the community found in the ecological orchard (Fig. 2).

Discussion

During the study, 1486 coccinellids belonging to 10 species were collected in the surveyed orchards and their surroundings. *C. septempunctata* and *H. axyridis* were the dominant species. Similar species composition

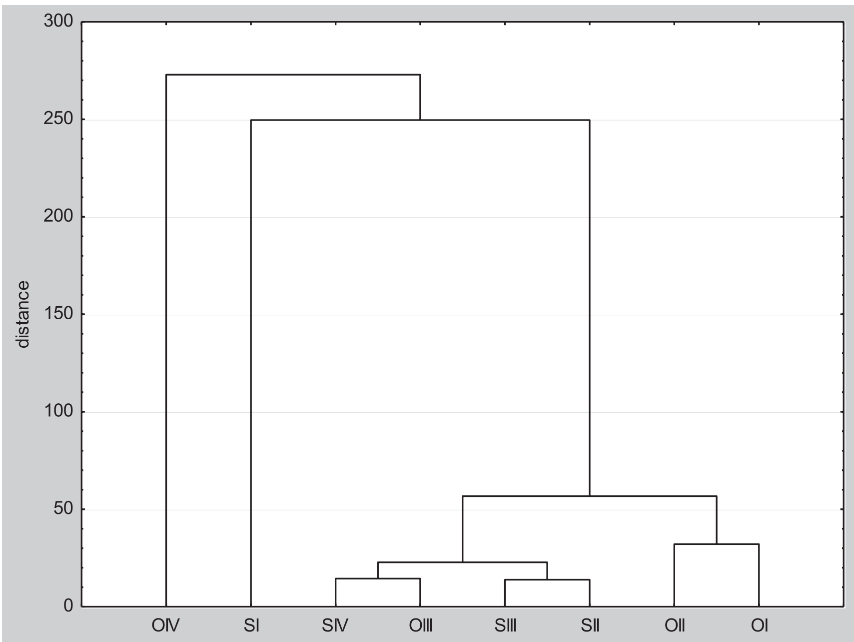

Fig. 1. Cluster analysis of habitats with group single linking as the clustering method (OI – orchard 1 IPM, OII – orchard 2 IPM, OIII – orchard 3 IPM, OIV – orchard 4 – ecological, SI – surroundings 1 , SII – surroundings 2, SIII – surroundings 3, SIV – surroundings 4).

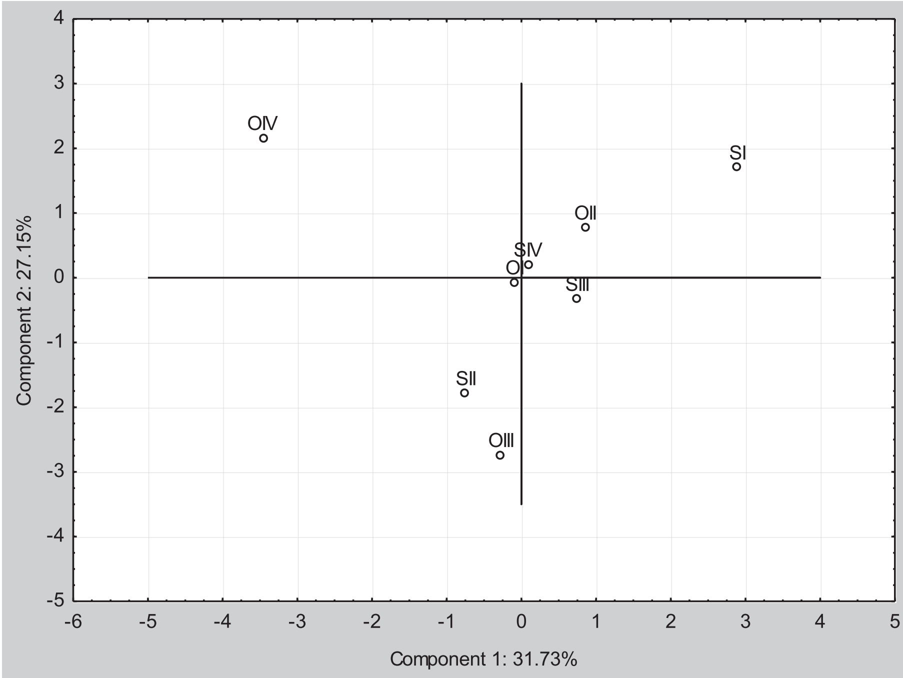

Fig. 2. Plot of the principal components analysis of habitats (OI – orchard 1 IPM, OII – orchard 2 IPM, OIII – orchard 3 IPM, OIV – orchard 4 – ecological, SI – surroundings 1 , SII – surroundings 2, SIII – surroundings 3, SIV – surroundings 4).

had been reported by Gardiner et al. [21], who noted that these species made up 90% of all coccinellid communities in soybean fields surrounded by forested habitats. The authors observed that landscape structure significantly affected the species composition of the predators occurring in the fields. Dominant presence of *H. axyridis* was also reported by Koch, Costamagna [22] working on the occurrence of ladybird beetles on different crops in North America.

According to Andreev et al. [6], coccinellids were the dominant group among beneficial insects occurring in apple orchards under biological pest management and played a significant role in reducing the numbers of aphids, scale insects and mites. The authors recorded 13 coccinellid species, dominated by *C. septempunctata, P. quatuordecimpunctata, A. bipunctata* and *Stethorus punctillum*. In IPM orchards, the number of coccinelids was lower, but their importance as natural enemies of aphids was still significant.

Colunga-Garcia et al. [7] and Shanker [8] pointed out that coccinellid beetles were very important predators of aphids feeding on different crops, but their occurrence depended on non-crop landscape elements such as shrubs, trees and hedgerows as places for hibernation. Coccinellids have a high capacity for dispersal and wide preference for different habitats, so large-scale patchiness may force them to disperse among habitats.

In our study, the surrounding vegetation affected the density and species composition of coccinellids in all the orchards under IPM management. The obtained results confirm the rule according to which the diversity of habitats is connected with the increase in the number of species, which often occurs as recedents and subrecedents contribute to increasing biodiversity.

These results support the conclusions of other studies on the impact of field boundary vegetation on the presence of beneficial insects [2, 3, 23, 24]. According to the authors, the surrounding vegetation seems to be crucial for predatory species, while Grez and Prado [3] suggested that coccinellids can be affected not only by the surrounding vegetation but also by plant patch shape. According to Simon et al. [12], the surface area within 100 m around a pear orchard with trees, shrubs and herbaceous plants was significantly and positively correlated with the number of beneficial insects occurring in the orchard and negatively correlated with the number of pests. Colunga-Garcia et al. [7] noted that *C. septempunctata* was the dominant species and had similar abundance on three sites with different cultivated plants. The authors found that a site with deciduous plants had higher species richness. Woltz and Landis [2] observed that the abundance and diversity of coccinellids within some crops were positively related to the number of natural habitats. The number of coccinellids was highest in the landscape dominated by grasslands and trees. Simon et al. [12] found that the boundaries of pear orchards increase the diversity of beneficial insects and that the distribution of insect predators within the orchard is affected by the hedgerow. Natural enemies of pests migrate from the surrounding plants to the orchard in relation to prey availability; however, the effect of the hedgerow on the presence of insect predators in orchards is not always evident. No significant correlation was found between the number of predators due to surrounding plants and the control of *C. pyri* in commercial pear orchards.

In all the years of the study, the lack of chemical treatments in the ecological orchard was the most important factor influencing the occurrence of beneficial coccinellids.

Porcel et al. [14], working on the relationship between orchard management and the occurrence of natural pest enemies, noted that an ecological system resulted in more diverse and abundant predators in the orchard. The authors also found that in an ecological orchard, as opposed to a conventional one, predators occurred earlier in aphid colonies, so they suggested that this management had an impact on the synchrony of pests and their natural enemies. Debras et al. [25] in France had reported larger numbers of Coccinellidae in ecological orchards than in pear orchards under IPM. Saunders, Luck [26] found out that floral diversity were very effective as a food source for beneficial insects whereas Rodríguez-Gasol et al. [27] suggested that habitat management (f.e. flower margins) can increase predators and parasitoids populations and support biological control.

Agricultural management systems affect biological pest control – a very important service for apple production [11, 14, 28]. Conventional agriculture often devastates populations of beneficial insects [12, 29], whereas ecological apple production increases the abundance and biodiversity of predators due to non-existent pesticide disruption, so higher aphid predation rates are observed in ecological than in conventional farming [14, 30, 31]. Apple orchards and their surroundings provide a stable habitat for many arthropods, which results in higher species biodiversity and abundance than in annual crops [12, 23, 32-35]. Based on the results obtained, it can be concluded that the surroundings of the orchards with integrated production was the place where more Coccinellidae occurred than in the orchards; however, in the ecological orchard the situation was reversed. This was probably related to the use of plant protection chemicals in the orchards with integrated production, which influenced some beneficial insects in a negative way. It should be emphasized that in the case of coccinellids, the impact of the vegetation surrounding the orchards on the presence of ladybugs in the orchard was smaller than in the case of other beneficial insects fe. syrphids or carabids [18, 23, 24]. Moreover, orchard surroundings also had an influence on the number and species richness of the Coccinellidae. It was shown that the neighbouring habitats contributed to the increase in the biodiversity of coccinellids, and in this way could improved the biological pest control in the orchards. The most attractive environment for the Coccinellidae were the plantings and bushes mid-field, and herbaceous vegetation. The presence of additional plants on which many aphid species were observed was the source of alternative food for the larvae and adults of predatory Coccinellidae. Also, these areas of hibernation for coccinellids appeared to be a key factor for the future occurrence of ladybird beetles in the orchards. They could be a source of coccinellids which have worse development conditions in orchards with IPM management due to the use of pesticides.

The least attractive environment for ladybugs was the nut orchard and sparse herbaceous vegetation, which shows that the selection of appropriate flora affects the occurrence of predatory insects. The presence of refuge sites also contributed to the enrichment of coccinellidae species composition; however, the number of coccinellids depended more on the orchard management system. Pesticide applications are most likely responsible for the decrease in predatory coccinellids in IPM orchards.

Conclusions

Based on the obtained results, it can be concluded suggested that the proper surrounding of orchards may be a source of beneficial ladybugs. The results of the study can be used by farmers to reduce the use of pesticides in orchards with integrated production by planting or seeding appropriate plants in orchard surroundings, thus increasing the number and effectiveness of the predators that control the populations of pests.

However more studies are needed that identify how neighbouring vegetation of orchards influence on beneficial insects communities, and relevant ecosystem functions, in agroecosystems.

Acknowledgments

This research was supported by the Ministry of Science and Higher Education of Poland as a part of the research subsidy to the University of Agriculture in Kraków.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Both authors contributed to this work.

References

1. CROSS J., FOUNTAIN M., MARKÓ V., NAGY C. Arthropod ecosystem services in apple orchards and their economic benefits. Ecol. Entomol, **40**, 82, **2015**.
2. WOLTZ J.M., LANDIS D.A. Coccinellid response to landscape composition and configuration. Agr. Forest Entomol., **16**, 4, 341, **2014**.

3. GREZ A.A., PRADO E. Effect of plant patch shape and surrounding vegetation on the dynamics of predatory coccinellids and their prey *Brevicoryne brassicae* (Hemiptera: Aphididae). Environ. Entomol., **29** (6), 1244, **2000**.
4. CAHENZLI F., PFIFFNER L., DANIEL C. Reduced crop damage by self-regulation of aphids in an ecologically enriched, insecticide-free apple orchard. Agron. Sustain. Dev.; **37**, 8, **2017**.
5. CAHENZLI F., SIGSGAARD L., DANIEL C., HERZ A., JAMAR L., KELDERER M., JACOBSEN S.K., KRUCZYŃSKA D., MATRAY S., PORCEL M., SEKRECKA M., ŚWIERGIEL W., TASIN M., TELFSER I., PFIFFNER L. Perennial flower strips for pest control in organic apple orchards – A pan-European study. Agric. Ecosyst. Environ. 43, **2019** . .
6. ANDREEV R., OLSZAK R., KUTINKOVA H. Harmful and beneficial entomofauna in apple orchards grown under different management systems. Pesticides and Beneficial Organisms. IOBC/wprs Bulletin. **29** (10), 13, **2006**.
7. COLUNGA-GARCIA M., GAGE S.H., LANDIS D.A. Response of an assemblage of Coccinellidae (Coleoptera) to a diverse agricultural landscape. Environ. Entomol., **26**, 8, 797, **1997**.
8. SHANKER CH, CHINTAGUNTA L., MUTHUSAMY S., VAILLA S, SRINIVASAN A KATTI G. Flora surrounding rice fields as a source of alternative prey for coccinellids feeding on the pests of rice Eur. J. Entomol. **115**, 364, **2018**
9. WOJCIECHOWICZ-ŻYTKO E., JANKOWSKA B. *Sambucus nigra* L. as a reservoir of beneficial insects (Diptera, Syrphidae). Folia Hortic., **28**, 2, 209, **2016**.
10. ALBERT L., FRANCK P., GILLES Y., PLANTEGENEST M. Impact of Agroecological Infrastructures on the Dynamics of *Dysaphis plantaginea* (Hemiptera: Aphididae) and Its Natural Enemies in Apple Orchards in Northwestern France. Environ. Entomol.; **46**, 528, **2017**.
11. SAMNEGÅRD U., ALINS G., BOREUX V., BOSCH J., GARCÍA D., HAPPE A.K., KLEIN A.M., MIÑARRO M., MODY K., PORCEL M., RODRIGO A., ROQUERBENI L., TASIN M., HAMBÄCK P.A. Management trade-offs on ecosystem services in apple orchards across Europe: Direct and indirect effects of organic production. J. Appl. Ecol.; **56**, 802, **2018**.
12. SIMON S., BOUVIER J-C., DEBRAS J-F., SAUPHANOR B. Biodiversity and pest management in orchard systems. A review. Agron. Sustain. Dev., **30**, 139, **2010**.
13. KUNDOO A.A., KHAN A.A. Coccinellids as biological control agents of soft bodied insects: A review Journal of Entomology and Zoology Studies, **5** (5), 1362, **2017**.
14. PORCEL M., GEORG K.S., ANDERSSON G., PÅLSSON J., TASIN M. Organic management in apple orchards: Higher impacts on biological control than on pollination. J. Appl Ecol. **55**, 27, 79, **2018**.
15. GBÈBLONOUDO DASSOU A., TIXIER P. Response of pest control by generalist predators to local-scale plant diversity: a meta-analysis, Ecol. Evol, 1143, **2016**.
16. TUCK S., WINQVIST C., MOTA F., AHNSTRÖM J., TURNBULL L.A., BENGTSSON J. Land-use intensity and the effects of organic farming on biodiversity: A hierarchical meta-analysis. J. Appl. Ecol., **51**, 746, **2014**.
17. LICHTENBERG E.M., KENNEDY C.M., KREMEN C., BATÁRY P., BERENDSE F., BOMMARCO R., WINFREE R. A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. Glob. Change Biol., **23** (11), 4946, **2017**.
18. PIEKARSKA-BONIECKA H., SIATKOWSKI M., TRZCIŃSKI P., SIATKOWSKI I. The impact of the vegetation of apple orchard edges on quantity and quality structure of predatory hoverflies (Diptera: Syrphidae) communities. Turkish Journal of Entomology. **394**, 333, **2015**.
19. BIELAWSKI R. Biedronki – Coccinellidae. Klucze do oznaczania owadów Polski, **XIX**, (76), Warszawa. **1959**.
20. CHAO A., CHAZDON R.L., COLWELL R.K. SHEN T-S. A new statistical approach for assessing similarity of species composition with incidence and abundance data. Ecol. Lett, **8**, 148, **2005**.
21. GARDINER M.M., LANDIS D.A., GRATTON C., SCHMIDT N., O'NEAL N.M., MUELLER E., CHACON J., HEIMPEL G.E., DIFONZO C.D. Landscape composition influences patterns of native and exotic lady beetle abundance. Divers. Distrib. 15, 554, , **2009**.
22. KOCH R., L., COSTAMAGNA A., C. Reaping benefits from an invasive species: role of *Harmonia axyridis* in natural biological control of *Aphis glycines* in North America BioControl **62**, 3, 331, **2017**.
23. FUNAYAMA K. Unmown groundcover conserves adult populations of the predatory ground beetle *Chlaenius micans* (Coleoptera: Carabidae) in commercial apple orchards. Appl. Entomol. Zool; **49**, 183, **2014**
24. WOJCIECHOWICZ-ŻYTKO E., WILK E. Effects of surrounding environment and management system in apple orchards on the occurrence of ground beetles. Pol. J. Environ. Stud. **28**, 5, 3489, **2019**.
25. DEBRAS J.F., TORRE F., RIEUX R., KREITER S., GARCIN M.S., VAN HELDEN M., BUISSON E., DUTOIT T. Discrimination between agricultural management and the hedge effect in pear orchards (south-eastern France). Ann. Appl. Biol., **149**, 3, 347, **2006**.
26. SAUNDERS M.E., LUCK G.W. Interaction effects between local flower richness and distance to natural woodland on pest and beneficial insects in apple orchards. Agric. For. Entomol., **20**, 279, **2018**.
27. RODRÍGUEZ-GASOL N, AVILLA J, APARICIO Y, ARNÓ J, GABARRA R, RIUDAVETS J, ALEGRE S, LORDAN J, ALINS G. INSECTS. The Contribution of Surrounding Margins in the Promotion of Natural Enemies in Mediterranean Apple Orchards. Insects, **10** (5), 148, **2019**.
28. SIMON S., LESUEUR-JANNOYER M., PLÉNET D., LAURI P.-É., LE BELLEC F. Methodology to design agroecological orchards: Learnings from on-station and on-farm experiences. Eur. J. Agron.; **82**, 320, **2017**.
29. RUSCH A., BIRKHOFER K., BOMMARCO R., SMITH H. G., EKBOM B. Management intensity at field and landscape levels affects the structure of generalist predator communities. Oecologia, **175**, 971, **2014**.
30. EMMERSON M., MORALES M.B., OÑATE J.J., BATÁRY P., BERENDSE F., LIIRA A., AAVIK T., GUERRERO I., BOMMARCO R., EGGERS S., PÄRT T., TSCHARNTKE T., WEISSER W., CLEMENT L., BENGTSSON J. How agricultural intensification affects biodiversity and ecosystem services. Adv. Ecol. Res., **55**, 43, **2016**.
31. JONSSON M., KAARTINEN R., STRAUB C.S. Relationships between natural enemy diversity and biological control. Curr. Opin. Insect. Sci., **20**, 1, **2017**.
32. RUSCH A., CHAPLIN-KRAMER R., GARDINER M. M., HAWRO, V., HOLLAND, J., LANDIS, D., THIES

C., TSCHARNTKE T, WEISSER W., WINQVIST C., WOLTZ M., BOMMARCO R. Agricultural landscape simplification reduces natural pest control: A quantitative synthesis. Agr. Ecosyst. Environ., **221**, 198, **2016**.
33. HAMBÄCK P., PORCEL M., TASIN M., SAMNEGÅRD U. Predatory arthropod community composition in apple orchards: Orchard management, landscape structure and sampling method. J Appl Entomol, 1 **2020**.
34. HAPPEA A-K., ALINSC G. BLÜTHGENA N., BOREUXD V., BOSCHE J. GARCÍAF D., HAMBÄCKG P-A., KLEIND A-M., MARTÍNEZ-SASTREH R., MIÑARROH M., MÜLLERA A-K., PORCELI M., RODRIGOE A., ROQUER-BENIE L., SAMNEGÅRDG U., TASINI M., MODYA K. Predatory arthropods in apple orchards across Europe: Responses to agricultural management, adjacent habitat, landscape composition and country, Ecosyst Environ, **273**, 141, **2019**.
35. HERZ A., CAHENZLI F., PENVERN S., PFIFFNER L., TASIN M., SIGSGAARD L. Managing Floral Resources in Apple Orchards for Pest Control: Ideas, Experiences and Future Directions Insects. **10**, 8, 247, **2019**.