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Vegetation succession and changes in carabid beetle (Coleoptera: Carabidae) communities in vineyards in Moravia, Czech Republic

Keywords: vineyard ecosystem, insects, succession, vegetation

Introduction

The structure of a plant community is the basis for a spatial and structural heterogeneity of a habitat. Vegetation provides diverse niches (microhabitats) offering different opportunities to animals, including insects, for acquiring food and shelter from predators (Gardiner et al., 2002; Schaffers et al., 2008; Badenhausser & Cordeau, 2015). Habitat fragmentation and destruction caused by agricultural

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intensification is one of the main drivers of arthropod decline in agroecosystems (Tscharntke et al., 2005; Bianchi et al., 2006; Landis, 2017). The loss of habitat complexity and diversity due to intensive agricultural practices results in fewer niches and less protection for arthropods, contributing to their decline.

Although vineyards belong to intensively managed agroecosystems, they still offer diverse habitats for a number of organisms (Geldenhuys et al., 2021). The mosaic of different microhabitats found in vineyards, combined with the alternation of bare soil and higher vegetation, meets the needs of different life stages of insects (Ingrisch & Köhler, 1998; Fischer et al., 2020). Different types of management can be found in the vineyards, e.g. a highly intensive inter-row management using a combination of herbicides and tillage; on the other hand, sowing of cover crops or allowing local vegetation to flourish (Winkler et al., 2017; Winter et al., 2018).

Greater microhabitat diversity leads to greater plant diversity and typically increases arthropod diversity, thereby enhancing the likelihood of introducing beneficial arthropods into the vineyard. Spontaneous vegetation, which is well adapted to local conditions, particularly supports this relationship in vineyards (Bischoff et al., 2016).

Inter-row vegetation of vineyards contributes to richness of native plant species (Beaumelle et al., 2021; Blaise et al., 2022) and increases arthropod biodiversity (Blaise et al., 2022; Rocher et al., 2022). Semi-natural habitats are very important for communities of arthropods, which are the key organisms in agroecosystems (Tscharntke et al., 2005; Saunders, 2018; Cahenzli et al., 2019). Spontaneous vegetation in vineyards increases the abundance of other insects that have the ability to engage in natural protection against pests in agroecosystems (Sáenz-Romo et al., 2019). Carabid beetles (Coleoptera: Carabidae) also increase arthropod richness in vineyards and are considered valuable contributors to integrated pest management (Rainio & Niemelä, 2003; Adamski et al., 2019). The composition and richness of vegetation are essential factors to be considered when assessing not only biodiversity, but also the sustainable development of agriculture and viticulture (Isaacs et al., 2009). The method of vineyard management is very specific and provides space for increasing the heterogeneity of the landscape. The inter-row vegetation is an integral part of the vineyard, which undergoes natural changes (successions) over time. Long-term vineyard management combined with the natural succession of vegetation changes the conditions of microhabitats.

Vegetation succession in vineyards plays a crucial role in shaping carabid beetle communities. Studies have shown that different inter-row ground cover treatments, such as bare soil, alternating, and full vegetation cover, can significantly affect carabid beetle density and species richness (Uzman et al., 2020; Porter et al., 2022).

In addition, structural heterogeneity of vegetation has been found to be a key factor influencing carabid beetle diversity, with vegetation structure explaining a significant proportion of the variation in species richness (Brose, 2003). Furthermore, the response of carabid beetles to changing conditions during succession varies, with different responses observed in diverse habitat types such as fallow and grassland (Taranto et al., 2023). Maintaining a balance between dense and sparsely vegetated elements in vineyard interrow may be optimal for supporting diverse carabid beetle communities and promoting biodiversity in vineyard ecosystems.

Despite the recognized importance of vegetation and habitat heterogeneity in supporting arthropod diversity, there is a lack of detailed understanding of how vegetation succession in vineyards of different ages influences carabid beetle communities. This study aims to fill this research gap by exploring the following questions: (i) What are the trends in carabid beetle communities in vineyards over the course of the year? (ii) How does vegetation succession affect these trends? (iii) What is the effect of vineyard age on carabid beetle biodiversity? Addressing these questions will not only improve our understanding of arthropod dynamics in vineyard ecosystems, but will also contribute to the development of sustainable viticultural practices.

Material and methods

Study area

The evaluated vineyards are located in Moravia in the Czech Republic. The area is located at the transition between Jevišovská vrchovina and Dyjskosvratecký úval. The average altitude is 280 m above sea level. The long-term air temperature is between 9°C and 10°C and the long-term precipitation is between 500 mm and 600 mm. The probability of dry seasons is 30–50%. Cambisols and Chernozems are the predominant soils (Culek, 1996; Czech Geotechnical Society, 2017, 2018). Table 1 gives an overview of the wine-growing villages, wine routes and years of establishment of the surveyed vineyards. The selected vineyards are conventionally farmed and have similar management practices. The selection of the monitored vineyards was based on several criteria. Vineyards were selected only in neighboring wine-producing villages with the same climatic and pedological conditions. Vineyards that were physically accessible and for which the year of planting was known were selected. The intention was to create a set of vineyards of different ages, with management conditions that could create different conditions for the occurrence of the carabid beetle community.

TABLE 1. General characteristics of selected vineyards

Winery village (vine lines)	GPS	Years of establishment of evaluated vineyards
Horní Dunajovice (Frédy, Stará hora)	48°56′41.153″N, 16°10′41.676″E	1995 (2 vineyards), 2000, 2002, 2009, 2016, 2018, 2020, 2021
Hostěradice (Volné pole)	48°57′17.479″N, 16°17′12.790″E	1972, 2003, 2014, 2015, 2016, 2017, 2018, 2020, 2021
Miroslav (U vinohradu, Weinperky)	48°56′37.223″N, 16°17′59.253″E	1996, 1998, 1999, 2001, 2002, 2003, 2004, 2007, 2011, 2014, 2015, 2017, 2019
Miroslavské Knínice (Stará hora, Zolos)	48°58′16.344″N, 16°19′50.606″E	2001, 2011

Source: own work.

Method of vegetation assessment

In 37 vineyards of different ages, plots were established to assess both the vegetation and carabid beetle community. These plots were located in the inter-rows of the vineyards. The vegetation in these inter-rows developed naturally through spontaneous revegetation and was managed through mulching practices. The vegetation evaluation was carried out in areas close to where the evaluation of the carabid community took place. Vegetation was assessed using phytocoenological relevés, according to the standard principles of the Zürich–Montpellier approach (Biondi, 2011). The extent of cover for each plant species was estimated and documented as a percentage of the total cover. Observations were conducted annually from 2020 to 2023, with assessments made during three separate periods each year: spring, summer, and fall. Within every vineyard, three phytocoenological relevés were captured, each covering an area of 2 × 4 m. The taxonomic naming of the plants adhered to the system outlined by Kaplan et al. (2019). The plant species identified were categorized into four groups: (i) annual dicotyledons, (ii) perennial dicotyledons, (iii) annual grasses, and (iv) perennial grasses.

Methodology of carabid beetle community assessment

Carabid beetles were captured in areas immediately adjacent to the areas of vegetation assessment. Capturing of carabid beetles was performed during the same period as the vegetation assessment in order to facilitate correlation of carabid beetle abundance with vegetation characteristics. Vegetation was removed from the area where carabid beetles were observed and captured. Subsequently, soil traps of 0.3 × 0.3 m in size and 0.3 m depth were excavated in 3 replicates. The carabid beetles were observed by direct observation of individuals for 30 min, at noon of the evaluated day and in sunny weather. Trapping was limited in time so that the abundance of beetle populations would not be affected by excessive trapping during the multi-year observation. The number of individuals occurring in the vineyard was recorded. The carabid beetles were captured and put in a bottle containing a medium impregnated with a lethal poison (ethyl acetate) in order to allow a later species identification of the collected individuals in a laboratory. Identification was performed according to Hůrka (1996).

Statistical data treatment

The data obtained on vegetation and carabid beetle populations were processed using weighted averages. The averages were calculated from 3 phytocenological relevé and 3 trap plots recorded in vineyards of the same age for 4 years of observation. The average vegetation cover and the average number of carabid beetle populations are graphically presented further in the text.

The basic data from individual observations were used for statistical processing. Data from each season (spring, summer, autumn) were analyzed separately. Multivariate analyses of ecological data were used to analyze the results of the assessment in terms of carabid abundance and coverage of different plant species groups.

The first analysis was the detrended correspondence analysis (DCA), which influences the selection of the most appropriate analysis. The result of the DCA is the length of the gradient. For the spring data, the response data were compositional and have a gradient length of 2.0 SD units, so the linear method is recommended. For the summer data, the response data are compositional and have a gradient length of 1.8 SD units, so the linear method is recommended. For the autumn data, the response data are compositional and have a gradient of 2.1 SD units in length, so the linear method is recommended.

A redundancy analysis was chosen based on the recommendations of the Canoco 5.0 software and the methodological approach. Computed axes 4, detrending none, hybrid analysis not performed, response data (species) transformation log (log transformation formula: $Y' = 1 \times Y + 1$), center and standardize by species yes. Statistical significance was assessed using the Monte Carlo test with 999 permutations. All multivariate analyses and necessary calculations were performed using Canoco 5.0 software (ter Braak & Šmilauer, 2012).

Results and discussion

The vegetation in the monitored vineyards consisted of 48 species of annual dicotyledons, 63 species of perennial dicotyledons, 9 species of annual grasses, and 10 species of perennial grasses.

The average coverage of plant groups in the vineyards is illustrated in Figure 1. Among the annual dicot taxa with dominant representation were *Amaranthus retroflexus*, *Geranium pusillum*, *Stellaria media*, *Chenopodium album*, and *Conyza canadensis*. Perennial dicot plant taxa with dominant presence included *Convolvulus arvensis*, *Trifolium repens*, *Achillea millefolium*, *Trifolium pratense*, *Cirsium arvense* and *Plantago lanceolata*. Annual grass taxa with dominant presence included *Hordeum murinum*, *Setaria pumila*, *S. viridis*, and

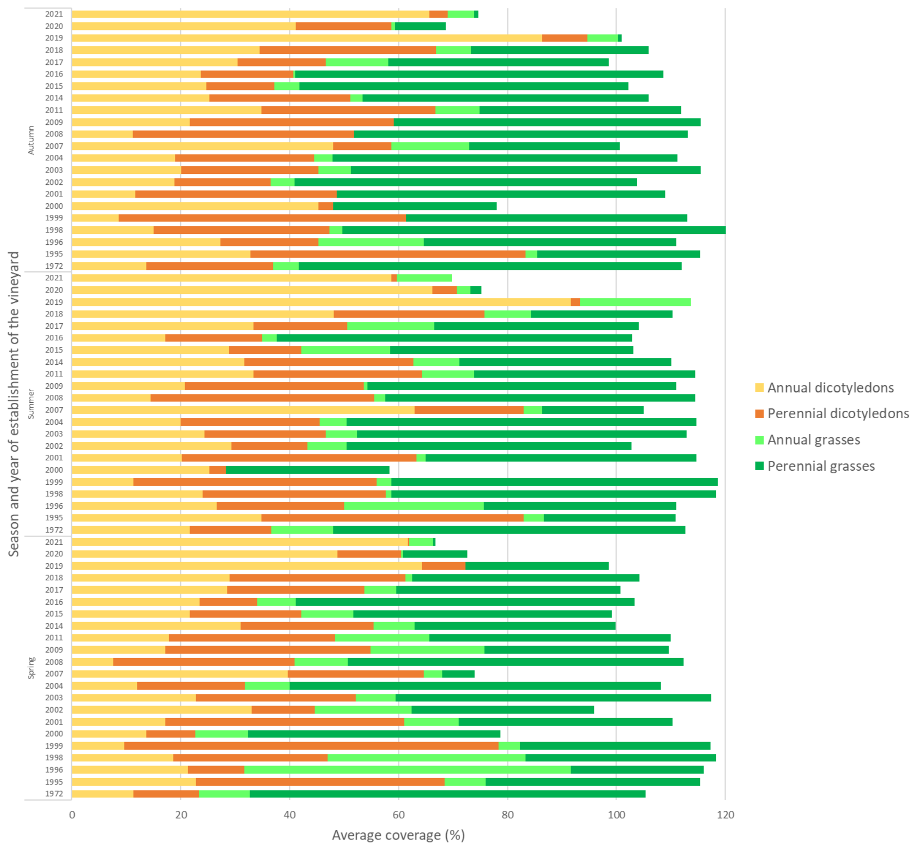


FIGURE 1. Representation of plant groups in monitored seasons in vineyards of different
Source: own work.

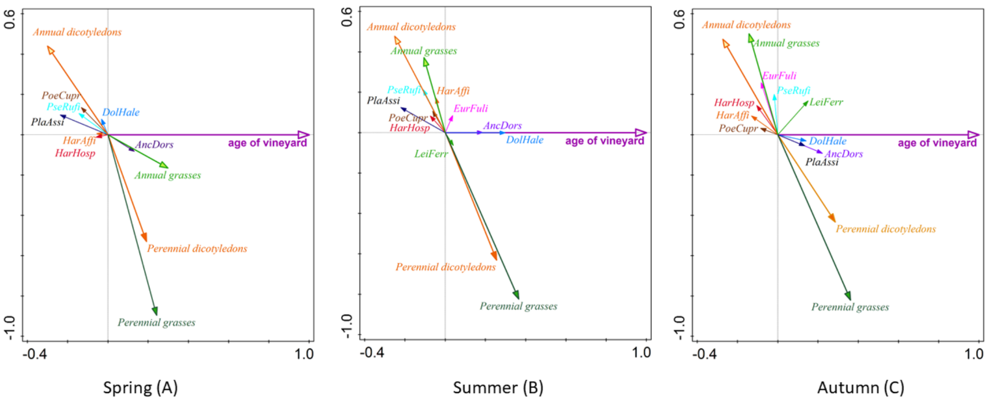
Echinochloa crus-galli. Perennial grass taxa with a dominant presence included *Lolium perenne*, *L. multiflorum*, and *Festuca rubra*.

In the monitored vineyards, 9 species of carabid beetles were captured during the observation; the total number of captured individuals is given in brackets, namely, namely *Anchomenus dorsalis* (172 individuals), *Dolichus halensis* (212 individuals), *Europhilus fuliginosus* (256 individuals), *Harpalus affinis* (132 individuals), *H. hospes* (264 individuals), *Leistus ferrugineus* (12 individuals), *Platynus assimilis* (300 individuals), *Poecilus cupreus* (440 individuals), and *Pseudoophonus rufipes* (972 individuals). The average number of captured carabid beetles is demonstrated in Figure 2.

FIGURE 2. Carabid beetle community in monitored seasons in vineyards of different ages

Source: own work.

The influence of the age of the vineyards on the coverage of plant groups and on the number of carabid beetles was statistically significant in all three monitored seasons. The results of data processing by RDA analysis are shown in Figure 3.



AncDors – Anchomenus dorsalis, *DolHale – Dolichus halensis*, *EurFuli – Europhilus fuliginosus*, *HarAffi – Harpalus affinis*, *HarHosp – Harpalus hospes*, *LeiFerr – Leistus ferrugineus*, *PlaAssi – Platynus assimilis*, *PoeCupr – Poecilus cupreus*, *PseRufi – Pseudoophonus rufipes*.

FIGURE 3. Relationship between vineyard age, plant groups and carabid beetle community for period of spring (A), summer (B), autumn (C), (result RDA; Fig. A: total explained variability = 6.3%, F-ratio = 8.7, P-value = 0.001; Fig. B: total explained variability = 7.1%, F-ratio = 9.9, P-value = 0.001; Fig. C: total explained variability = 7.4%; F-ratio = 10.3, P-value = 0.001)

Source: own work.

In the spring season, the younger vineyards create more favorable conditions for annual dicotyledons plant taxa. Higher numbers of the following carabid beetle species were recorded: *Dolichus halensis*, *Europhilus fuliginosus*, *Harpalus affinis*, *H. hospes*, *Leistus ferrugineus*, *Platynus assimilis*, *Poecilus cupreus*, and *Pseudoophonus rufipes*. Older vineyards provide more favorable conditions during the spring season for annual grasses, perennial dicotyledons, perennial grasses, and for carabid beetles of the species *Anchomenus dorsalis*.

In summer season, younger vineyards create more favorable conditions for the following plant taxa: annual dicotyledons and annual grasses. A higher number of the following carabid beetle species was recorded: *Europhilus fuliginosus*, *Harpalus affinis*, *H. hospes*, *Leistus ferrugineus*, *Platynus assimilis*, *Poecilus cupreus*, and *Pseudoophonus rufipes*. Older vineyards offer more favorable conditions during the summer season for perennial dicotyledons, perennial grasses, and for a higher number of carabid beetles of the species *Anchomenus dorsalis*, *Dolichus halensis*, and *Leistus ferrugineus.*

In autumn, younger vineyards create more favorable conditions for the following plant taxa: annual dicotyledons and annual grasses. A higher number of carabid beetles of the following species was recorded: *Europhilus fuliginosus*, *Harpalus affinis*, *H. hospes*, *Leistus ferrugineus*, *Poecilus cupreus*, *Pseudoophonus rufipes.* In autumn, older vineyards provide more favorable conditions for the plant groups: perennial dicotyledons, perennial grasses, and for carabid beetles of the species *Anchomenus dorsalis*, *Dolichus halensis*, *Leistus ferrugineus*, and *Platynus assimilis.*

The biodiversity of carabid beetles is mainly supported by the presence of spontaneous vegetation in the vineyards. Additionally, carabid beetles are affected by the management applied in the vineyard, which alters the ecosystem services provided by carabid beetles (Porter et al., 2022). Changes in inter-row vegetation in vineyards can negatively affect the biodiversity and the number of invertebrate insect species (Ragasová et al., 2021). According to our results, it is evident that carabid beetle communities change seasonally. The composition of the vegetation changes with the age of the vineyards. During the aging of vineyards, representatives of perennial dicotyledons and perennial grasses groups increase and representatives of the annual dicotyledons group decrease. Members of the annual grasses group change markedly during the seasons. In spring, they have a higher coverage in older vineyards, while in summer and autumn, they reach higher coverage in younger vineyards. The species composition of the vegetation corresponds to the grassed inter-row vegetation in the observed region, which occurs in vineyards (Ragasová et al., 2021) and in orchards (Winkler et al., 2023).

A higher quantity of carabid beetles was recorded in summer and autumn, which might be attributed to a higher food supply and a sufficiency of microhabitats enabling wintering. The age of the vineyards also affected the community of carabid beetles – the species *Anchomenus dorsalis* was more common in older vineyards during the monitored seasons. The species *Dolichus halensis*, *Leistus ferrugineus*, and *Platynus assimilis* were recorded with a higher frequency in summer and autumn in older vineyards. The other species preferred younger vineyards. Vegetation does not form a continuous cover in younger vineyards, therefore it creates habitats favorable for a number of carabid beetle species (Kromp, 1999; Holland, 2002; Kotze et al., 2011).

Gradual changes in the composition of the vegetation combined with the age of the vineyards can also impact the carabid beetles. Older vineyards were dominated by grasses, which may be the cause of a smaller food supply for carabid beetles. Grasses are less attractive for a number of arthropods (Del-Claro et al., 2016), which may be reflected in a decrease in abundance and species diversity of carabid beetles, as noticeable from our results.

Taxa from the annual dicotyledons group had a higher share in the vegetation of young vineyards. These plants produce large amounts of biomass, which die relatively quickly due to dry and warm weather. The biomass of these plants serves as a food source for a number of organisms. Gaigher and Samways (2010) found that biomass creates structural diversity in vineyards and supports different arthropod species. As our results show, thanks to the higher presence of arthropods, the food supply offer for predatory carabid beetles increased and a higher frequency of carabid beetles was recorded mainly in summer and autumn. The total number of beetles captured is relatively low in our observation, which is a consequence of our method and particularly of the short period of time during which the beetles were captured. The sample of beetles caught had only a limited influence on their occurrence in subsequent years. Despite the low number of beetles caught, our results show trends that characterize changes in the beetle population in vineyards of different ages.

According to Porter et al. (2022), seasonal changes in carabid beetle community composition are affected by applied inter-row management in vineyards. The timing of management operations should take into account the carabid beetle community dynamics to minimize harm caused to their communities. Predatory carabid beetles reduce the occurrence of a number of agricultural pests (Rainio & Niemelä, 2003; Adamski et al., 2019). The species of the *Harpalus* genus contribute to the predation of weed seeds, thereby reducing unwanted vegetation in vineyards (Rusch et al., 2015; De Heij & Willenborg, 2020). Protection of carabid beetle communities in the form of limited vineyard management creates synergies for wine production and reduced pesticide applications.

Conclusions

The succession of vineyards induces a dynamic transformation of the ecosystem, which is manifested by a change in the species composition of the vegetation and the carabid beetle community. The composition and changes in the vegetation of the vineyards provoke a response in the community of carabid beetles that use the vineyards as their habitat:

– The community of carabid beetles in vineyards changes with the season. Carabid beetles find more favorable conditions in young vineyards during summer and autumn.

– This is mainly due to the biomass growth of the annual dicotyledons plant group in summer and fall. The biomass of living and dead vegetation increases the food supply for carabid beetles, and thus their abundance and the attractiveness of vineyards.
– The proportion of perennial grasses, which are not so attractive to carabid beetles, increases with the aging of vineyards.
– The study of vineyard biodiversity must take into account the temporal dynamics of changes in vegetation and carabid beetle communities.
– The age of vineyards affects the representation of certain plant and animal species.

The vineyard ecosystem changes dynamically over time, both during the changing seasons and over a longer time span. When assessing the carabid beetles community in vineyards, it is essential to consider the dynamics of development and to understand the changes in the biodiversity of vineyard ecosystems over time.

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Summary

Vegetation succession and changes in carabid beetle (Coleoptera: Carabidae) communities in vineyards in Moravia, Czech Republic. Vineyards provide space for microhabitats and require a very specific way of management. Vineyard vegetation undergoes succession over time, which affects insect communities. The selected vineyards are located in Moravia in the Czech Republic. The vegetation of the vineyards consisted of 48 species of annual dicotyledons, 63 species of perennial dicotyledons, 9 species of annual grasses, and 10 species of perennial grasses. During the observation, 9 species of carabid beetles were recorded in the monitored

vineyards. The composition of the vegetation in the vineyards changes with the age of the vineyard. Over time, representatives of the perennial dicotyledons, perennial grasses groups increase and representatives of the group annual dicotyledons decrease. The age of the vineyards also changed the carabid beetle community – the *Anchomenus dorsalis* species was more common in older vineyards. The *Dolichus halensis*, *Leistus ferrugineus* and *Platynus assimilis* species were more frequently recorded in summer and fall in older vineyards. The other species preferred younger vineyards. A higher abundance was recorded in summer and fall, which may be due to a higher food supply and sufficient amount of microhabitats for hibernation.