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Original Research

Ecological Characteristics of Habitats Suitable for *Solidago* × *niederederi* Khek (Asteraceae) Establishment

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Abstract

In this study, phytosociological plots are used to describe species composition and ecological conditions of habitats in which *Solidago* ×*niederederi*, a natural hybrid between the North American *S. canadensis* and the European *S. virgaurea*, was found as established in Poland. Four groups of phytosociological plots have been distinguished based on the unweighted pair group method with arithmetic mean. The groups did not differ significantly in the mean number of species per plot and in the species evenness, in contrast to the mean values of Shannon-Wiener index and Simpson index. In each group of phytosociological plots, *S.* ×*niederederi* and *S. virgaurea* had the highest value of constancy degree. Meadow species of the class *Molinio-Arrhenatheretea* had the highest share in all groups of phytosociological plots. Considering the Ellenberg's indicators, the groups of phytosociological plots differed significantly in the mean values of the light and thermal conditions, soil moisture, soil reaction, and nutrients. The results suggested that *S.* ×*niederederi* can be established in well light places with partial shade and temperate conditions, on moist, moderately acidic to almost neutral soils with average fertility and is strongly associated with *S. virgaurea* and meadow species of *Molinio-Arrhenatheretea*.

Keywords: alien species, ecological indicators, hybrid, phytosociological plots

Introduction

Natural hybridization between alien and native plant species reflects the consequences of introduction, establishment and invasion of alien plants [1-8]. According to recommendation by Pyšek et al. [9], hybrids between alien and native plant species should be treated as alien species and they can pose a threat to native biodiversity [1-4]. In extreme cases, when hybridization between alien and native species is common in the wild and the hybrids are fully vigorous

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and fertile, pure native species cannot be recovered by removing the alien, resulting in replacement or local extinction of native species by introgressive hybridization [10]. It is commonly known that plant hybrids are usually found in disturbed habitats, as disturbance creates intermediate conditions in which hybrids can survive [2, 5]. However, the persistence of many plant hybrids is often limited by their sterility and non-fitness [11-12]. Phytosociological studies on habitat preferences of hybrids between alien and native plants are rarely undertaken [13]. Considering the need for nature conservation, it is important to determine the species composition of habitats in which such hybrids can occur and, what is more important, to evaluate their impacts on native biodiversity.

Solidago ×niederederi Khek (Asteraceae), a natural hybrid between the North American *S. canadensis* L. and the European *S. virgaurea* L., has been reported from several countries in Europe [14-19]. It is a perennial plant which spreads by wind-dispersed fruits (cypselas). However, the fruit set in the hybrid can be negatively affected by its reduced pollen viability [17, 20]. *Solidago ×niederederi* is considered as an established alien in Austria, Poland, Lithuania, and Latvia [19, 21]. According to Pliszko and Kostrakiewicz-Gierałt [22], the hybrid can pose a threat to native *S. virgaurea* by competing for pollinators. Moreover, there is a probability that the hybrid can cause genetic erosion of *S. virgaurea* populations by introgressive hybridization. As currently known, *S. ×niederederi* occurs in anthropogenic habitats such as abandoned fields, roadsides, railway embankments, disused quarries, tree plantations, forest clearings, and arable fields with grass-legume mixtures, usually together with its parental species [7, 13-15, 23-25]. Moreover, Pliszko and Kostrakiewicz-Gierałt [23] evidenced that the most abundant populations of the hybrid in Poland were found on abandoned fields. Unfortunately, phytosociological studies on the habitats occupied by the hybrids have not been undertaken so far. Moreover, in the context of its establishment habitat requirements of *S. ×niederederi* are insufficiently recognized [17]. In this paper, we aimed to describe the conditions of habitats suitable for *S. ×niederederi* establishment, using phytosociological data.

Materials and Methods

Phytosociological Survey

The study was based on 90 phytosociological plots (relevés) of 25 m^2 made in agricultural landscape, at the altitude from 104 to 567 m above sea level, in north-eastern, central and southern parts of Poland, in 2013-2016 (Table 1), including vascular plant species

Table 1. Origin of phytosociological plots sampled for the study.

Plot number	Name of Location	GPS coordinates	Altitude [m a.s.l.]	Habitat	Date of sampling
1	Wysieka near Bartoszyce	54º17.631′N/20º43.481′E	104	Abandoned field	17 Aug 2013
2	Kraków	50º05.297′N/19º50.601′E	241	Disused limestone quarry	24 Aug 2013
3	Kraków	50º05.391′N/19º50.440′E	226	Disused limestone quarry	24 Aug 2013
4	Kraków	50º05.420′N/19º50.473′E	229	Disused limestone quarry	24 Aug 2013
5	Kraków	50º05.414′N/19º50.473′E	230	Disused limestone quarry	24 Aug 2013
6	Kraków	50º05.443′N/19º50.444′E	228	Disused limestone quarry	24 Aug 2013
7	Izdebnik	49º51.972′N/19º43.986′E	350	Abandoned field	29 Aug 2013
8	Izdebnik	49º51.974′N/19º43.982′E	350	Abandoned field	29 Aug 2013
9	Izdebnik	49º51.995′N/19º44.156′E	363	Abandoned field	29 Aug 2013
10	Głogoczów	49º54.689′N/19º52.338′E	241	Abandoned field	7 Sep 2013
11	Wrzosy	50º03.648′N/19º36.800′E	308	Abandoned field	15 Sep 2013
12	Wrzosy	50º03.585′N/19º37.035′E	331	Abandoned field	15 Sep 2013
13	Suwałki	54º04.528′N/22º57.068′E	165	Abandoned field	18 Aug 2014
14	Suwałki	54º04.534′N/22º57.065′E	165	Abandoned field	18 Aug 2014
15	Suwałki	54º04.529′N/22º57.076′E	164	Abandoned field	18 Aug 2014
16	Suwałki	54º04.515′N/22º57.026′E	165	Abandoned field	18 Aug 2014
17	Suwałki	54º04.505′N/22º56.998′E	166	Abandoned field	18 Aug 2014
18	Karasiewo	54º03.744′N/22º40.526′E	163	Abandoned field	19 Aug 2014

Table 1. Continued.

19	Bakałarzewo	54º06.004′N/22º39.489′E	169	Abandoned field	19 Aug 2014
20	Bakałarzewo	54º05.964′N/22º39.560′E	169	Abandoned field	19 Aug 2014
21	Bakałarzewo	54º05.962′N/22º39.558′E	168	Abandoned field	19 Aug 2014
22	Bakałarzewo	54º05.958′N/22º39.538′E	169	Abandoned field	19 Aug 2014
23	Bakałarzewo	54º05.981′N/22º39.525′E	169	Abandoned field	19 Aug 2014
24	Mieruniszki	54º10.788′N/22º33.522′E	191	Abandoned field	20 Aug 2014
25	Taciewo	54º09.287′N/22º48.435′E	202	Abandoned field	21 Aug 2014
26	Taciewo	54º09.289′N/22º48.429′E	203	Abandoned field	21 Aug 2014
27	Czajowice	50º11.444′N/19º48.554′E	438	Abandoned field	29 Aug 2014
28	Czajowice	50º11.467′N/19º48.529′E	440	Abandoned field	29 Aug 2014
29	Czajowice	50º11.487′N/19º48.507′E	442	Abandoned field	29 Aug 2014
30	Czajowice	50º11.528′N/19º48.470′E	443	Abandoned field	29 Aug 2014
31	Czajowice	50º11.461′N/19º48.403′E	445	Abandoned field	29 Aug 2014
32	Czajowice	50º11.429′N/19º48.395′E	448	Abandoned field	29 Aug 2014
33	Czajowice	50º11.128′N/19º48.421′E	436	Abandoned field	29 Aug 2014
34	Czajowice	50º11.136′N/19º48.438′E	436	Abandoned field	29 Aug 2014
35	Czajowice	50º11.142′N/19º48.433′E	435	Abandoned field	29 Aug 2014
36	Suwałki	54º07.409′N/22º57.129′E	178	Abandoned field	2 Sep 2014
37	Suwałki	54º07.398′N/22º57.132′E	180	Abandoned field	2 Sep 2014
38	Suwałki	54º07.392′N/22º57.124′E	179	Abandoned field	2 Sep 2014
39	Suwałki	54º07.392′N/22º57.124′E	179	Abandoned field	2 Sep 2014
40	Suwałki	54º07.389′N/22º57.122′E	179	Abandoned field	2 Sep 2014
41	Kociołki near Pluszkiejmy	54º17.415′N/22º27.762′E	198	Abandoned field	7 Sep 2014
42	Kociołki near Pluszkiejmy	54º17.445′N/22º27.740′E	193	Abandoned field	7 Sep 2014
43	Kociołki near Pluszkiejmy	54º17.451′N/22º27.804′E	192	Abandoned field	7 Sep 2014
44	Kociołki near Pluszkiejmy	54º17.444′N/22º27.831′E	194	Abandoned field	7 Sep 2014
45	Kociołki near Pluszkiejmy	54º17.442′N/22º27.835′E	193	Abandoned field	7 Sep 2014
46	Kociołki near Pluszkiejmy	54º17.436′N/22º27.830′E	194	Abandoned field	7 Sep 2014
47	Kociołki near Pluszkiejmy	54º17.448′N/22º27.887′E	197	Abandoned field	7 Sep 2014
48	Kociołki near Pluszkiejmy	54º17.458′N/22º27.933′E	198	Abandoned field	7 Sep 2014
49	Kociołki near Pluszkiejmy	54º17.398′N/22º27.926′E	200	Abandoned field	7 Sep 2014
50	Kociołki near Pluszkiejmy	54º17.394′N/22º27.734′E	196	Abandoned field	7 Sep 2014
51	Łapczyca	49º58.070′N/20º21.432′E	282	Abandoned field	13 Sep 2014
52	Warszawa Jeziorki	52º06.883′N/20º59.524′E	106	Abandoned field	16 Sep 2014
53	Warszawa Jeziorki	52º06.885′N/20º59.524′E	106	Abandoned field	16 Sep 2014
54	Warszawa Jeziorki	52º06.888′N/20º59.505′E	106	Abandoned field	16 Sep 2014
55	Warszawa Jeziorki	52º06.933′N/20º59.526′E	106	Abandoned field	16 Sep 2014
56	Warszawa Jeziorki	52º06.946′N/20º59.536′E	106	Abandoned field	16 Sep 2014
57	Zalesie Górne	52º01.483′N/21º00.685′E	109	Abandoned field	17 Sep 2014
58	Zalesie Górne	52º01.415′N/21º00.659′E	109	Abandoned field	17 Sep 2014
59	Zalesie Górne	52º01.412′N/21º00.664′E	110	Abandoned field	17 Sep 2014

Table 1. Continued.

60	Zalesie Górne	52º01.408′N/21º00.667′E	110	Abandoned field	17 Sep 2014
61	Lipna Wola	50º15.610′N/20º02.172′E	268	Abandoned field	19 Sep 2014
62	Lipna Wola	50º15.609′N/20º02.177′E	268	Abandoned field	19 Sep 2014
63	Januszowice near Celiny	50º15.316′N/20º02.585′E	293	Abandoned field	19 Sep 2014
64	Miechów	50º21.570′N/20º00.263′E	304	Balk	21 Sep 2014
65	Budzów near Jachówka	49º45.096′N/19º40.636′E	567	Abandoned field	30 Sep 2014
66	Harbutowice near Sułkowice	49º48.781′N/19º45.453′E	536	Abandoned field	30 Sep 2014
67	Harbutowice near Sułkowice	49º48.778′N/19º45.416′E	542	Abandoned field	30 Sep 2014
68	Dąbrowskie Osada	54º03.221′N/22º33.467′E	168	Roadside ditch	1 Aug 2015
69	Gołdap	54º17.870′N/22º18.505′E	170	Abandoned field	6 Aug 2015
70	Gołdap	54º17.881′N/22º18.534′E	173	Abandoned field	6 Aug 2015
71	Możne	54º03.259′N/22º31.038′E	163	Abandoned field	13 Aug 2015
72	Możne	54º03.231′N/22º30.983′E	166	Abandoned field	13 Aug 2015
73	Suwałki	54º06.126′N/22º53.240′E	177	Abandoned field	17 Aug 2015
74	Suwałki	54º06.079′N/22º53.153′E	179	Abandoned field	17 Aug 2015
75	Suwałki	54º06.050′N/22º53.059′E	176	Abandoned field	17 Aug 2015
76	Suwałki	54º06.054′N/22º53.020′E	176	Abandoned field	17 Aug 2015
77	Suwałki	54º06.023′N/22º52.999′E	180	Abandoned field	17 Aug 2015
78	Las Garbaski	54º08.092′N/22º36.597′E	178	Forest clearing	24 Aug 2016
79	Dąbrowskie	54º06.280′N/22º33.415′E	189	Roadside slope	25 Aug 2016
80	Pieńki near Możne	54º03.585′N/22º30.532′E	175	Roadside ditch	25 Aug 2016
81	Górne	54º15.672′N/22º26.507′E	180	Abandoned field	27 Aug 2016
82	Wolbrom	50º22.144′N/19º44.715′E	395	Abandoned field	9 Sep 2016
83	Wolbrom	50º22.137′N/19º44.697′E	394	Abandoned field	9 Sep 2016
84	Wolbrom	50º22.100′N/19º44.723′E	389	Abandoned field	9 Sep 2016
85	Podleśna Wola	50º24.704′N/20º00.923′E	343	Roadside slope	24 Sep 2016
86	Podleśna Wola	50º24.487′N/20º01.200′E	381	Abandoned field	24 Sep 2016
87	Palcza	49º49.231′N/19º44.665′E	537	Abandoned field	1 Oct 2016
88	Palcza	49º49.269′N/19º44.614′E	529	Abandoned field	1 Oct 2016
89	Palcza	49º49.485′N/19º44.413′E	478	Abandoned field	1 Oct 2016
90	Palcza	49º49.591′N/19º44.253′E	476	Abandoned field	1 Oct 2016

in accordance with the Braun-Blanquet method [26]. Initially, the hierarchical-numerical classification of phytosociological plots was performed using two methods, namely unweighted group pair method with arithmetic means (UPGMA) and weighted pair method with arithmetic means (WPGMA). The grouping of plots for each method was based on the presence/absence of species (0, 1 binary scale) and cover-abundance degree. In this way four dendrograms were obtained. However, only one dendrogram by the UPGMA method based on the presence/absence of species [27] was used in this study. This classification allowed us to separate four groups of phytosociological plots that were the most consistent with field observations. The classification was performed using a SYN-TAX 2000 package [28]. The constancy degree and the cover coefficient were calculated for species occurring in the plots. Habitat conditions within the plots were characterized by the Ellenberg's indicator values [29, 30], using a JUICE package [31]. The mean values of indicators of light

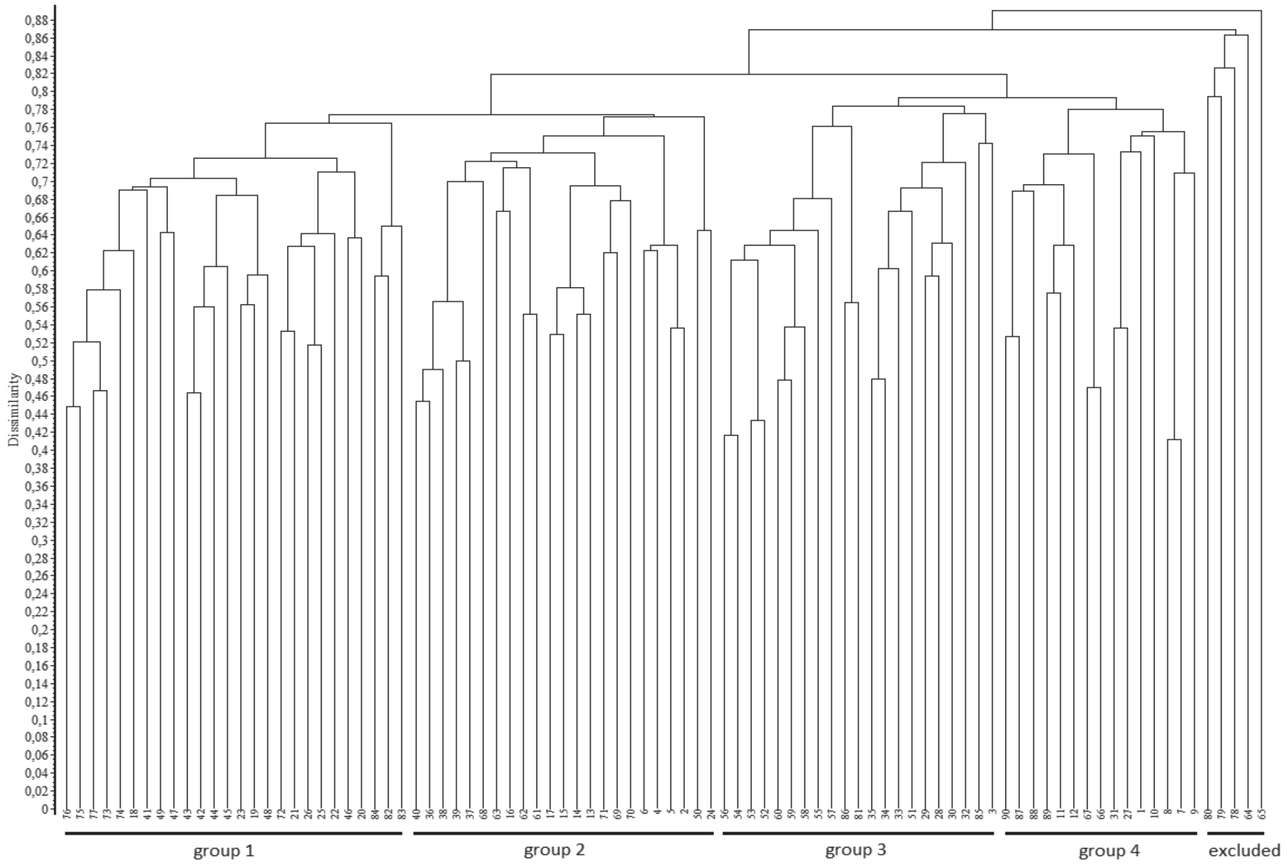

Fig. 1. Phytosociological plots grouping by UPGMA method.

conditions (L), thermal conditions (T), continentality (K), soil moisture (F), soil reaction (R), and nutrients (N) were calculated for the groups of phytosociological plots. To evaluate the diversity and quantitative relationships between the species in vegetation developed in different habitat conditions, the Shannon-Wiener index of diversity [32], species evenness [33], and Simpson index [34] were calculated as well. The affiliation of the species to syntaxonomic units followed Matuszkiewicz [35].

Statistical Analysis

The normality of the untransformed data was tested using the Kolmogorov-Smirnov test, while the homogeneity of variance was checked using the Levene test at the significance level of $P<0.05$. As the data in some groups were not consistent with the normal distribution and/or the variance was not homogeneous, the non-parametric Kruskal-Wallis *H* test was applied to check the statistical significance of differences in: (i) the number of species per plot, Shannon-Wiener index (H′), species evenness (J′), and Simpson index (SIMP) among particular groups of phytosociological plots and (ii) the values of Ellenberg's indicators among particular groups of phytosociological plots. The statistical analysis was performed using a STATISTICA 13 software.

Results and Discussion

Based on the UPGMA method, four groups of phytosociological plots (1-4) were established, excluding the plots number 80, 79, 78, 64 and 65, in which floristic composition differed significantly from the others and which were not uniform in comparison to all data (Fig. 1). The groups consisted of 26, 23, 21 and 15 plots with 109, 118, 114 and 103 vascular plant species, respectively. The groups did not differ significantly in the mean number of species per plot and in the species evenness (Table 2). On the other hand, the differences in the mean values of Shannon-Wiener index and Simpson index between the groups were statistically significant (Table 2). The highest value of Shannon-Wiener index was evidenced in group 4, while the lowest was in group 3, whereas the highest value of Simpson index was evidenced in group 1, and the lowest in group 3 (Table 2).

Species having a value of constancy degree equal to III or higher for at least one of the four groups of plots are presented in Table 3. In each group of plots, *Solidago ×niederederi* and *S. virgaurea* had the highest value of constancy degree, whereas *S. canadensis* had the highest value of constancy degree only in groups 3 and 4 (Table 3). The values of the cover coefficient of *S. ×niederederi* were higher in groups 1 and 2 than in groups 3 and 4. Moreover, *S. virgaurea* had the highest

Table 2. Mean number of species per plot (±SD), Shannon-Wiener index (H´), species evenness (J´), and Simpson index (SIMP) in four groups of phytosociological plots with *Solidago ×niederederi*.

Group of phytosociological plots	Mean number of species per plot	H´	J´	SIMP
1	21.7 (±4.3)	2.43[a]	0.79	0.85[a]
2	22.2 (±4.6)	2.36[ab]	0.76	0.81[ab]
3	19.8 (±3.5)	2.21[b]	0.74	0.79[b]
4	23.3 (±6.0)	2.44[ab]	0.78	0.84[ab]
The Kruskal-Wallis *H* test; *P* value	H=5.6; P=0.13[ns]	H=9.2; $P\leq0.05$	H=5.5; P=0.13[ns]	H=8.0; $P\leq0.05$

values of the cover coefficient in groups 1 and 4, whereas *S. canadensis* had the highest values of the cover coefficient in groups 3 and 4 (Table 3). Meadow species of the class *Molinio-Arrhenatheretea* had the highest share in all groups of plots. Floristic composition in groups 1 and 2 suggested more mesic soil habitats than those of groups 3 and 4. In group 1, *Dactylis glomerata* L. predominated together with other species of the class *Molinio-Arrhenatheretea* (i.e., *Arrhenatherum elatius* (L.) P. Beauv. ex J. & C. Presl and *Phleum pratense* L.). Also, some ruderal species of the class *Artemisietea vulgaris* (i.e., *Artemisia vulgaris* L. and *Picris hieracioides* L.) and *Agrostis capillaris* L. of the class *Trifolio-Geranietea* had a high cover coefficient value in this group. Moreover, a thermophilic character of some phytosociological plots of group 1 was indicated by the presence of *Trifolium arvense* L. and *Senecio jacobaea* L. Similarly, in group 2, *Arrhenatherum elatius* and *Dactylis glomerata* predominated with a high share of two ruderal species of the class *Artemisietea vulgaris*

Table 3. Constancy degree (Cd) and cover coefficient (Cc) values of selected species in four groups of phytosociological plots with *Solidago ×niederederi*. Species having a value of constancy degree equal to III or higher for at least one of the four groups of plots are presented in this table.

Group of phytosociological plots	1		2		3		4	
Constancy degree (Cd) and cover coefficient (Cc)	Cd	Cc	Cd	Cc	Cd	Cc	Cd	Cc
Solidago ×niederederi Khek	V	250.0	V	241.3	V	71.4	V	80.0
Solidago virgaurea L.	V	1084.6	V	717.4	V	754.8	V	1493.3
Solidago canadensis L.	III	592.3	III	497.8	V	1109.5	V	1360.0
ChCl. *Molinio-Arrhenatheretea*								
Achillea millefolium L.	V	244.2	IV	39.1	V	195.2	V	216.7
Dactylis glomerata L.	IV	1394.2	IV	1297.8	II	278.6	III	773.3
Arrhenatherum elatius (L.) P. Beauv. ex J. Presl & C. Presl	II	701.9	IV	2978.3	III	1454.7	I	150.0
Festuca rubra L. s. l.	II	242.3	II	532.6	III	1133.3	II	666.7
Rumex thyrsiflorus Fingerh.	IV	221.1	III	47.8	III	45.2	II	13.3
Phleum pratense L.	III	655.8	II	47.8	I	154.8	I	150.0
Taraxacum F.H. Wigg. sp.	III	290.4	II	34.8	I	83.3	II	76.7
Poa pratensis L.	III	101.9	I	45.6	I	285.7	I	3.3
Galium mollugo L.	II	94.2	III	376.1	I	47.6	II	303.3
Knautia arvensis (L.) J.M. Coult.	I	5.8	III	26.1	I	2.4	I	10.0
Vicia cracca L.	I	19.2	III	284.8	II	33.3	I	123.3
Holcus lanatus L.	I	19.2	-	-	III	492.8	I	3.3
Ranunculus repens L.	-	-	-	-	I	47.6	IV	296.7
Lysimachia vulgaris L.	-	-	I	2.2	-	-	IV	263.3
Angelica sylvestris L.	-	-	-	-	I	23.8	III	86.7

Table 3. Continued.

ChCl. *Trifolio-Geranietea*								
Agrostis capillaris L.	IV	1298.1	I	43.4	III	692.8	V	2320.0
Galium verum L.	I	3.8	III	102.2	II	38.1	I	36.7
ChCl. *Koelerio glaucae-Corynephoretea canescentis*								
Trifolium arvense L.	IV	355.8	II	89.1	-	-	I	33.3
ChCl. *Artemisietea vulgaris*								
Artemisia vulgaris L.	V	328.8	V	293.5	II	11.9	I	70.0
Tanacetum vulgare L.	I	67.3	II	395.6	IV	511.9	II	523.3
Picris hieracioides L.	IV	523.1	III	156.5	I	26.2	-	-
Epilobium montanum L.	III	21.1	I	6.5	I	4.8	II	46.7
ChCl. *Agropyretea intermedio-repentis*								
Convolvulus arvensis L.	I	26.9	IV	54.3	I	9.5	I	10.0
Equisetum arvense L.	I	25.0	III	115.2	II	40.5	III	83.3
ChCl. *Nardo-Callunetea*								
Hieracium umbellatum L.	II	225.0	I	82.6	V	902.4	II	246.7
ChCl. *Epilobietea angustifolii*								
Holcus mollis L.	-	-	-	-	I	133.3	IV	640.0
Others								
Erigeron annuus (L.) Desf. s. str.	IV	367.3	IV	302.2	II	123.8	II	73.3
Hypericum perforatum L.	III	107.7	II	10.9	IV	97.6	IV	383.3
Senecio jacobaea L.	IV	126.9	III	43.5	II	14.3	-	-
Pimpinella saxifraga L.	I	1.9	IV	223.9	II	33.3	I	10.0

(i.e., *Artemisia vulgaris* and *Tanacetum vulgare* L.). In contrast, a high share of *Holcus lanatus* L., *Ranunculus repens* L. and *Lysimachia vulgaris* L. in groups 3 and 4 suggested a more moist environment than in groups 1 and 2. In group 3, *Festuca rubra* L. and *Arrhenatherum elatius* predominated, whereas in group 4 *Dactylis glomerata* and *Festuca rubra* were the dominant species. Moreover, in groups 3 and 4 there was also a high share of *Tanacetum vulgare* (Table 3).

Considering the Ellenberg's indicators, the groups of phytosociological plots significantly differed in the mean values of the light and thermal conditions, soil moisture, soil reaction, and nutrients, while the differences in the mean value of continentality were non-significant (Table 4). In general, the results suggest that habitats occupied by the plants of the groups 3 and 4 were moister and less nutrient rich than those of the groups 1 and 2, and habitats

Table 4. Mean values (±SD) of Ellenberg's indicators in four groups of phytosociological plots with *Solidago ×niederederi*.

Group of phytosociological plots	Ellenberg's indicator values					
	L	T	K	F	R	N
1	7.00 (±0.3)^{ab}	5.79 (±0.2)^{a}	3.90 (±0.5)	4.64 (±0.3)^{a}	5.70 (±0.9)^{ac}	5.00 (±0.9)^{ab}
2	7.20 (±0.3)^{a}	5.51 (±0.2)^{b}	4.07 (±0.6)	4.65 (±0.4)^{a}	6.81 (±0.3)^{b}	5.55 (±0.7)^{a}
3	7.03 (±0.4)^{ab}	5.67 (±0.3)^{ab}	4.24 (±0.7)	4.83 (±0.4)^{a}	5.81 (±0.9)^{c}	4.86 (±0.9)^{b}
4	6.78 (±0.4)^{b}	5.68 (±0.2)^{ab}	3.98 (±0.4)	5.29 (±0.4)^{b}	4.99 (±0.7)^{c}	4.88 (±0.7)^{b}
The Kruskal-Wallis *H* test; *P* value	H=10.0; $P \leq 0.05$	H=14.4; $P<0.01$	H=2.8; $P=0.42^{ns}$	H=22.5; $P<0.001$	H=37.2; $P<0.001$	H=11.1; $P \leq 0.05$

Explanations: L – light conditions, T – thermal conditions, K – continentality, F – soil moisture, R – soil reaction, N – soil fertility (nutrients). The diverse letters in superscript indicate the significant differences between the samples.

occupied by the plants of group 4 were the most acidic (Table 4).

In Europe, habitat preferences of *Solidago canadensis* seem to be very different from those of *S. virgaurea*; however, both species can be found in close proximity in disturbed habitats, where their hybrid also occurs. According to Mucina [36], *S. canadensis* is a diagnostic species of nitrophilous synanthropic herb-rich communities of shaded woodland and riparian fringes of *Galio-Urticetea*. It is also known from ruderal communities of *Artemisietea vulgaris* [37]. In contrast, *S. virgaurea* occurs in conifer and mixed forests (e.g., *Peucedano-Pinetum*, *Betulo-Quercetum*, *Carici fritschii-Quercetum roboris*, *Galio odorati-Fagenion*), on fringes of temperate woodlands (*Trifolion medii*), in woodland clearings (*Epilobietea angustifolii*), as well as in meadow and grassland vegetation (e.g., *Arrhenatheretum elatioris*, *Scabioso canescentis-Genistetum*, *Koelerion glaucae*) [35, 37-39]. Moreover, Szymura and Szymura [40] demonstrated that in south-western Poland, *S. virgaurea* was associated with typical forest and acidophilous species such as *Vaccinium myrtillus* L., *Oxalis acetosella* L., and *Hieracium murorum* L., whereas *S. canadensis* occurred mostly with ruderal species such as *Artemisia vulgaris* and *Tanacetum vulgare*.

In this study, we showed that *S.* ×*niederederi* and *S. virgaurea* occur equally in all observed moisture levels whereas the abundance of *S. canadensis* is shifted towards more moist environment and the hybrid is mostly associated with meadow plant species of *Molinio-Arrhenatheretea*. It should be mentioned that the majority of phytosociological plots with *S.* × *niederederi* were taken on abandoned fields (Table 1) and they mainly represented the early stages of secondary succession. The vegetation in such places is difficult to classify and usually has a temporary character. During the early stages of secondary succession on abandoned fields, many segetal, ruderal, meadow, and grassland species find suitable conditions for their growth [e.g., 41, 42]. The occurrence of *S. canadensis* and *S. virgaurea* on abandoned fields has been well documented in Poland and other European countries [40, 43-45]. Moreover, Rola and Rola [46] pointed out that *Solidago* species are bioindicators of fallow lands and they usually achieved a high cover on abandoned fields after 5-10 years from the abandonment.

Studies of many authors confirmed that plant communities dominated by alien *Solidago* species are characterized by much lower species richness and a decline in biodiversity [44, 47-48]. In our study, the values of Shannon-Wiener index (Table 1) were similar to those observed in segetal plant communities of *Stellarietea mediae* in Central Pomerania [49] and Lower Silesia [50]. It should be emphasized that the general biodiversity of plant communities with *S. canadensis* depends on the extent of its invasion – the greater the share of *S. canadensis*, the lower the value of Shannon-Wiener index [44, 48]. In our study, the species evenness and Simpson index achieved the higher values compared to the results obtained for abandoned meadows [51], segetal plant communities of *Stellarietea mediae* and ruderal plant communities of *Artemisietea vulgaris* [49-50]. Generally, the values of Ellenberg's indicators in habitats with *S.* ×*niederederi* were similar to those evidenced on fallow lands with *S. canadensis* and *S. gigantea* Aiton [49, 51]. However, Bielecka et al. [52] noticed that *S. canadensis* grows on diverse habitats from strongly acidic to alkaline. Moreover, field studies in Lithuania revealed that *S. canadensis*, *S. gigantea* and *S.* ×*niederederi* can occupy similar soils with slightly lower pH [17]. Since the hybrid is on the early stage of its establishment and spread in Poland a further research is needed to confirm its association with meadow communities.

Conclusions

Solidago ×*niederederi* can be established in well light places with partial shade and temperate conditions, on moist, moderately acidic to almost neutral soils with average fertility. It is strongly associated with *S. virgaurea* and meadow species of *Molinio-Arrhenatheretea*.

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Conflict of Interest

The authors declare no conflict of interest.

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