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Silaum silaus (L.) Schinz and Thell.—Habitat Conditions and Variation in Selected Characteristics of Populations at Different Densities

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Abstract: Grasslands are one of the most diverse and species-rich ecosystems in the agricultural landscape of Central Europe. However, they are gradually being overgrown or transformed into arable fields due to their abandonment and the intensification of economic activities. This leads to a drastic decline in biodiversity and the disappearance of many rare species, e.g., *Silaum silaus*. Research on *Silaum silaus* populations was conducted in the years 2020 and 2022. Data were obtained from two Natura 2000 sites. The Jaćmierz site is located in a dispersed range of *Silaum silaus* in south-eastern Poland. The site at Zagórzyce is located in a dense range of the species in the south-western part of the country. Research on the habitat conditions was conducted on two permanent study surfaces with the dimensions of 10 × 10 m. This research included a soil study and measurements of herbaceous vegetation. To determine the habitat conditions, use was also made of Ellenberg ecological indicator values. At each site, 10 phytosociological relevés were conducted with the Braun-Blanquet method. In each study year, the manner of land use was determined. For detailed population study, one permanent surface of the dimensions 10 × 10 m was marked out, on which each year the generative and vegetative specimens were counted and biometric studies were conducted on 30 randomly chosen generative specimens. The species occurred in two different meadow communities (*Arrhenatheretum elatioris*, *Molinietum caeruleae*), which were characterised by different habitat conditions, and the greatest differences were evident in the chemical properties of the soil and in the method of management. The meadows at Jaćmierz were mowed twice a year, while at Zagórzyce mowing was performed once every two years. The communities were also varied in terms of flora, characterised by a high species richness and a high Shannon–Wiener index. *Silaum silaus* had significantly greater numbers and an over four times higher cover coefficient at Jaćmierz. The largest differences in the analysed traits of the species occurred in the case of generative traits. It was observed that management practices at Jaćmierz had a strong influence on the condition of specimens and the population size of *Silaum silaus*, which was much better preserved at this site.

Keywords: *Silaum silaus*; meadow species; population studies; habitat conditions; management

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1. Introduction

Destruction and fragmentation of natural and semi-natural habitats as a result of anthropogenic activities lead to considerable losses in biodiversity [1–5]. This problem is also evident in grasslands situated in river valleys, which not only play a key role in the preservation of biodiversity but also fulfil a protective function for the environment [6].

This issue has been discussed in many publications and concerns a range of European countries, e.g., [7–9].

It is generally understood that the intensification of agricultural practices has had the largest influence on reducing the share of grasslands since the mid-20th century [10,11]. This manifests itself mainly in the use of artificial fertilizers, earlier mowing and an increase in continuous grazing [12]. Numerous studies have been carried out which have also clearly indicated a drop in species diversity after fertilizing and grazing, e.g., [13–17]. Also of importance is the draining of meadows and their conversion into agricultural land [7,18,19]. However, a threat is posed not only by intensification of use but also by complete abandonment, leading to overgrowth by succession flora [20–23].

Following the concept of ecosystem services [24], it can be seen that grasslands are of great importance not only in economic terms but in terms of their natural and cultural value. Therefore, the sustainable management of such areas is extremely important. The exploitation of grasslands to perform only one service, for example provisioning in order to provide the largest possible amount of biomass with intensive land use practices, may lead to the degradation of the habitat and a drop in biodiversity, thus negatively impacting the other ecosystem services. This problem has been described in detail with regard to alpine shrub meadows [25].

Currently, awareness of the necessity of protecting grasslands has risen due to their importance and the above-mentioned causes of their decline and in the context of ecosystem services. In many countries, they are protected in the framework of Habitat Directives [26], which establish their proper manner of management. Moreover, grasslands, and especially alluvial meadows, have found themselves at the centre of attention of projects for the protection and restoration of nature. Many countries are conducting intensive research on their renaturalisation. Meadow complexes are being recreated on formerly arable land [27,28] as well as on land intensively managed in the past, with low biodiversity [29,30].

Along with the restoration of grasslands, there are also efforts to bring back populations of rare or endangered species which formerly occurred on them and have declined in many places. It is noteworthy that the decline of each plant species is associated with depletion of genetic, medical and even ornamental resources [24]. Given these considerations, it seems extremely important to elucidate the relationship between the habitat and the condition of the populations of its constituent species. This is particularly crucial in the case of rare and endangered species. Hence, *Silaum silaus* became our focus of research interest. This taxon is characterised by quite low seed longevity; seeds are viable in the soil for only a year [31,32], and their sprouting is not always effective. Even if environmental conditions are favourable, this species has limited abilities to spread and repopulate sites at which it previously receded [33].

There are not many publications dedicated to the biology and ecology of *Silaum silaus*. The species has been frequently noted in floristic texts, as well as in phytosociological relevés during research on plant communities, e.g., [34–39]; however, detailed information on its habitat preferences can be found in only a few older phytosociological studies [40–42]. Somewhat more attention has been dedicated to restoring grasslands with the involvement of *Silaum silaus*, where the proliferation of this species, the longevity of seeds, germination capacity and colonisation of new areas were studied [32,33,43]. Nevertheless, data on the population numbers and variation in certain species traits can be found in only three studies. The first work of Guardiola et al. [44] estimated the population of sites in Catalonia, determined the geographic range, the type of habitat, phenology and density, and also analysed threats and the state of protection of the species. The second work of Khapugin [45] undertook population research concerning reproduction biology, morphometrics of specimen features and seed characteristics and their germination capacity in areas in Russia. Meanwhile, the third work of Anishchenko et al. [46] conducted a study which aimed to discover the characteristics of the seasonal rhythm of growth and development, to uncover morphometric indicators and to evaluate the success of introducing *Silaum silaus* to cultivation conditions. Until now, no population research has been conducted on

this species in the region of Central Europe. In this study, two sites of *Silaum silaus* were selected in Poland, which were considerably distant from each other and characterised by different habitat conditions. Site 1 was situated in the south-eastern part of the country in the Central Beskidy Foothills and had a dispersed character. Site 2 was located in a range of dense occurrence of *Silaum silaus*, in the Silesian Lowlands in south-western Poland.

The main aim of this work was to check if there exist statistically significant differences between the south-western and south-eastern populations. In order to realise this overriding goal, detailed aims were determined: to conduct an analysis of the habitat conditions in the studied populations (I); of the vegetation in the compared areas (II); and of the population numbers and selected metric features (vegetative and generative) of specimens in the populations (III).

2. Materials and Methods

2.1. Study Species

Silaum silaus belongs to a monotype genus in the family *Apiaceae* [47]. It is a hemicryptophyte reaching a height of 40 to 100 cm. Its stem is cylindrical and striate in its lower part, as well as angular and branched in its upper part. It has leaves with a triangular outline; the lower ones on long petioles with spathous extensions at their base are 2–4-pinnate, the upper ones have smaller dimensions and the highest are scaly. The inflorescence is a compound umbel usually made up of 5–10 multi-flower umbellets. Most often there are no sepals; small sepals are formed by narrow leaves. The opposite ovoid petals have a yellowish-green colour, are grooved at the top and bear a patch. Blooming occurs in the period from June to September and fruiting from August to November. The fruit is a schizocarp [44,48].

The species' range, within which two regions of dense occurrence can be, stretches in a narrow belt from the Iberian Peninsula to western Siberia. In the first of these regions, the density of *Silaum silaus* sites is the greatest—it includes Central and Western Europe (mainly France, Great Britain, Germany, Switzerland) and reaches western Poland. In other countries of this region (including Spain, Belgium, Holland, eastern Poland, Slovakia, Hungary, Moldova), the species is noted at individual sites. The second region where *Silaum silaus* occurs in dense range concentrations stretches from eastern Ukraine to Siberia, where the density of sites is considerably lower in comparison with Central and Western Europe [49–51].

Due to the wide range of distribution, *Silaum silaus* occurs in various plant communities. It most often grows in mesotrophic habitats, on damp meadows, meadows with a fluctuating water table and mesic meadows [38,40–42,52]. This species has been variously recognised in syntaxonomic classification. In Central Europe, phytocoenoses including it have been described among the association *Sanguisorbo-Silaëtum pratensis* of the alliance *Calthion palustris* [40,42,53]. Currently, the dominant opinion is that *Silaum silaus* is regarded as a species characteristic of the alliance *Molinion caeruleae* [36,37]. It is most frequently noted within variably moist *Molinion caeruleae* meadows [40,42,54,55]. It also occurs in alluvial meadows of the alliance *Cnidion dubii* [33,41–43,56–58], as well as on mesic meadows of the alliance *Arrhenatherion elatioris* [42,59]. It is sporadically noted on grasslands of the alliance *Mesobromion* [59], on semi-dry grasslands of the class *Festuco-Brometea* at the foot of hillsides [60] and even in scrubs and marsh woodland [61]. In Western Europe, *Silaum silaus* occurs on mesophilic and alluvial meadows of the class *Molinio-Arrhenatheretea* [7,62] and in tall humid herb grasslands of the class *Molinio-Holoschoenion* [63]. Meanwhile, in Asia, it is found in halophytic communities of rushes and meadows of the class *Asteretea tripolium* [39,45,64,65].

Over most of its range, the species is rare and threatened; therefore, in many countries and regions, it has been put on Red Lists, such as [66–75].

The literature on the uses of *Silaum silaus* is poorly developed. In former times, it was used in folk medicine, for example for the treatment of bladder diseases. Its leaves were also used as a potherb. Recently, its high nutritional and medicinal value has been noted, arising from its

content of numerous valuable compounds. Research on the essential oil content of *Silaum silaus* has been conducted primarily by Chizzola [76] and Widelski et al. [77].

2.2. Study Area

For the study, two sites in Poland were chosen, situated in different geographic regions (Figures 1 and 2). Site 1 is located by the town of Jaćmierz in the south-eastern part of the country, in the mesoregion of the Jasło-Krosno Basin within the Central Beskidy Foothills [78]. Jaćmierz is situated in the valley of the Wisłok River at an elevation of 281–282 m above sea level, where alluvial soil and black soil occur. The average annual precipitation in this area is 744 mm, while the average annual temperature is 8.3 °C [79]. The study was conducted within the area of Natura 2000 "Jaćmierz PLH180032", where the natural habitat 6510 (*Arrhenatherion elatioris*) has been placed under protection. In the past, in this area there were moist meadows, which have been significantly drained. Currently, it is dominated by mesic, extensively managed meadows. In low areas of terrain, there are damp meadows and rushes dominated by *Phragmites australis* [80]. For the study, a mesic meadow of *Arrhenatheretum elatioris* was selected, with a surface area of 2 ha, which is regularly mowed, within which *Silaum silaus* occurs. Site 1 is situated outside the dense range of occurrence of the species.

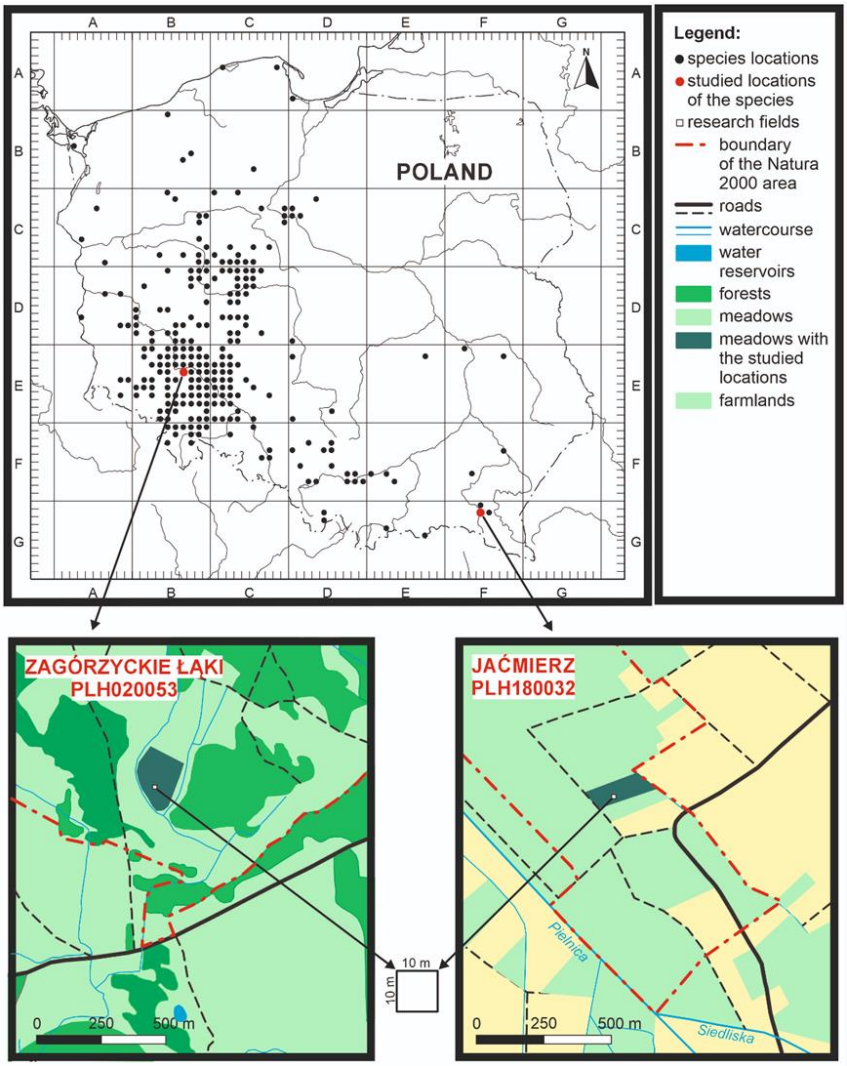

Figure 1. Location of studied sites on the ATPOL grid squares presenting the distribution of *Silaum silaus* in Poland (own work based on ATPOL grid squares [50] and the map from the website Geoportal 2).

Figure 2. A view of plant communities with *Silaum silaus* individuals at study sites: (**A**) Site 1—Jaćmierz; (**B**) Site 2—Zagórzyce (photos: (**A**) T. Wójcik; (**B**) A. Stadnicka-Futoma).

Site 2 is situated by the town of Zagórzyce in the south-western part of the country, in the mesoregion of the Rościsławice Heights in the Silesian Lowland [78]. The studied area lies in low terrain, at an elevation of 107 m above sea level. It is dominated by brown acidic soils and alluvial soils, where the average annual precipitation reaches 600 mm, and the average annual temperature is 8.5 °C [81]. In this terrain is found the Natura 2000 area "Zagórzyckie Meadows PLH020053", which protects the natural habitat 6410 (*Molinion caeruleae*). Part of the patches of *Molinion caeruleae* meadows occurring here are used extensively and part undergo secondary succession [82]. A surface area of 2.5 ha was studied, which is mowed in a two-year system, allowing protection of the community and rare species occurring there. Site 2 lies within the area of the dense western occurrence of the species.

2.3. Study of Habitat Conditions

Research on the habitat conditions was conducted in 2020 on two permanent study surfaces with the dimensions of 10 × 10 m. This included a soil study and measurements of herbaceous vegetation and of soil moisture. For the soil study, 5 samples of surface soil were taken. The samples were taken at 4 marginal points and in the centre of the marked-out surface. Soil analysis included determination of the granulometric composition, pH level, calcium carbonate content, electrolyte conductivity, organic carbon and total nitrogen content, and of available forms (P, K, Mg), hydrolytic acidity and the sum of interchangeable cations (Na^+, K^+, Mg^{++}, Ca^{++}). All of the analyses were carried out according to methods used in soil laboratories.

For measuring the height of herbaceous vegetation and soil moisture, 30 points were marked out on a random basis on permanent surfaces. The vegetation was measured with a measuring tape. Measurements of soil moisture were conducted with use of a hygrometer Extech MO750 (Manufacturer: Extech, Country of Origin: Taiwan).

To determine the habitat conditions, use was also made of Ellenberg ecological indicator values [83]. Calculations were made in the JUICE program [84] on the basis of phytosociological relevés. Next, for singled-out syntaxons, the average value of the following indicators was calculated: light intensity (L), temperature (T), continentalism (K), soil moisture (F), soil pH (R) and nutrient content (N).

2.4. Vegetation Survey

The vegetation was studied at the two sites in the years 2020 and 2022. In each study year, the manner of land use was determined. At each site in July 2020, 10 phytosociological relevés were conducted with the Braun-Blanquet method [85] on a surface of 25 m^2. Syntaxonomic classification was conducted based on the Matuszkiewicz guide [53]. The nomenclature of vascular plants was given as in Mirek et al. [86] and that of moss as in Ochyra et al. [87]. Protected species were distinguished on the basis of the Decree of the Ministry of the Environment [88] while those endangered were noted based on the work of Kaźmierczakowa et al. [73]. For each species within the two distinguished plant communities, the constancy degree and cover coefficient were calculated. The cover coefficient was calculated by converting the degree of abundance to the "average percentage of cover" [89] and calculating the average value by syntaxon. The variety and quantitative relations between species on the studied surfaces were calculated based on the Shannon–Wiener Diversity Index [90], the Evenness Index [91] and the Simpson Index [92].

2.5. Analysis of Population Numbers and Selected Traits of Generative Specimens

At each site, the range of occurrence of *Silaum silaus* was determined with use of a GPS receiver, and the surface area occupied by it was calculated. For detailed study, one permanent surface of the dimensions 10 × 10 m was marked out, on which each year the generative and vegetative specimens were counted and biometric studies were conducted on 30 randomly chosen generative specimens. The following traits were analysed: height of the main stem, number of lateral shoots, number of leaves, length of basal leaves, number of umbels, number of umbellets in the top umbel, number of flowers in the top umbel.

2.6. Statistical Analyses

For all analysed variables, the normality of distribution was checked using the Kolmogorov–Smirnov test. Homogeneity of variance was tested using the Levene test at the significance level of $p < 0.05$.

Non-parametric tests were performed for each case. The Mann–Whitney U test was applied to check whether the contribution of particular soil fractions (sand, silt and clay) varied significantly among the Jaćmierz and Zagórzyce patches in the year 2022. The Mann–Whitney U test was also used to check if the values of other soil parameters (pH, electrical conductivity, hydrolytic acidity, content of organic carbon and total nitrogen, as well as available phosphorus, potassium and magnesium) varied significantly. Soil moisture and the height of standing vegetation in two plant communities with *Silaum silaus* in the year 2020 were compared by the Mann–Whitney U test as well as Ellenberg values and the total number of species, mean (range) number of species in a phytosociological relevé and Shannon–Wiener (H'), Pielou (E') and Simpson (*SIMP*) indices. To describe the number of generative and vegetative individuals, a radar chart was used.

To check if the measured vegetative traits (length of the main shoot, number of side shoots, number of leaves, basal leaf length) and generative traits (number of umbels, number of umbellets in the top umbel, number of flowers in the top umbel) varied significantly between the Jaćmierz and Zagórzyce patches in the years 2020 and 2022, the Mann–Whitney U test was also used. The statistical analysis was performed using STATISTICA 13.3 software (TIBCO Software Inc., Headquarters: Palo Alto, CA, USA).

3. Results

3.1. Habitat Conditions

At both sites, there was soil of a loamy silt composition, but in the case of two fractions (sand and silt), statistically significant differences were noted (Table 1). At site 1 (Jaćmierz), the soils had a considerably higher average silt content. Meanwhile, the average sand content was higher at site 2 (Zagórzyce). The difference in the content of clay was not statistically significant.

Table 1. The mean (range) ± SD contribution of particular soil fractions in the granulometric composition of 5 soil samples taken from 2 research sites in the year 2020.

Soil Fraction	The Particular Soil Fractions (%) in		The Mann–Whitney U Test Value; *p* Value
	1	2	
sand (2–0.05 mm)	22.6 ± 7.57	33.6 ± 4.04	U = 2.0; $p < 0.05$
silt (0.05–0.002 mm)	67.8 ± 5.26	58.0 ± 3.67	U = 1.0; $p < 0.05$
clay (>0.002 mm)	9.6 ± 2.51	8.4 ± 1.34	U = 8.5; $p = 0.46$

As regards physical–chemical properties, most parameters indicated statistically significant differences between the surveyed sites, with the exception of available forms of phosphorus and potassium and interchangeable forms of potassium and sodium (Table 2). At Jaćmierz, the soil had a neutral pH level, whereas at Zagórzyce it was slightly acidic. This relationship was also evident in the case of hydrolytic acidity, which reached a three-times higher average value at Zagórzyce. The high pH at Jaćmierz influenced the higher total content of alkaline cations (BS) and the higher sorption capacity (CEC). Among the interchangeable cations, Ca^{++} and Mg^{++} were distinguished, as they dominated at Jaćmierz. This influenced electrolytic conductivity, which was over twice as high at Jaćmierz. Among the available forms, only MgO showed differences between the studied sites. The content of this parameter was significantly higher at Zagórzyce. In the case of organic substances, a higher average content was noted at Jaćmierz, demonstrated by the parameters of organic carbon and total nitrogen.

Table 2. The mean (range) ± SD of particular soil properties of 5 soil samples taken from 2 research sites in the year 2020.

Soil Parameters	1	2	The Mann–Whitney U Test; *p* Value
pH H_2O	6.72 ± 0.19	5.48 ± 0.12	U = 0.0; $p < 0.05$
pH KCl	6.25 ± 0.21	4.88 ± 0.41	U = 0.0; $p < 0.05$
EC [$\mu S \cdot cm^{-1}$]	190.28 ± 21.59	90.34 ± 20.42	U = 0.0; $p < 0.01$
$CaCO_3$	0.28 ± 0.06	0.19 ± 0.01	U = 0.0; $p < 0.05$
C_{org} [%]	6.24 ± 0.82	4.69 ± 0.60	U = 1.0; $p < 0.05$
N [%]	0.63 ± 0.10	0.37 ± 0.05	U = 0.0; $p < 0.05$
C/N	9.94 ± 0.39	12.54 ± 0.51	U = 0.0; $p < 0.05$
P_2O_5 [$mg \cdot 100\ g^{-1}$]	3.36 ± 0.72	2.65 ± 0.14	U = 3.0; $p = 0.06$
K_2O [$mg \cdot 100\ g^{-1}$]	9.54 ± 1.53	12.80 ± 3.36	U = 6.0; $p = 0.21$
MgO [$mg \cdot 100\ g^{-1}$]	60.18 ± 9.00	26.19 ± 5.88	U = 0.0; $p < 0.05$
Hh [$Molc \cdot kg^{-1}$]	2.37 ± 0.99	7.60 ± 1.00	U = 0.0; $p < 0.05$
BS [$Molc \cdot kg^{-1}$]	40.33 ± 4.99	16.77 ± 4.15	U = 0.0; $p < 0.05$
CEC [$Molc \cdot kg^{-1}$]	42.71 ± 5.67	24.37 ± 4.62	U = 0.0; $p < 0.05$
Na^+ [$Molc \cdot kg^{-1}$]	0.14 ± 0.04	0.11 ± 0.03	U = 7.0; $p = 0.30$
K^+ [$Molc \cdot kg^{-1}$]	0.28 ± 0.06	0.23 ± 0.07	U = 7.0; $p = 0.30$
Mg^{++} [$Molc \cdot kg^{-1}$]	6.49 ±1.02	2.06 ± 0.65	U = 0.0; $p < 0.05$
Ca^{++} [$Molc \cdot kg^{-1}$]	33.41 ± 4.00	14.35 ± 3.49	U = 0.0; $p < 0.05$

At Jaćmierz, the average height of herbaceous vegetation was 54.7 cm, whereas at Zagórzyce it amounted to 58.3 cm (Figure 3). The statistical analysis showed no significant difference in the height of herbaceous vegetation between the patches. Soil moisture was significantly higher at site 1 than at site 2. At Jaćmierz, the average soil moisture was considerably higher (25.6%) in comparison with Zagórzyce (17.2%).

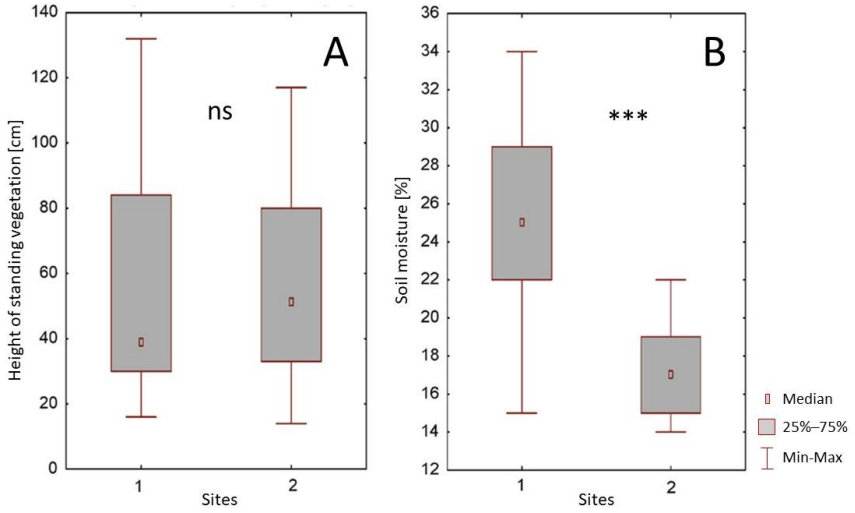

Figure 3. The median (±Min–Max) of soil moisture (**A**) and height of herbaceous vegetation (**B**) from 2 research sites in the year 2020. The asterisks show the statistical significance of differences at the level <0.001 (***); ns—not significant.

Analysis of climatic indicators for the two studied sites showed a lack of statistically significant differences in the case of temperature (T) (Table 3). Both plant communities occurred in well lit and moderately warm places. There were significant differences concerning the K indicator. At Jaćmierz, its value gave evidence of a moderately oceanic climate, while at Zagórzyce it was weakly oceanic. Significant differences were obtained in the case of edaphic indicators. A higher F value (moderately moist soil) was obtained at site 2, whereas at site 1 the F value indicated a mesic habitat. Small differences were noted for the R indicator; however, these were not statistically significant. Its value for site 1 indicated neutral soils, while that at site 2 was indicated as slightly acidic. The sites differed considerably regarding nitrogen content. At Jaćmierz, the N indicator attained a value appropriate for moderately fertile habitats, whereas at Zagórzyce its value was appropriate for poor habitats.

Table 3. Mean values (range) ± SD of Ellenberg indicators from 2 research sites with *Silaum silaus*.

Ellenberg Indicators	1	2	The Mann–Whitney U Test; p Value
L	7.09 ± 0.10	6.87 ± 0.05	U = 1.0; $p < 0.05$
T	5.65 ± 0.10	5.67 ± 0.08	U = 49.5; $p = 1.0$
K	3.82 ± 0.12	4.54 ± 0.30	U = 0.0; $p < 0.05$
F	5.65 ± 0.28	6.15 ± 0.20	U = 6.5; $p < 0.05$
R	6.93 ± 0.12	6.60 ± 0.47	U = 33.0; $p = 0.21$
N	5.01 ± 0.49	3.37 ± 0.20	U = 0.0; $p < 0.05$

3.2. Vegetation

At site 1, the meadows were mowed twice a year and occasionally grazed in the autumn. Based on the species composition, the studied phytocoenoses were classified in the *Arrhenatheretum elatioris* association (Table S1). In total, 80 taxa occurred in the whole community, including 79 species of vascular plant and 1 moss species. The herbaceous layer reached full cover in all phytosociological relevés. A moss layer covered from 1 to 20% of the surface. Between 35 and 48 species (mean 40.8) were noted in the relevés. *Silaum silaus* reached high of abundance values. The highest constancy degree and a high cover coefficient was reached by species characteristic of the association *Arrhenatheretum elatioris*: *Arrhenatherum elatius* and *Geranium pratense*. These were accompanied by many species of the alliance *Arrhenatherion elatioris* (5 species), of the order *Arrhanatheretalia elatioris* (10 species) and of the class *Molinio-Arrhenatheretea* (15 species). Species representing the re-

maining syntaxonomic units within the class *Molinio-Arrhenatheretea* occurred sporadically in general. Exceptions were *Silaum silaus* of the association *Molinietum caeruleae* and *Cirsium canum* of the alliance *Calthion palustris*, as well as *Deschampsia caespitosa* and *Colchicum autumnale* of the order *Molinietalia caeruleae*. Species of other classes had a marginal presence. Among other taxa, a greater share was reached by *Briza media* and *Geum rivale* in the herbaceous level, as well as *Calliergonella cuspidata* in the moss level. In the community, two species placed under species protection were noted (*Colchicum autumnale*, *Primula elatior*) and two endangered species were seen *Silaum silaus* with the category NT and *Allium scorodoprasum* with the category VU.

At site 2, the meadows were mowed once every two years in late summer. The studied phytocoenoses were classified in the association *Molinietum caeruleae* (Table S1). In the whole community, 90 taxa occurred, including 87 vascular plants and 3 moss species. The herbaceous vegetation layer reached 100% cover in all the phytosociological relevés. The moss layer occupied 5 to 20% of the coverage. In the phytosociological relevés, between 38 and 47 species were noted (mean 41.3). In most phytosociological relevés, *Silaum silaus* had low abundance values. Eleven species characteristic of the association *Molinietum caeruleae* were noted, among which the highest constancy degree and a high cover coefficient was reached by *Molinia caerulea*, *Galium boreale*, *Betonica officinalis* and *Silaum silaus*. The order *Molinietalia caerulea* was represented by seven species, of which high cover was reached by *Sanguisorba officinalis* and *Serratula tinctoria*. There were numerous other species characteristic of the class *Molinio-Arrhenatheretea* (13 species). Species of the remaining syntaxa within the class *Molinio-Arrhenatheretea* occupied a high share in the community structure. Of other classes, high abundance values and constancy degrees were reached by the species *Filipendula vulgaris* of the class *Festuco-Brometea* and *Potentilla erecta* of the class *Nardo-Callunetea* and in the moss layer *Plagiomnium undulatum* of the class *Querco-Fagetea*. Among other species, only *Briza media* and *Anthoxanthum odoratum* had somewhat greater cover in the herbaceous layer and *Calliergonella cuspidata* in the moss layer. Four species placed under species protection were noted in the community (*Dianthus superbus*, *Gentiana pneumonanthe*, *Ophioglossum vulgatum*, *Centaurium erythraea*), as well as four threatened species: *Silaum silaus* with the category NT and *Dianthus superbus*, *Gentiana pneumonanthe*, *Ophioglossum vulgatum* with the category VU.

The studied communities were similar regarding the total number of species (Table 4). The two communities did not have statistically significant differences regarding the average number of species in the phytosociological relevés and the diversity indicators (H', E', *SIMP*). The values of these indicators give evidence of great floristic diversity and species richness in the surveyed communities.

Table 4. The total number of species and mean (range) ± SD of number of species in a relevé, as well as Shannon–Wiener (H'), Pielou (E') and Simpson (*SIMP*) indices calculated in two plant communities with *Silaum silaus*.

Plant Community	1 *Arrhenatheretum elatioris*	2 *Molinietum caeruleae*	The Mann–Whitney U Test; *p* Value
Total number of species	80	90	-
Number of species in relevé	40.7 ± 4.47	41.3 ± 2.58	U = 46.0; $p = 0.79$
H'	2.933 ± 0.17	2.983 ± 0.13	U = 38.0; $p = 0.38$
E'	0.794 ± 0.03	0.810 ± 0.03	U = 35.0; $p = 0.27$
SIMP	0.892 ± 0.03	0.909 ± 0.02	U = 30.0; $p = 0.14$

3.3. Population Numbers and Characteristics of Generative Specimens

At site 1, the *Silaum silaus* population existed on two adjacent hay meadows with a combined surface area of ca. 2 ha. At site 2, the *Silaum silaus* population occurred in an area on one isolated meadow occupying an area of about 2.5 ha.

The largest population of *Silaum silaus* was noted at site 1, where 314 generative specimens and 786 vegetative specimens were identified in 2020, as well as 480 generative specimens and 1105 vegetative specimens in 2022 (Figure 4). At site 2, 74 generative

specimens and 410 vegetative specimens were noted in 2020 and 145 generative and 375 vegetative specimens in 2022.

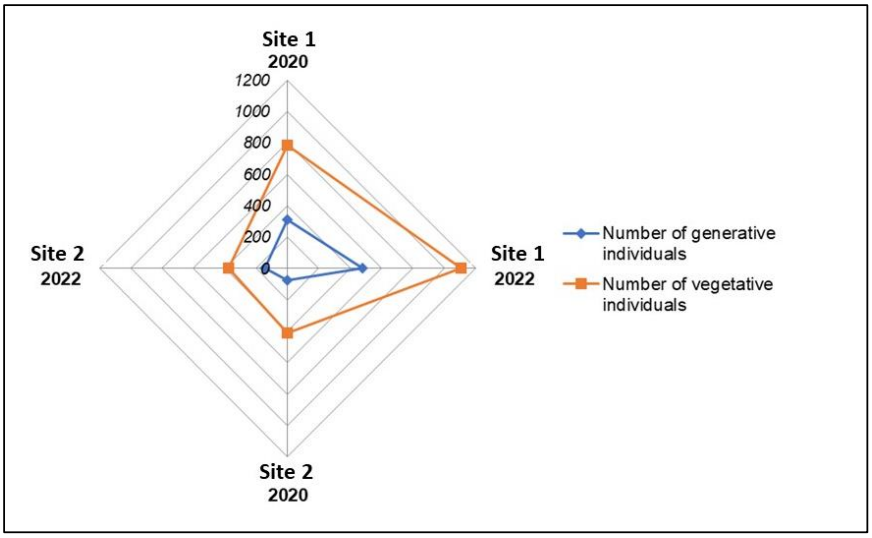

Figure 4. The radar chart presenting the number of generative and vegetative individuals at sites 1 (Jaćmierz) and 2 (Zagórzyce).

The length of the main stem and number of side stems did not differ among the populations in the years 2020 and 2022. The number of leaves in 2020 was higher at site 2, whereas this number was higher in 2022 at site 1. The length of the basal leaf in 2020 was significantly higher at site 1 (Table 5).

Table 5. The mean (±SD) for vegetative traits of individuals of *Silaum silaus* within the studied sites in the years 2020 and 2022.

Trait	Year	1	2	U	Z	*p*
Length of the main stem [cm]	2020	91.63 ± 14.48	92.70 ± 15.15	433	−0.24394	0.80
	2022	85.40 ± 16.52	88.330 ± 10.81	373	−1.13101	0.26
Number of side stems	2020	5.00 ± 1.25	5.20 ± 1.32	414.5	−0.51745	0.60
	2022	5.57 ± 1.43	5.10 ± 1.24	342	1.58933	0.11
Number of leaves	2020	9.00 ± 1.84	10.93 ± 2.75	243.5	−3.04559	<0.05
	2022	18.10 ± 5.96	13.67 ± 8.33	206	3.60001	<0.001
Length of the basal leaf [cm]	2020	44.53 ± 8.13	37.70 ± 7.47	249.5	2.95689	<0.001
	2022	47.63 ± 9.71	43.40 ± 5.45	333.5	1.71499	0.09

In 2020, considerably more flowers formed in the top umbellet at site 2 than at site 1. The differences between the number of umbels and number of umbellets in the top umbel in this year were not statistically significant. In 2022, the number of umbels was greater at site 1, and the number of umbellets in the top umbel was higher at site 1 (Table 6).

Table 6. The mean (±SD) for generative traits of individuals of *Silaum silaus* within the studied sites in the year 2020 and 2022.

Trait	Year	1	2	U	Z	*p*
Number of umbels	2020	12.67 ± 4.83	13.47 ± 5.83	435	−0.21437	0.83
	2022	19.20 ± 7.18	16.63 ± 5.35	309	2.07721	<0.05
Number of umbellets in the top umbel	2020	9.83 ± 1.55	9.77 ± 2.13	434.5	0.22177	0.82
	2022	10.47 ± 2.22	9.17 ± 1.68	294	2.29898	<0.05
Number of flowers in the top umbellet	2020	19.17 ± 4.24	22.83 ± 5.46	254.5	−2.88296	<0.05
	2022	19.10 ± 4.64	20.10 ± 5.15	407.5	−0.62095	0.53

4. Discussion

4.1. Habitat Conditions

Silaum silaus is a sub-Atlantic species occurring in moderately warm and warm lowland areas, on open sites with full or partial light intensity [93,94], which was also confirmed by the results of our research. This species prefers soil from slightly acidic to slightly alkaline. It grows in moist, mesotrophic habitats, rich in organic material [93,94]. Analysis of edaphic indicators in this study demonstrated considerable differences. At Jaćmierz, *Silaum silaus* occurred in moderately moist and averagely rich habitats with a neutral pH level. Meanwhile, at Zagórzyce it occurred in mesic habitats, poor in nutrients and slightly acidic.

The large variations in habitat conditions result from the specific characteristics of the places occupied by *Silaum silaus*. The mentioned species exists in valleys of large, medium and small rivers, where there are considerable fluctuations in water availability during the vegetative season. During the winter and early spring months, low alluvial areas of river valleys are affected by flooding, while in the summer the water level falls considerably, leading to soil dryness. Additionally, in places situated in the higher parts of a valley, not affected by flooding, the ground water level can be highly variable [7,32,40,42,62,95]. Access to ground water and the amount of precipitation influence the soil's moisture condition. Significant differences were noted in soil moisture at the surveyed sites. At Jaćmierz, this parameter reached a mean value of 25%, while at Zagórzyce it was 17%. The differences in soil moisture of the studied sites may result from the amount of precipitation as well as from the soil type. Jaćmierz is located in the Jasło-Krosno Basin, where the average yearly precipitation amounts to 744 mm, and the soil consists of alluvial soil and black soil, which can retain moisture for a longer time [79]. Meanwhile, at Zagórzyce, the average annual precipitation is 600 mm, and the dominant soil types are acidic brown soils and alluvial soils [81]. Another important factor determining the soil moisture is its management. Swacha et al. [96] pointed out the higher moisture content in soils of mowed meadows in comparison with that of unmowed meadows.

Silaum silaus may also occur on mineral soils, as well as on muck soils. It most often grows on floodplains in alluvial soil with a variable granulometric composition, where there occur large fluctuations in the water level. In these locations, fine-grained soils, heavy alluvial clay and soils with a predominant sand fraction may be formed [32,35,40,55,56,65,95,97]. This species also occurs in places that do not undergo regular flooding, and even in areas considerably distant from a riverbed, where brown and gley soils, black soils and mucky soils are formed [35,55,56,98]. In this study, the analysed sites were distant from riverbeds and were not influenced by flooding. The large variability in the *Silaum silaus* habitat demonstrates the broad ecological tolerance of this species. According to Leuschner and Ellenberg [52], *Silaum silaus* is bound to river valleys with a moderate level of nutrients. Often, these are areas rich in calcium carbonate [40] with a neutral or slightly alkaline pH [7,32,35,62,95,98]. Nevertheless, this species has also been noted on slightly acidic and acidic soil [7,56,58,62,82,96]. In our study, the site at Jaćmierz was characterized by a neutral soil pH level and higher calcium carbonate content, while at Zagórzyce, the pH value indicated acidic and slightly acidic soils, as well as being distinguished by a low calcium carbonate content, which has been confirmed in previous studies [82,96]. Analysis of the organic carbon and total nitrogen content indicated the soils at Jaćmierz had a significantly higher percentage of these elements. This may be connected to the meadow management at this site, which was mowed twice a year and sporadically grazed. Meanwhile, the lower percentage of C and N at Zagórzyce may result from the lack of regular management, which at this site is limited to one late mowing, once every two years. Swacha et al. [96] pointed out that mowing of low intensity favours the accumulation of organic material, because a large part of the above-ground biomass undergoes decomposition. This dependency finds confirmation in the research of other authors [32,35,56,95,97]. The content of available forms indicated significant differences in magnesium content and small differences in the case of phosphorus and potassium. The high concentration of MgO and somewhat lower concentration of P_2O_5 at Jaćmierz could be caused by occasional organic fertilizing of these meadows. The higher values of available forms of P and K on restored grasslands are also mentioned by

Bischoff [32,95], who states that the higher values of P and K may be retained longer in locations where intensive use was ceased long ago. Meanwhile, Swacha et al. [96] demonstrate that low intensity and a late mowing period restrict the export of nutrients from the ecosystem to a minute, negligible level.

4.2. Phytocoenotic and Species Diversity

Silaum silaus demonstrates a broad range of phytocoenotic tolerance, from alluvial meadow, variably moist and moist communities to mesic meadows and even dry grasslands. Occasionally, it may also appear in herbaceous and shrubby communities and even in halophytic communities. This is related to its occurrence in river valleys, where the vegetation shows large variation influenced by the soil type, water regime and management. However, two clear phytocoenotic optima for this species can be observed. The first of these are meadows of variable moisture, where the species is noted most frequently [40,42,54,55,97]. In communities of variably moist meadows (*Molinietum caeruleae*, *Junco effusi-Molinietum caeruleae*, *Selino carvifoliae-Molinietum caeruleae*, *Galio veri-Molinietum*, *Galietum borealis*), *Silaum silaus* reaches a high cover coefficient and the highest constancy degree; therefore, it is regarded as a species characteristic for the alliance *Molinion caeruleae* [35–37]. The second optimum environment for this species is alluvial meadows of the alliance *Cnidion dubii* occurring on wide alluvial plains, where the water regime is highly variable [33,41–43,56–58]. Long-lasting catastrophic floods may lead to its dying out. However, short floods result only in rotting of basal leaves and lower stem leaves. Once the water recedes, *Silaum silaus* forms new stem leaves in the higher parts of shoots. Its population on alluvial meadows falls drastically after long-lasting and catastrophic floods, whereas it increases during dry years and in periods of short, sporadic flooding [42]. This gives evidence of the high ecological plasticity of this species.

The existence of this species in various plant communities can be explained by their location and management. Alluvial and variably moist meadows occur in a mosaic of river valley plant communities, where *Arrhenatheretum elatioris* is frequently the contact community. This is why *Silaum silaus* has been often noted on mesic meadows [7,40,42,62]. The second factor affecting the occurrence of *Silaum silaus* is land management. This species develops best on meadows mowed 1–2 times a year or extensively grazed, whereas overly intensive use results in its gradual decline, which has been observed many times in Central and Western Europe [7,32,42,55,57,95,99–101]. The study we conducted has indicated that in a habitat optimal for it, i.e., variably moist *Molinietum caeruleae* meadows at Zagórzyce, *Silaum silaus* reaches a four-times lower cover coefficient in comparison with mesic *Arrhenatheretum elatioris* meadows at Jaćmierz. The relatively low cover coefficient at Zagórzyce may be caused by too infrequent mowing. While this allows preservation of the local population of *Silaum silaus*, its dissemination is restricted. Moreover, some patches of meadow at Zagórzyce have been completely abandoned, resulting in the encroachment of invasive species (*Solidago gigantea*), the development of bushes and trees and the decline in species characteristic of the alliance *Molinion caeruleae* [82,96]. The cessation of use and its negative influence on the species composition of *Molinion caeruleae* meadows is generally known. Many researchers have indicated the necessity of regular mowing of these meadows, which would allow maintenance of the desired species composition for this habitat, e.g., [9,21,23]. Meanwhile, at Jaćmierz, the high cover of *Silaum silaus* may be explained by regular mowing. We know from an interview with the owner of the surveyed meadow that is mowed twice a year and occasionally grazed in the summer. The owner noticed that cows are not keen on eating *Silaum silaus*, and late mowing of shoots not bitten by the animals increases the cover of this species in subsequent years. Most likely, seeds of *Silaum silaus* are carried then to neighbouring meadows, which occurs partly because of agricultural machines.

In spite of differences in habitat conditions and phytocoenosis and varied methods of management, the meadows at Jaćmierz and Zagórzyce were characterised by a similar number of species and similar diversity indicator values. Both meadows were species-rich and floristically diverse. In the phytosociological relevés of the two communities, an aver-

age of 41 species was noted, and the Shannon–Wiener Index reached the value of 2.9. In the whole community, there occurred 80 (Jaćmierz) and 90 (Zagórzyce) species. The average height of herbaceous vegetation was also similar, reaching, respectively, 54 and 58 cm. The differences concerned the species composition. At Jaćmierz, species characteristic of *Arrhenatherion elatioris* meadows were dominant, while at Zagórzyce, these were species characteristic for *Molinion caeruleae*. The obtained results are in accordance with the research of other authors. In phytosociological relevés with *Silaum silaus*, between 23 and even 54 species were noted [35,42,96], and the Shannon–Wiener Diversity Index for the communities with this species reached high values, between 2.7 and 3.37 [35,96].

One of the most important threats to phytocoenosis including *Silaum silaus* is its improper management. In the 20th century, a considerable part of these meadows was converted into cultivated fields or pasture grasslands, where large doses of non-organic fertilizers are used [9,32,33,95]. In Germany, Bergmeier et al. [42] observed the negative influence of a high level of fertilization, which leads to the decline in typical plant species, which are insufficiently competitive, and the development of expansive species. In the opinion of these authors, other threats are land draining, seeding of fodder species and ploughing of meadows. Meanwhile, in France, Grevilliot and Muller [7] pointed out that excessively intensive grazing of alluvial meadows in the Meuse valley resulted in diminished diversity and the decline in such species as *Silaum silaus*. A negative influence on floristic composition was also seen in the regular use of nitrogen fertilizers in large doses, which led to a considerable loss of biodiversity through eutrophic, competitive development and quickly growing species, such as *Lolium perenne* and *Festuca pratensis*. Similar observations were conducted in Poland, where Krasicka-Korczyńska and Korczyński [55] observed that the use of agrotechnical methods and seeding of fodder grass species, such as *Lolium multiflorum*, *Festuca arundinacea* and *Festuca pratensis*, lead to decreased cover of *Silaum silaus*.

The sites surveyed by us are found in areas of Natura 2000, whose framework protects the natural habitats 6510 (*Arrhenatherion elatioris*) and 6410 (*Molinion caeruleae*) occurring within it. Both were preserved in good condition, which resulted from their proper management. It seems that the meadows mowed once every two years at Zagórzyce allow the maintenance of an appropriate species composition and the local population of *Silaum silaus* in an unchanged state. However, it should be emphasized that some of the meadow patches in this area have been completely abandoned and are subject to secondary succession [82,96]. Meanwhile, the extensive use of mesic meadows at Jaćmierz may influence the further spreading of *Silaum silaus* onto neighbouring meadows and increase its cover, which requires undertaking further observations in order for this be clearly confirmed.

4.3. Population Numbers and Analysis of Selected Specimen Characteristics

A study presenting the European population of *Silaum silaus* was undertaken by Guardiola et al. [44] in the region of Catalonia. In her work, she analysed areas at an elevation of over 1000 m above sea level within various communities. For the analysed surfaces, the density of *Silaum silaus* ranged from 0.03 specimen/m^2 to 0.4 specimen/m^2. For most populations, the density was below 0.04 specimen/m^2. This is in accordance with our data, where for the stable population of Jaćmierz, in subsequent years the obtained values were, respectively, 0.055 specimen/m^2 and 0.059 specimen/m^2, while for the declining population at Zagórzyce, these were 0.167 and 0.021. At the same time, Guardiola et al. [44] demonstrated how the density of *Silaum silaus* varies between various community types. As in the case of observed Central European populations, the highest density was noted in moist habitats, such as *Aegopodion* (1.72), *Cynosurion* (1.30) and *Juncion* (1.18). For *Arrhenaterion*, the value was 0.93, which is significantly higher in relation to the populations analysed by us. The value in 2020 for the population of the *Molinion* habitat at Zagórzyce referred to values of the class *Molinio-Arrhenatheretea*; however, the drastic fall over two years confirms the threat to the existing population there. Such a decline can be especially dangerous for this taxon, as it does not possess a durable seed bank in the soil [19,31]. Moreover, in conducted experimental research, it also turned out that this species spreads weakly and

at short distances, in the vicinity of seed sources [32]. Appropriate abiotic conditions may not be sufficient to maintain full biodiversity in the surveyed habitats, as dispersion may be a factor restricting colonisation [95]. *Silaum silaus*, despite its good germination rate of 66%, was characterised by a low survival rate of seedlings—ca. 3% of seeds produced by parent plants survived. Simultaneously, only 0.9% of seeds spread to a distance of over 3.5 m [95]. For the maintenance and colonisation of appropriate habitats by *Silaum silaus*, also of importance is the distance from other, species-rich meadow communities, and migration from source locations is slow—after 15 years it reached only 40 m [43]. In our case, the population at Zagórzyce is endangered in this regard.

The population at Jaćmierz was characterised by a generally greater number of specimens, at the generative as well as vegetative stages. In the phytosociological relevés, as much as 5 times greater abundance of this species was noted there than at Zagórzyce, and due to the similar value of average density between the years, the population may be considered stable. Apart from habitat conditions and varied mowing regimes, the species' different population numbers may also be affected by the low presence of gaps in the ground vegetation that would facilitate the introduction of seedlings [95,102–104], as well as by the availability of seeds and the mulching effect [33,57,97].

Studies of the metric characteristics of *Silaum silaus* have not been undertaken very often so far. An attempt at assessing the population on the basis of morphological traits was undertaken by Khapugin [45], who considered that knowledge should be sought on the structure and condition of peripheral and central plant populations, as well as their state of preservation in populations of central Russia. The metric characteristics of *Silaum silaus* were also analysed by Anishchenko et al. [46], conducting research at the experimental botanical garden at Ufa, in Bashkortostan, Russia.

Among the features measured by us, the general height of plants fita in the range given in a Polish plant identification key [48], whereas the average number of umbels in umbellets was greater and amounted to 15.49.

Our results demonstrate that of generative characteristics, the number of umbels per plant is similar to the number provided by Anishchenko et al. [46] from research on crops in the late vegetative season (15.4). There are considerable differences in the values for the total number of umbels per plant in the plant communities in Russia and they are significantly higher, averaging 61.2 [45], while in this study these values reached an average 15.49 for all measurements. At the same time, the populations analysed by us differed significantly regarding this feature: in 2022, the specimens at Zagórzyce formed more umbels. The number of umbellets in the top umbel was 9.08 on average, fluctuating from an average of 9.17 to 10.47 at Zagórzyce; in 2022, this difference was statistically significant. The values we measured were on average lower than in the work of Anishchenko et al. [46] but higher than in Khaphugin's study [45]. The number of flowers in the top umbellet averaged 19.1 at Zagórzyce in 2022 to 22.8 at Jaćmierz in 2020. This value was higher than in the Anishchenko et al. study [46]; however, the latter did not indicate peak umbellets, which can be the most numerous in flowers. Meanwhile, Khapugin [45] indicated the formation of an average of 10 fruits in an umbellet, which may suggest that only part of the flowers in an umbellet bear fruit.

Our results show relative agreement in the case of the height of shoots with measurements of comparable studies (in that of Khapugin [45] 92.6, Anishchenko et al. [46] 123). At the same time, regarding this trait, the population analysed by us did not significantly differ. The number of side stems amounted to an average of 5.21, and this is a higher value than in natural Russian populations [45], though lower than in specimens grown in a garden [46], amounting to 2.1 generative shoots and 10 generative stems, respectively. The number of leaves is a characteristic which in our study demonstrated considerable variation both between sites as well as in subsequent years. The population at Jaćmierz had the lowest average in 2020, while the highest was at Zagórzyce in 2022. Khapugin [45] gave an average of only 3.0, whereas with Anishchenko et al. [46] it was 7.0. The length of

the basal leaf was similar to values provided by Anishchenko et al. [46] in the second half of the vegetative season.

Our research partially indicates the spatial (but also temporal) changeability of particular traits of *Silaum silaus*. Specimens in the south-eastern population (Jaćmierz), simultaneously more stable, in 2022 formed significantly more umbels and umbellets than the specimens at Zagórzyce. Meanwhile, the specimens with less numerous umbellets in the Zagórzyce population had more flowers in the top umbels in 2020. Also, at Jaćmierz in 2022, the specimens formed considerably more leaves. However, the length of the basal leaf reached the highest values there in 2020. This situation may be related to the generally better habitat conditions and better management of meadows in the south-eastern part of Poland. These preliminary considerations require further research on the population of this species, including those present in other regions of its occurrence range, with particular emphasis on the impact of sustainable management of meadows, which has great importance for the preservation of the species, as shown in this study. This is the case of not only *Silaum silaus* but also many other taxa that are currently becoming extinct.

5. Conclusions

The conducted research has indicated differences in habitat conditions for the two studied sites. The largest differences were related to chemical properties of the soil and soil moisture. *Silaum silaus* occurred in two different plant communities (*Arrhenatheretum elatioris*, *Molinietum caeruleae*), which varied in their floristic and phytocoenotic aspects, though the total average number of species in the phytosociological relevés, species richness and diversity indicators for the two communities reached similar values.

There were differences in the population numbers of specimens at the analysed sites; the population at Jaćmierz was clearly higher. The analysis of metric characteristics indicates differences between the populations regarding generative traits; however, statistically significant differences for each of these occurred only in one year. Of vegetative characteristics, the number of leaves differed between the sites in both years, while the length of the basal leaf differed only in 2020. The observed differences between the studied populations may constitute a point of departure for broader morphometric research on *Silaum silaus* within the borders of their range of dense occurrence, as well as in dispersed locations.

The south-eastern population is in a better state of preservation than the south-western population. Most likely, this results above all from the manner of meadow use management. Occasional management contributes to a decline in the abundance and gradual disappearance of the species. In contrast, regular mowing promotes an increase in the population size and spread of *Silaum silaus*. It can therefore be concluded that the species can be preserved by sustainable meadow management focused on biomass production with maintenance of high species diversity.

The obtained results do not provide an unambiguous answer to the matter of variation in morphological traits and habitat preferences of the species within and outside of the range of dense occurrence. These may depend on a variety of factors, including methods of management; thus, further studies are necessary in this regard.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16051844/s1, Table S1: Plant communities with *Silaum silaus*.

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