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The Multifaceted Botanical Impact of the Invasive Common Milkweed (*Asclepias syriaca* L.) in a Protected Sandy Grassland in Central Europe

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Abstract: *Asclepias syriaca* L.is a perennial broad-leaved species native to North America. It has become established in many regions of Europe, and has spread with increasing rapidity in recent decades. Its reproductive behaviour allows this species to proliferate rapidly. The selected grasslands are located in the Carpathian Basin in Hungary, in the area of Kiskunság National Park, near Lake Kolon. In the framework of the research, in two consecutive years (2021 and 2022), and in two different seasons (spring and autumn), we examined the percentage cover of vascular plant species in the stands degraded by *A. syriaca* and the natural control (without *A. syriaca*), and their seasonal and interannual dynamics. Between the *A. syriaca*-degraded and natural control stands, there was no significant difference in the number of species in the spring and autumn of any of the examined years. Surprisingly, in the spring, the degraded stands were somewhat richer in vascular plant species. In autumn, the control stands had more vascular plant species, but to a lesser extent. The Shannon diversity was higher in the *A. syriaca*-dominated stands than in the control in all recording periods. Simpson diversity showed a similar pattern to Shannon diversity, with one exception in spring 2022. In the case of the social behaviour type, it can be clearly seen that the alien competitor (AC) species dominated in spring and autumn in both years in the stand dominated by *A. syriaca*. In the natural control stand, specialists (S) and competitors (C) dominated in both years and in both seasons. The negative effect of the invasive species on the number and diversity of species was presumably significantly reduced by the significant drying of the study area experienced in recent years.

Keywords: invasive plant; common milkweed; diversity indices; sandy grassland; Hungary

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Citation: Meinhardt, S.; Saláta, D.; Tormáné Kovács, E.; Ábrám, Ö.; Morvai, E.; Szirmai, O.; Czóbel, S. The Multifaceted Botanical Impact of the Invasive Common Milkweed (*Asclepias syriaca* L.) in a Protected Sandy Grassland in Central Europe. *Land* **2024**, *13*, 1594. https://doi.org/10.3390/land13101594

Academic Editor: Todd Robinson

Received: 15 August 2024
Revised: 25 September 2024
Accepted: 26 September 2024
Published: 30 September 2024

1. Introduction

The common milkweed (*Asclepias syriaca* L.) is one of the most problematic invasive plant species in Hungary [1] and it is also included on the list of invasive alien species of European Union concern [2,3]. This species is native to North America [4], but it has also established viable populations in many European countries, including Hungary, Austria, Romania and Slovakia [5–7]. In recent decades (>1980s), it has been expanding in the above countries, causing increasing damage to native ecosystems [8]. The conservation sector is under great pressure not only to control the species, but also to restore degraded habitats [8,9].

A. syriaca successfully invades heavily degraded or abandoned areas exposed to anthropogenic influences [10]. It causes damage by spreading in sandy grasslands, but also in other agricultural areas, such as vineyards and young forest plantations [11–14]. Its removal from railway line sides and other linear objects is very costly [15].

However, the habitats or areas that are successfully invaded by *A. syriaca* can vary by country. Based on field and geospatial data, *A. syriaca* is found throughout Hungary, mostly with extensive populations. It is particularly widespread in the Plain, the North Hungarian Mountains and the Transdanubien hills [16]. About a decade ago, this species spread aggressively in intensively cultivated agricultural areas in Central Slovakia. Based on 2011 data, it had colonized an area of abandoned vineyards and permanent grasslands in the Vel'ký Krtíš district [17]. Follak et al. [18] studied an area (Lower Austria) invaded by *A. syriaca* and found that the species was regularly found along unpaved roads and roads bordered by woodland and grassland. The road network typically contributes to the spread of invasive plant species, providing connectivity between habitats. The spread of *A. syriaca* in Romania varies from region to region. For example, in Transylvania it occurs with larger populations along roads, from where it is spreading to adjacent areas occupied mainly by crops and grasslands; while in Banat it is potentially invasive in wetlands [19–21].

There are also countries where *A. syriaca* has smaller populations but is still able to cause damage. Based on data from 2017, this species is mostly scattered in several parts of the Czech Republic, with some invasions in Moravia [22]. Studies by PuchaŁka et al. [23] in and around Toruñ (Poland) indicate that *A. syriaca* appeared a decade ago in dry, ruderal areas (wastelands, oat cultivation areas, etc.), indicating that the species was already present in an increasing number of habitat types. Studies by Vladimirov and Georgiev [24] also confirm the occurrence of *A. syriaca* in an increasing number of Bulgarian regions and in various habitat types: abandoned grasslands; anthropogenic herb stands; along roadsides; intensively cultivated agricultural fields; and small inner-city gardens. The presence of the species has also been detected in studies in anthropogenic habitats in Serbia in different types of crops, and also in urban and rural areas [25]. *A. syriaca* is currently sporadic in natural and anthropogenic habitats in Lithuania, but Gudžinskas et al. [26] suggest that it is worth considering as a potential invasive species.

The mass spread of *A. syriaca* is causing significant damage to native vegetation, especially to grassland species with low competitiveness [27]. It also has the potential to transform native ecosystems through its allelopathic effects and effective seed dispersal ability [27,28]. Fully grown plants are drought-tolerant because of their deep taproot [29], but the extreme drought caused by climate change has already had a significant negative impact on plant development and production in recent years [30].

There are studies that have investigated the impact of *A. syriaca* on native vegetation. Kelemen et al. [27] recorded the cover of vascular plants in seven sandy old-fields in the area of Kiskunság National Park in Hungary, comparing plots with varying *A. syriaca* cover to control plots without the species. They used linear mixed-effect models to assess the effects of *A. syriaca* on the species richness and cover of native grassland species. They also applied trait-based analyses to identify the common traits of the most affected native species (competitiveness). Sărăţeanu et al. [21] examined a grassland affected by *A. syriaca* in the Lunca Mureșului Național Park (Western Romania). This study analyzed whether there is a relationship between some vegetation characteristics and the presence of *A. syriaca* in grassland ecosystems.

Early detection and eradication are important in preventing the spread of alien invasive species [31]. Controlling the species described in this study is extremely difficult and can only be successful with continued management. In the absence of follow-up, it can re-establish itself in an area in a short period of time. In general, chemical foliar spraying (Glyphosate) has proved to be the most effective approach. In addition, mechanical methods and grazing are also used to control the populations of the species [7,32–34].

The aim of this study was to compare the changes in the species composition, diversity and social behaviour types of an alien invasive species around Lake Kolon, comparing *A. syriaca*-dominated stands and uninvaded control stands. In addition, we also examined the seasonal and interannual dynamics that occurred in the above parameters. The latter was made possible by the fact that, during our research, we examined the changes in vegetation in a year with an average rainfall distribution (2021) and an extremely dry year during the growing season (2022), which established the basis for studying the effect of years with different climatic conditions.

2. Materials and Methods

2.1. Study Sites

Our field surveys were conducted in sandy grasslands around Lake Kolon, which is located in Kiskunság National Park in Hungary, in the Carpathian Basin. The most extensive stands of sandy grassland are found in the Danube–Tisza basin. These habitats are of outstanding conservation value. Several protected plant species can be found here, such as *Stipa borystenica* Klokov, *Alkanna tinctoria* L. and *Dianthus serotinus* L., which also occur in the study area. The sample sites are located near Izsák and Soltszentimre. The areas marked with 'A' are degraded by *A. syriaca* and the areas marked with 'C' are the natural controls (Figure 1). Sites close to the roads were previously excluded in order to avoid the effect of this kind of disturbance on our results. To better our understanding of the research period's vegetation, we considered the precipitation—as the most important environmental factor in the region—of a local Techno Line WS 2350-type weather station (Figure 2).

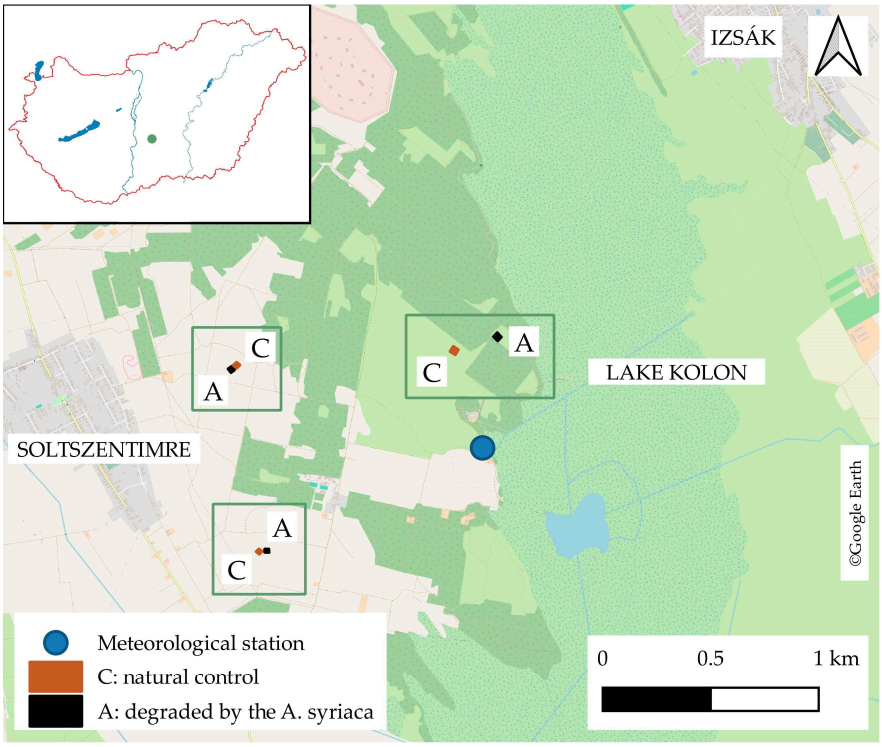

Figure 1. Location of the study sites (A—degraded by the *Asclepias syriaca*; C—natural control)—source: Open Street Map.

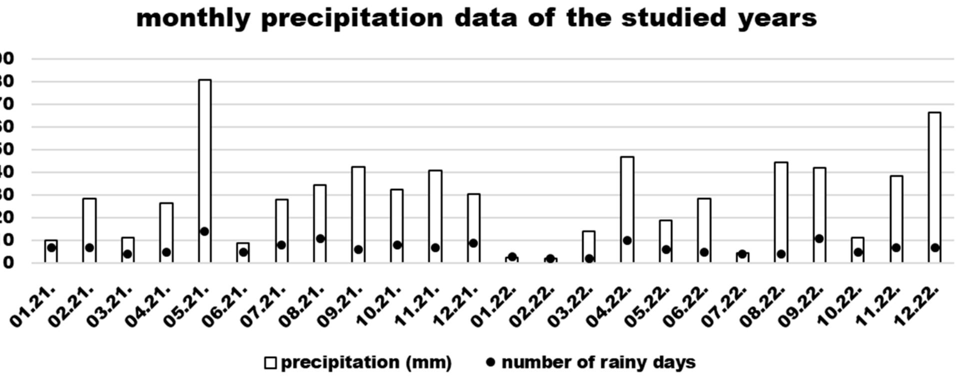

Figure 2. Monthly precipitation data of the studied years.

2.2. Vegetation Sampling

The vegetation survey was conducted in the spring and autumn of 2021 and 2022, in May and September–October, in a total of 3–3 degraded by *A. syriaca* and natural control stands. Five quadrats were recorded at each study site, and a total of 30 quadrats were marked out for investigation. The quadrats were randomly assigned. The corners of the 2 × 2 m-sized quadrats were visibly marked with stakes. A percentage of cover was visually estimated for each vascular plant species in the stands degraded by *A. syriaca* and the natural control. Following these investigations, species lists were generated to map seasonal and interannual cover dynamics.

2.3. Statistical Analysis

Statistical and visualization analyses were performed using the PAleontological STatistics (PAST) Version 3.21 and 4.05 [35,36] statistical software packages.

To better understand the similarities between the vegetation of *A. syriaca*-invaded and non-degraded (natural control) sites, the datasets were analyzed with multivariate statistical methods. As a first step, we used a distance-based classical cluster analysis (the unweighted pair-group average (UPGMA)) [36]. This popular classification method reduces the dimensions of the dataset and groups it based on the species and abundance of the sites in our case. This method is based on the average distance between all members of the groups [36]. We used the Euclidean mean distance, and the result is a dendrogram representing the distance/similarity of the studied invaded vs. non-degraded sites in different seasons and years. As a further multivariate method, we also used a principal components analysis (PCA). This method helped to reduce dimensions of the dataset to only two variables, components to plotting the studied plots [36] based on the floral composition. Moreover, with biplot setting, the result graph (scatter plot) helped us to identify the most important plant species as grouping factors.

To compare diversity of plots, seasons and years, we used Rényi's diversity profiles from the diversity module of PAST [36,37]. The most common diversity indices have different sensitivities, e.g., the Shannon index is sensitive to the number of taxas, while the Simpson index measures the evenness [36]. To avoid arbitrary choice of diversity indices, Rényi's diversity profiles, as a single continuous parameter-based method, provided a formal way [37] to compare our plots' diversity. The result graph contained profiles which made the diversity of different plots comparable if they were not crossing each other [36]. To ensure comparability with results of other research projects, diversity was also examined, specifically for the most commonly used Shannon and Simpson diversity indices.

For a deeper look into the studied plant communities' composition and naturalness, we used Borhidi's Social Behaviour Type (SBT) classification [38]: S—stress-tolerant specialist; C—competitors of natural habitats; G—stress-tolerant generalists; NPs—natural pioneers; DTs—disturbance-tolerant plants; W—native weed species; RC—ruderal competitors of the natural flora; ACs—alien competitors, aggressive invaders. We hereby mention that one of the identified plant species (*Gaillardia pulchella* Foug.) has still no social behaviour type—we marked it with ND: no data.

3. Results

3.1. Composition of Vegetation and Similarity of Study Sites

The distance-based classification analysis shows that the stands dominated by *A. syriaca* and the control stands dominated by natural species were well separated (Figure 3). In the case of both types, the spring and autumn vegetation clearly formed a separate unit. The principal component analysis showed the same result as the dendrogram—the natural control sites formed a separate group, while the invaded sites formed two smaller groups based on the seasons. Moreover, PCA showed that, in addition to the invasive *A. syriaca*, the separation of the invaded stand was caused by the abundance of *Secale sylvestre* Host in the spring, while in the autumn it was caused by the massive presence of *Gaillardia pulchella* Foug. and Conyza canadensis L. On the other hand, in the control stand dominated by natural species, the vegetation was characterized by the dominance of *Festuca vaginata* W. et. K. and *Stipa borysthenica*, which are characteristic species of the Pannonian open sandy grasslands, supplemented in autumn by the also-native *Salsola kali* L. and *Gypsophila paniculata* L. in the studied type.

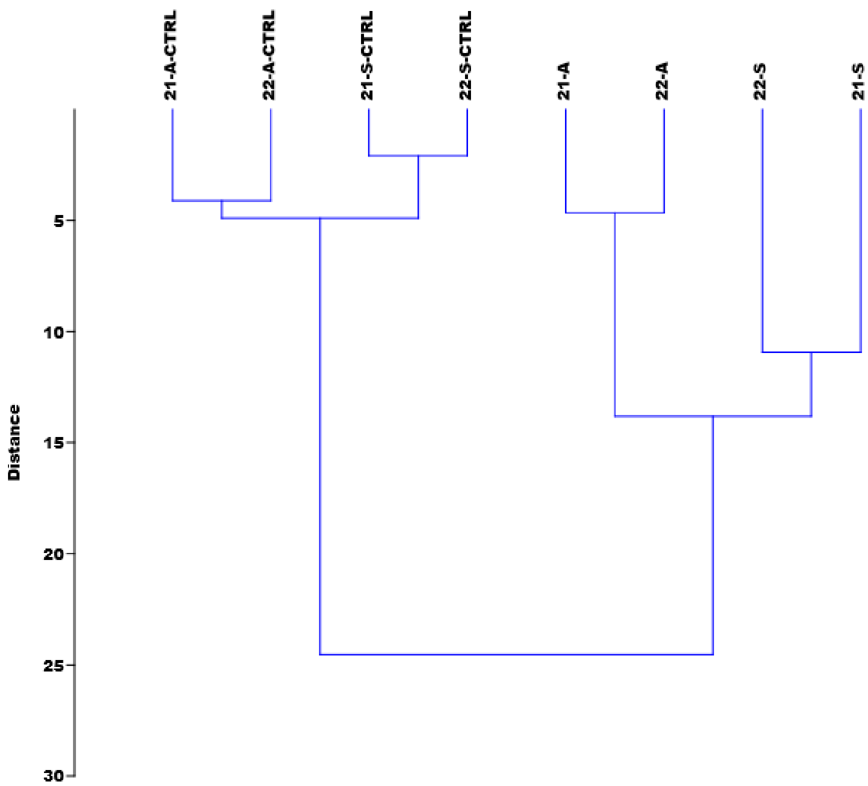

Figure 3. Result of unweighted pair-group average (UPGMA) analysis (21—2021, 22—2022, S—spring, A—autumn, CTRL—natural control).

3.2. Diversity of Invaded and Natural Control Stands

The results of simple comparison of species richness of invaded and non-invaded stands are presented in Table 1. It can be said that, in all cases, the number of species was higher in spring than in autumn. For the two consecutive years, the invaded stands were clearly more species-rich in spring. In contrast, in the autumn of 2021, the non-invaded stands had more species, and in the autumn of 2022, the invaded stands had only one additional species.

Table 1. Comparison of species richness of invaded and non-invaded stands (21–2021, 22–2022, S—spring, A—autumn, CTRL—natural control).

Stand	21-S	21-S-CTRL	21-A	21-A-CTRL	22-S	22-S-CTRL	22-A	22-A-CTRL
species number	45	40	30	35	47	38	32	31

Looking at the comparison of Rényi's diversity profiles within years, it can be said that in 2021, the diversity of the spring test areas infected with *A. syriaca* was greater than the diversity of the spring and autumn vegetation of the control areas (Figure 4). In 2022, we established that the control areas had greater diversity in spring than in autumn. Comparing the areas infected with the invasive species and the control areas, it can be said that the diversity of the areas infected with *A. syriaca* cannot be compared based on the Rényi diversity profiles, while in the case of the control areas, the diversity of the vegetation in the spring of 2021 was greater than that of the autumn of 2022. Looking at the diversity profiles between recording times, i.e., between seasons, it can be said that in the spring, the diversity of the vegetation of the areas infected by *A. syriaca* in 2021 was higher than the diversity of both the 2021 and 2022 control areas. From the examination of the data collected in the autumn, it can be concluded that in 2022, the diversity of the areas characterized by invasive species was greater than that of the control area, and that the diversity of the control areas was greater in 2021 than in 2022.

The Shannon diversity—based on average values of sites—was higher in the *A. syriaca*-dominated stand than in the control in all recording periods (Figure 5). The Shannon diversity values of 2021 exceeded the values of 2022 in both types and study periods. The Shannon diversity did not show a significant difference between the invaded and the control stands either within the examined years or between the years, comparing the same seasons.

Simpson diversity showed a similar pattern to Shannon diversity, with the difference that in the spring of 2022, it was higher in the natural control stands than in the invaded stands (Figure 5).

3.3. Social Behaviour Types

In the case of the social behaviour type, it can be clearly seen that the alien competitor (AC) species dominated in spring and autumn in both years in the stand dominated by *A. syriaca* (Figure 6). The share of the latter was more than 50% in the spring of 2022. For this type, natural pioneers (NPs) and specialists (Ss) were still present in a significant proportion in the spring, while the proportion of specialists (Ss) and non-defined (ND) species increased noticeably in autumn.

In the natural control stand, specialists (Ss) and competitors (Cs) dominated in both years and seasons (Figure 6). The proportion of generalists (Gs) and natural pioneers (NPs), which are present in an even greater proportion in spring, decreased for both autumn periods.

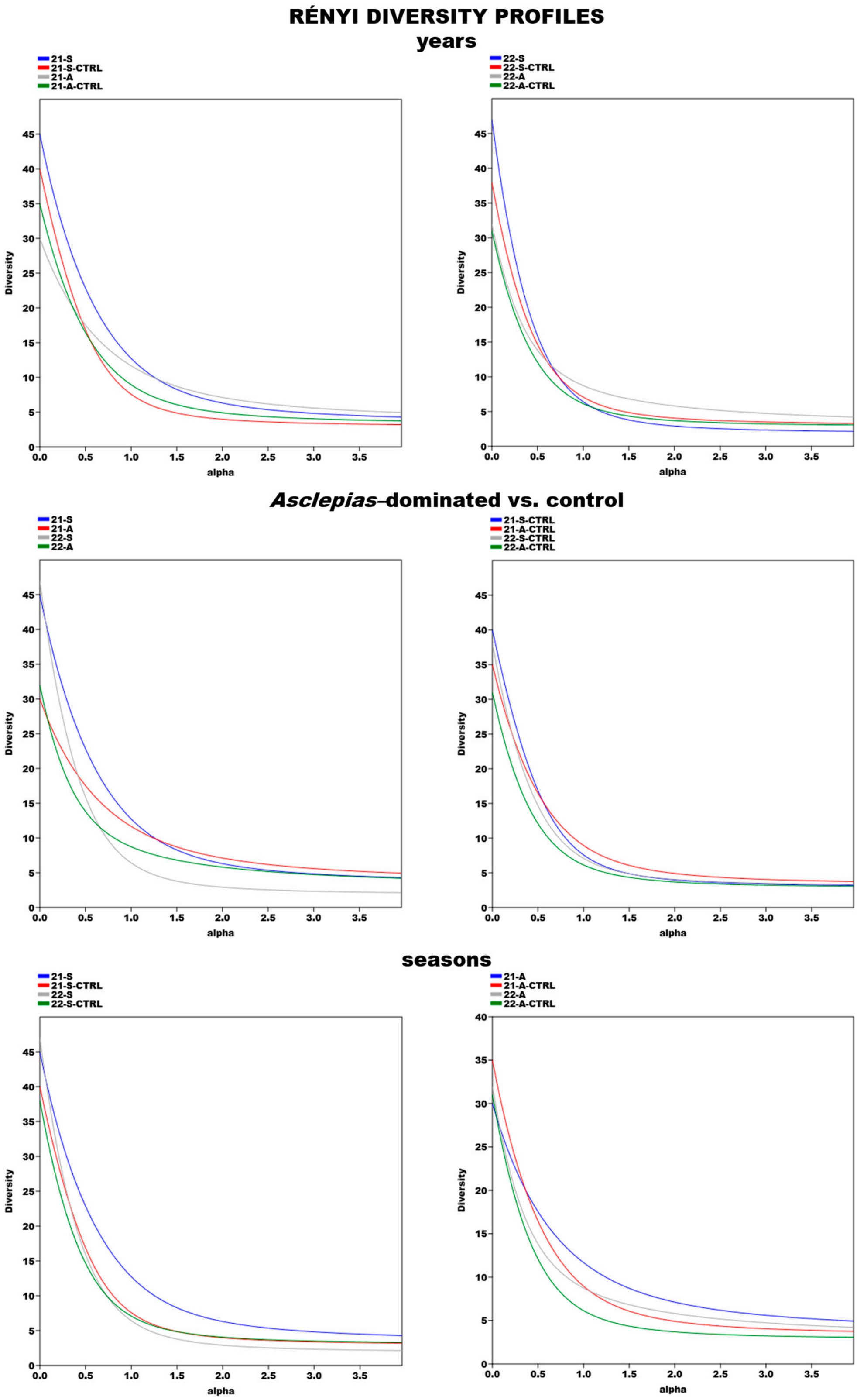

Figure 4. Diversity based on Rényi's diversity profiles (21–2021, 22–2022, S—spring, A—autumn, CTRL—natural control).

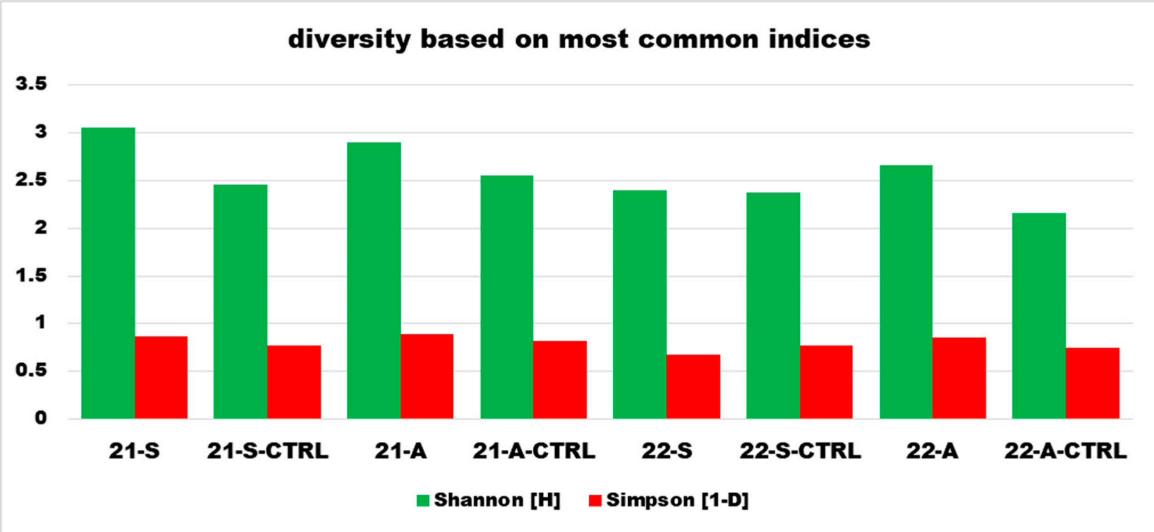

Figure 5. Diversity based on Shannon and Simpson diversity indices (21–2021, 22–2022, S—spring, A—autumn, CTRL—natural control).

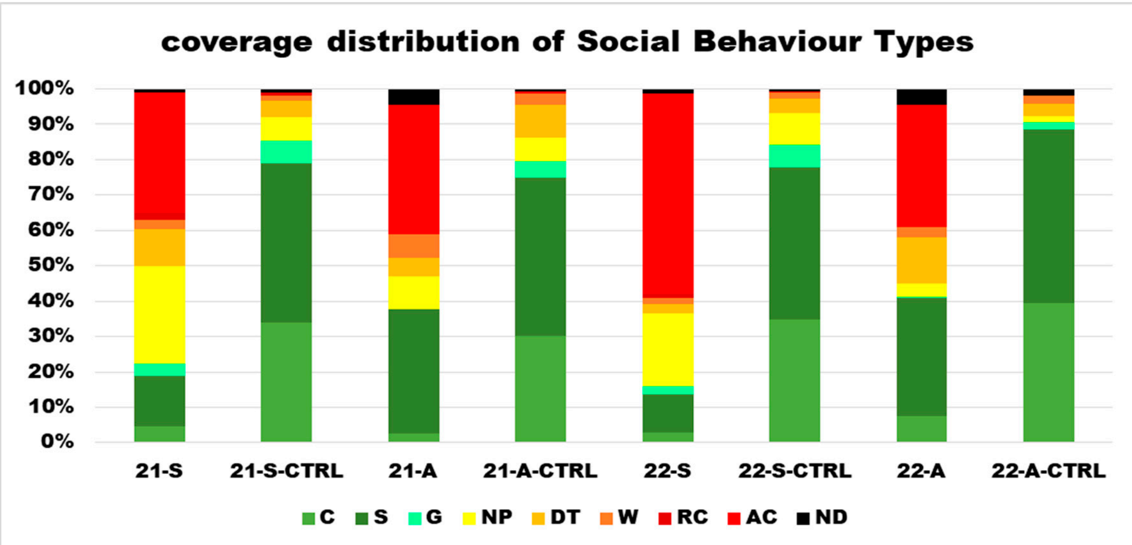

Figure 6. Coverage distribution of social behaviour types—for abbreviations, see Sections 2.3 and 3.3 (21–2021, 22–2022, S—spring, A—autumn, CTRL—natural control).

4. Discussion

4.1. Composition of Vegetation and Similarity of Study Sites

The earlier separation of *A. syriaca*-dominated stands (Figure 3) indicates that their species pool is more heterogeneous compared to natural stands. The latter is partly caused by the large number of weed species in the invaded stand, like *Chenopodium album* L., *Descurainia sophia* L., *Galium aparine* L., *Lamium amplexicaule* L., *Melandrium album* Mill. and *Verbascum phlomoides* L. The clear separation of spring and autumn vegetation can be seen in both types, with the disappearance of spring species with a shorter life cycle (such as *Secale sylvestre*), the later development of some species (e.g., *Artemisia absinthium* L., *Dianthus serotinus*, *Gypsophila arenaria* Waldst.), and the mass growth of T4 weed species in autumn (e.g., *Conyza canadensis*, *Gaillardia pulchella*).

The PCA clearly shows that the autumn vegetation of the invasive dominated stand and the spring vegetation of the control stand were very similar (Figure 3). The latter also indicates the greater resistance of grasslands dominated by natural species [39–41] in extreme climatic conditions, such as the extreme drought in the spring of 2022 in the research area.

4.2. Diversity of Invaded and Natural Control Stands

In many cases, species richness and diversity showed similar changes and differences between the invaded and natural control stands, especially in the case of Rényi diversity. The latter indicates that, among the types of diversity examined, Rényi's diversity correlates to the highest degree with the change in the number of species.

The surprisingly greater diversity of the infected stand (Figures 4 and 5) can be primarily explained by the fact that *A. syriaca* does not form a very dense stand, so there is a chance for the natural species to survive. The less dense stands of *Asclepias* may also indicate that this invasive species can suffer during long, hot and dry summer periods in the case of sandy soil with poor water management, which is also supported by long-term observations of local nature conservation guards. Interviews with the representatives of the apiculture sector also show that beekeepers are witnessing a decline in *A. syriaca* populations due to climate change [30].

At the same time, the degradation of vegetation favours the establishment of weeds and even other invasive species (see *Gaillardia*). In addition to the number of species, the latter can also increase diversity values, as in the case of the present study area.

The Simpson diversity values obtained for 2021 exceeded the 2022 values in both types and study periods, similarly to Shannon diversity (Figure 5). The lower diversity values in 2022 were caused by the lower cover value and species richness due to the dry spring and autumn periods—the number of rainy days was almost 1.5 times greater in 2021 than in 2022. On the other hand, the spring period was very dry in 2022, because only two-thirds of the spring precipitation fell in 2021 compared to 2022 (67%). Moreover, 21% less autumn precipitation fell in 2022 than in 2021 (Figure 2). The diversity-reducing effect of drought in grasslands is also supported by the publications of [42–44].

Other studies have highlighted the vulnerability of grassland species to *A. syriaca*. Kelemen et al. [27] detected no effect of *A. syriaca* on total species richness, but a negative effect on the cover of grassland species, especially on species with low competitive ability. They also found that the *A. syriaca* cover in the studied grassland types was typically below 50%. Sărățeanu et al. [21] showed in their study that the vegetation type had a significant influence on the contribution of *A. syriaca*. Disturbance had an important role in the increased occurrence of the species in grasslands, as shown in Bakacsy's work [9].

4.3. Social Behaviour Types

The social behaviour types (SBT) were represented in significant numbers both in the *A. syriaca*-dominated area and in the natural control area, regardless of the recording period (Figure 6). The coexistence of a large number of SBT types is, on the one hand, a feature of open sandy grasslands, where the empty patches between the incompletely connected vegetation allow the establishment of new plant propagules, as well as the appearance of some seasonal types (e.g., spring natural pioneers and T4-type weed species that appear in late summer and autumn). The less dense populations of the invasive *A. syriaca* species enable the survival of valuable SBT types, specialists and competitor species in the infected patches, which also increases the diversity of SBT occurring in grasslands. Berki et al. [45] found that the cover of specialists was higher in the control stands.

Among the alien competitors, *A. syriaca* dominated. The other species that could be classified here (e.g., *Conyza canadensis*, *Stenactis annua*) were only present in the vegetation with little cover. In the spring of 2022, the significant increase in the proportion of alien competitors was also caused by the increased coverage of the species in the invaded stand.

Among the competitors, *Festuca vaginata* dominated in both types, but the absence or minimum proportion of *Koeleria glauca* in the degraded stand is striking. The latter is a characteristic species of Pannonian open sandy grassland. In the case of specialist species, *Stipa borysthemica* was the most abundant in almost all recordings, but the higher cover of *Euphorbia seguierana* is typical in the degraded type.

5. Conclusions

The investigated stands dominated by invasive *A. syriaca* were well separated from the stands dominated by indigenous species, regardless of the years and recording periods, both by classification and ordination evaluation. Our research proves that the appearance of an aggressive invasive species in natural or near-natural treeless vegetation is not necessarily accompanied by a decrease in the species richness and diversity. However, the distribution of social behaviour types showed that the ratio of specialists and competitors—the most important elements of the natural species pool in terms of resistance and resilience—can be significantly reduced in the case of a massive presence of the invasive species. This can be exacerbated by climatic anomalies such as frequent droughts in grasslands, which can further reduce the ability of the grassland to renew and regenerate.

Author Contributions: Conceptualization, S.C., S.M. and E.T.K.; methodology, S.C.; software, D.S.; formal analysis, D.S.; investigation, S.M., S.C., Ö.Á. and E.M.; data curation, S.M.; writing—original draft preparation, S.M., S.C., D.S. and E.T.K.; writing—review and editing, S.M., S.C., D.S. and E.T.K., Ö.Á., E.M. and O.S.; visualization, D.S., S.M. and Ö.Á.; supervision, S.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Acknowledgments: The research was supported by the Doctoral School of Environmental Sciences of the Hungarian University of Agriculture and Life Sciences.

Conflicts of Interest: The authors declare no conflicts of interest.

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