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The Influence of Invasive Alien Plants on Umbrella Butterflies of the Genus *Phengaris* and Diversity of Heteroptera True Bugs

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Abstract
The Natura 2000 initiative and National Parks are the most important forms of nature protection in European countries. However, conservation efforts are often hampered by biological invasions, which are some of the most serious environmental problems. The aim of this study was to assess, in protected areas, the impacts of invasive plants – alien *Solidago* spp. on *Phengaris* butterflies and *Heracleum mantegazzianum* on Heteroptera true bugs. *Ph. teleius* and *Ph. nausithous* were surveyed in the Jaworzno Meadows Natura 2000 site using the Capture-Mark-Recapture method. Heteroptera were surveyed using transect captures in Magurski National Park. The sizes of local populations of the butterflies were lower in patches with higher goldenrod cover. A high cover of the host plant may mitigate the negative impact of goldenrod during the early stage of invasion. In the case of poor habitat quality, nearby unprotected habitat patches act as ecological traps for butterflies due to the application of mowing during the butterfly flight period. The invasive giant hogweed had the most significant impact on reducing the number of Heteroptera individuals. Its influence was also observed at the assemblage level. The negative impact of hogweed has been detected despite the application of the first eradication treatments of this plant. Success in eradicating hogweed may be limited due to the spread of the plants from locations where removal is not applied.

1. INTRODUCTION

Conservation initiatives like the Natura 2000, the largest and the oldest programme in the European Union, aim to preserve local biodiversity through extensive land management practices [Evans 2012]. Wet meadows and calcareous grasslands of northwestern Europe are considered an important habitat for many plants and animals. Their biological diversity is renowned, including a variety of species listed under the habitat directives [Van Swaay 2002; Pe'er et al. 2014].

In Central Europe, various protected insects, birds and plants rely on such management, including mowing and cattle grazing. By employing low-intensity management on grasslands, heathlands and peatlands, threatened species like the butterflies, *Phengaris teleius* (Bergsträsser, 1779) and *Ph. nausithous* (Bergsträsser, 1779) find support and serve as key flagship symbols in European biodiversity conservation efforts. Managed landscapes play a crucial role for many protected bird species, like *Crex crex* (Linneus, 1758), a bird facing a high risk of extinction according to IUCN (The International Union for Conservation of Nature). Mowed or grazed meadows are also vital for the survival of threatened plants such as orchids, *Iris sibirica* (Linneus, 1753), or other plants such as *Trollius europaeus* (Linneus, 1753) [Evans 2012]. Unfortunately, despite significance of the grassland habitats, these mostly agriculture-associated habitats currently have the poorest conservation status among all ecosystems [Pe'er et al. 2014]. Conservation efforts additionally hamper biological invasions, which are one of the most serious environmental problems threatening biodiversity on a global scale.

The serious threat for biodiversity are invasive alien plants. Giant hogweed *Heracleum mantegazzianum* (Sommier & Levier, 1895) has emerged as a major ecological concern due to its invasive nature and the profound impact it poses on biodiversity in meadow ecosystems. The rapid spread of giant hogweed commenced in the late 1980s, coinciding with significant changes in agricultural production systems and markets following the collapse of communism [Bogdanov et al. 2021]. As agriculture experienced a dramatic decline, hogweeds were no longer subjected to regular mowing. Giant hogweed has spread aggressively across various regions, displacing native flora. Giant hogweed's rapid and uncontrolled growth significantly disrupts the ecological integrity of meadow ecosystems [Bogdanov et al. 2021]. Its extensive foliage forms dense

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stands, leading to habitat degradation by outcompeting native plant species. This degradation reduces habitat availability for other flora, thereby diminishing the overall biodiversity of the ecosystem [Baležentiene 2013; Renčo et al. 2019; Grzędzicka, Reif 2020]. This invasive plant is a problem even in national parks.

Another particularly troublesome invasive alien plants are the goldenrods (*Solidago spp*.). Goldenrods have a remarkable ability to colonize meadows, Natura 2000 sites, abandoned fields and rural areas [Szymura et al.2016]. In Central Europe, they have become dominant in up to 90% of former grasslands, leading to the creation of homogenous habitat patches with their dominance reaching almost 100%. Previous studies suggests that goldenrods significantly impact biodiversity [Bezemer et al. 2014].

The aim of this study was to assess the impact of invasive plants – alien goldenrods on the population size of *Phengaris* butterflies – *Ph. teleius* and *Ph. nausithous,* and giant hogweed on the diversity of the Heteroptera fauna. A second objective was to assess the effectiveness of the conservation measures carried out in the protected areas and to prepare further conservation recommendations. I hypothesized the negative impact of these alien invasive plants on insect abundance and assemblages.

2. METHODS

2.1. Meta-population of *Phengaris* butterflies near Jaworzno (Silesian Voivodeship)

Phengaris teleius and *Ph. nausithous* were caught at a location near Jaworzno (Śląskie Voivodeship) in the Jaworzno Meadows PLH240042 Natura 2000 site and adjacent area (Fig. 1 a). Butterflies were caught by two people using the Capture-Mark-Recapture method in two complexes of habitat patches: JA - Jaworzno Górka (six habitat patches) (Fig. 1 b) and JB - Łąki Ciężkowickie (five habitat patches) (Fig. 1 c). The area of the patches did not exceed 1 ha (Fig. 1 a, b, Table 1, Table 2).

Surveys took place at the time of peak of butterfly flight period and just afterwards between 21 July 2022 and 5 August 2022 between 09:00 and 17:00, on rain-free days, with temperatures no lower than 20 ℃. In the JA complex, capturing of individuals was carried out for eight days, while in the JB complex trapping lasted for seven days, due to reduced butterfly numbers and the mowing of the J4B meadow (Fig. 1 c).

Butterflies were captured on each habitat patch for one hour. Individuals were captured with an entomological net, marked on the wing with a unique identifier and finally released. In addition, for each habitat patch, data were recorded on the relative cover of the host plant *Sanguisorba officinalis* (Linneus, 1753), the two invasive goldenrod species (pooled cover of *S. canadensis* (Linneus, 1753) and *S. gigantea* (Aiton, 1789)) and the cover of the expansive species – *Calamagrostis epigjos* (L.) (Roth,1788) and *Phragmites australis* (Cav.) Trin. ex Steud, 1841). An 11-point scale was used, where 0 - none, 1 - cover up to 10%, 2 - cover above 10% to 20%, etc. Plant coverages were allowed to add up to a number greater than 10, that is, greater than 100%.

Each habitat patch was mapped. The boundaries of the habitat patches were marked using a GPS receiver. A polygon layer was created to calculate the area of the patches and prepare overview maps.

Using the POPAN model in programme MARK 10.0 [White, Burnham 1999], abundances of local butterfly populations were estimated with 95% confidence intervals. Abundances for each species were calculated by sex. In some cases it was not possible to estimate population abundances or confidence intervals, due to very low probability of capture and very low numbers of captured butterfly individuals. In such cases, only numbers of individuals caught are presented (Table 1, Table 2, Figs. 2 a, 2 b).

For further analysis, the estimated butterfly abundances were converted to relative densities of individuals per 1 ha of area (Table 1, Table 2, Figs. 2 a, 2 b). Butterfly densities, separately for butterfly species, were correlated with goldenrod cover and the ratio of expansive plant cover (sum of goldenrod and other aforementioned plants) to host plant cover. In addition, the effect of goldenrod and host plant on the summed density of both butterfly species was tested using ANOVA in the Statistica 13 software. In this analysis, plant cover was included as a categorical factor: low cover (up to 10%) and high cover (above 10%).

2.2. Heteroptera bugs in Krempna (Magurski National Park) (Podkarpackie Voivodeship)

The capturing of Heteroptera bugs was carried out in the area of the village of Krempna (Podkarpackie Voivodeship) on sites with *H. mantegazzianum* giant hogweed and reference sites free from this invasive plant (Fig. 3). Field work took place on rain-free days between 11:00 and 16:00, at temperatures not lower than 19 ℃, after giant hogweed removal treatments. The surveys covered the cadastral plots designated for the project, where transects were selected within open grassland habitats (Fig. 3). A total of 19 transect sections of 50 m were delineated – 11 invasive plant sections and eight reference transects (Fig. 3). Heteroptera bug capturing was carried out three times on the same transects in order to cover a full season of surveys and to be able to include the whole spectrum of species. The first was the spring capture that took place on 21–22 June 2022; the second was the summer trapping on 8–9 August 2022, and the third one was the autumn capture that took place on 28 September 2022.

Insects were caught using a sweep net. A 50-m section consisted of 100 scoops. Each step was followed by one blow with the sweep net. A total of 100 scoop strokes were made on each section. The above methodology ensures that the results obtained are standardised, due to the

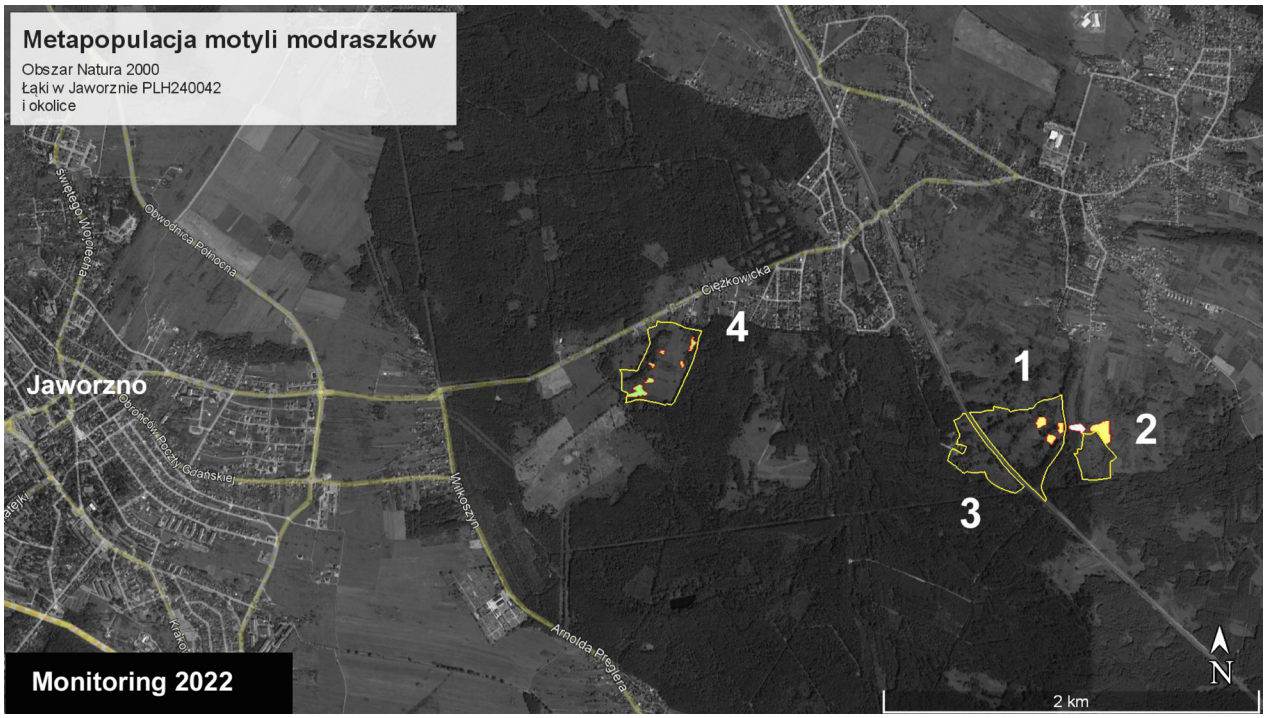


Figure 1. The location of surveyed habitat patches where the abundance of *Ph. nausithous* and *Ph. teleius* populations was studied: (a) Location of patches in individual parts 1-4 of the Natura 2000 site "Łąki w Jaworznie" PLH240042; (b) Complex of patches JA - Jaworzno Górka; (c) Complex of patches JB - Łąki Ciężkowickie.

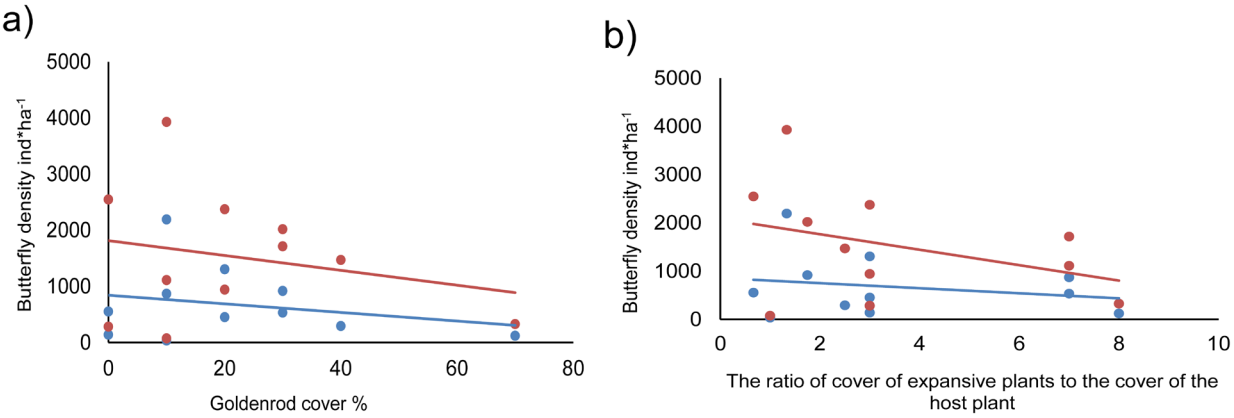


Figure 2. (a) The relationship between the relative density of butterflies and the coverage of invasive hawkweeds and (b) the ratio of coverage of invasive plants to the coverage of the butterflies' host plant. *Ph. teleius* is marked in red, and *Ph. nausithous* is marked in blue. "Density" denotes relative butterfly density (abundance) expressed as number of individuals per one ha of area.

equal sample size and identical effort on each section. Material from each transect was poured into insect bags and labelled with the transect ID and date of trapping. The collected material was placed in a freezer to kill the insects and store them until sorting.

Heteroptera bugs from a given trapping and transect were separated from other captured insects and plant fragments, then sorted into small containers and described. The insects were then labelled to species and the numbers of individuals per bug species were counted. Finally, the number of species and the number of individuals present on each transect section were summarised.

The effect of environment type – transects with giant hogweed vs. reference transects – on the number of species (Poisson model) and the number of individuals (negative binomial model) was tested. Next, permutation

Table 1. Population sizes with 95% confidence intervals of *Ph. nausithous* butterfly in habitat patches within the Natura 2000 site "Łąki w Jaworznie" PLH240042 and its vicinity in the year 2022.

ID	Patch area [ha]	Sex	N	CI -	CI +	Density [ind*ha^{-1}]
J1A	**0.159**	M	56	39	80	553
		F	32	15	67	
J2A	**0.057**	M	62	34	113	2193
		F	63	35	114	
J3A	0.062	M	24	12	45	871
		F	30	18	51	
J4A	0.109	M	31	19	51	532
		F	27	15	48	
J5A	**0.413**	M	208	119	363	918
		F	171	84	348	
J6A	0.072	M	41	33	50	1306
		F	53	46	63	
J1B	**0.167**	M	33	22	49	293
		F	16	8	35	
J2B	0.204	M	*13*	x	x	123
		F	*12*	x	x	
J3B	**0.274**	M	61	23	165	453
		F	63	24	166	
J4B	0.315	M	*6*	x	x	35
		F	*5*	x	x	
J5B	**0.815**	M	57	40	81	141
		F	58	41	82	

In cases where it was not possible to estimate the population size, the numbers of captured individuals were italicized. "Density" denotes relative butterfly density (abundance) expressed as number of individuals per 1 ha of area.

Table 2. Population sizes with 95% confidence intervals of *Ph. teleius* butterfly in habitat patches within the Natura 2000 site "Łąki w Jaworznie" PLH240042 and its vicinity in the year 2022.

ID	Patch area [ha]	Sex	N	CI -	CI +	Density [ind*ha^{-1}]
J1A	**0.159**	M	213	133	343	2547
		F	192	113	326	
J2A	**0.057**	M	114	61	212	3930
		F	110	58	210	
J3A	0.062	M	37	x	x	1113
		F	32	x	x	
J4A	0.109	M	130	82	206	1716
		F	57	36	91	
J5A	**0.413**	M	433	367	510	2019
		F	401	336	479	
J6A	0.072	M	84	64	110	2375
		F	87	67	113	
J1B	**0.167**	M	134	87	206	1473
		F	112	67	188	
J2B	0.204	M	20	13	29	328
		F	47	33	66	
J3B	**0.274**	M	135	64	282	942
		F	123	56	267	
J4B	0.315	M	*8*	x	x	76
		F	*16*	x	x	
J5B	**0.815**	M	137	91	206	285
		F	95	63	143	

In cases where it was not possible to estimate the population size, the numbers of captured individuals were italicized. "Density" denotes relative butterfly density (abundance) expressed as number of individuals per 1 ha of area.

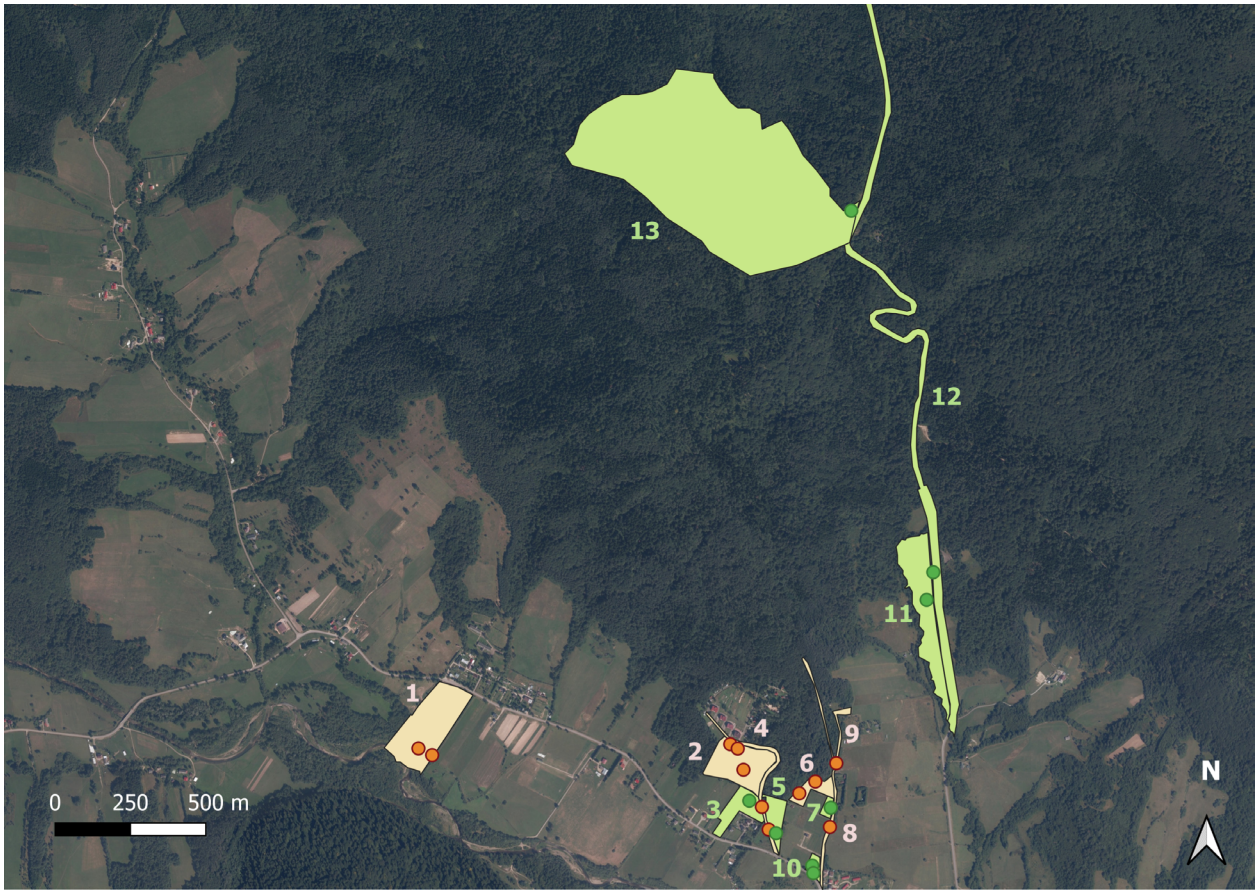


Figure 3. The location of research sites in Krempna within cadastral parcels. Sites with invasive hogweed are marked in orange, while reference sites are marked in green. Points indicate the locations of transect sections.

methods, based on the Bray-Curtis dissimilarity measure, were tested whether species assemblages differed between transects with the invasive plant and reference transects. The analyses were performed in R 4.1.3 [R Core Team 2022] using a vegan package [Oksanen et al. 2022].

3. RESULTS

3.1. Habitat quality and populations of *Phengaris* butterflies in the Jaworzno Meadows Natura 2000 site

The JA complex of patches (Fig. 1a, 1b) was characterised by higher cover of *S. officinalis* – the host plant of the butterflies – and lower cover of goldenrod compared to the JB complex (Fig. 1a, 1c). The JA complex was entirely located in part 4 of the Natura 2000 site, while the JB complex was located in the north-eastern location of one part of the site, patches J1B-J3B, and in the buffer zone of part 2 of the site, patches J4B and J5B (Fig. 1a, according to the [Regulation… 2019]). Part 3 was not surveyed, as no butterfly populations were found there, and a significant area of this part of the site was overgrown with dense patches of goldenrod, which often reached 100% coverage. Butterflies may be sparsely distributed there but could not be detected. Parts 1 and 2 of the area are also largely overgrown with goldenrod and shrubs. In the case of part 2, a fairly good habitat for butterflies is provided by the site's buffer zone, which attracts them. However, patch J4B was mown around 2 August, during the butterfly flight period (Fig. 1b). Part 4 of the area is the best preserved. The large area in its centre (between patches J4A and J3A and patches J2A and J1A) is regularly mown, and the remaining unmown patches have good habitat conditions (Fig. 1b). The largest area is patch J5A, which is covered with vegetation characteristic of Molinietalia meadows (Fig. 1b, Table 1, Table 2).

Both butterfly species surveyed occurred in each of the habitat patches studied. *Ph. teleius* was a more abundant species than *Ph. nausithous*. All local populations of *Ph. teleius* surveyed in both the JA and JB complexes were characterised by higher numbers of individuals than populations of the sympatric species *Ph. nausithous* (Table 1, Table 2).

Populations of both species inhabiting the JA complex were more numerous than those living in the JB complex. The most abundant populations of both species occur sequentially in patches J5A, J1A and J2A in the JA complex

and J3B, J1B and J5B in the JB complex. Patches J2A and J6A were characterised by high relative butterfly densities in the JA complex, and patches J1B and J3B in the JB complex (Table 1, Table 2).
There were trends of decreasing butterfly densities with increasing goldenrod cover and increasing the ratio of expansive plant to host plant cover (Figs. 2a, 2b). However, these trends did not reach statistical significance. For goldenrod and *S. officinalis* cover treated as categorical variables – low cover vs. high cover – host plant cover proved to be the decisive factor (low 1392 ± 518 SE, high 3482 ± 679 SE) F = 5.99, P = 0.044, while goldenrod cover and interaction did not reach statistical significance, F = 0.46, P = 0.520 and F = 3.88, P = 090; N = 11, respectively.

3.2. Diversity of Heteroptera bugs in Krempna under pressure of giant hogweed invasion

A total of 60 species Heteroptera bugs were found. Forty-two species were found on sites with hogweed present, while 44 species were found on reference sites (Table 3). The mean number of individuals was more than twice as high at the reference sites compared to the mean number of individuals at the hogweed sites (Wald Stat. = 9.24, P = 0.002) (Fig. 4). A similar effect was observed for the mean number of species. However, this effect was at the limit of statistical significance (Wald Stat. = 3.39, P = 0.065) (Fig. 4). Species assemblages of Heteroptera bugs occurring in the reference sites differed significantly from those in the sites where invasive giant hogweed was growing (pseudo-F = 1.66, P = 0.046). Mean species abundances in both habitat types are shown in Table 3. Species are ranked from those that occurred most abundantly. Species with a cumulative weight of 0.8 are most responsible for the difference found. Species whose abundances were statistically different have been highlighted. Of the most abundant species, all those whose contribution was statistically significant reached higher abundances at the reference sites (Table 3). Other species that were statistically significantly different were also more abundant at the reference sites (Table 3). It should be noted that the group of reference sites included more species found only in this environment compared to the opposite situation – the number of species found only in sites with invasive giant hogweed (Table 3).

4. DISCUSSION AND CONSERVATION RECOMMENDATIONS

The study showed negative impacts of invasive plants on insects: two umbrella species, the butterflies *Ph. teleius* and *Ph. nausithous,* whose habitat is overgrown by alien goldenrod and the Heteroptera bugs of meadow habitats invaded by invasive hogweed. The negative impact of invasive plants is reflected in the displacement of native plant species and the alteration of habitat conditions due to allelopathic substances secreted by invasive plants and the disruption of naturally occurring vegetation structure. Invasive plants reduce the abundance of surveyed insects and, in the case of Heteroptera bugs, also the number of species living in such an environment. Invasive hogweed also significantly affects the assemblage structure of the Heteroptera bugs.

4.1. *Phengaris* species and invasive goldenrods

The habitat of the surveyed butterflies is in the Molinion meadows [Sielezniew, Dziekańska 2010]. These butterflies require two key resources in their life cycle: the host plant bloodroot and the host ants of the genus *Myrmica*. Females lay their eggs on the heads of flowering *S. officinalis* [Sielezniew, Dziekańska 2010]. Conservation efforts should specifically aim to maintain a habitat that can provide key resources described – a flowering host plant from July to September and the presence of host ants [Nowicki et al. 2007].
For the inventoried Natura 2000 site Łąki w Jaworznie (Meadows in Jaworzno), the most important threats are listed in order (according to the Order of the Regional Director for Environmental Protection): abandonment/non-mowing, alien invasive species, problematic native species, land filling, land reclamation and drainage, and change in vegetation composition (succession). The threats listed continue to exist, and the state of habitat conservation and its impact on current butterfly population numbers is a result of land use regime, insufficient or misfunctioning conservation measures or even a lack of such measures from the establishment of the Natura 2000 site to the present.
The higher abundance of *Ph. teleius* populations than the sympatric *Ph. nausithous* can be considered a typical situation, as this is most often found in Poland [Nowicki et al. 2007]. Very important from the point of view of the protection of the population of *Phengaris* butterflies and the importance of the studied Natura 2000 site is the fact that on each patch of habitat in the two studied complexes JA and JB both butterfly species occur simultaneously.
Part 4 of the site with the JA complex is the best preserved in terms of habitat, and the most abundant local butterfly populations were recorded there. These patches have not been mown for many years and are overgrown with goldenrod and shrubs. There is also a succession towards vegetation from the association Filipendulion [Matuszkiewicz 2008]. The largest, central fragment of part 4 is regularly mown, however, not at the recommended time, but at a time convenient for the plot owners. With the current management – centre of the site mowed regularly but at the wrong time, and overgrowing edges of the Natura 2000 site – butterfly populations may still persist for a long time, even in a 20-year perspective.
In order to maintain abundant butterfly populations in the long-term perspective, parts of the area that have

Table 3. Mean difference in Heteroptera bug species assemblages along 50m transect sections between reference sites and sites with invasive hogweed. Species with significantly different mean abundances are highlighted.

Species	Reference sites	Invaded sites	Cumulative weight	P-value
Leptopterna dolabrata (L., 1758)	22.1	6.8	0.22	0.153
Acetropis longirostris P., 1785	16.3	1.5	0.39	0.016
Stenotus binotatus (F., 1794)	5.0	2.7	0.48	0.85
Aelia acuminata (L., 1758)	3.1	0.6	0.54	0.04
Stenodema laevigata (L., 1758)	1.0	2.5	0.59	0.995
Adelphocoris lineolatus (G., 1788)	3.3	0.4	0.62	0.446
Megaloceroea recticornis (G., 1785)	0.8	0.9	0.65	0.931
Capsodes gothicus (L., 1758)	0.5	1.1	0.67	0.993
Notostira erratica (L., 1758)	0.9	1.0	0.69	0.861
Eysarcoris aeneus (S., 1763)	0.9	1.2	0.72	0.995
Nabis flavomarginatus S., 1847	2.8	0.1	0.74	0.045
Strongylocoris leucocephalus (L., 1758)	0.8	0.1	0.76	0.003
Adelphocoris seticornis (F., 1775)	0.9	0.2	0.77	0.024
Capsus ater (L., 1758)	0.0	0.8	0.78	0.992
Eurygaster maura (L., 1758)	0.9	0.0	0.80	0.002
Dolycoris baccarum (L., 1758)	0.4	0.5	0.81	0.994
Orthotylus flavosparsus (S., 1841)	0.1	0.4	0.82	0.965
Lygus pratensis (L., 1758)	0.1	0.5	0.83	0.996
Peribalus strictus (F., 1803)	0.0	0.5	0.84	0.955
Acteropis carinata (H-S., 1841)	0.4	0.2	0.85	0.608
Horistus orientalis (G., 1790)	0.3	0.5	0.86	0.994
Coptosoma scutellatum (G., 1785)	0.5	0.0	0.87	0.01
Nabis rugosus (L., 1758)	0.3	0.5	0.88	1
Closterotomus fulvomaculatus (De G., 1773)	0.0	0.4	0.89	0.989
Plagiognathus bipunctatus (R., 1883)	0.3	0.0	0.90	0.004
Polymerus nigrita (F., 1807)	0.1	0.3	0.91	0.979
Lygus rugulipennis P., 1911	0.1	0.2	0.91	0.945
Lygocoris pabulinus (L., 1761)	0.3	0.1	0.92	0.569
Coreus marginatus (L., 1758)	0.0	0.3	0.93	0.986
Heterocordylus genistae (S., 1763)	0.1	0.2	0.93	0.976
Rubiconia intermedia (W., 1811)	0.1	0.1	0.94	0.839
Notostira elongate (G., 1785)	0.3	0.0	0.94	0.01
Globiceps fulvicollis J., 1877	0.1	0.0	0.95	0.006
Picromerus bidens (L., 1758)	0.3	0.0	0.95	0.016
Carpocoris purpureipennis (De G., 1773)	0.1	0.0	0.95	0.006
Podops inunctus (F., 1775)	0.1	0.0	0.96	0.016
Adelphocoris reichelii (F., 1836)	0.1	0.0	0.96	0.016
Nabis limbatus D., 1851	0.1	0.0	0.96	0.016
Orthocephalus brevis (P., 1798)	0.0	0.2	0.97	0.988
Polymerus unifasciatus (F., 1794)	0.1	0.1	0.97	0.962
Rhopalus parumpunctatus S., 1829	0.1	0.0	0.97	0.01
Adelphocoris quadripunctatus (F., 1794)	0.1	0.0	0.97	0.018
Himacerus boops (S., 1870)	0.1	0.0	0.98	0.017
Apolygus spinolae (M-D., 1841)	0.0	0.1	0.98	0.978
Plagiognathus chrysanthemi (W., 1804)	0.0	0.1	0.98	0.978
Eurygaster testudinaria (G. 1785)	0.4	0.0	0.98	0.031
Lygus punctatus (Z., 1838)	0.0	0.1	0.99	0.98

Continued **Table 3**. Mean difference in Heteroptera bug species assemblages along 50m transect sections between reference sites and sites with invasive hogweed. Species with significantly different mean abundances are highlighted.

Species	Reference sites	Invaded sites	Cumulative weight	P-value
Apolygus lucorum (M-D., 1843)	0.0	0.1	0.99	0.983
Carpocoris fuscispinus (B., 1850)	0.0	0.1	0.99	0.988
Pinalitus cervinus (H-S., 1841)	0.0	0.1	0.99	0.988
Stenodema calcarata (F., 1807)	0.0	0.1	0.99	0.987
Phylus coryli (L., 1758)	0.0	0.1	0.99	0.987
Orthops basalis (C., 1853)	0.0	0.1	0.99	0.987
Teratocoris antennatus (B., 1852)	0.0	0.1	1.00	0.987
Corizus hyoscyami (L., 1758)	0.0	0.1	1.00	0.991
Myrmus miriformis (F., 1807)	0.1	0.0	1.00	0.029
Thyreocoris scarabaeoides (L., 1758)	0.1	0.0	1.00	0.031
Palomena prasina (L., 1761)	0.1	0.0	1.00	0.031
Pentatoma rufipes (L., 1758)	0.1	0.0	1.00	0.031

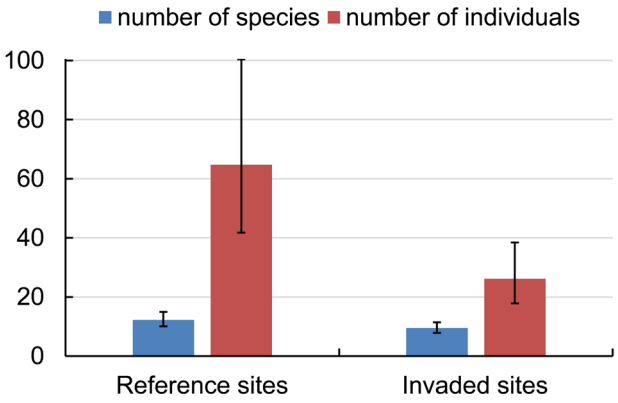


Figure 4. Mean number of species and mean number of individuals of Heteroptera bugs with a 95% confidence interval at reference sites and sites with invasive hogweed.

not been mown so far should be mown in rotation, every other year [Sielezniew, Dziekańska 2010; Kalarus et al. 2013]. This frequency of mowing is fully sufficient, as goldenrod is present sparsely in part 4. In addition, the negative impact of goldenrod on butterflies at the initial stage of the invasion can be partly compensated by the high cover of the host plant. However, the time of mowing is very important. Much of the area in the centre of part 4 is mown in June or early July before the flight period of the butterflies, thus sterilising the habitat and making it inaccessible to the butterflies. Butterflies of the genus *Phengaris* require a flowering host plant to reproduce [Sielezniew, Dziekańska 2010]. Mowing should absolutely be carried out no earlier than mid-September and no later than the end of November [Nowicki et al. 2007, 2013; Sielezniew, Dziekańska 2010].

In parts 1 to 3 of the Natura 200 site, the problem of goldenrod invasion and succession is much greater than in part 4, which has had a negative impact on the abundance of butterflies. In addition, the problem of land drainage is also visible – in parts 1 and 2. In the JB complex, less abundant local butterfly populations were found with critically low abundance in patch J2B, where goldenrod cover reached 70%. In parts 1–3, mowing was mostly abandoned, leading to a situation where goldenrod coverage in part 3 reaches up to 100% and no butterflies could be found there. In the area where goldenrod cover is higher than 60%, mowing should be carried out at least twice a year at times before goldenrod flowering and later when regrowth of the cut invasive plant occurs [Kalarus et al. 2013]. Where goldenrod cover is lower patches of habitat should be mown once a year at the correct autumn date.

For the smallest part of the Natura 2000 site, part 2, there is an additional threat not previously considered. Part 2 is threatened by succession, invasion of goldenrod and deterioration of habitat conditions. On the other hand, in its buffer zone there are regularly mown, large patches of habitat that attract butterflies – for example, patches J4B and J5B. When habitat condition deteriorates in part 2 of the Natura 2000 site, butterflies disperse in search of the resources they need to survive [Nowicki, Vrabec 2011; Nowicki et al. 2014] and end up in the habitat patches in the buffer zone. There, the butterflies lay their eggs on the flowering host plant. However, their reproductive efforts are wasted, and a new generation of butterflies will not emerge due to the mowing of these patches when the butterflies fly, leading to the death of the eggs laid and the young larvae already feeding on the host plant. Patches such as meadows J4B and J5B are an ecological trap for the investigated butterflies. In order to ensure the survival of the butterflies in the long term, the habitat within the Natura 2000 site should be maintained in the best possible condition. The mowing schedule must be unconditionally aligned with conservation goals, even if other objectives appear profitable [cf. Szyszko-Podgórska 2019; Wróbel

et al. 2022]. One should also remember about proper drainage, which will prevent the drying out of the butterfly habitat [cf. Syed, Shuqi 2022].
It is worth noting that even small patches of poorer quality habitat are important for butterflies. High relative densities of the butterflies have been observed in such patches. Such habitat patches can play an important role in the butterfly migration process and act as stepping-stones, thereby improving landscape connectivity [Kalarus, Nowicki 2015].

4.2. Heteroptera bugs and invasive hogweed

Invasive hogweed is a major problem in the Magurski National Park. The hogweed appears on meadows, forest paths, forest edges, roadsides, along drainage ditches and even in the gardens of private properties and often reaches large coverages. The study was carried out in the first year that active hogweed removal treatments were introduced in the study area. Despite this fact, a significant negative impact of hogweed on the abundance and number of Heteroptera bug species was found. Hogweed, also affects the bugs at the assemblage level. The most abundant species in the assemblages occurred less abundantly on sites with hogweed. Similarly, among the less abundant species, there were more species (especially those with a statistically significant proportion) that occurred only on reference sites.
The flowers of invasive hogweeds were characterised as simple habitus and not specialised for any particular type of pollination. They relied on insects for pollination and were attractive to a diverse group of generalist pollinators. A wide range of insects, including Hymenoptera (bees, wasps, ants), Diptera (flies), Coleoptera (beetles), and Hemiptera (bugs), visited these flowers for nectar and pollen [Grace, Nelson 1981; Hansen et al. 2007; Nielsen et al. 2008]. Previous studies have shown that hogweeds are used mostly by polyphagous insect species or species specific for *Heracleum* [Hansen et al. 2006]. Other studies reported negative effects on solitary bees [Davis et al. 2018]. Little was known of the influence of hogweeds on whole insect assemblages, for example, Heteroptera bugs in light of comparisons of invaded and not invaded grasslands.
Hogweed appears to exclude stenotopic species and those with specialist habitat requirements. The negative impact of hogweed can be considered a strong impact, as both abundant and less abundant species of Heteroptera bugs were found in lower abundance on sites with hogweed compared to reference sites. In addition, the negative impact of hogweed has emerged, despite the removal treatments carried out.
Removal treatments have only recently been introduced, and the reduction of hogweed and its negative effects on biodiversity may take several years to become apparent. Efforts should be made to increase the abundance and diversity of Heteroptera bugs, on sites where hogweed was growing.
A major constraint that will affect the success of hogweed removal efforts is the fact that not all landowners and municipalities will undertake simultaneous hogweed removal. The hogweed removed in one location may be replaced by hogweed that arrives/spreads from another nearby location where no removal action has been carried out. In order to reduce the negative effects of hogweed, consistent, long-term management to remove the invasive plant is essential.
Giant hogweed is known for its substantial size, reaching heights of up to 4–5 m, featuring extensive clusters of leaves measuring 2–3 m in length, and exhibiting stable flowering shoots that resemble woody plants [Panasenko 2017]. Additionally, it produces large inflorescences. Its invasion has resulted in a complex system that encompasses various aspects of ecosystems, including environment, agriculture, forestry, land use, hydrosphere, soil system, global change ecology, biodiversity, management, and conservation. The understanding of its invasion requires a multidisciplinary research system that attract specialists from diverse fields who have conducted extensive studies on these plants.

4.3. Conclusions

- *Phengaris* butterflies absolutely require two resources – a flowering host plant and host ants of the genus *Myrmica*.
- In the JA and JB grassland complexes both species occur, and *Ph. teleius* is more numerous.
- Part 4 of the Natura 2000 site has the best habitat condition and the most abundant butterfly populations.
- Parts 1–3 of the site are seriously threatened by succession and invasion of goldenrods.
- In the smallest part 2, its buffer zone attracts butterflies and provides an ecological trap for them, which negatively affects butterfly populations.
- The negative effect of goldenrod on butterflies at the initial stage of invasion may be partially offset by the high cover of the butterfly host plant.
- Meadows providing habitat for the butterflies must be mown in the autumn from mid-September to the end of November.
- Mowing meadows during butterfly flight, or just before butterfly flight, is not allowed and is contrary to conservation objectives.
- In areas where goldenrod cover reaches more than 60%, more frequent mowing should be used – the first before this invasive plant flowers.
- Small, poorer quality patches of habitat are also important for butterfly conservation, as they support butterfly dispersion and improve habitat connectivity.
- Invasive hogweed has a negative impact on the abundance and assemblage structure of the assemblage of Heteroptera bugs.
- The negative impact of hogweed has been detected despite the application of the first eradication treatments.

– The effects of hogweed control may only become apparent after several years.
– Success in eradicating hogweed may be limited due to the spread of hogweed from locations where removal is not applied.

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