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ORIGINAL RESEARCH PAPER

Grassland communities of traditional orchards in the Western Carpathians (Slovakia)

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Abstract

Traditional orchards are a valuable feature of the rural landscape and they are specific for regions with scattered settlement such as the Myjava hilly land and White Carpathians. Here, the permanent species-rich grasslands beneath trees were regularly managed in the traditional manner until some were replaced in the 1970's and 80's by intensively managed orchards, some of which were abandoned in the early 1990's. Our 2011–2015 phytosociological research followed the standard Braun-Blanquet approach. We classified 178 phytosociological relevés recorded in orchard meadows (156 relevés), former intensively managed orchards (16 relevés), and two relevés from a semi-intensively grazed orchard. Traditionally managed orchard meadows were classified in the following five units: (***i***) *Pastinaco sativae-Arrhenatheretum elatioris* – thermophilous variant, (***ii***) *Pastinaco sativae-Arrhenatheretum elatioris* – transitional variant to *Alchemillo-Arrhenatheretum elatioris*, (***iii***) *Ranunculo bulbosi-Arrhenatheretum elatioris*, (***iv***) *Onobrychido viciifoliae-Brometum erecti*, and (***v***) *Brachypodio pinnati-Molinietum arundinaceae*. Formerly intensively managed large-scale orchards were classified as *Pastinaco sativae-Arrhenatheretum elatioris* association and the semi-intensively grazed orchard as *Lolio perennis-Cynosuretum cristati* association. The species composition varies considerably due to tree-shading and different management treatments applied in the orchards, so the relevés of the delimited syntaxonomic units are not typical and have transitional character. Moisture, soil nutrients, and soil reaction were identified as the main environmental gradients influencing species composition. We tested four management treatments in direct gradient analysis and found that abandonment has the strongest effect on species composition. Comparison of grassland vegetation in the studied traditional orchards with that described in Germany reveals differences in species composition. Moreover, species richness of the compared *Arrhenatherion elatioris* and *Bromion erecti* alliances in Slovakian orchard meadows was higher than in the German orchards.

Keywords

orchard meadows; vegetation; scattered settlements; management; syntaxonomy; diversity; Myjava hilly land; White Carpathians

Introduction

Traditional old orchards are one of the most valuable and endangered habitats of the European cultural landscape [1]. The fruit tree and grassland undergrowth subsystems combine conditions of both forest and non-forest habitats and they are known for their high biodiversity [2–5]. They are important in maintaining old local fruit tree varieties

[6]. The grassland undergrowth protects the soil against erosion and positively affects its physical and chemical properties [7–9]. This provides an excellent example of traditional European agroforestry systems as well as olive orchards, wood pastures, *dehesa* and *montado* (cf. [10]), which were and are still used in Europe [11]. Nowadays, their importance is increasing in order to maintain biodiversity in the cultural landscape [10]. Orchard meadows form part of the landscape in most countries in Western, Central, and Eastern Europe. Although traditional orchards are often under-utilized compared to the past, they still thrive in Germany, Spain, France, England, Poland, Czech Republic, Slovenia, and Ukraine [6,12,13]. These persist despite the dramatic loss of traditional orchard meadow area during the second half of the twentieth century recorded in southwestern, southern, and eastern Germany [13–15], Switzerland [6], Austria [16,17], France [18], and Slovenia [19,20]. Here in Slovakia, Špulerová et al. [21] report that 70.25% of traditional orchard landscape is threatened by abandonment of traditional farming and this has now become one of the greatest threats to traditional orchards. Biodiversity in the European agricultural landscape has also been severely affected by agricultural intensification with ensuing landscape simplification and biodiversity loss [22–24]. Agricultural collectivization also played an essential role in former socialist countries, where small fields were merged into large blocks under uniform management. This had negative impact on orchards in the study area [1,25] where part of traditional orchards disappeared and some intensively managed large-scale apple and plum orchards were established in the 1970's. The fall of socialism in Eastern and Central Europe then caused decreased management intensity, and even its cessation in some areas [26].

The Slovak orchard meadows have a specific type of land use typical for regions with scattered settlement called "kopanice", which are present throughout the Myjava hilly land and White Carpathians. This settlement type expanded from the second half of the sixteenth century in poorly accessible forested areas [27]. While the main function of traditional orchards was fruit production in the past, today it is their nature that is highly valued rather than economic importance because they serve as biodiversity hotspots and contribute significantly to cultural landscape diversity [12,28]. The small-scale orchards with 0.5-hectare average area produced mostly plums and apples with fewer pears, cherries, common walnuts, and rarely, even true service trees. The undergrowth was used for grazing and producing hay and some orchards were used to grow vegetables and grain. Traditional management usually included biannual mowing and 1–3 head of cattle, sheep, or goat grazing per orchard. Tree litter was removed annually, usually in spring, and although orchards were fertilized with manure and slurry, chemical spraying of trees was rare [29].

The frequency and intensity of traditional orchard management has decreased in Slovakia over the last 25 years [21,29] as in other European countries [6,12,30]. This trend threatens not only their functions but their very existence. Management of intensive orchards has also changed in the study area, and while most have been gradually abandoned following the 1989 sociopolitical changes, some are still in use. Because grassland diversity depends on long-term regular management [31–33], it is therefore necessary to maintain orchard meadow biological values by ensuring traditional management continuity and traditional ecological knowledge. This entails combining elements of theoretical knowledge and the practical experience and beliefs [34] which are eroding today. Maintaining traditional ecological knowledge is obligatory to protect countryside landscape effectively [35]. The study of orchard meadow plant communities helps us understand the impact of various management regimes on their species composition.

While phytosociological research of orchard meadows in Europe was mainly performed in Germany [36–39], some information on the occurrence of this habitat is also reported from other Central European countries [6,10–12] but phytosociological data is lacking or poorly accessible. In Slovakia, floristic and vegetation research of orchard meadows has only been partly carried out and historical data is relatively missing. The most important papers focused directly on the study area orchard meadows were published by Ružičková [40] (50 relevés) and Labuda and Žarnovičan [1] (13 relevés). The detailed research of subxerophilous and mesophilous grasslands of the White Carpathians dealt partly with orchard meadows [41], but these were classified together with other grassland vegetation types. However, additional phytosociological orchard meadow research outside our study area has been conducted in the vicinity of Banská Štiavnica (19 relevés) [42] and Nová Baňa (22 relevés) towns [43].

This study contributes to the complex phytosociological characteristic of the contemporary state of orchard meadow vegetation in the western part of the Western Carpathians, including the Myjava hilly land region and the White Carpathians.
The main aims of our research were:

- syntaxonomic classification of orchard vegetation of scattered settlement region in the Myjava hilly land and the southern part of the White Carpathians;
- analysis of the main gradients in species composition;
- evaluation of the effects of management treatments on species composition in the grasslands;
- comparison of the studied orchard vegetation with that present in other regions.

Material and methods

Study area

The study area is located in western Slovakia in two geomorphological units – Myjava hilly land and White Carpathians (Fig. 1). The area is approximately 58 200 ha, with three bedrock types; the northern part is flysch [44], the central area is the klippen belt with typical combined flysch and limestone, and the eastern and western parts lie on Quaternary sediments [45]. The soils are mainly Eutric and Stagnic Cambisols, and more rarely Albic Stagnic Luvisol [46: p. 24], and the climate is classified moderately warm with mild winters and average July temperature of ≥16°C [47]. The altitude ranges from 196 to 970 m and annual precipitation is from 600 to 800 mm [48]. The prevailing potential natural vegetation in the studied area is oak-hornbeam forests (*Carpinion betuli*), which occupy large areas at middle altitudes [49]. Beech forests of *Fagion sylvaticae* are the climax community at altitudes above 500 m a.s.l., fir-beech forests are present at high altitude in the northern part of the territory and oak forests with dominant *Quercus petraea* agg. and admixed *Quercus cerris* (*Quercion confertae-cerris*) are present in the southern part of the territory. Mesophilous oat-grass meadows of *Arrhenatherion elatioris* alliance prevail in Myjava hilly land. The most widespread vegetation type is *Pastinaco sativae-Arrhenetheretum* association and *Ranunculo bulbosi-Arrhenathertum elatioris* association found on the warmer slopes. Grasslands here contain thermophilous species, including *Festuca rupicola*, *Ranunculus bulbosus*,

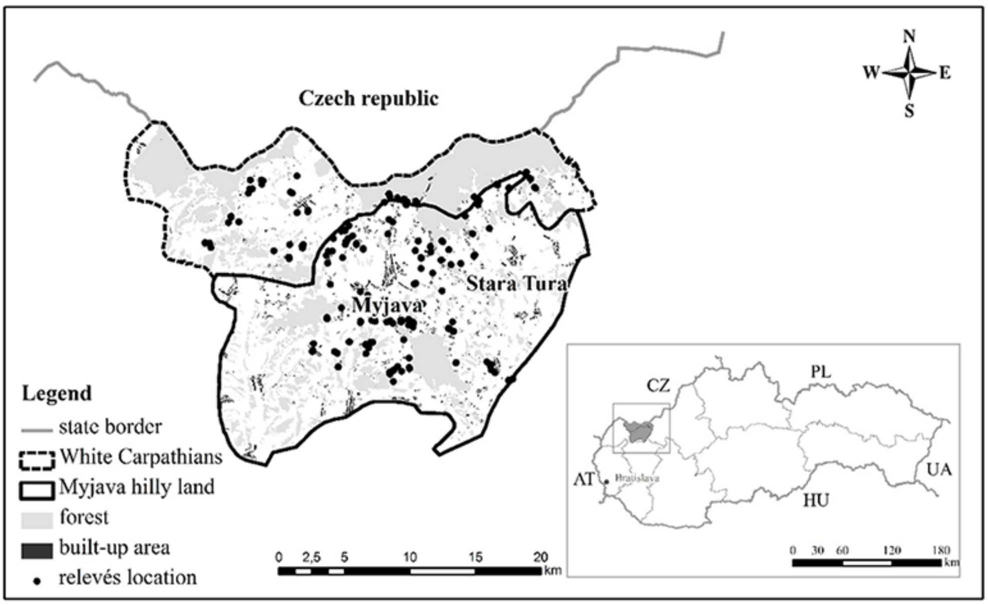

Fig. 1 Distribution of phytosociological relevés in the study area.

Salvia pratensis, and *Plantago media*, which indicate transition to *Bromion erecti* alliance. In addition, on the slopes of the White Carpathians the following grasslands are common: *Brachypodio pinnati-Molinietum arundinaceae* association with *Carex montana*, *Onobrychido viciifoliae-Brometum erecti* association with dominating *Bromus erectus*, *Anthoxantho-Agrostietum tenuis* association that occurs on neutral soils, and *Campanulo rotundifoliae-Dianthetum deltoidis* association found on nutrient poor and acidic soils [40,41].

Data collection and analysis

Phytosociological relevés were sampled during the 2011–2015 vegetation seasons, with research based on the classical Zürich–Montpellier geobotanical school [50]. Some relevés were used in diploma theses of Sivecká [51], Tichá [52], Fašungová [53], and Kršiaková [54]. Mosses were not collected, and only the layer cover was recorded. The area of relevés was set at 25 m^2. The relevés were stored in the TURBOVEG database [55] and analyzed by Juice software [56]. The initial dataset contained 183 relevés.

Optimclass analysis [57] was used to select the optimal numerical classification method. Beta-flexible method ($\beta = -0.25$), Jaccard coefficient, and square-root data transformation were used for classification of all dataset. Ordination analysis was used to identify outliers in the dataset. Numerical classification clearly separated the relevés from abandoned, formerly intensively managed large-scale orchards (16 relevés), semi-intensively grazed large-scale orchard (two relevés), abandoned, successionally changed orchard meadows (four relevés), and also the outliers (five relevés). The remaining dataset (156 relevés from traditional orchards) was then analyzed separately using the same method for more detailed classification. Numerical classification divided the dataset into five clusters. The diagnostic species of all delimited communities (five clusters of traditional orchards, one cluster of abandoned intensively managed orchards, and one cluster of grazed orchard) were defined based on the table containing 174 relevés (without five outliers and four relevés from abandoned, successionally changed orchard meadows). We calculated the phi coefficient [58,59]. The number of relevés in all clusters was standardized to equal size, with each target group size set at 12.5% of the total dataset [60]. Species simultaneously showing phi ≥0.20 and significant concentration in a particular cluster at $p < 0.05$ by Fisher's exact test were accepted as diagnostic. Delimited diagnostic species were compared to diagnostic syntaxa species in a revised review of grassland vegetation [61] and synanthropic vegetation of Slovakia [62]. The final classification of delimited vegetation types to syntaxonomic units was based on combining the following methods: expert system [61,63], numerical classification, gradient analysis, and comparison of species composition with the diagnostic species of grassland vegetation units delimited in Slovakia.

The main species composition gradients were analyzed by correspondence analysis (CA) in CANOCO 5 [64]. The unimodal method of correspondence analysis comprising the square-root transformation of cover data and downweighting of rare species was chosen because gradient length was 3.2 for the first axis. For ecological interpretation of the ordination axes, we plotted the mean unweighted Ellenberg ecological indicator values (EIV) [65] for the relevés on the CA ordination diagram as supplementary environmental data. Ecological indicator values for the delimited communities and altitude were then compared on box-and-whisker plots. Significant differences in Ellenberg indicator values and altitude among vegetation types were tested by ANOVA and Fisher LSD test ($p < 0.01$) in Statistica software [66]. Clusters with less than nine relevés were not included in the comparison.

The relationships between species composition and management treatments were analyzed by canonical correspondence analysis (CCA). As in the previous analysis, the species cover values were square-root-transformed and rare species downweighted. The effect of management treatments was tested using a Monte Carlo permutation test with 999 unrestricted permutations.

A structured interview [67] with farmers provided information on management regime for the 143 relevés. This included mowing, grazing, mulching, and abandonment as well as the intensity applied between 2004 and 2013. Regime intensity was determined according to the following scales (***i***) mowing: 0 – no mowing, 1 – mowing once a year, 2 – mowing twice a year; (***ii***) grazing: 0 – no grazing, 1 – grazing in the last 5 years, 2 – grazing longer than last 5 years; (***iii***) mulching: 0 – no mulching, 1 – mulching in the last 5 years, 2 – mulching longer than last 5 years, and (***iv***) degree of abandonment: 0 – no abandonment, 1 – abandoned for the last 1–5 years, 2 – abandoned longer than the last 5 years.

The synoptic tables of accessible phytosociological data from orchards in various regions of Slovakia and the southern Hessen region of Germany were used to compare the floristic composition of communities in the *Arrhenatherion elatioris* and *Bromion erecti* alliances. In these tables, we highlighted taxa differentiating compared clusters of vegetation units from various regions by either unique occurrence or markedly higher frequency, and only species with over 30% frequency in at least one cluster were included in the table. Syntaxa nomenclature follows Jarolímek and Šibík [68] and vascular plants nomenclature accords with Marhold and Hindák [69] with the exception of the following aggregate species: *Achillea millefolium* agg., *Alchemilla* spec. div., *Carex muricata* agg., *Festuca pratensis* agg., *Festuca rubra* agg., *Galium mollugo* agg., *Lotus corniculatus* agg., *Luzula campestris* agg., *Pimpinella saxifraga* agg., *Poa pratensis* agg., *Ranunculus auricomus* agg., *Rosa canina* agg., *Rubus* subgen. *Rubus*, and *Taraxacum* sect. *Ruderalia*.

Results

Syntaxonomic classification of the distinguished communities

Class: *Molinio-Arrhenatheretea* R. Tx. 1937
  Order: *Arrhenatheretalia* R. Tx. 1931
    Alliance: *Arrhenatherion elatioris* Koch 1926
      Association: *Pastinaco sativae-Arrhenatheretum elatioris* Passarge 1964 thermophilous variant (Tab. S1, relevés 1–45)
      Association: *Pastinaco sativae-Arrhenatheretum elatioris* Passarge 1964 transitional variant to *Alchemillo-Arrhenatheretum elatioris* (Tab. S1, relevés 46–92)
      Association: *Pastinaco sativae-Arrhenatheretum elatioris* Passarge 1964 ruderalised variant (abandoned, formerly intensively managed large-scale orchards) (Tab. S4, relevés 157–172)
      Associaction: *Ranunculo bulbosi-Arrhenatheretum elatioris* Ellmauer in Ellmauer et Mucina 1993 (Tab. S2, relevés 93–136)
    Alliance: *Cynosurion cristati* R. Tx. 1947
      Association: *Lolio perennis-Cynosuretum cristati* R. Tx. 1937 (Tab. S5, relevés 173, 174)
Class: *Festuco-Brometea* Br.-Bl. et R. Tx. ex Soó 1947
  Order: *Brometalia erecti* Koch 1926 em. Br.-Bl. 1936
    Alliance: *Bromion erecti* Koch 1926
      Association: *Onobrychido viciifoliae-Brometum erecti* Th. Müller 1966 (Tab. S3, relevés 137–147)
      Association: *Brachypodio pinnati-Molinietum arundinaceae* Klika 1939 (Tab. S3, relevés 148–156)

We classified a total of 178 phytosociological relevés from orchard meadows, former intensively managed orchards and one semi-intensively grazed orchard. Within Cluster 1 (45 relevés), expert system (ES) identified 11 relevés as *Pastinaco sativae-Arrhenatheretum elatioris* and seven relevés as *Alchemillo-Arrhenatheretum elatioris*; within Cluster 2 (47 relevés) ES identified 15 relevés as *Pastinaco sativae-Arrhenatheretum elatioris* and two relevés as *Alchemillo-Arrhenatheretum elatioris*; within Cluster 3 (44 relevés) ES identified two relevés as *Onobrychido viciifoliae-Brometum erecti*, two relevés as *Pastinaco sativae-Arrhenatheretum elatioris*, and one relevé as *Alchemillo-Arrhenatheretum elatioris*; within Cluster 4 (11 relevés) ES identified two relevés as *Onobrychido viciifoliae-Brometum erecti* and one relevé as *Alchemillo-Arrhenatheretum elatioris*; within Cluster 5 (nine relevés) ES identified two relevés as *Brachypodio pinnati-Molinietum* *arundinaceae*, and within Cluster 6 (16 relevés) ES identified four relevés as *Pastinaco sativae-Arrhenatheretum elatioris*.

However, the ES success-rate was very low, with only 28% of the dataset classified to associations, and therefore comparison of diagnostic species with revised review of the grassland vegetation of Slovakia was used in the final assignment of delimited vegetation types to syntaxonomic units [61].

Phytosociological and ecological characteristics of orchard vegetation

Pastinaco sativae-Arrhenatheretum elatioris (Tab. S1, relevés 1–92). This is the most widespread community in the study area, usually with three-layered stands. The physiognomy is determined by tall grasses such as *Arrhenatherum elatius* and *Dactylis glomerata*. The middle layer is also dominated by grasses, including *Trisetum flavescens*, *Anthoxanthum odoratum*, and *Poa pratensis* agg., but with a higher frequency and cover of the following rosette herbs typical in mesophilous meadows: *Crepis biennis*, *Leontodon hispidus*, *Campanula patula*, and *Taraxacum* sect. *Ruderalia*. Higher soil nutrient content is also indicated by the presence of *Trifolium pratense* and *Trifolium repens*. The herb layer cover ranged from 90% to 100%. This community prefers deep Eutric Cambisol on slopes with average 7° inclination and northwest to northeast exposure. It is mostly distributed in the Myjava hilly land, but also merges with thermophilous vegetation of the *Bromion erecti* alliance on the southern slopes.

Thermophilous variant (relevés 1–45). In addition to the constant presence of *Arrhenatherion elatioris* alliance species, this variant includes light-demanding and thermophilous species such as *Briza media*, *Jacea pratensis*, *Luzula campestris* agg., *Cynosurus cristatus*, and *Plantago media*. An average 48 species per relevé was recorded for this species-rich vegetation.

Transitional variant to *Alchemillo-Arrhenatheretum elatioris* (relevés 46–92). In contrast to the thermophilous variant, this is species-poor with average 41 species per relevé. Less heliophilous species are present and the higher constancy and abundance of *Anthriscus sylvestris* and *Pastinaca sativa* indicate nutrient-richer soils.

Ranunculo bulbosi-Arrhenatheretum elatioris (Tab. S2, relevés 93–136). This community of thermo- and xerophilous false oat-grass meadows prefers sunny, moderately inclined slopes where it replaces previous vegetation types. The top layer of *Arrhenatherum elatius* and *Dactylis glomerata* grasses are accompanied, and occasionally dominated by *Bromus erectus*. The middle layer is rich in grasses with a prevalence of *Festuca rubra* agg., *Trisetum flavescens*, and *Briza media* and herbs are also abundant. Species preferring neutral or calcareous soils, such as *Campanula glomerata*, *Tragopogon orientalis*, *Primula veris*, and *Salvia pratensis* accompany the mesophilous species of *Arrhenatherion elatioris* alliance. This is the most species-rich false oat-grass meadow in the study area, with average 54 species per relevé and 95% herb layer cover.

Onobrychido viciifoliae-Brometum erecti (Tab. S3, relevés 137–147). This association includes species-rich thermophilous meadows dominated by *Bromus erectus* and co-dominated by *Avenula pubescens*, *Arrhenatherum elatius*, and *Dactylis glomerata* grasses. Smaller grasses, including *Anthoxanthum odoratum*, *Poa pratensis* agg., and *Festuca rubra* agg., are constant but less abundant. The average number of recorded species in one relevé is 58, and together with *Brachypodio pinnati-Molinietum arundinaceae* association it is one of the most species-rich orchard meadow communities in the study area. Some dicotyledonous herbs commonly accompany the grasses; especially those typical in semidry meadows such as *Pimpinella saxifraga* agg., *Viola hirta*, *Medicago lupulina*, *Plantago media*, *Fragaria viridis*, and *Galium verum*. Species such as *Filipendula vulgaris*, *Potentilla heptaphylla*, and *Primula veris* indicate higher soil reaction. There is gradual transition to *Ranunculo bulbosi-Arrhenatheretum elatioris* association, differentiated by less constancy of *Bromus erectus* and thermophilous herbs such as *Filipendula vulgaris*, *Avenula pubescens*, *Ajuga genevensis*, and *Ornithogalum kochii*. The 88% herb layer cover is lower than the average found in other orchard meadow communities. This vegetation is widespread in the northern part of the study area; situated on 10° southeastern and southwestern slopes of the White Carpathians.

Brachypodio pinnati-Molinietum arundinaceae (Tab. S3, relevés 148–156). This community includes bilayered species-rich thermophilous stands of grasses and dicotyledonous herbs. The upper layer is dominated by *Bromus erectus* and *Brachypodium pinnatum*, with *Arrhenatherum elatius* and *Dactylis glomerata* also often abundant. Late spring aspect is determined by *Cirsium pannonicum*. The lower layer is species-rich and it is formed mostly by thermophilous species which prefer neutral and calcareous soils, such as *Trifolium montanum*, *Filipendula vulgaris*, *Primula veris*, and *Salvia pratensis*. The presence of *Betonica officinalis* and *Potentilla alba* indicates intermittently wet soils typical in flysch bedrock [70]. This community merges with stands of *Onobrychido viciifoliae-Brometum erecti* association. It is widespread in the orchard meadows in the northern part of the area on average 12° southern and southwestern slopes of the White Carpathians. It is species-rich vegetation with average 58 species per relevé and high 95–100% herb layer cover.

Abandoned, formerly intensively managed large-scale orchards (Tab. S4, relevés 157–172). These include grasslands previously used in the intensively managed large-scale apple and plum orchards established in the 1970's–80's. Regular management gradually terminated after sociopolitical reform in 1989, except for one orchard in Krajné village, which initiated semi-intensive pasture management in 2010 with 150 head of sheep and irregular mechanized mowing. While this grassland type is classified as *Pastinaco sativae-Arrhenatheretum elatioris* association, it is strongly influenced by *Artemisietea*, *Stellarietea mediae*, and *Epilobietea angustifolii* synanthropic species due to succession triggered by management changes (Tab. S4). There is also obvious increase in the expansive grasses (*Elytrigia repens*, *Calamagrostis epigejos*) and herbs which indicate abandoned sites (*Agrimonia eupatoria*, *Hypericum perforatum*, and *Cirsium vulgare*). The accumulation of soil nutrients is indicated by nitrophilous species (*Anthriscus sylvestris*, *Pastinaca sativa*, and *Symphytum officinale*) and woody species gradually formed shrub and, more rarely, a tree layer. These successional changes caused retreat of some light-demanding and thermophilous species. The relatively high diversity of these orchards with average 57 species per relevé complies with the general succession pattern where original species are temporarily combined with introduced synanthropic species. Altered management regimes caused heterogeneous herb layer cover ranging from 60% to 95%.

Semi-intensively managed large-scale orchard (Tab. S5, Relevés 173, 174). This is a large-scale orchard over 50-year-old, regularly mown until 1990, abandoned between 1991 and 1999, and grazed by 50 head of cattle until 2013. The height of the herb layer is lower than in mown grasslands and the community mainly comprises low grasses such as *Lolium perenne*, *Cynosurus cristatus*, *Festuca pratensis* agg., *Agrostis capillaris*, and *Poa trivialis*. *Prunella vulgaris* and *Plantago major* are typical pasture species resistant to trampling and nibbling by herbivores, and these are combined with *Trifolium repens* and *Potentilla reptans* with their creeping stems. Soil surface disturbance by cattle created favorable conditions for weed species, including *Capsella bursa-pastoris*, *Xanthoxalis stricta*, *Cirsium arvense*, and *Geranium dissectum*. We classified this grassland as *Lolio perennis-Cynosuretum cristati* association. Although semi-intensive grazing affected species composition, it did not significantly degrade or impoverish the species pool. There is 95–100% herb layer cover here and the mean number of 54 species per relevé is higher than in comparable vegetation types (cf. [71]).

Abandoned, successionally changed orchard meadows (Tab. S6, relevés 175–178). Orchard management termination altered orchard species composition and decreased plant diversity. However, plant diversity temporarily increased in the early stages of succession (relevés 175, 176) because the species composition is enriched by tree species and species typical for abandoned sites. While plant litter accumulation restrained the growth of nutrient-conserving low herbs, its subsequent decomposition enriched the soil with nutrients favoring nitrophilous species (*Urtica dioica*, *Galium aparine*, *Anthriscus sylvestris*, *Lamium maculatum*, *Geum urbanum*, *Geranium robertianum*, and

Heracleum sphondylium). The competitively weaker thermophilous and light-demanding species, *Daucus carota*, *Campanula patula*, *Leontodon hispidus*, *Leucanthemum vulgare*, *Trifolium pratense*, and *Achillea millefolium* agg. retreated, while some weed grasses (*Calamagrostis epigejos* and *Elytrigia repens*) and tufted species (*Brachypodium sylvaticum*, *Carex muricata* agg.) expanded. In addition, the occurrence of *Aegopodium podagraria*, *Deschampsia cespitosa*, and *Poa trivialis* indicates increased soil moisture. The tree species gradually increased in number and abundance. One year after management termination, the number of shrub juveniles increased (*Rosa canina* agg., *Crataegus* sp., *Swida sanguinea*, and *Ligustrum vulgare*) together with tree juveniles (*Prunus domestica*, *Acer campestre*, *Acer pseudoplatanus*, *Quercus petraea*, and *Fraxinus excelsior*). Species composition of the initial succession stage is documented by relevés 175 and 176, while relevés 177 and 178 indicate advanced succession stages.

Indirect gradient analysis

Gradient analysis was performed with 174 relevés (four relevés representing the abandoned, successionally changed orchard meadows were excluded from the analysis because they were extremely heterogeneous and different to the rest of the dataset) (Fig. 2).

The first axis significantly positively correlated with altitude (0.56) and negatively correlated with indicator values for soil nutrients (−0.78), temperature (−0.51) and moisture (−0.49). The subxerophilous *Bromion erecti* community relevés are depicted in the upper right area of the diagram together with increasing altitude. Statistical comparison of the altitude of delimited communities confirmed that orchards classified as *Brachypodio pinnati-Molinietum arundinaceae* and *Onobrychido viciifoliae-Brometum erecti* associations occur at significantly higher altitude than the *Pastinaco sativae-Arrhenatheretum elatioris* association (Fig. 3). The mesophilous communities of *Arrhenatherion elatioris* and *Cynosurion cristati* alliances are displayed in the lower left area of the chart where nutrient indicator values increase. The EIV for nutrients significantly differ between the mesophilous *Pastinaco sativae-Arrhenatheretum* association and the semidry *Ranunculo-Arrhenatheretum* and *Bromion erecti* communities (Fig. 3).

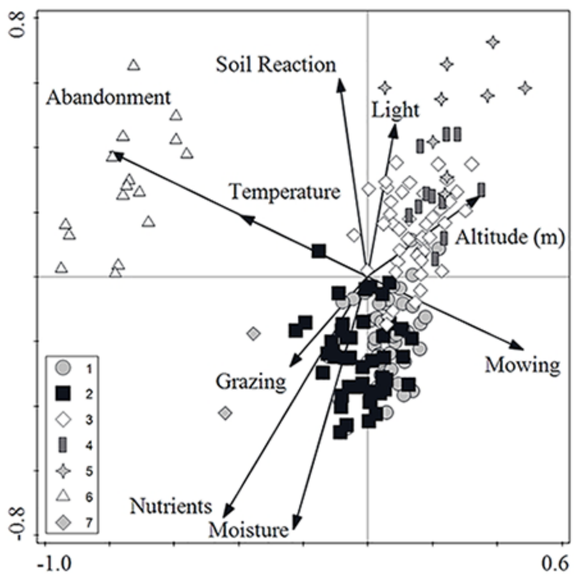

Fig. 2 Correspondence analysis of phytosociological relevés. 1 – *Pastinaco sativae-Arrhenatheretum elatioris* thermophilous variant; 2 – *Pastinaco sativae-Arrhenatheretum elatioris* transitional variant to *Alchemillo-Arrhenatheretum elatioris*; 3 – *Ranunculo bulbosi-Arrhenatheretum elatioris*; 4 – *Onobrychido viciifoliae-Brometum erecti*; 5 – *Brachypodio pinnati-Molinietum arundinaceae*; 6 – *Pastinaco sativae-Arrhenatheretum elatioris* ruderalized variant (abandoned, formerly intensively managed large-scale orchards); 7 – *Lolio perennis-Cynosuretum cristati* (grazed orchard).

The second axis significantly positively correlated with indicator values for soil reaction (0.74) and light (0.53) and negatively correlated with moisture (−0.90) and nutrients (−0.83). The *Pastinaco sativae-Arrhenatheretum elatioris* and *Lolio perennis-Cynosuretum cristati* mesophilous communities occurring on moist sites with nutrient-rich soils are indicated in the lower part of the ordination diagram, while the relevés of subxerophilous *Brachypodio pinnati-Molinietum arundinaceae* and *Onobrychido viciifoliae-Brometum erecti* associations are separated in the upper part. Statistical comparison of EIV for moisture and nutrients highlighted significant differences between *Pastinaco sativae-Arrhenatheretum elatioris* and the semidry *Bromion erecti* alliance grasslands.

There was no significant correlation between axis and management treatments. The diagram depicts relevés of abandoned, formerly intensively managed large-scale orchards in the upper left part in the direction of increasing intensity of abandonment, while grazed orchards are separated in the lower left part of the diagram in the direction of increasing grazing intensity.

Direct gradient analysis

The relationship between species composition and management treatments was analyzed by canonical correspondence analysis. The total inertia was 5.997, and eigenvalues were 0.370 (axis 1) and 0.129 (axis 2). The first canonical axis

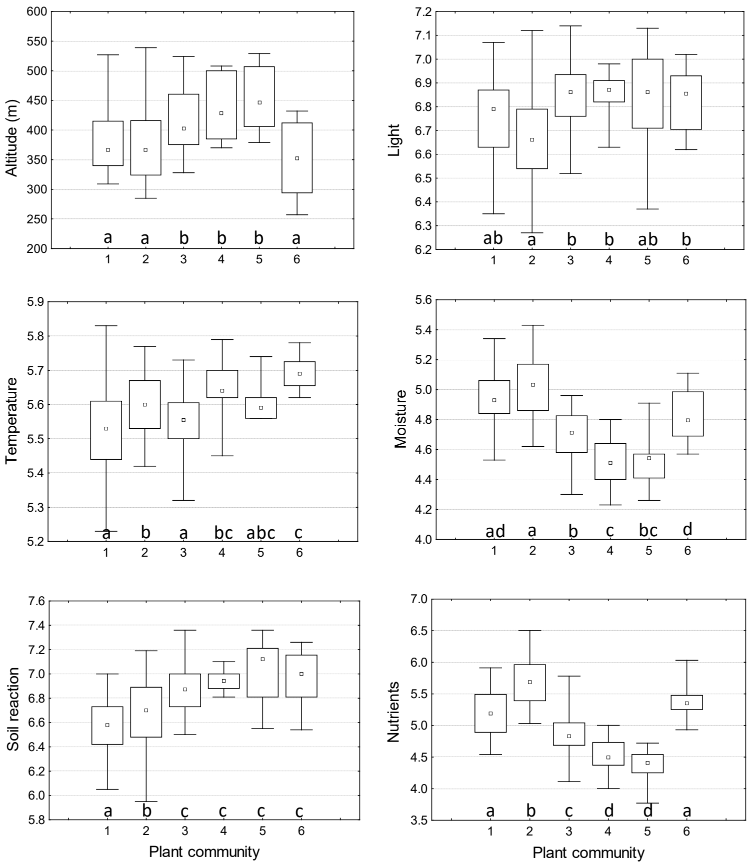

Fig. 3 Comparison of Ellenberg's indicator values and altitude for the studied plant communities. Median values, quartiles (25–75%), and ranges are shown. Communities are numbered as follows: 1 – *Pastinaco sativae-Arrhenatheretum elatioris* thermophilous variant; 2 – *Pastinaco sativae-Arrhenatheretum elatioris* transitional variant to *Alchemillo-Arrhenatheretum elatioris*; 3 – *Ranunculo bulbosi-Arrhenatheretum elatioris*; 4 – *Onobrychido viciifoliae-Brometum erecti*; 5 – *Brachypodio pinnati-Molinietum arundinaceae*; 6 – *Pastinaco sativae-Arrhenatheretum elatioris* ruderalized variant (abandoned, formerly intensively managed large-scale orchards). Significant differences between groups (Fisher LSD test) are marked with different letters (a, b, c, d).

explained 6.18% of the variance in species composition data and 66.91% of the variance in the species-environment relationship. This highlights that the 66.91% variability in our data set caused by selected environmental variables is reflected in the first ordination axis, while the second axis explained 2.16% of the variance in the species data and 23.4% of the variance in the species-environment relationship. Of the three factors significant in the Monte Carlo permutation test, abandonment explained 6.2% of total variability (p = 0.001), grazing 2.1% (p = 0.001), and mowing 0.9% (p = 0.027).

Evaluation of orchard meadows management regime

We recorded orchard meadow management regimes applied to 143 plots over the last 10 years. Mowing was the most frequent treatment on 93 plots (65%), followed by combined mowing and grazing on 12 plots (8.4%). Orchards managed exclusively by grazing are currently very rare in the study region (two plots). Although mulching is not a traditional management form and was employed only after the 1989 political changes, eight plots (5.6%) were managed by mulching during the monitored period. Orchard management changed dynamically over the past 10 years and although it was completely eliminated in some cases, we recorded 21 (14.6%) plots in abandoned or irregularly managed orchards. Parallel or alternating combination of mowing, mulching, and grazing was applied on seven plots (4.9%).

Comparison of orchard meadows from study area and other regions

Comparison of available phytosociological data from Slovakia and Germany confirms that orchard meadows in Slovakia are floristically richer. This is substantiated in both compared alliances. Orchard meadows classified in *Arrhenatherion elatioris* alliance in Slovakia have average 46 species per relevé compared to Germany's 27 (Tab. S7). Similarily, thermophilous grasslands classified in *Bromion erecti* alliance in Slovakia are richer in species (58 species per relevé) than in Germany (28 species per relevé) (Tab. S8).

Discussion

Syntaxonomic classification of distinguished communities

Syntaxonomic classification of phytosociological data of orchard meadows has specifics not applicable to grasslands without a tree layer. Species with varied and even opposite ecological requirements occur in orchard areas [72]. Diagnostic species adopted from the nationwide grasslands vegetation synthesis [61] are not fully representative because of ecological heterogeneity and the regional origin of relevés. The poor success of ES in classifying our relevés highlights the transitional character of orchard grasslands. Importantly, ES assigns relevés from a single vegetation stand to a particular association with respect to the typical association core and some transitional or atypical relevés consisting of mainly generalist species are not assigned to any association and thus remain unclassified [73]. Delimited vegetation types in our dataset were classified in associations with the knowledge that not all relevés can be considered typical. Although ES assigned several relevés in some clusters to the *Alchemillo-Arrhenatheretum elatioris* association, we did not accept this assignation, and after consideration of the overall floristic composition and their position in ordination space, we classified them in other delimited syntaxonomic units.

Comparison of orchard meadows in the study area and other regions

Although complex syntaxonomic study of the Slovakian orchard meadows has not been previously processed, regional studies with valuable information are available. Important work in our study area was performed by Ružičková [40], who described orchard meadow plant communities in the Myjava hilly land and White Carpathians and classified them in association *Dauco-Arrhenatheretum elatioris*. This name is recognized as a synonym for *Pastinaco sativae-Arrhenatheretum elatioris* [74]. The mesophilous stands of subassociation *typicum* and submesophilous *brometosum erecti* were distinguished; with the latter determined by the dominant *Bromus erectus* species and the presence of neutrophytes and calciphytes such as *Campanula glomerata*, *Primula vulgaris*, and *Filipendula vulgaris*; these species are also common in our relevés. Herein, we designated stands resembling this subassociation to *Ranunculo bulbosi-Arrhenatheretum elatioris* and partly to *Onobrychido viciifoliae-Brometum erecti*. Some relevés sampled in the White Carpathians orchard meadows were published by Škodová et al. [41]. These were included with other subxerophilous and mesophilous meadows and classified in *Pastinaco sativae-Arrhenatheretum elatioris*, *Ranunculo bulbosi-Arrhenatheretum elatioris*, and *Onobrychido viciifoliae-Brometum erecti* associations. Orchard meadows in the Štiavnické vrchy Mts were described by Ružičková and Halada [42] as association *Ranunculo bulbosi-Arrhenatheretum elatioris*. Compared to our study area, *Bromus erectus* and some calciphytes such as *Medicago lupulina*, *Securigera varia*, and *Filipendula vulgaris* were absent in these orchards, but some additional thermophytes such as *Steris viscaria*, *Dianthus carthusianorum*, *Jacea pseudophrygia*, and *Thymus pulegioides* were present. These differences are caused by the different bedrock, soils and altitudes – while the study area is situated in the flysch zone at 328–508 m a.s.l., the Štiavnické vrchy Mts lie on volcanic bedrock at 600–750 m a.s.l. The compared territory of Banská Štiavnica town and its surroundings lacked the mesophilous meadows of *Pastinaco-Arrhenatheretum elatioris* association. Ružičková and Halada [42] classified mesophilous orchard meadows there as the *Poo-Trisetetum flavescentis* association, with differential species, including *Primula elatior*, *Geranium phaeum*, *Hypericum maculatum*, and *Cardamine pratensis* (Tab. S7), and they also recorded *Phyteuma spicatum*, *Thlaspi caerulescens*, and *Silene vulgaris* species, typical in mountain meadows. Although Ružičková [40] classified some meadows in the Myjava hilly land (Krajné village) in the *Poo-Trisetetum flavescentis* association, these were not confirmed in our study. Sillinger [75], Tlusták [76], and Škodová et al. [77] consider *Brachypodio-Molinietum arundinaceae* association the common vegetation type in the White Carpathians, and we also found it in several orchards at Vrbovce village. In contrast, Ružičková [40] and Škodová et al. [41] recorded this vegetation type in the study area only outside orchards. The Nová Baňa scattered settlement ("štále" region) in central Slovakia also has large grassland areas with fruit trees. This settlement type was related to local mining, logging, and grazing [78]. These grasslands were classified by Žarnovičan and Marek [43] in *Ranunculo bulbosi-Arrhenatheretum elatioris* (mown grassland) and *Lolio perennis-Cynosuretum cristati* (pastures) associations.

We compared our phytosociological results with those from other orchard meadows of Slovakia and accessible phytosociological data from orchard meadows in Germany (Tab. S7, Tab. S8). The most common vegetation type in orchards managed by mowing and grazing in the hilly area of Hessen, Baden-Württemberg, and Bavaria

[36,38,39,79,80] is *Arrhenatheretum elatioris* association. These authors delimited seven subassociations – *typicum*, *alopecuretosum*, *luzuletosum*, *salvietosum*, *brometosum*, *brachypodietosum*, and *betonicetosum*. Comparison of *Arrhenatherion elatioris* alliance communities from southern Hessen [39] and Slovakia (Tab. S7) showed that common floristic base is formed by species such as *Arrhenatherum elatius*, *Dactylis glomerata*, *Poa pratensis* agg., *Plantago lanceolata*, *Trifolium pratense*, *Acetosa pratensis*, and *Achillea millefolium* agg. Plant communities of the *salvietosum* subassociation were the most similar to those in the Western Carpathians, but there are some differences in frequency and absence of some thermophilous species (*Campanula glomerata*, *Festuca rupicola*, *Ranunculus polyanthemos*, *Dianthus carthusianorum*, *Pimpinella saxifraga* agg.), and also species typical for Carpathian oat-grass meadows (*Campanula patula*, *Cruciata glabra*) and some forest species (*Viola reichenbachiana*, *Ranunculus auricomus* agg.). In addition, while *Tragopogon pratensis* is common in Hessen orchards, it is substituted by *T. orientalis* in orchards in Slovakia. There are also several German orchard species missing in Slovakian orchards (*Campanula rotundifolia*, *Vicia angustifolia*), or found only in abandoned large-area stands (*Picris hieracioides*) (Tab. S7). Subassociation *salvietosum* is the most common in orchard meadows in the Wertheim am Main region of northern Baden-Württemberg [36], but no phytosociological tables accompany that publication. The occurrence of subassociation *salvietosum* orchard grasslands is also noted in northwestern Bavaria (Hoffenheim) [38].

The comparison of thermophilous orchard grasslands classified in the *Bromion erecti* alliance from Slovakia and southern Hessen showed that common alliance species such as *Bromus erectus*, *Salvia pratensis*, *Galium verum*, *Plantago media*, *Primula veris*, and *Medicago lupulina* are frequent in both countries. While the compared German orchards have absence or lower frequency of some common Slovakian orchard species (*Filipendula vulgaris*, *Campanula glomerata*, *Tragopogon orientalis*, *Festuca rupicola*, *Carex caryophyllea*, *Ranunculus bulbosus*, *Pimpinella saxifraga* agg.), and also the mesophilous *Arrhenatherion* species group, Hessen orchards are enriched with some thermophilous species, including *Colymbada scabiosa*, *Tithymalus cyparissias*, *Agrimonia eupatoria*, and *Koeleria pyramidata* agg. (Tab. S8).

The vegetation of grazed orchards in south Hessen includes *Lolio-Cynosuretum* and *Festuco-Cynosuretum* associations of *Cynosurion cristati*. Langensiepen and Otte [37] published 135 relevés of *Lolio-Cynosuretum* association and consider this community the most common in orchards in the foothills of the Bavarian Alps at 600–720 m a.s.l. In contrast, stands of *Cynosurion cristati* alliance are rare in our studied region because grazing in orchards in the Western Carpathians almost ceased to exist, and therefore detailed comparison with available German data was not possible. Despite this, two Slovakian relevés were classified in *Lolio-Cynosuretum*; similar to the German authors' classification.

The species richness of both *Arrhenatherion elatioris* and *Bromion erecti* compared alliances was higher in Slovakian orchard meadows than in the German orchards (Tab. S7, Tab. S8). These differences in species richness are most likely due to the regions' specific natural conditions, different management regimes, and manner of land use.

Management changes and their impact on the orchards

Of all tested management treatments, abandonment has the strongest influence on the species composition of our dataset, and the absence of management and consequent succession caused changes in species composition and degradation of the grassland community. Moreover, orchards and orchard meadows have been threatened by management changes and abandonment since the second half of the twentieth century [81], with different causes in different countries. Hammel and Arnold [12], Plieninger [14], and Plieninger et al. [13,15] supplied detailed analysis in Germany's Baden-Württemberg, identifying the complex causes of orchard abandonment as environmental, demographic, and socioeconomic. Žarnovičan [29] documented decreasing orchard management intensity and frequency in the Myjava hilly land and White Carpathians. The current state of orchard management reflects loss of knowledge and skills, especially due to population migration to urban areas, lack of ownership transparency, demographic trends, and lack of state and EU financial support. In order to maintain the biological value of meadow orchards, it is therefore necessary to ensure the continuity of traditional management through financial subsidies similar to those provided for Germany and Switzerland [82].

The species composition and vertical structure of abandoned orchards is gradually changing. Shrub layer is established, especially close to trees, creating a system of islands with fruit trees at the center, but overgrown by shrubs, nitrophilous herbs, and expansive grasses. This phenomenon was also reported by Milton et al. [83] and they established that it is largely due to tree species distribution from seeds in mammal excrement and from birds using these orchards as a convenient shelter and food source. A higher frequency of species sensitive to mowing was also recorded in the herb layer of abandoned orchards. These included *Agrimonia eupatoria*, *Hypericum perforatum*, *Vicia hirsuta*, and *Stenactis annua*, and also some nitrophilous species. This is also reported from abandoned orchards in Hessen [39], where xerophilous species such as *Origanum vulgare* and *Campanula rapunculus* are present in addition to listed species. It is interesting that while succession induces species composition changes and general plant diversity decrease, faunal diversity often increases. This is obvious in bird species in abandoned orchards exceeding those in both intensively managed orchards and orchard meadows [84]. Benton et al. [24] declare that habitat heterogeneity is crucial in maintaining the agricultural landscape. Therefore orchards with terminated or limited management still have an important role in the cultural landscape, although this should be only a transitory phase in land use.

Conclusion

Valuable remnants of traditional orchards are still present in the Myjava hilly land and White Carpathians. The phytosociological study of relevés of these orchard meadows reveals their affiliation to *Arrhenatherion elatioris* and *Bromion erecti* alliances. We established eight delimited vegetation types corresponding to five associations and transitional variants. The species composition of grasslands developed under the fruit trees is influenced by shade from trees and the various orchard management treatments applied. The continuity of traditional orchard management is essential to maintain high orchard grassland species diversity, specific functions, and the cultural and botanical values of rural landscapes.

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Supplementary material

The following supplementary material for this article is available at http://pbsociety.org.pl/journals/index.php/asbp/rt/suppFiles/asbp.3552/0:

Tab. S1 Phytosociological relevés of *Pastinaco sativae-Arrhenatheretum elatioris*.

Tab. S2 Phytosociological relevés of *Ranunculo bulbosi-Arrhenatheretum elatioris*.

Tab. S3 Phytosociological relevés of *Onobrichido viciifoliae-Brometum erecti* (relevés 137–147), *Brachypodio pinnati-Molinietum arundinaceae* (relevés 148–156).

Tab. S4 Phytosociological relevés of *Pastinaco sativae-Arrhenatheretum elatioris* ruderalized variant (abandoned, formerly intensively managed large-scale orchards).

Tab. S5 Semi-intensively managed large-scale orchard.

Tab. S6 Abandoned, successionally changed orchard meadows.

Tab. S7 Comparison of orchard meadows of *Arrhenatherion* alliance in Slovakia and Germany.

Tab. S8 Comparison of orchard meadows of *Bromion erecti* alliance in Slovakia and Germany.

Appendix S1 Species with occurrence in one or two relevés in Tab. S1–Tab. S4.

Appendix S2 Extended header data of Tab. S1–Tab. S4.

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