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Gradient of decline of epigeic arthropods depending on ecotone distance and seasonal dynamics in agriculturally used land

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Epigeic arthropods participate in the regulation of pest populations, the decomposition of organic matter, and the maintenance of soil structure and quality, thus playing an important role in the functioning of vineyards. During 2021–2023, we analysed the spatial dispersion of epigeic arthropods in different types of vineyard habitats (semi-intensive vineyard, intensive vineyard, abandoned vineyard and meadow). During the investigation, a total of 56,726 individuals belonging to 23 taxa were recorded. The highest numbers of taxa were recorded in traps located in the ecotone, while the number of taxa decreased toward the interior of each of the studied habitats. The redundancy analysis confirmed the significant influence of habitat type on the spatial distribution of taxa. We confirmed statistically significant differences in the abundance of individuals between individual seasons and traps in all studied habitats. Linear regression showed a strong to moderate relationship between the distance of pitfall traps from the field edge and the abundance of individuals, while we predictied a trend of decreasing numbers of individuals another 20 m into the field. The results point to the importance of ecotones for epigeic arthropods in the assessment of biodiversity in agroecosystems.

Keywords: biodiversity; epigeic fauna; management; vineyard; Slovakia.

Introduction

Epigeic invertebrate communities, especially arthropods, represent an important component of soil and spatially bound ecosystems in agrocenoses, where they play a significant ecological role in processes such as organic matter decomposition, biological pest control, nutrient cycling, and soil structure formation (Giller, 1996; Lavelle et al., 2006). Viticulture as a form of intensive land use can significantly affect the biodiversity of these groups depending on the intensity of management, spatial arrangement of the landscape, and seasonal dynamics (Burel & Baudry, 2003; Ćurčić & Stanković, 2011; Altieri & Nicholls, 2018).

The spatial distribution of epigeic taxa within vineyards is closely linked to marginal zones and transitional ecotones, which represent important refuges for many species, especially during adverse seasons (Duelli & Obrist, 2003). Different types of vineyard habitat – from intensively managed to extensive or abandoned areas – show differences in the composition and abundance of these taxa, which reflects the ecological stability and quality of the given environment (Tscharntke et al., 2005; Batáry et al., 2010). In particular, predator groups such as Coleoptera or Araneae function as key representatives of biological protection, whose presence is desirable, especially in organic and integrated viticulture (Kromp, 1999; Symondson et al., 2002). Previous research shows that the edge zones of habitats host the greatest diversity and abundance of individuals, while toward the interior of the vineyards their numbers decrease due to less favourable microclimatic conditions and lower structural heterogeneity (Holland & Luff, 2000; Bennewicz & Barczak 2020).

The seasonal dynamics of epigeic arthropods in agroecosystems, including vineyards, are significantly influenced by environmental factors such as temperature, humidity, vegetation cover, and the phenological phase of the stand (Schowalter, 2016). These factors determine not only the overall activity and migration of species, but also their spatial distribution and ecological function in a given environment (Torma et al., 2011). In the case of vineyards, it is confirmed that the highest activity of epigeic taxa occurs in the summer months, when conditions are optimal for reproduction, food and shelter (Pétillon et al., 2007; Moreira et al., 2008). Studies show that during spring and autumn, diversity stabilizes, but the total number of individuals tends to be lower than in summer, which is related to the reduced metabolic activity of many species due to fluctuating temperatures and decreasing food availability (Magura et al., 2001). In winter, with a decrease in temperature and reduced vegetation cover, the activity of most epigeic arthropods decreases dramatically, and a large part of the community enters diapause or hibernates in deeper soil layers (Southwood & Henderson, 2000). In agroecosystems such as vineyards, seasonal dynamics are also influenced by practical interventions such as plowing, chemical treatments or mowing, which can reduce the abundance of some groups in the short term, but in the longer term, adaptation and repopulation occur (Bianchi et al., 2006). The spatial configuration of the vineyard also plays a significant role, where marginal ecotonal zones provide more stable microclimatic conditions that dampen seasonal fluctuations and serve as refuges for species during adverse periods (Magura, 2002; Brygadyrenko & Reshetniak, 2014; Avtaeva et al., 2021).

Given the climatic and environmental challenges of modern agricultural production, the study of these groups and their ecological links is essential for the design of measures to support biodiversity in agricultural landscapes (Bengtsson et al., 2005; Bavec & Bavec, 2015).

In this study, therefore, we analyze the spatial distribution and seasonal dynamics of epigeic arthropods in vineyard habitats of varying degrees of intensity of management, focusing on the influence of ecotonal zones and habitat types on the composition of taxa and abundance of individuals.

Materials and methods

During the years 2021 to 2023, we conducted research in eight study areas. The studied area has a warm, temperate to humid climate and mild winters, the soil type is predominantly brown earth. Geomorphologically, it falls under the Danube upland. The description of the study areas is as follows:

S1 – overgrown, abandoned vineyard, the vines are overgrown with *Prunus spinosa* and *Rosa rubiginosa* species; it is located 282 m above sea level; geographic coordinates: 48°25'15" N 18°26'27" E;

S2 – meadow, originally a vineyard 50 years ago, was mowed twice a year; it is located at an altitude of 282 m above sea level; geographic coordinates: 48°25'15.8" N 18°26'27.6" E;

S3 – meadow, originally a vineyard 50 years ago, mowed twice a year; it is located at an altitude of 284 m above sea level; geographic coordinates: 48°25'16.9" N 18°26'29.5" E;

S4 – overgrown, abandoned vineyard, the vines are overgrown with *Prunus spinosa* and *Rosa rubiginosa* species; it is located 281 m above sea level; geographic coordinates: 48°25'17.8" N 18°26'32.4" E;

S5 – intensive vineyard, once a year the grass is mowed, the old vines are removed, and new ones are planted; it is located 262 m above sea level; geographic coordinates: 48°25'31.6" N 18°26'46.0" E;

S6 – semi-intensive vineyard, once a year the grass is cut and the vines are pruned; the old vines are removed and no new ones are planted; it is located 280 m above sea level; geographic coordinates: 48°25'35.2" N 18°26'48.8" E;

S7 – semi-intensive vineyard, once a year the grass is cut and the vines are pruned; the old vines are removed and no new ones are planted; it is located 278 m above sea level; geographic coordinates: 48°25'36.0" N 18°26'49.7" E;

S8 – intensive vineyard, once a year the grass is mowed, the old vines are removed, and new ones are planted; it is located 274 m above sea level; geographic coordinates: 48°25'41.5" N 18°26'54.2" E.

During the years 2021 to 2023 from April to October, we collected epigeic arthropods at regular monthly intervals. We used the pitfall traps method, in each study area we placed five pitfall traps in a line and used formalin (4%) as a fixative. The distance between the traps is 10 m, so the total distance between all traps is 40 m. We determined the study material into orders according to Schierwater & DeSalle (2021).

The association of taxa with vineyard biotopes (intensive vineyard, semi-intensive vineyard, overgrown, meadow) and pitfall traps (1–5) during the seasons was analysed by Redundancy Analysis (RDA). Statistical significance was tested by the Monte Carlo permutation test in the Canoco5 program (Ter Braak & Šmilauer, 2012).

We tested the normality of the distribution of the number of individuals using the Shapiro-Wilks test. We tested the difference in the number of individuals between pitfall traps (1–5) between seasons using the Friedman test. We predicted the number of individuals in pitfall traps 7 using linear regression, which represents 60 m from the edge of the habitat. We performed the analyses in Python 3.12 (2023).

Results

During our research, we recorded a total of 56,726 individuals. We recorded the most individuals in the meadow habitat, 17,522 individuals belonging to 21 taxa. We confirmed the lowest number of taxa in the overgrown habitat, 12,082 individuals belonging to 19 taxa. The Coleoptera and Hymenoptera taxa were eudominant (> 10%) in all habitats. Araneida had eudominant representation only in two habitat types, intensive vineyard and overgrown. The highest number of individuals in all habitats was recorded in pitfall traps 1, totalling 30.6%. The number of individuals decreased toward the interior of the field in the pitfall traps 2 (23.5%), pitfall traps 3 (16.9%), pitfall traps 4 (14.9%) and pitfall traps 5 (14.0%, Table 1).

By redundancy analysis (SD = 0.8 on the first ordination axis) we determined the influence of habitats (semi-intensive vineyard, intensive vineyard, abandoned vineyard, meadow) on the spatial distribution of epigeic groups during the seasons and pitfall traps. The values of the explained cumulative variability of the species data were 45.7% on the first ordination axis and 61.2% on the second ordination axis. Due to the influence of land use, the variability on the 1st ordination axis increased to 69.9%, and on the second cumulative axis there was an increase to 93.7%. A significant influence on the spatial distribution of epigeic arthropods was confirmed in semi-intensive vineyards (P = 0.002), intensive vineyards (P = 0.002), pastures (P = 0.0002) and overgrown (P = 0.006).

Table 1
Representation of arthropods in pitfall traps (1–5)

Biotopes / arthropods	Pitfall Traps					∑ individuals
	1	2	3	4	5	
Meadow						
Acarina	1	5	2	0	0	8
Araneida	579	397	250	231	188	1645
Auchenorrhyncha	0	0	0	0	2	2
Blattodea	0	2	0	1	1	4
Coleoptera	1187	1097	436	470	690	3880
Collembola	295	44	71	109	147	666
Dermaptera	42	12	15	15	8	92
Geophilomorpha	1	0	1	0	0	2
Glomerida	326	222	305	221	234	1308
Hemiptera	149	65	97	75	93	479
Hymenoptera	2067	1420	833	960	560	5840
Isopoda	256	173	164	208	188	989
Julida	378	204	149	110	159	1000
Lithobiomorpha	40	25	22	22	22	131
Lumbricida	38	21	9	8	15	91
Mantodea	0	1	0	0	0	1
Opilionida	100	37	36	55	56	284
Orthoptera	288	150	202	236	217	1093
Polydesmida	2	0	0	0	0	2
Pseudoscorpiones	0	2	0	0	0	2
Zygentoma	2	1	0	0	0	3
Semi-intensive vineyard						
Acarina	4	0	0	0	0	4
Araneida	485	230	159	196	228	1298
Coleoptera	634	354	283	320	267	1858
Collembola	53	0	0	0	0	53
Dermaptera	19	16	25	21	36	117
Geophilomorpha	1	2	2	1	1	7
Glomerida	143	106	111	80	107	547
Hemiptera	90	54	45	42	39	270
Hymenoptera	1229	2879	1748	618	944	7418
Chordeumatida	1	0	0	0	0	1
Isopoda	150	72	85	61	76	444
Julida	97	63	95	93	89	437
Lithobiomorpha	19	5	9	5	7	45
Lumbricida	25	11	15	10	15	76
Opilionida	69	62	42	16	23	212
Orthoptera	72	73	69	48	41	303
Zygentoma	1	0	0	0	0	1
Intensive vineyard						
Araneida	533	275	365	333	299	1805
Auchenorrhyncha	0	6	2	5	1	14
Coleoptera	955	490	495	367	548	2855
Collembola	128	43	0	0	0	171
Dermaptera	32	16	55	37	72	212
Geophilomorpha	2	0	16	10	12	40
Glomerida	194	142	143	149	108	736
Hemiptera	156	101	86	100	73	516
Hymenoptera	1639	1092	811	895	485	4922
Isopoda	314	212	136	128	146	936
Julida	186	157	146	124	137	750
Lithobiomorpha	29	14	5	11	21	80
Lumbricida	27	15	17	14	11	84
Opilionida	99	48	59	29	49	284
Orthoptera	150	107	144	109	105	615
Polydesmida	1	0	1	5	0	7
Pseudoscorpiones	0	1	0	0	0	1
Zygentoma	0	2	1	0	0	3
Overgrown						
Acarina	0	0	0	1	0	1
Araneida	616	388	250	311	260	1825
Blattodea	0	0	0	2	0	2
Coleoptera	693	402	276	261	307	1939
Collembola	289	0	21	52	19	381

Biotopes / arthropods	Pitfall Traps					∑ individuals
	1	2	3	4	5	
Dermaptera	22	14	15	17	7	75
Ensifera	3	0	0	0	0	3
Geophilomorpha	2	1	0	0	0	3
Glomerida	341	188	129	153	119	930
Hemiptera	116	54	61	54	70	355
Hymenoptera	1351	1458	748	830	329	4716
Chordeumatida	0	0	1	0	0	1
Isopoda	237	98	154	116	159	764
Julida	189	129	88	43	68	517
Lithobiomorpha	26	7	14	14	15	76
Lumbricida	33	17	5	8	9	72
Opilionida	78	44	42	31	46	241
Orthoptera	53	26	50	26	25	180
Zygentoma	0	0	0	0	1	1
∑ individuals	17337	13352	9616	8467	7954	56726

The ordination plot shows that the highest number of taxa occurred during the summer months in all types of vineyard habitats. It was also confirmed for all seasons that the strongest taxa preference was recorded for pitfall traps 1 and 2 located in the ecotone. Toward the interior of the habitat (pitfall traps 3–5), the number of taxa decreased (Fig. 1).

The Shapiro-Wilks test confirmed the broken normality of the distribution of individuals in all habitat types. The results are as follows: semi-intensive vineyard (P = 0.0001), intensive vineyard (P = 0.0001), meadow (P = 0.001) and overgrown (P = 0.00001). Based on the broken normality of the data distribution, we used the non-parametric Friedman test, which tested the difference in the number of individuals between seasons and pitfall traps (1–5). We confirmed a significant difference in all types of vineyard habitat: semi-intensive vineyard (P = 0.0229, Fig. 2), intensive vineyard (P = 0.0062, Fig. 3), pasture (P = 0.0123, Fig. 4) and overgrown (P = 0.0031, Fig. 5).

From the results of the analysis we can say that during all seasons we confirmed a decrease in individuals from the ecotone (pitfall traps 1–2) to the interior of each studied habitat (pitfall traps 3–5). We found this trend in all investigated vineyard habitats (semi-intensive vineyard, intensive vineyard, overgrown meadow). We confirmed that the greatest number of individuals in all pitfall traps occurred during the summer, while in spring and autumn the number of individuals was lower than in summer and balanced between spring and autumn.

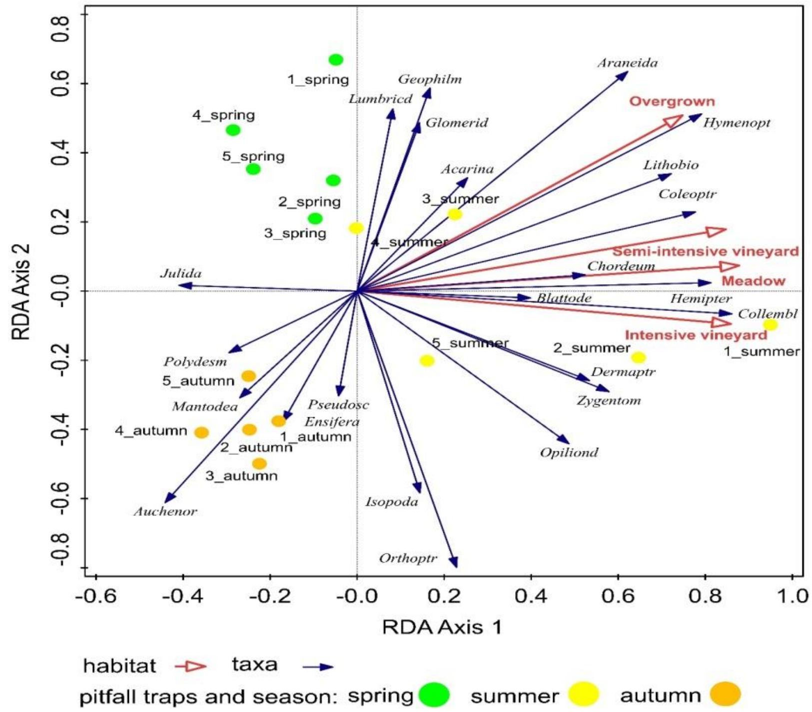

Fig. 1. RDA analysis of taxa in habitats during seasons and pitfall traps

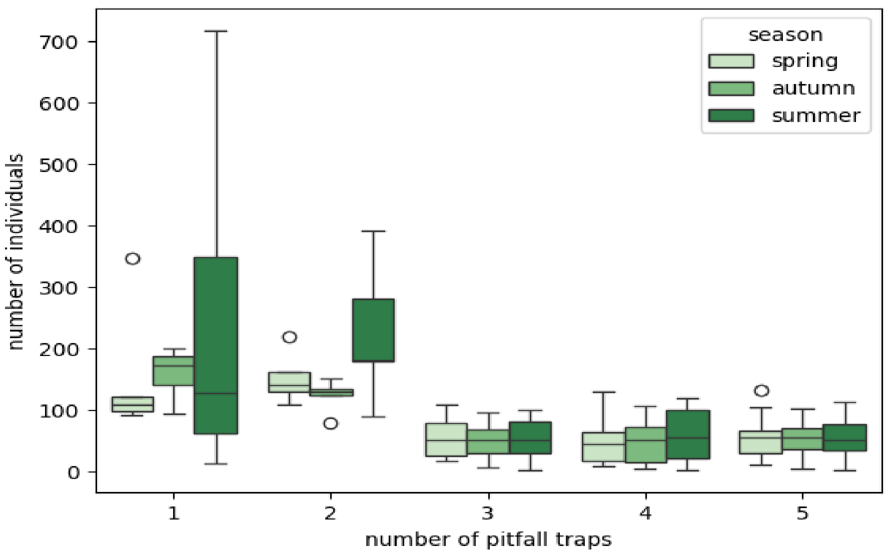

Fig. 2. Difference in the number of individuals between pitfall traps (1–5) and season in intensive vineyard habitat

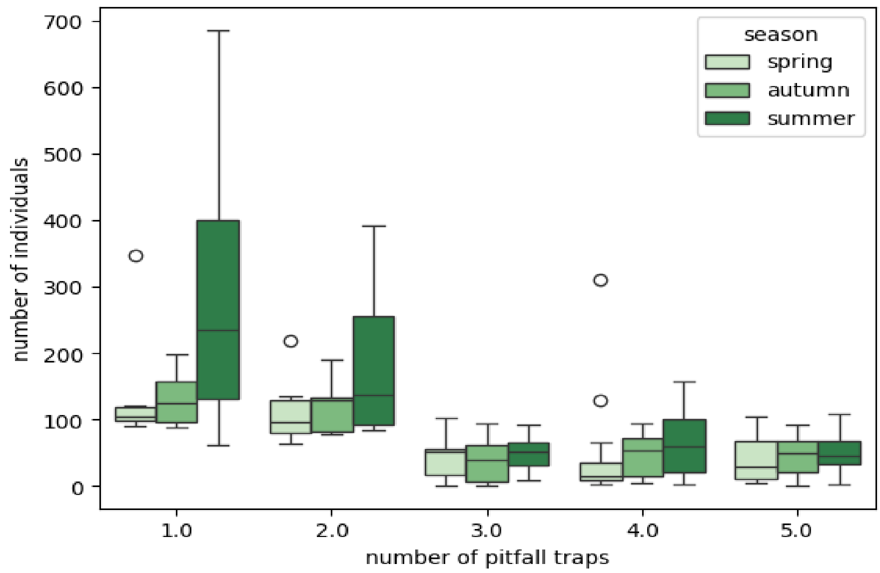

Fig. 3. Difference in the number of individuals between pitfall traps (1–5) and the season in the meadow habitat

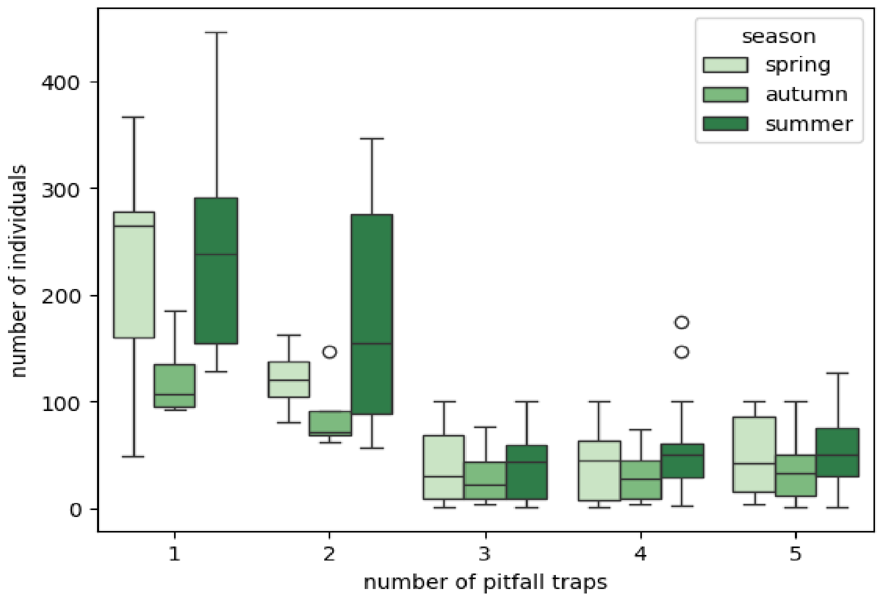

Fig. 4. Difference in the number of individuals between pitfall traps (1–5) and season in semi-intensive vineyard habitat

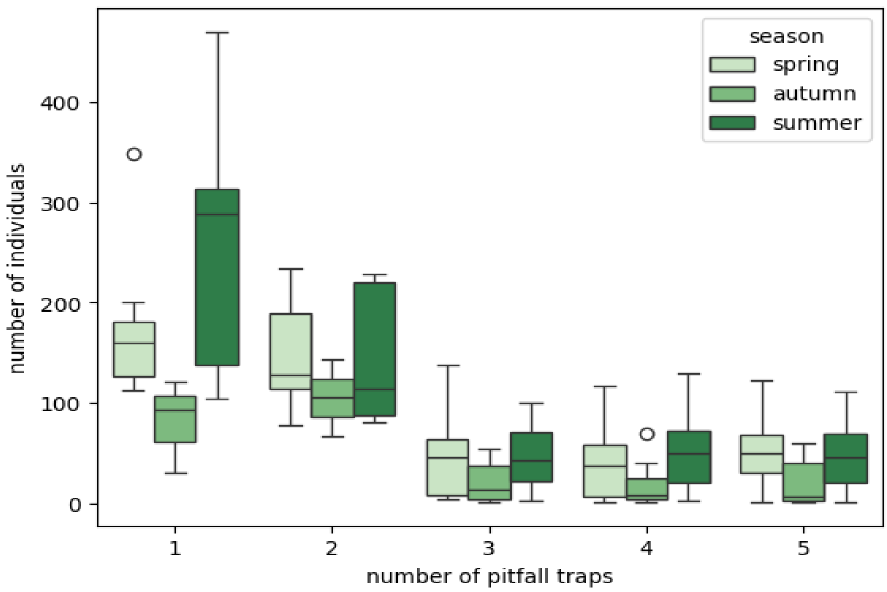

Fig. 5. Difference in the number of individuals between pitfall traps (1–5) and the season in overgrown habitat

We expressed the relationship between the number of individuals and the pitfall traps (1–5) using linear regression and subsequently predicted the development of pitfall traps 7. The highest variability of 97.6% (R^2 = 0.9662), high relationship (high dependence) between the investigated variables, was confirmed in the semi-intensive vineyard habitat, the lowest 58.4% (R^2 = 0. 5839) in the intensive vineyard habitat. We recorded a moderately strong relationship in the meadow (75.1%, R^2 = 0.7511) and overgrown habitats (69.0%, R^2 = 0.6900). We also predicted the number of individuals in pitfall traps 7, which represents 60 m from the edge of the habitat. In all habitats, we recorded a decrease in the number of individuals towards pitfall traps 7. The highest value was in the intensive habitat vineyard (1,047 individuals in pitfall traps 7, Fig. 6). The decrease in predicted values was followed by the meadow (623 individuals in pitfall traps 7, Fig. 7), semi-intensive vineyard (538 individuals in pitfall traps 7, Fig. 8) and the lowest in the overgrown habitat (463 individuals in pitfall traps 7, Fig. 9).

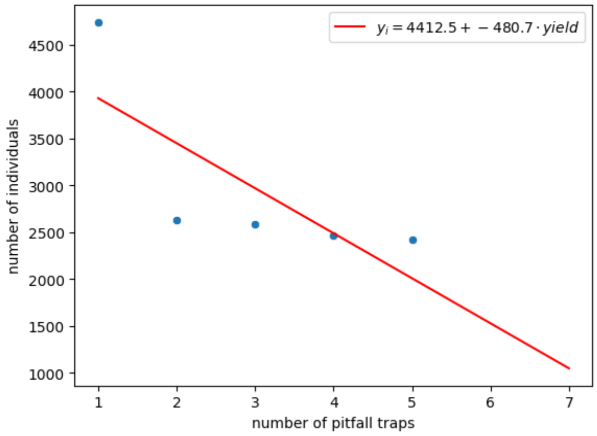

Fig. 6. Linear regression with prediction for 7 pitfall traps in the intensive vineyard habitat

Discussion

The results of our research confirm significant spatial and seasonal differences in the abundance and composition of epigeic arthropods in vineyard habitats of different management intensities, including the reference meadow habitat. The greatest number of individuals was recorded in the meadow habitat, which corresponds to previous studies indicating that natural or extensively managed habitats exhibit greater diversity and abundance of soil invertebrates compared to intensively used agroecosystems (Bengtsson et al., 2005; Batáry et al., 2010).

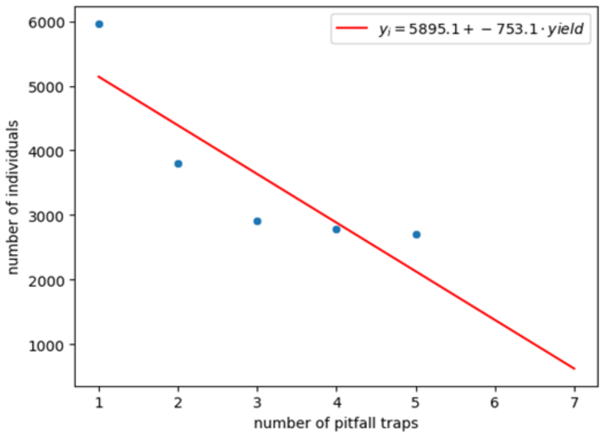

Fig. 7. Linear regression with prediction for 7 pitfall traps on meadow habitat

The strong dominance of Coleoptera and Hymenoptera taxa in all habitats, as well as the local eudominant representation of Araneae, points to the ecological plasticity of these groups and their ability to adapt to different environmental conditions. From an ecological point of view, the occurrence of predators such as Carabidae and spiders is important for the functioning of ecosystems, as these groups participate in the natural regulation of pest populations (Kromp, 1999; Symondson et al., 2002).

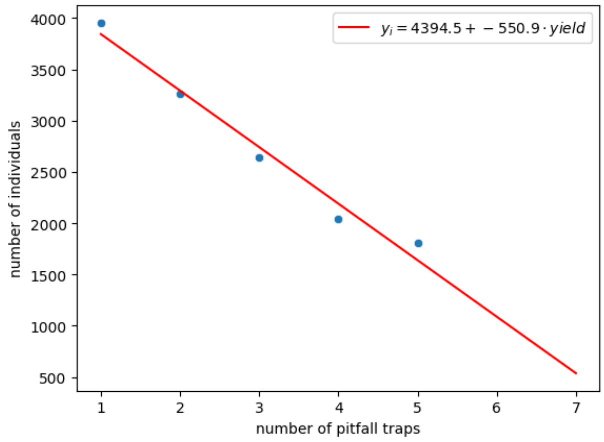

Fig. 8. Linear regression with prediction for 7 pitfall traps on semi-intensive vineyard habitas

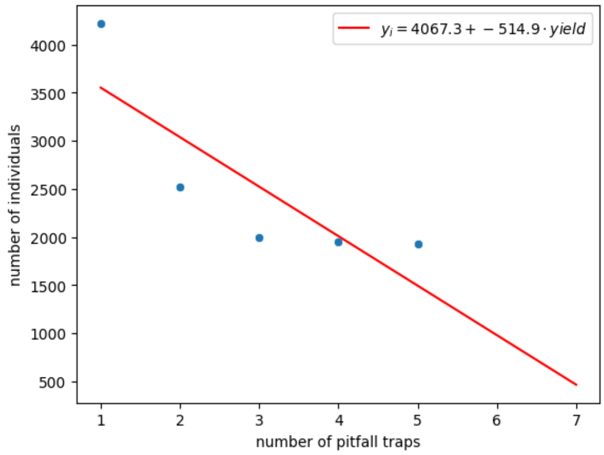

Fig. 9. Linear regression with prediction for 7 pitfall traps on overgrown vineyard habitat

In terms of spatial arrangement, the highest abundance of taxa was recorded in traps located in ecotonal zones (pitfall traps 1 and 2), while the number of taxa decreased significantly towards the interior of the habitats. This trend was repeatedly confirmed in all habitat types and corresponds to the assumptions of the so-called "edge effect", i.e., increased activity or accumulation of species in transition zones between two environments (Magura, 2002; Duelli & Obrist, 2003). Ecotones in agroecosystems often provide more stable microclimatic conditions, higher food availability, and greater structural complexity, which makes them preferred locations for many epigeic species (Torma et al., 2011).

By redundancy analysis, we confirmed the significant influence of different vineyard managements on the spatial distribution of epigeic groups, indicating a strong effect of anthropogenic management on the composition of soil communities. These findings are consistent with studies that have shown that intensity of management, including the use and mechanical cultivation, has a major impact on the biodiversity of epigeic groups in agricultural systems (Bianchi et al., 2006; Altieri & Nicholls, 2018).

In terms of seasonality, the highest number of individuals was recorded during the summer months. This phenomenon is typical for most communities of epigeic groups, which show increased activity at higher temperatures and during the period of maximum vegetation (Pétillon et al., 2007; Moreira et al., 2008). On the contrary, during spring and fall, the number of individuals was significantly lower and stabilised. This seasonal course of activity was also statistically confirmed by the Friedman test, which revealed significant differences between seasons in all habitats studied. The seasonal dynamics of communities are also influenced by the microclimate, the phenological development of vegetation, and the life cycle of specific taxa (Southwood & Henderson, 2000; Schowalter, 2016).

Linear regression analysis confirmed a strong relationship between the distance of pitfall traps from the edge of the habitat and the abundance of individuals, most significantly in the semi-intensive vineyard ($R^2 = 0.9762$). This strong correlation points to the spatial structure of epigeic taxa populations and their connection to landscape-ecological interfaces. The prediction of the number of individuals per seventh pitfall trap (60 m from the edge) showed a general downward trend, most significantly in the abandoned vineyard. These results point to the importance of protecting the marginal and less disturbed parts of vineyards as biodiversity refuges (Burel & Baudry, 2003; Tscharntke et al., 2005; Chao et al., 2014).

Epigeic arthropods represent sensitive bioindicators of the ecological quality of vineyard habitats and at the same time play an irreplaceable role in maintaining their ecological functions. Managing the spatial structure of vineyards, supporting ecotonal elements and reducing the intensity of chemical management represent effective measures to support biodiversity and ecological stability of these agroecosystems (Litavský et al., 2021; Porhajášová & Babošová, 2022; Putchkov & Brygadyrenko, 2022).

Conclusions

The research results showed that the abundance and diversity of epigeic arthropods significantly depend on the type of vineyard use, the season, and the spatial position with respect to the ecotone. There was a clear decrease in abundance from the ecotone to the interior of the habitat, with the greatest activity and occurrence of taxa concentrated near traps placed at the interface of habitats. These findings point to the high ecological value of ecotone zones, which represent key microhabitats that support biodiversity in agriculturally used landscapes. At the same time, it was confirmed that the intensity of vineyard management significantly affects the distribution and occurrence of epigeic fauna, with semi-intensive and meadow habitats creating more favourable conditions for the development of diversified communities. From a practical point of view, this knowledge represents an important tool for agroecological planning. An appropriate management measure is the preservation or restoration of ecotone structures, as well as the establishment of boundaries, flower belts, and unmowed edges of vineyards. These elements can serve as stable refugia for soil fauna, thus supporting natural pest regulation, improving soil quality, and strengthening the ecological stability of agrosystems. Integrating these measures into regular viticultural practices can significantly contribute to sustainable land use and biodiversity conservation.

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