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Controlling invasive alien shrub species, enhancing biodiversity and mitigating flood risk: A win–win–win situation in grazed floodplain plantations

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ABSTRACT

The high nature conservation value of floodplain ecosystems is severely threatened by invasive alien species. Besides adversely affecting native biodiversity, these species also pose a major threat from a wider socio-ecological perspective (e.g. 'roughness' increases flood risk). Finding options to control dense shrub layers consisting of invasive alien species is therefore of high priority for multipurpose management. We studied cattle grazing impacts on the cover, composition and diversity of the herb and shrub layers in floodplain poplar plantations along the Tamiš river, Serbia. Non-grazed, moderately grazed, intensively grazed and resting place stands were sampled in five locations in three sampling points. Non-grazed stands had substantially higher cover of invasive alien shrub species (on average 65%) than moderately and intensively grazed stands, and resting places (5.17, 0.02 and 0.00%, respectively), but without considerable differences between the grazing intensity categories. The number of invasive alien species in the shrub layer decreased considerably from non-grazed to intensively grazed stands. Species composition in the herb layer changed from non-grazed to intensively grazed stands, while resting places differed substantially from the other categories. Total species richness, richness of native generalist herbaceous grassland species, and the cover of palatable grasses were the highest in moderately and intensively grazed stands. Our results suggest that cattle grazing in floodplains is effective at controlling invasive alien shrub species. Furthermore, continuous moderate or intensive grazing would contribute to multifunctional management of invaded floodplains by enhancing local biodiversity, reducing flood risk, and providing additional grazing areas for the local community.

1. Introduction

Biological invasion is one of the key drivers of biodiversity loss and environmental change (Vitousek et al., 1996; Hejda et al., 2009; Cronk and Fuller, 2014). Besides adversely affecting native biodiversity, the invasion of alien species also poses a major threat from a socio-ecological perspective (García-Llorente et al., 2008). Among other impacts on society, invasive alien species contribute to changing cultural identity/value of landscapes and impact negatively on human health and safety (García-Llorente et al., 2008; Selge et al., 2011; Shackleton et al., 2019). Damage and loss triggered by invasive alien species and the cost of control measures also result in a high and rising economic burden (Diagne et al., 2021).

Natural floodplain ecosystems (e.g. softwood forests and meadows)

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have high nature conservation value and supply multiple ecosystem services (Tockner and Stanford, 2002; Schindler et al., 2014, 2016). However, they are severely threatened by invasive alien species, for which they function as ecological corridors (Pyšek and Prach, 1993; Richardson et al., 2007). Invasions by alien species are more pronounced in the regularly inundated areas of floodplains (Schmiedel and Tackenberg, 2013; Radovanović et al., 2017). The rapid spread of invasive alien species is facilitated by the nutrient-rich circumstances, frequent disturbances and alluvial sediments deposited by regular floods (Tickner et al., 2001; Richardson et al., 2007; Wang et al., 2015). Besides the above-mentioned socio-ecological impacts, alien shrubs may alter floodplain roughness (obstacles in the floodway, like stems and twigs) (Kiss et al., 2019; Nagy et al., 2018), reduce flow velocity and increase sedimentation and accumulation rates (Wang et al., 2015; Delai et al., 2018). These can reduce flood conveyance, while increasing flood levels and flood risk (Wang et al., 2015; Nagy et al., 2018; Sendzimir et al., 2018).

Preventing the colonization or establishment of invasive alien species, let alone suppressing or eradicating them, has posed a major challenge to nature conservation for decades (Hobbs and Huenneke, 1992; Richardson et al., 2007; Sendzimir et al., 2018). Most research and nature conservation measures focus on the effectiveness of mechanical or chemical removal and control of invasive alien species on invaded sites, so knowledge on the effectiveness of these restoration measures is widely available (Richardson et al., 2007; Seibold and Fischer, 2013; Wittenberg and Cock, 2001).

Among other measures, the effectiveness of livestock grazing at removing invasive alien species has so far scarcely been researched (Seibold and Fischer, 2013; Schindler et al., 2016). Moreover, little is known about the impact of different intensities of livestock forest grazing on the shrub and herb layer, as research often focuses only on grazed vs. ungrazed situations, while the effects of intensive or moderate grazing are not sufficiently studied (Öllerer et al., 2019). Reduction of the density of the shrub layer in forests as well as changes in species composition in the herb and shrub layers are among the well-known impacts of livestock grazing on forest ecosystems (Mitchell and Kirby, 1990; Kirby et al., 1994; Öllerer et al., 2019). Some recent studies recommend grazing as a tool for controlling invasive alien tree and shrub species (Chauchard et al., 2006; Rathfon et al., 2014), so forest grazing may be useful against invasive species in the shrub layer of floodplain plantations and native softwood forests.

Since the first half of the 20th century, non-native poplar plantations have been promoted in many floodplains of Europe to produce pulpwood and raw material for furniture (Heilman, 1999; Kiss et al., 2019). Such plantations are intensive forms of land use and require a short rotation system, soil preparation, and intensive soil management for the first seven years (Heilman, 1999). These kind of disturbances alongside frequent floods support the spread of invasive alien shrub species in these plantations, such as *Amorpha fruticosa* L. (Nagy et al., 2018; Kiss et al., 2019). *Amorpha fruticosa* is one of the most widespread invasive alien plant species in East-Central Europe, and has already invaded a considerable part of river floodplains (Schnitzler et al., 2007; Seibold and Fischer, 2013). The species alters the main properties of riverine ecosystems, causing cascading effects on soil function and decreasing plant diversity (Boscutti et al., 2020). Its impenetrable thickets have been shown to have severe effects on vegetation roughness and flood levels, slowing down flood passage (Delai et al., 2018; Nagy et al., 2018; Kiss et al., 2019).

Despite their economic utility, poplar plantations can also have adverse effects, contributing to a notable loss of ecosystem services and native biodiversity compared to the near-natural habitats they often replace, and increasing the risk of flood calamities (Archaux and Martin, 2009; Kiss et al., 2019). However, poplar plantations seem to be not equally detrimental to all groups of organisms (e.g. they are often preferred by ground beetles, Elek et al., 2010). Furthermore, the plantation canopy provides a shady resting place and fresh pasture for livestock during hot summer months (Nordenstahl et al., 2011; Varga et al., 2020). Adequate management tools that eliminate or prevent the establishment of a dense shrub layer of invasive alien species could provide more favourable conditions in poplar plantations from ecological, local community and flood control perspectives.

Nowadays there is increasing interest in shifting back from single-commodity land uses (e.g. timber production) towards those combining multiple uses (Mitchell and Kirby, 1990; Erős and Bányai, 2020). Agroforestry systems (Mosquera-Losada et al., 2005) and multi-functional floodplain management (Schindler et al., 2014, 2016) including grazing are complex tools which may also better serve the interests of other stakeholder groups (e.g. local communities and nature conservation). Integrating different land-use practices (including traditional management systems – e.g. forest grazing, Öllerer et al., 2019; Varga et al., 2020) into the management of floodplain poplar plantations may result in a ‘win–win–win’ situation, by simultaneously promoting provisional, regulating, and cultural services (Schindler et al., 2014).

The Tamiš river floodplain in Serbia provides a rare opportunity to study a living agroforestry system working in the long term. Our main objective was to analyse the impact of grazing intensity on the composition and cover of the shrub and herb layer, focusing on invasive alien species. This is the first empirical and quantified study revealing that livestock grazing can contribute to a decrease in the number and cover of invasive alien shrub species while promoting the species richness of the native herbaceous species in a European floodplain.

2. Methods

2.1. Study area

Our study area is located in the Tamiš river floodplain in Serbia (Vojvodina Province, 45°12′N, 20°31′E; Fig. 1). The climate is subhumid (mean annual temperature 10-12 °C; annual precipitation 600 mm) (Tucakov, 2013), with moderate aridity (the annual evaporation is 738 mm, Mihailović et al., 2004). The surveyed section of the river cut its way through a quaternary loess plateau (70-80 m a.s.l.) (Tucakov, 2013). The floodplain is dominated by alluvial soils with saline patches (Arends, 2012).

The zonal natural vegetation of the landscape is a *Quercus robur* L. dominated forest-steppe with extensive treeless wetlands and water surfaces in the lower parts (Niklfeld, 1973) and saline grassland on the elevations. The last patches of natural riverine hardwood forests most probably disappeared from the floodplain in the second half of the 18th century (http1). The meadows of the predominantly treeless floodplain were used for grazing and haymaking in the 18th and 19th centuries (http2). The present semi-natural vegetation of the riverine area consists mostly of valuable mesic and wet meadows, saline grasslands, tall-herb communities, and marshes with a uniquely extensive size (approx. 15, 000 ha) harbouring rich birdlife, especially of colonial waterbirds (Tucakov, 2011, 2013). The Tamiš river floodplain is a Category I Protected Landscape, according to the Law of Nature Conservation in Serbia. It is also an Ecologically Important Area of the Serbian National Ecological Network, with two Important Bird Areas RS012IBA and RS013IBA (Puzović et al., 2009; Tucakov, 2011, 2013).

Regulation of the studied section of the Tamiš river started at the turn of the 20th century, but only a few riverbed cuts and wetland drainage interventions were carried out (Tomić, 1989). Flooding occurs regularly in the study area from precipitation and snow melt from the Carpathians. Spring and early summer floods (April–June) are more frequent than autumn and winter floods. Due to the very wide inundation area and slow evaporation, the duration of inundations can last for several weeks (Tomić, 1989; Tucakov, 2011).

Afforestation of treeless pastures started after the Second World War mostly with poplar cultivars (*Populus* × *euramericana*). Many of these stands, together with the remaining treeless vegetation, have been used for extensive cattle grazing since then (Tucakov, 2011), as a

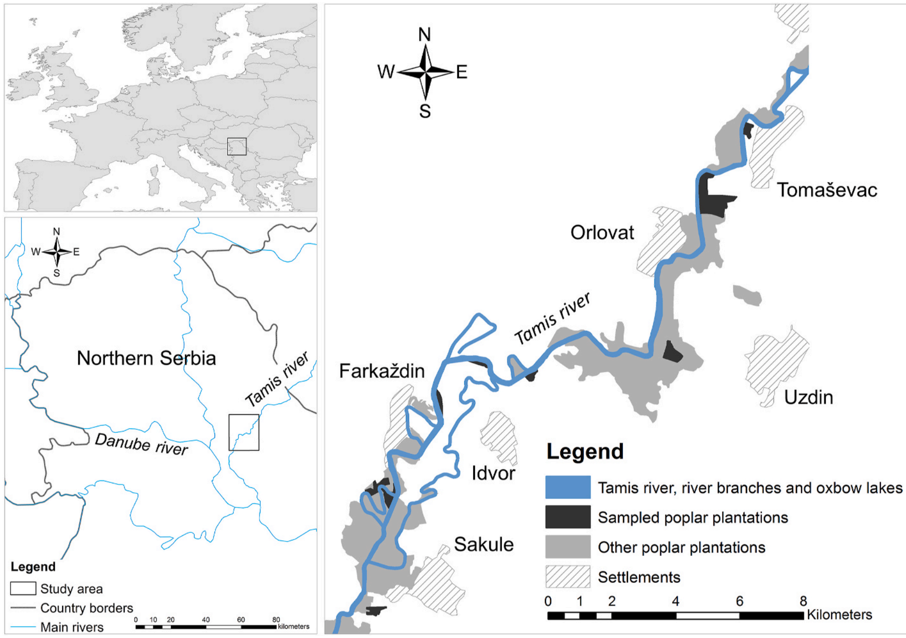

Fig. 1. Geographical location of the study area in Serbia. Maps were prepared using ArcGIS.10.1 (ESRI), Natural Earth open layers (http3), and Corine Landcover Map (http4). See Supplementary A Table S1 for more details on the location and management history of the studied stands.

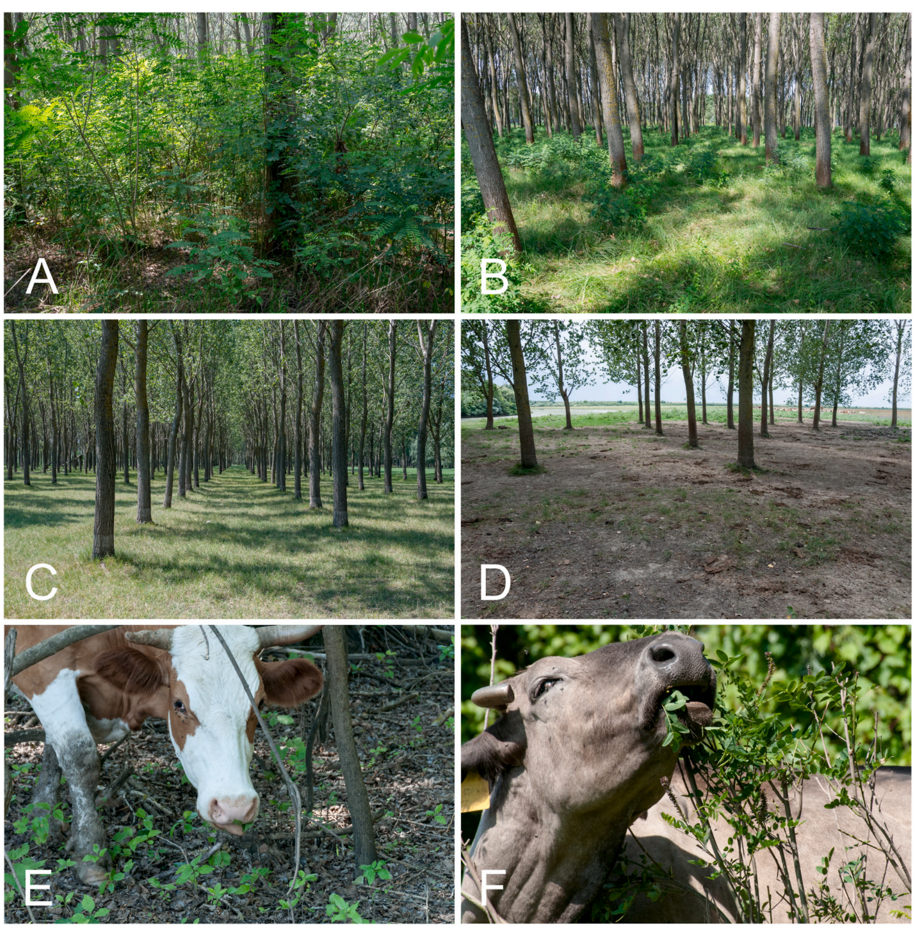

Fig. 2. Typical features of poplar plantations in the four grazing intensity categories (A, B, C, D) and cattle browsing on *Fraxinus pennsylvanica* (E) and *Amorpha fruticosa* (F). A) non-grazed, B) moderately grazed, C) intensively grazed poplar plantations and D) resting place under the canopy of mature stands.

continuation of former practices. Traditional grazing intensity decreased considerably in the floodplain area by the end of the 20th century, but is still ongoing with lower amounts of livestock, mostly cattle, sheep and horses.

In the 2010s, the livestock in the study area, kept mostly extensively in households, numbered approx. 8500 heads (Tucakov, 2013). Former herds with 200-300 livestock were reduced to herds with 50-70 animals (herders' and foresters' personal communication). Poplar plantations are used with different intensities of grazing from not grazed to intensively grazed stands, and places used for resting (Fig. 2). Resting places are the most intensively used parts of the grazed stands with substantial effects of trampling and manuring on vegetation. Plantations are state owned and managed by the Public Enterprise Vojvodinašume, Forest Estate Banat, Pančevo. The majority of meadows and pastures belong to the villages and are traditionally grazed by herds and flocks belonging to the locals.

We studied monospecific poplar plantations of the *Populus* × *euramericana* cv. I-214 clone. The sampled poplar plantations are in inundated areas and were established on unploughed pastures.

2.2. Forestry management of poplar plantations

The establishment of poplar plantations in this area started in the 1950-60s. During the clearcut of the first generation of poplars, the stumps are only drilled, with new saplings planted in the spaces between. After the exploitation of the second generation of poplars, following the drilling of the stumps, the area is usually ploughed before the plantation of a new stand. Nowadays most of the poplar plantations are third-generation stands, and a few are second-generation.

Recently, plantings are generally carried out in a 5 × 5 m or 6 × 6 m grid (seldom 4 × 6 m). Additional plantings to compensate for potential sapling loss are carried out in the first year. The interlinear grounds are managed twice a year (in spring and autumn) for six years by disk ploughing and/or stem-crushing. The lower branches are cut first in the third year and then in the sixth year. There is no forestry management following the sixth year. The stands are usually exploited at 25-30 years of age (FMP, 2004–2013).

The grazing of plantations until the sixth year is forbidden by law, after which the forestry service can decide whether to authorize grazing. Grazing can be conducted throughout the year, but the livestock mostly graze in the plantations during summer, in conditions of drought and shortage of biomass in open pastures.

2.3. Invasive alien woody species in the studied floodplain

Native shrub species (e.g. species in genera *Salix*, *Rosa*, *Crataegus*, *Prunus*) are very rare in this floodplain, while expansion of the invasive alien false indigo-bush (*Amorpha fruticosa*) has been reported since the 2000s (FMP, 2004–2013; cf. 1990s in Hungary, Biró, 2009; Borsos and Sendzimir, 2018). Today, the shrub layer of ungrazed poplar stands is characterized mainly by a monospecific *Amorpha fruticosa* layer, while the lower canopy level consists mostly of green ash (*Fraxinus pennsylvanica* Marshall), present in varying amounts, which is another invasive alien species spreading spontaneously in recent decades.

Amorpha fruticosa and *Fraxinus pennsylvanica* are native to North America and were introduced to Europe in the 18-19th centuries as ornamental plants (Csiszár, 2012, http5). Nowadays, both species are distributed across much of Asia and Europe, and are considered invasive, spreading mainly in floodplains and near waterways (Botta-Dukát, 2008; Csiszár, 2012; http5). Cattle regularly feed on the leaves of both invasive species (Fig. 2)

2.4. Data collection

The studied poplar stands were predominantly grazed by cattle and only marginally by sheep. Several unmanaged stands were used in our study as control sites. We conducted 7 oral history interviews with foresters and other land users to gain a detailed understanding of the landscape and land-use history of the study area. Field work was carried out in July 2018.

The impact of grazing was studied in four management (grazing intensity) categories: (i) non-grazed (NG), (ii) moderately grazed (MG), (iii) intensively grazed (IG), and (iv) resting place (RP) (Fig. 2). In this study, grazing means all the activities (e.g. feeding, trampling, manuring) of the livestock in poplar plantations. Trampling and manuring by cattle was more pronounced at RP sites, while feeding dominated the MG and IG sites.

Poplar stands included in the four management categories along the grazing intensity gradient were selected based on the above mentioned oral history interviews. NG category sampling sites were designated in stands which have not been grazed in the last 10 years. MG and IG categories were identified based on local herders' indications. They suggested selecting IG sampling sites close to the resting place where most of the herd grazes daily during the grazing period, and MG sampling sites in stands where most of the herd grazes a couple of days per week during the grazing period. Resting places were selected for sampling only if they were in use for at least 10 years. There are ca. 50-100 livestock heads in the herds grazing in and around the studied stands in the last 3-5 years.

From each of the four grazing intensity categories, five sampling sites were surveyed with 3 sampling points in each (10 × 10 m quadrats, 60 sampling points in total). We surveyed the vegetation composition and structure in each sampling point. The species list and percentage cover of vascular plant species were recorded in the herb layer, the shrub layer, and the upper and lower canopy layers. Species were identified using Király (2009) and Josifović (1970–1977). The full scientific names of species are provided in Supplementary B Table S1.

Twelve vegetation variables were defined in order to describe the characteristics of the herb, shrub and canopy layers of the studied poplar plantations (Table 1). Herb layer species were grouped as shade-tolerant forest species or light-demanding grassland species and according to their social behaviour type (i.e. generalists, ruderals or invasive species; Borhidi, 1995; Horváth et al., 1995). The social behaviour type of several herb species was overruled according to the authors' experiences in the study region (see Supplementary B Table S1). Herbaceous species were grouped according to their palatability for livestock (Supplementary B Table S1; Molnár et al., 2020).

2.5. Statistical analysis

Five land use/forest management parameters were collated from the

Table 1
Names of variables and data types used in the analysis.

Variables, describing the vegetation conditions	Acronyms	Data types
Cover of the shrub layer	shrubL_allC	percentage
Species richness of invasive alien woody species in the shrub layer	shrubL_alienR	number of species
Cover of invasive alien woody species in the shrub layer	shrubL_alienC	percentage
Cover of the herb layer	herbL_allC	percentage
Species richness of the herb layer	herbL_allR	number of species
Cover of generalist herbaceous grassland and marsh species	herbL_generalistC	percentage
Cover of ruderal herbaceous grassland and marsh species	herbL_ruderalC	percentage
Cover of forest species	herbL_forestC	percentage
Cover of invasive alien species in the herb layer	herbL_alienC	percentage
Cover of palatable herbaceous species	herbL_palatableC	percentage
Cover of the upper canopy layer	upperL_allC	percentage
Cover of the lower canopy layer	lowerL_allC	percentage

oral history interviews conducted with local foresters (Supplementary A Table S1). To validate our field experiences on the importance of grazing intensity, a preliminary pairwise Spearman's correlation analysis was performed between land use/forest management variables and vegetation variables. The preliminary correlation analysis proved that grazing intensity is the key determining factor (Supplementary A Table S2). Other land-use variables (like plantation grid size, stand age, ploughing prior to the planting of young trees, generation rank) had weaker correlations with the studied vegetation variables. Only the age of plantation and ploughing had significant and relatively high negative correlation with the cover of the upper canopy layer (Supplementary A Table S2).

Separately for all twelve vegetation variables, Generalized Linear Mixed Models (GLMMs) were built and multiple comparison of the means was done using Tukey contrasts, i.e. contrasts that define comparison between all possible pairs of grazing intensity categories. For richness parameters, Poisson distribution and log link were used in GLMM. For vegetation parameters describing percentage data (i.e. layer cover values and species cover values), beta distribution with logit link was selected. The maximum and minimum coverage values (i.e. 0, 1) were previously adjusted with a small number (1×10^{-5}) to enhance computability. In case the GLMM with beta distribution turned out to be not computable (due to matrix inversion problem of sparse data), GLMMs were built with quasi-binomial distribution and logit link. To avoid pseudoreplication, the 4×5 sites were used as random factors in the GLMMs. Model assumptions were tested by simulation-based statistics (overall uniformity, outliers of the simulation envelope, over/underdispersion) and diagnostic plots (Supplementary A Fig. S1). Significance groups of the multiple comparison were interpreted only if none of the assumptions were violated.

A Principal Component Analysis (PCA) was performed on the 12 vegetation variables after Studentization. PCA is one of the oldest and most widely-used eigenanalysis-based ordination methods that can be well applied to vegetation variables with different measurement units if they are converted to a common scale. The variables were displayed on the ordination space by finding the directions towards which they changed most rapidly (i.e. have maximal correlations with). Detrended Correspondence Analysis (DCA; Hill and Gauch, 1980) on the abundance data of the herb layer species was performed. Curvature of straight gradients and packing of sites at the ends of the gradient of the underlying correspondence analysis were removed using 30 detrending segments and five rescaling cycles (the selected parameters are close to the default and have little effect on the result). Rare species were not downweighted, i.e. original abundance data were used without weighting. In all ordination plots, sites were grouped according to the grazing intensity categories, and ordination ellipses were drawn based on standard deviation of point scores, where the directions of the major axis of the ellipse were defined by the weighted correlation.

Data analyses were carried out in R Statistical Software (R Core Team, 2018) using packages 'DHARMa' (Hartig, 2020), 'emmeans' (Lenth, 2020), 'glmmTMB' (Brooks et al., 2017), 'multcomp' (Hothorn et al., 2008) and 'vegan' (Oksanen et al., 2019).

3. Results

3.1. Effect of grazing intensity on species composition and plant species diversity

Shrub layer cover was considerably higher in non-grazed than in grazed stands (Fig. 3). Out of 30 sampling points of IG and RP stands, 28 had zero shrub layer cover. We found a very low number of shrub species in all groups. Non-grazed stands had substantially higher cover of invasive alien shrub species on average (65.40%) than moderately and intensively grazed stands and resting places (5.17, 0.02 and 0.00%, respectively), but without considerable differences between grazing intensity categories. The species richness of invasive alien woody species in the shrub layer decreased from NG to RP stands, but differences were not statistically significant.

Out of ten species found in the shrub layer, eight were invasive alien species (*Acer negundo, Amorpha fruticosa, Echinocystis lobata, Fraxinus pennsylvanica, Gleditsia triacanthos, Morus alba, Populus* × *euramericana, Vitis vulpina*). Among them, *Amorpha fruticosa* and *Fraxinus pennsylvanica* had the highest average cover in NG and MG categories, at 56.40% and 4.70%, respectively, while in RP and IG categories, average cover of these species ranged between 0.00 and 0.01%.

MG and IG stands had greater variety and cover of palatable herbaceous species than NG stands and RP (Fig. 3, Supplementary B Table S1).

We found altogether 140 plant taxa in the herb layer (Supplementary B Table S1). DCA analysis showed that species composition in the herb layer changed from non-grazed (NG) to intensively grazed stands (IG) (Fig. 4). The species composition of NG stands differed markedly from IG stands, while the MG stands showed similarities with both NG and IG stands. The species composition of the RP category proved substantially different from the other categories (Fig. 4).

MG and IG stands had a significantly higher total cover, species richness, and cover of generalist herbaceous grassland and marsh species in the herb layer than NG and RP stands (Fig. 3). Only some ruderals/weeds (e.g. *Cirsium vulgare, Polygonum aviculare*) typical of overgrazed pastures and invasive alien herbs (e.g. *Ambrosia artemisiifolia, Chenopodium strictum, Conyza canadensis, Echinochloa crus-galli, Erigeron annuus, Xanthium orientale* subsp. *italicum*) with low cover were present in moderately and intensively grazed stands (average total cover was between 0.61 and 4.42%, respectively) (Fig. 3., Supplementary B Table S1). We found only two generalist forest species (*Geum urbanum, Rumex sanguineus*) in two NG stands with low cover (Supplementary B Table S1).

Multivariate analysis revealed that the majority of sampling points were arranged along a grazing intensity gradient (Fig. 5). The left section of the biplot represents non-grazed stands, which showed high correlation with the cover of the shrub layer, the cover of invasive alien shrub species, and the species richness of invasive alien shrub species, while the right section represents moderately and intensively grazed stands correlated with the cover of the herb layer, the species richness of the herb layer, and the cover of generalist herbaceous grassland and marsh species. The sampling points of resting places were located outside this gradient, and showed negative correlation with the cover of the herb layer and the cover of invasive alien species in the herb layer. Sampling points were separated well according to the *a priori* grazing intensity categories.

4. Discussion

4.1. Grazing effects on the shrub layer

Medium and high intensity grazing had a strong impact on the characteristics of the shrub layer in the studied poplar plantations (Supplementary A Table S2, Figure 2, 3, 4 and 5). The total cover of the shrub layer and the cover of invasive alien shrub species, which are strongly overlapping variables in poplar plantations, proved to be considerably reduced by moderate grazing and almost completely removed by intensive grazing (Fig. 3). Regarding the total cover of the shrub layer, our results correspond well to those known from the literature. It is proven that grazing in forests decreases the density of the shrub layer (reviewed by Öllerer et al., 2019), similarly to browsing by wild animals (Kirby et al., 1994). On the other hand, grazing may impact the abundance of native and alien shrub species differently (Galleguillos et al., 2018; Rathfon et al., 2014). Semi-feral cattle were shown to control the invasive potential of non-native woody species in the Mediterranean region (Chauchard et al., 2006). Both farmers and professionals mentioned the potential of grazing to help manage a variety of invasive species (e.g. *Acer negundo*, *Zanthoxylum americanum*)

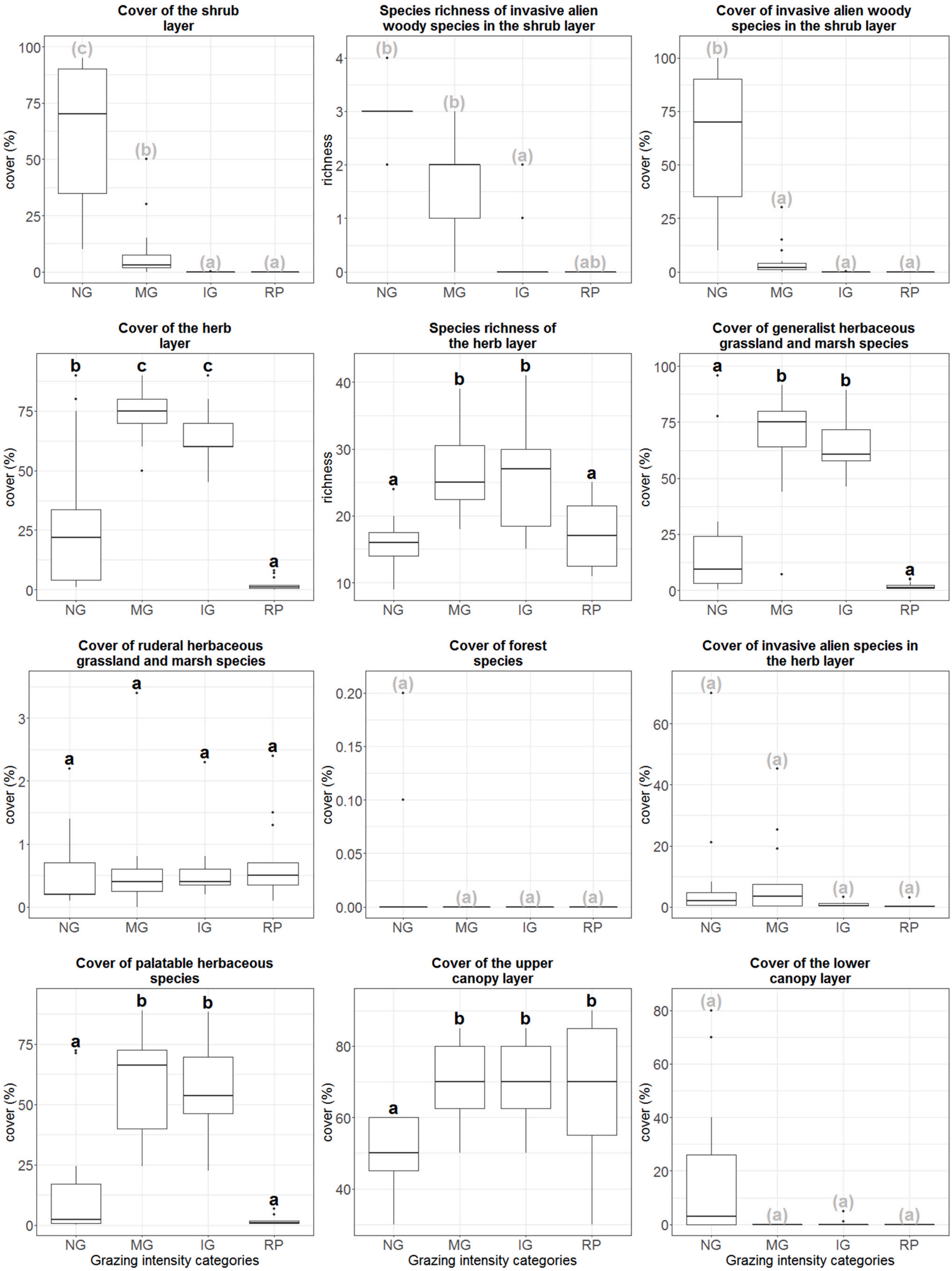

Fig. 3. Boxplots represent vegetation variables subdivided by grazing intensity categories. Groups with identical letters are not significantly different from each other ($p < 0.05$). If any of the model assumptions of the underlying GLMM was violated, letters are displayed in grey in brackets and the significant differences between groups should be interpreted with caution. Grazing intensity categories: NG – non-grazed, MG – moderately grazed, IG – intensively grazed, RP – resting place.

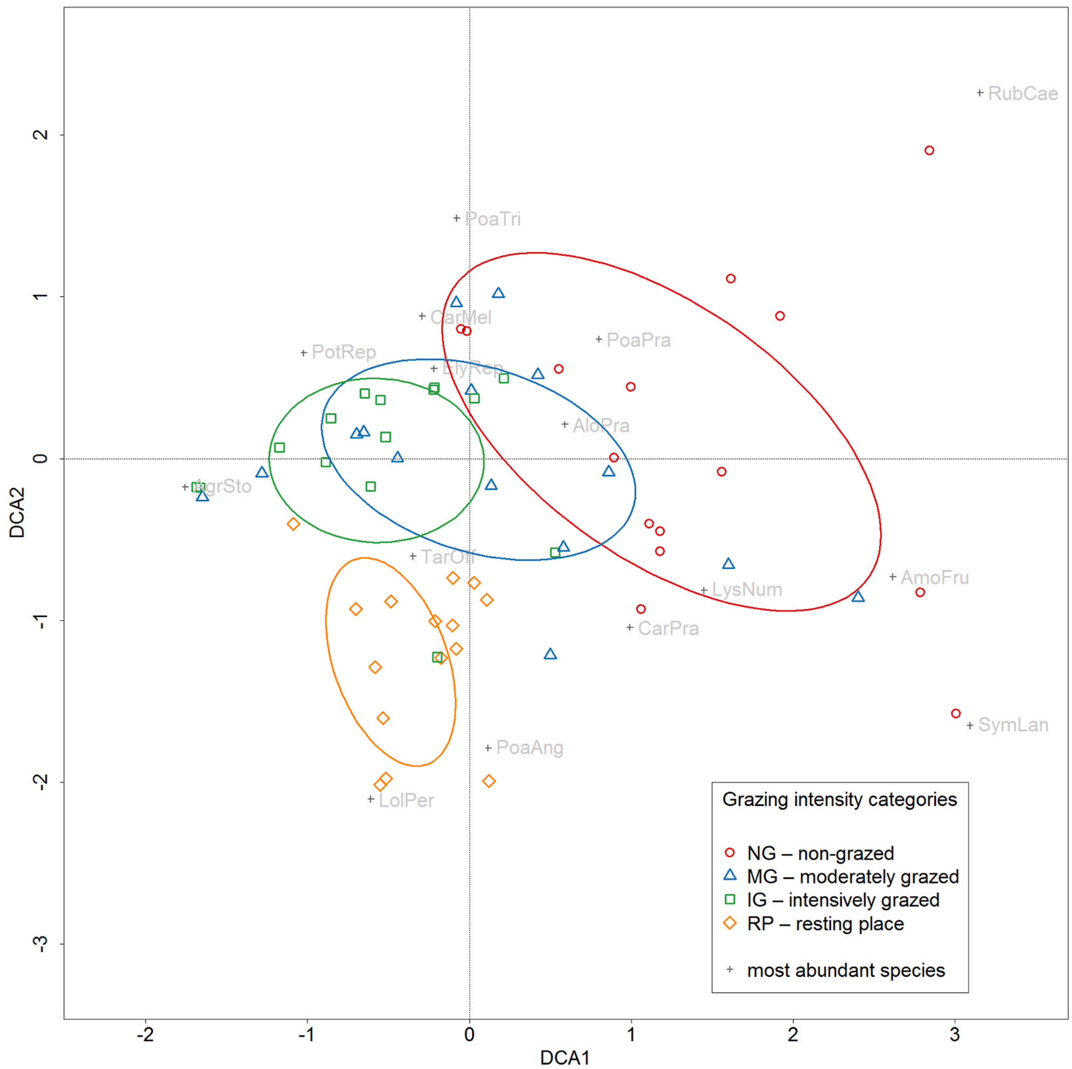

Fig. 4. Biplot of DCA performed on coverage data of species in the herb layer. Full name of species: AgrSto – *Agrostis stolonifera* L., AloPra – *Alopecurus pratensis* L., AmoFru – *Amorpha fruticosa* L., CalMel – *Carex melanostachya* Willd., CarPra – *Carex praecox* Schreb., ElyRep – *Elytrigia repens* (L.) Nevski, LolPer – *Lolium perenne* L., LysNum – *Lysimachia nummularia* L., PoaAng – *Poa angustifolia* L., PoaPra – *Poa pratensis* L. *s.str*, PoaTri – *Poa trivialis* L., PotRep – *Potentilla reptans* L., RubCae – *Rubus caesius* L., SymLan – *Symphyotrichum lanceolatum* (Willd.) G. L. Nesom, TarOff – *Taraxacum officinale* Weber.

(Mayerfeld et al., 2016). Our situation is simpler, as native shrub species were almost absent not only from the studied poplar plantations but from most regularly inundated areas in the Pannonian region. At the same time, Pannonian floodplain areas are seriously invaded by invasive alien woody species such as *Amorpha fruticosa*, *Acer negundo*, and *Fraxinus pennsylvanica* (Botta-Dukát, 2008). The grazing impact on native shrub species can thus be regarded as negligible.

The effect of livestock on the abundance of invasive alien woody species is an important question in nature conservation. In the studied landscape, grazing has been practised for centuries, maintaining a predominantly treeless floodplain landscape (Lazić, 2011). Invasive alien woody species (e.g. *Amorpha fruticosa*, *Fraxinus pennsylvanica*) were reported to expand aggressively after 2000 (FMP, 2004–2013). Processes along the Tisza and Hármas-Körös river (close to the study area) were similar, most probably due to the decreasing number of livestock, and the abandonment of former grazing areas (incl. natural softwood forests) and arable fields in the regularly inundated areas (Biró, 2009; Szigetvári and Tóth, 2012; Molnár, 2018; Biró et al., 2020). Our results concur with those of Kiss et al. (2019), who found that *Amorpha fruticosa* was most abundant in the areas where grazing was once common but has now been abandoned. The continuation of grazing is recommended to avoid invasive alien shrub establishment (cf. Szigetvári, 2002; Szigetvári and Tóth, 2012; Seibold and Fischer, 2013; Schindler et al., 2016).

Once a dense shrub layer has developed (ca. 2-3 years after grazing abandonment, Szigetvári, 2002; Szigetvári and Tóth, 2012), livestock are unwilling to go there to graze (personal communication of herders, Sipos, 2015; Varga et al., 2020). In such cases, grazing can be reintroduced after mechanical interventions (Schindler et al., 2016; Molnár, 2017). Although free ranging grazing livestock can efficiently help conservation management to decrease invasive alien shrubs in floodplains (Sipos, 2015; Schindler et al., 2016; Biró et al., 2020), grazing together with other activities of herders (e.g. mechanical removal of shrubs or forcing livestock into dense patches of shrubs) may eliminate invasive alien shrub species even more effectively in the long term (Chauchard et al., 2006; Rathfon et al., 2014; Sipos, 2015; Sallainé Kapocsi and Danyik, 2015; Schindler et al., 2016; Molnár, 2017). The mechanical removal of invasive alien shrub species alone seems to be ineffective, as without grazing, dense vegetation re-establishes rapidly in subsequent years (Sallainé Kapocsi and Danyik, 2015).

The cover and density of the shrub layer, which was considerably higher in non-grazed stands, can be regarded as a proxy for floodplain roughness. This is an increasing problem for flood risk management, both in invaded plantations and semi-natural softwood forests in the Pannonian region, and along many Central European rivers (Tickner

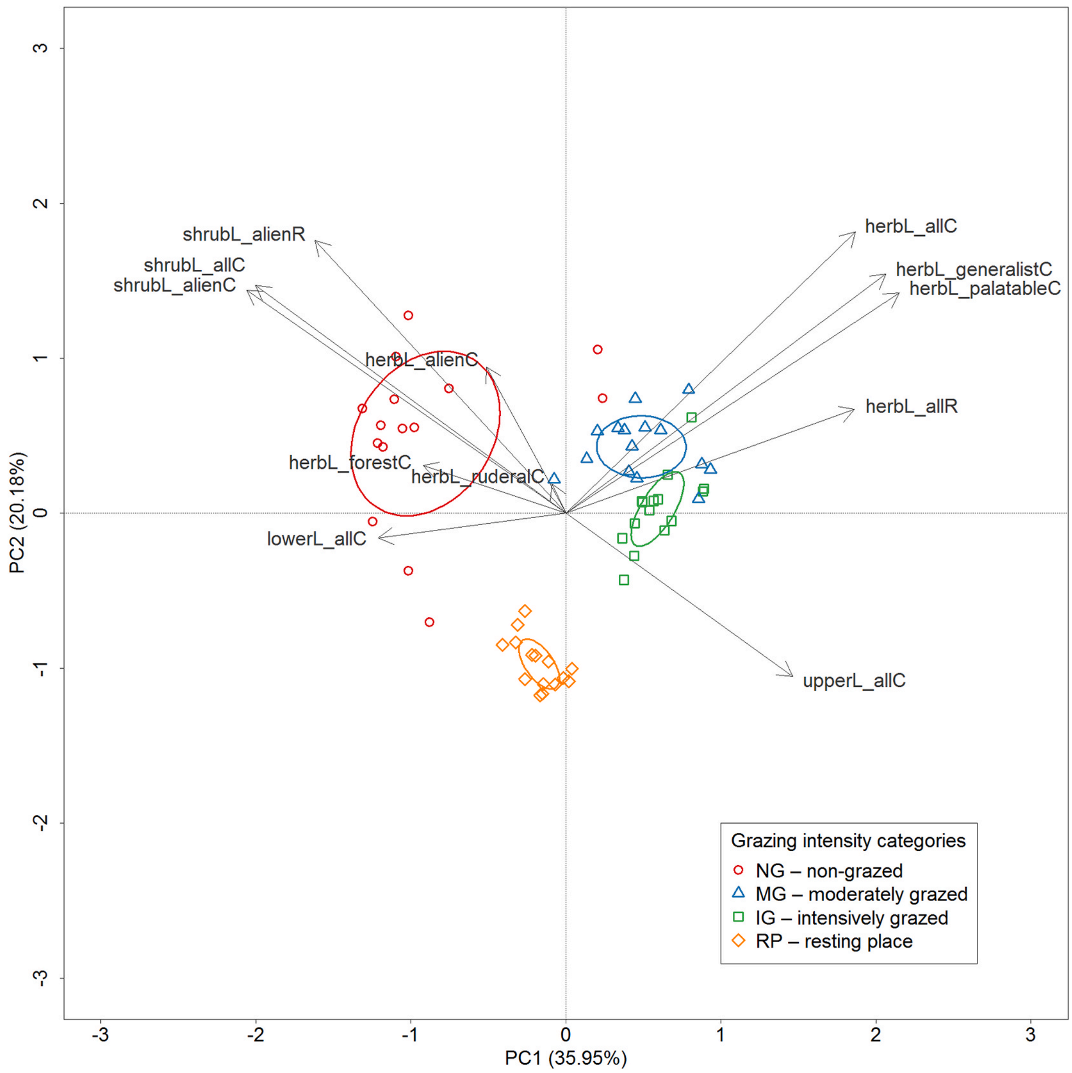

Fig. 5. PCA ordination of sampling points and vegetation variables. Grazing intensity categories: NG – non-grazed, MG – moderately grazed, IG – intensively grazed, RP – resting place. Full name of variables: shrubL_allC – Cover of the shrub layer, shrubL_alienR – Species richness of invasive alien woody species in the shrub layer, shrubL_alienC – Cover of invasive alien woody species in the shrub layer, herbL_allC – Cover of the herb layer, herbL_allR – Species richness of the herb layer, herbL_generalistC – Cover of generalist herbaceous grassland and marsh species, herbL_ruderalC – Cover of ruderal herbaceous grassland and marsh species, herbL_forestC – Cover of forest species, herbL_alienC – Cover of invasive alien species in the herb layer, herbL_palatableC – Cover of palatable herbaceous species, upperL_allC – Cover of the upper canopy layer, lowerL_allC – Cover of the lower canopy layer.

et al., 2001; Nagy et al., 2018; Sendzimir et al., 2018; Kiss et al., 2019). In the last decade, multifunctional projects, for example in neighbouring Hungary, have reintroduced grazing in order to suppress invasive species (Schindler et al., 2016). By suppressing invasive shrub species, grazing in plantations and even in semi-natural softwood forests can be an efficient way of reducing the roughness of floodways (Kiss et al., 2019). Furthermore, by promoting a regulating ecosystem service, grazing could also enhance the multifunctionality of these systems (Schindler et al., 2014).

Forest grazing is often criticized for destroying young trees in (semi-) natural forests (Öllerer et al., 2019). However, in rotation forestry where artificial regeneration techniques are used, grazing can be applied without damaging young trees, pending on strict controls (McEvoy and McAdam, 2008; Öllerer et al., 2019; Varga et al., 2020). In poplar plantations, as reported by local foresters, grazing could be reintroduced to stands without any damage six years after planting. This practice exists in the study area, though it is not widespread.

4.2. *Grazing effects on the herb layer*

Our results showed that, from a nature conservation perspective, grazing favourably modifies species composition and diversity of the herb layer in poplar plantations (Fig. 4). This has been observed in other forest types, and studies argue that grazing in forests decreases shrub volume (that would otherwise shade out the herb layer), slows the rate of competitive exclusion, increases herb richness and diversity, and often leads to a higher abundance of grasses or grassland species (Öllerer et al., 2019; Varga et al., 2020). In a recent review Öllerer et al. (2019) also emphasize that in combination with active canopy management, cattle grazing can reduce shrub cover and simultaneously increase the cover of higher quality grasses when forage production is a goal.

Other studies found that in non-grazed forests the abundance of light-dependent ruderals is lower and the abundance of shade-tolerant forest species is higher, with greater differences experienced under more developed tree canopies (Öllerer et al., 2019). In the studied non-grazed poplar stands we did not expect shade-tolerant species (cf. Boothroyd-Roberts et al., 2013), due to the long-term absence of forests along the Tamiš river, and also the short rotation time of stands.

However, the cover of ruderals was unexpectedly low (cf. Lunt et al., 2012; Öllerer et al., 2019), though beneficial from an ecological and conservation management point of view.

Grazing can also indirectly alter the composition of the herb layer by reducing or preventing the development of a dense shrub layer of invasive species (Radovanović et al., 2017). Studies show that the development of a dense *Amorpha fruticosa* layer alters species composition and reduces species richness and the cover of generalist subordinate species in the herb layer (Szigetvári, 2002; Boscutti et al., 2020). Others also conclude that without the mediating control of grazers, invasive species cover increases and diversity decreases as native species are outcompeted (Radovanović et al., 2017; Lodge and Tyler, 2020). Our results support these findings. Gazing pressures (moderate/intensive) that are able to eliminate or prevent the establishment of the invasive shrub layer indirectly increased native herbaceous diversity. Furthermore, palatable grasses were also more abundant in grazed than in non-grazed stands. Thus, stands which are free from a dense invasive alien shrub layer also provide higher quality pasture than non-grazed stands and are therefore more valuable to local livelihoods.

4.3. *Implications for nature conservation and multifunctional floodplain management*

Our results suggest that cattle grazing in floodplains is effective both at preventing patches of *Amorpha fruticosa* and *Fraxinus pennsylvanica* from becoming established and at eradicating established patches. Moreover, moderate and intensive cattle grazing increases the species richness of the herb layer of poplar plantations without increasing the cover of ruderal and invasive herb species. On the other hand, the abandonment of ongoing grazing, even for short time periods, has been shown to trigger the development of a dense shrub layer of invasive alien woody species, which may contribute to a higher flood risk. At the same time, grazing may also reduce invasive pressure on neighbouring floodplain meadows. Therefore, where there is a high risk of these invasive alien species becoming established and spreading, moderate and/or intensive continuous grazing is highly recommended. Such a management regime, in accordance with traditional pastoral practices, enables the seasonal rotation of grazed habitats, reducing grazing pressure on neighbouring endangered floodplain meadows during the arid summer period. Encouraging cattle grazing in these forests would result in an increase of grazeable biomass and provide grazing areas that are more sheltered, which is of great significance in the context of climate change. It would thus benefit local livelihoods and floodplain meadow biodiversity.

Floodplains are among the most threatened ecosystems due to the spread of invasive alien species. Since nature conservation is expected to respond to this threat by applying – where possible – close-to-nature management measures, extensive (semi-)traditional agroforestry systems (in our case forest grazing) may provide cost-effective solutions. Such multifunctional use of floodplain plantations and softwood forests in European riverine areas could produce a 'win–win–win' situation. Grazing can simultaneously enhance the herbaceous diversity of floodplain, mitigate flood risk, and maintain traditional land-use practices and local livelihoods in areas which otherwise would be overgrown by invasive alien woody species, with numerous disadvantages to nature and society.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.113053.

Author statement

László Demeter, Ábel Péter Molnár and **Zsolt Molnár** conceived and designed the study. **László Demeter**, **Ábel Péter Molnár** and **Anna Varga** conducted the field work. **László Demeter** and **Ákos Bede-Fazekas** analysed the data and **László Demeter, Ábel Péter Molnár** and **Zsolt Molnár** wrote the first draft. **Kinga Öllerer, Anna Varga, Klára Szabados, Marko Tucakov, Alen Kiš, Marianna Biró** and **Jelena Marinkov** discussed the results, reviewed the first draft and contributed to developing conceptual ideas and writing the manuscript.

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