JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2024.151805
2024, No. 63 (X-XII): 191–199

Endangered *Ostericum palustre* – ecological spectrum in the Natura 2000 Bagno Bubnów site and protection methods

Dorota Sienkiewicz-Paderewska*, Jakub Paderewski

Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Nowoursynowska 159, 02-776 Warsaw, Poland

* Corresponding author

RECEIVED 30.09.2024 ACCEPTED 15.11.2024 AVAILABLE ONLINE 23.12.2024

Highlights

- PLB 060001 Bagno Bubnów is an important European refuge of *Ostericum plaustre*.
- In the study area, ANKPA grow mainly in meadows from the *Molinion* alliance.
- ANKPA occupy eutrophic habitats located on mineral soils with neutral pH.
- These the sorption complex of the soil is highly saturated with basic cations.
- These soils show high content of Ca^{2+} cations.

Abstract: PLB 060001 Bagno Bubnów is situated within the boundaries of the Polesie National Park, Poland, representing one of the most significant wetland areas in Europe. It is home to protected phytocenoses and associated flora, including *Ostericum palustre* (ANKPA), a species covered by the Habitats Directive, the Bern Convention, and strict species protection in Poland. ANKPA is a species of Community importance, requiring the designation of an area within the Natura 2000 network. In Poland, it is classified as a vulnerable species. The current global trend of its population remains uncertain. The IUCN emphasises that there is insufficient data to determine its status. This paper presents geobotanical findings from Bagno Bubnów (2021–2022). Based on these findings, the conditions of ANKPA's occurrence were determined. These include the physicochemical properties of soils and the syntaxonomic structure of phytocoenoses it inhabits. In the study area, ANKPA grew mainly in phytocoenoses of the *Molinion* alliance. The analysis indicates that ANKPA exhibits a broad ecological spectrum with respect to numerous habitat parameters. ANKPA was most frequently observed in eutrophic habitats. These habitats had an average organic matter content of 14.73% and an average organic carbon content of 6.7%. The pH of these habitats was neutral, averaging 7.14. They were also saturated with basic cations, with calcium being predominant (average saturation 95.8%). Findings demonstrate that PLB 060001 Bagno Bubnów is a significant location for the conservation of ANKPA. Furthermore, the environmental conditions at this site are conducive to the survival of this species.

Keywords: alkaline fens, *Angelica palustris*, Bagno Staw, biodiversity of wetlands, distribution of *Ostericum palustre*, marsh angelica, restoration of semi-natural ecosystems, threatened plant species

INTRODUCTION

A reduction in the extent of wetlands has been linked to a decline in the population size of numerous species. Thus includes protected species such as *Ostericum plaustre* Besser, (synonym *Angelica palustris* (Besser) Hoffm.), commonly known as marsh angelica, referred to as ANKPA according to international standard (EPPO Global Database, no date). ANKPA is an Eurasian species. Its range, with the exception of a few isolated locations, extends in a narrow belt from Central Europe through

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

Eastern Europe to Western and Central Asia. In Europe, it is distributed from the Baltic states to the Balkans (Serbia), and from eastern Germany to Russia (Bilz, 2011; Czarna *et al.*, 2014).

In Poland, the recorded locations of ANKPA form a belt that extends from the southeast through the centre of the country to the northwest. The highest number of recorded locations were found in the following regions: Pojezierze Wielkopolskie, in the eastern part of the Pradolina Toruńsko-Eberswaldzka, in the Nizina Środkowomazowiecka, Nizinia Południowopodlaska, and the Wyżyna Lubelska. The most northerly location in Poland was recorded in the Nizina Północnopodlaska (Czarna *et al.*, 2014 by: Wołkowycki, 2012).

The global population trend of ANKPA remains unknown. However, there is a reasonable suspicion that it is in decline (Bilz, 2011). Reports from UE member countries (EEA, 2024) and numerous additional sources (including: Załuski, 2004; Nobis, 2012; Czarna *et al.*, 2014; Krasicka-Korczyńska, Stosik and Korczyński, 2014), highlight the most common threats to this species. These include the abandonment of grassland management, leading to natural succession, modification of the hydrological regime, conversion of land to other types of use, intensification of grassland management (e.g. fertilisation and increased mowing frequency), invasive alien species, and problematic native species.

The ANKPA is listed in both Annex II and Annex IV of the EU Habitats Directive (Council Directive, 1992). Furthermore, it is included in Annex I of the Bern Convention (Convention, 1979), and in Revised Annex I of Resolution 6 (1998) of the Bern Convention, revision 2011 (EEA, 2024). As a species of Community importance (Natura 2000 code: 1617), ANKPA requires the designation of areas within the Natura 2000 network (Ustawa, 2004; Rozporządzenie, 2014b). As reported by the EEA, ANKPA is present in 114 Natura 2000 areas designated for its protection in eight Member States (EEA, 2024). The highest number of locations were reported in Poland (54), Hungary (18), Estonia (15), and Germany (12). The International Union for Conservation of Nature (IUCN) lists ANKPA as occurring in 15 countries within its geographical range. However, in most of these countries, ANKPA is seriously endangered or even considered extinct (Bilz, 2011).

In Poland, ANKPA has been a protected species since 2001 (Rozporządzenie 2001; Rozporządzenie, 2014a). Its status on the red lists of plant species has changed over time (Zarzycki and Kaźmierczakowa, 2001; Mirek *et al.* (eds.), 2006; Zarzycki *et al.*, 2014; Kaźmierczakowa *et al.* (eds.), 2016). Currently, the species is classified as vulnerable (VU) in the Polish Red Data Book of Plants (Zarzycki *et al.*, 2014). It is also categorised as near threatened (NT) in the Polish Red List of Pteridophytes and Flowering Plants (Kaźmierczakowa *et al.*, 2016).

In accordance with the IUCN habitat classification system, ANKPA is associated with the following habitats: 4.4 – grassland (temperate) and 5.1 – wetlands (inland) – bogs, marshes, swamps, fens, and peatlands. Based on data provided by EU member states and the nomenclature outlined in the Habitat Directive, ANKPA is found in the following habitat types: 1630 – Boreal Baltic coastal meadows, 6410 – *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*), 6440 – Alluvial meadows of river valleys of the *Cnidion dubii*, and 7230 – Alkaline fens.

A review of the literature reveals a considerable ecological diversity of ANKPA across its geographical range (Michalska-Hejduk and Kopeć, 2010; Bilz, 2011; Krasicka-Korczyńska, Stosik and Korczyński, 2014; Kostrakiewicz-Gierałt, Stachurska-Swakoń and Towpasz, 2018; Ćušterevska and Stojchevska, 2024). However, there is a lack of precise data concerning the physicochemical properties of the soils in which this species has been observed (Dittbrenner, Partzsch and Hensen, 2005). In most cases, authors refer to Ellenberg's (Ellenebrg *et al.*, 1991) or Zarzycki's (Zarzycki, 2002) phytoindicators (Dittbrenner, Partzsch and Hensen, 2005; Michalska-Hejduk and Kopeć, 2010; Nobis, 2012; Krasicka-Korczyńska, Stosik and Korczyński, 2014; Ćušterevska and Stojchevska, 2024). As a result, it is challenging to ascertain which habitats are most prevalent for ANKPA.

The available data regarding the conditions under which ANKPA occurs is incomplete and requires further verification and supplementation. Most habitats are described as follows: the soil moisture: reported as moderate; light requirements: medium; and nutrient content in the soil: "mid" or moderate. However, one can also find information that these are soils with a high content of organic carbon and calcium, rich in nutrients, and the soil reaction is described as slightly acidic, but also reported as neutral to slightly alkaline (Michalska-Hejduk and Kopeć, 2010; Nobis, 2012; Krasicka-Korczyńska, Stosik and Korczyński, 2014; Ćušterevska and Stojchevska, 2024).

PLB 060001 Bagno Bubnów (51°19'–51°23'N, 23°15'–23°21'E) constitutes part of the network of Special Protection Areas for birds. It largely overlaps with the area of protection of habitats PLH Ostoja Poleska 060013 (GDOŚ, no date). PLB 060001 Bagno Bubnów and PLH 060013 Ostoja Poleska are located within the boundaries of the Polesie National Park. These areas have been designated as a Ramsar site, a UNESCO Transboundary Biosphere Reserve (shared by Poland, Belarus, and Ukraine), and an Important Bird and Biodiversity Area (IBBA). The region plays a crucial role in the protection of endangered wetland plant communities and related plant species.

The PLB 060001 Bagno Bubnów is one of the largest areas of eutrophic, low carbonate peatlands in eastern Poland, covering 2344 ha (Dobrowolski and Pietruczuk, 2020). It constitutes part of the most extensive complex of peatlands and marshes in Europe, which includes Western Polesie and Volyn Polesie. The area comprises two peatland complexes: Bagno Bubnów and Bagno Staw. From a physiographic standpoint, Bagno Bubnów is situated in Western Polesie, whereas Bagno Staw is located in Volyn Polesie (Dobrowolski *et al.*, 2021). PLB 060001 Bagno Bubnów is situated within the source area of the Włodawka River, on Pleistocene sands and silts, which were deposited on Upper Cretaceous carbonate rocks and are additionally supplied with waters rich in calcium cations (Dobrowolski and Pietruczuk, 2020). The distinctive geological and edaphic conditions of this region have resulted in the formation of phytocenoses comprising a diverse array of characteristic species, including protected species such as ANKPA.

The authors propose a hypothesis that our knowledge of the conditions favourable for maintaining ANKPA remains poorly developed. Although ANKPA has been recorded in over 150–200 locations in Poland (Nobis 2012; Krasicka-Korczyńska, Stosik and Korczyński, 2014) and at least 114 in Europe (Ćušterevska and Stojchevska, 2024; EEA, 2024), precise data, e.g. physicochemical properties of soils in which this species is found, remains scarce.

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

The knowledge available on this subject is often based only on phytoindication methods (i.e. Dittbrenner, Partzsch and Hensen, 2005; Michalska-Hejduk and Kopeć, 2010; Krasicka-Korczyńska *et al.*, 2014; Ćušterevska and Stojchevska, 2024). Additionally, the IUCN (Bilz, 2011) indicates that data on this species remains incomplete, and its current population trend is regarded as unknown. Consequently, it has been assigned the status of DD (data deficient). As outlined by Ćušterevska and Stojchevska (2024, p. 24) "The aim (...) is to gather as much information as possible on *Angelica palustris* in order to improve its conservation status." For this reason, the research focused on identifying the conditions under which ANKPA occurs, analysing the physicochemical properties of soils and the syntaxonomic structure of phytocoenoses it inhabits. The research extends existing knowledge on ANKPA's ecological spectrum and habitat requirements, thus potentially enhancing the efficacy of its protection. This task, however, is a challenging, given that ANKPA is a component of communities that require active protection tailored to the genesis and specificity of the habitat (Załuski, 2004; Nobis, 2012; Ćušterevska and Stojchevska, 2024). The novelty of the research lies in its integrated approach, combining phytosociological analysis with soil research, with the objective of determining the habitat preferences of ANKPA.

MATERIALS AND METHODS

MATERIAL

The *Ostericum plaustre* Besser (syn. *Angelica palustris* (Besser) Hoffm.), common name: marsh angelica) is a species of the *Apiaceae* family (Mirek *et al.*, 2002). It is a biennial or perennial hemicryptophyte (Kostrakiewicz-Gierałt, Stachurska-Swakoń and Towpasz, 2018). ANKPA forms vegetative and generative shoots (Nobis, 2012). The stem length is usually within the range of (30) 50–80 cm (Szafer *et al.*, 1953; Nobis, 2012), though it can reach up to 150 cm (220 cm) (Czarna *et al.*, 2014; Kostrakiewicz-Gierałt *et al.*, 2018). The stem is hollow inside, naked, longitudinally ridged, often reddish in colour at the bottom (Photo 1a). In its upper part, the stem is slightly winged on the edges (Szafer, Kulczyński and Pawłowski, 1953) – Photo 1a. The lower leaves are 2–3-pinnate, the petioles of the first-order segments are bent, the last-order leaflets are heart-shaped-ovate, unevenly serrated, with the underside on the veins rough-haired (Szafer, Kulczyński and Pawłowski, 1953) – Photos 1b, 2b. ANKPA flowers from June to September (Bliz, 2011). Its inflorescence is a compound umbel. The small, white, 5-petalled flowers are clustered in umbellules, and these are clustered in umbels. The apical umbel is larger than the others, consisting of 8–30 umbellules (Szafer, Kulczyński and Pawłowski, 1953) – Photo 2a. The plant typically lacks bracts or has at most 1–3. The umbellules have sparse, lanceolate bracts with serrated edges. The corolla petals are indented at the top. Pollination is primarily facilitated by diptera insects (Zych, Michalska and Krasicka-Korczyńska, 2014). The fruit is a schizocarp that splits into two elliptical, ribbed mericarps, measuring 4.0–6.0 mm in length and 2.5–4.0 mm in width. Seeds dispersal occurs predominantly through wind (Nobis, 2012).

Photo 1. Morphology of *Ostericum palustre*: a) the stem length is usually in the range of (30) 50–80 cm though it can reach up to 150 cm (220 cm); the stem is hollow inside, naked, longitudinally ridged, often reddish in colour at the bottom. In the upper part, the stem is slightly winged on the edges, b) the veins on the underside of the leaflets are rough-haired (phot.: *D. Sienkiewicz-Paderewska*)

Photo 2. Morphology of *Ostericum palustre*: a) *Ostericum palustre* inflorescence is a compound umbel; the small, white, 5-petalled flowers are clustered in umbellules, and these are clustered in umbels; the apical umbel is larger than the others, b) the leaflets are heart-shaped-ovate, unevenly serrated (phot.: *D. Sienkiewicz-Paderewska*)

METHODS

The locations of ANKPA in the Natura 2000 site PLB 060001 Bagno Bubnów (Fig. 1) were recorded during geobotanical studies conducted between June and August of 2021 and 2022. In the 19 locations where the presence of ANKPA was confirmed, phytosociological relevés were made using the Braun-Blanquet method (Braun-Blanquet, 1964) on square plots of 100 m^2 each. Soil samples were collected from 12 randomly selected sites to determine the physicochemical properties of the soil.

Soil samples were collected in duplicate at the same locations and times as the phytosociological relevés. They were collected from the topsoil layer at a depth of 0–30 cm, then air-dried and ground. Laboratory analyses were subsequently performed using standard methods (Reeuwijk van, 2002). The following determinations were made: pH in water (pH (H_2O)) was measured using a potentiometric method with an Elmetron IP67 pH meter equipped with a GPX-105 electrode. The total organic carbon and total nitrogen content were analysed by dry combustion using the VarioMAX CNS apparatus, calcium carbonate equivalent content by volumetric method using Scheibler's apparatus, and organic matter content was determined

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

Fig. 1. Location of study area and distribution of the *Ostericum palustre*; source: own elaboration with the use Geoserwis GDOŚ (no date) and Copernicus, EESA (no date)

based on the loss on ignition by burning the sample in a muffle furnace at 550°C. Then, the content of exchangeable cations such as calcium, magnesium, potassium, and sodium (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) were measured after extraction of samples in 1 M ammonium acetate solution at pH = 7.0; using atomic absorption spectrometry with an AA 220 FS spectrometer (Varian), and hydrolytic acidity using the Kappen method.

The 19 phytosociological relevès of 100 m^2 each were sampled using the Braun-Blanquet (1964) method. The abundance of species was estimated using the Braun-Blanquet 7-degree cover-abundance scale. Cover-abundance values were transformed as follows: r = 0.1%; + = 0.5%; 1 = 5.0%; 2 = 15.0%; 3 = 37.5%; 4 = 62.5%; 5 = 87.5% in order to calculate the cover of species.

Frequency, mean cover, and relative mean cover were then calculated for each species included in the phytocoenosis. The calculations were made as follows: (i) frequency – the number of species in relation to the total number of relevés; (ii) average cover – the cover of each species per 1 phytosociological relevé; (iii) relative average cover – the percentage of the average cover of one species in relation to the sum of the average covers of all species. Due to the absence of a normal distribution for soil parameters (as evidenced in Table 1, where the standard deviation is comparable to the mean, indicating strong skewness), it would be incorrect to provide statistical measures such as confidence intervals. Consequently, we limited our analysis to fundamental statistics, including the median, mean, standard deviation (*SD*), minimum (min.) and maximum (max.).

The affiliation to syntaxa was based on Matuszkiewicz (2008), while the species nomenclature was given after Mirek *et al.* (2002). The presented results are primarily based on our own research, but they have also been enhanced by the analysis of literature data, with the aim of providing a comprehensive overview of ANKPA's ecological spectrum.

RESULTS

SOIL CONDITIONS

Of the 19 recorded locations of ANKPA within the PLB 060001 Bagno Bubnów area, the majority (14) were found in the southern part of Bagno Staw, while 5 were located in the southwestern part of Bagno Bubnów (Fig. 1). ANKPA was found to predominantly inhabit habitats located on mineral soils, although it also occurred on mineral-organic and organic soils (Tab. 1). The average organic matter content of the soils was 14.73%, with the organic carbon (C_{org}) constituting 6.7%. These soils generally exhibited a neutral pH (average 7.14). The sorption complex was significantly saturate with alkaline cations (average 95.8%). Among these, Ca^{2+} predominated, with an average content of 27.33 cmol(+)·kg^{-1} (Tab. 1).

Table 1. Soil properties of the examined *Ostericum palustre* sites in the area of PLB 060001 Bagno Bubnów (*n* = 12)

Soil parameter	Mean (standard deviation)	Median	Range
pH (H_2O)	7.13 (0.44)	7.25	6.3–7.8
OM (%)	14.7 (8.5)	10.8	6.5–31.1
C_{org} (%)	6.68 (4.10)	4.91	2.73–15.20
N_t (%)	0.554 (0.365)	0.415	0.22–1.28
C:N ratio	12.5 (1.3)	12.7	10.6–14.8
$CaCO_3$ (%)	7.69 (13.88)	0.50	0.0–36.3
Na^+ cmol(+)·kg^{-1}	0.0442 (0.0394)	0.04	0.0–0.1
Mg^{2+} cmol(+)·kg^{-1}	0.297 (0.121)	0.28	0.15–0.57
K^+ cmol(+)·kg^{-1}	0.118 (0.052)	0.105	0.06–0.23
Ca^{2+} cmol(+)·kg^{-1}	27.3 (14.7)	20.7	13.2–55.8
EBC cmol(+)·kg^{-1}	27.8 (14.9)	21.2	13.4–56.5
Ha cmol(+)·kg^{-1}	0.900 (0.538)	0.70	0.35–2.20
CEC cmol(+)·kg^{-1}	28.7 (14.6)	22.0	14.8– 57.0
BS (%)	95.8 (3.7)	96.9	86.9–99.1

Explanations: *n* = number of examined sites, OM = organic matter, C_{org} = organic carbon, N_t = total nitrogen content, $CaCO_3$ = calcium carbonate content, Na^+ = sodium content, K^+ = potassium content, Mg^{2+} = magnesium content, Ca^{2+} = calcium content, EBC = base cations, *Ha* = hydrolytic acidity, *CEC* = cation exchange capacity, *BS* = base saturation.
Source: own study.

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

FLORISTIC COMPOSITION

In the Natura 2000 site PLB Bagno Bubnów, ANKPA was predominantly observed in phytocoenoses of meadows belonging to the *Molinion* alliance. Species belonging to the *Molinio-Arrhenatheretea* class constituted 67.9% of the relative average cover of the studied phytocenoses (Fig. 2a), including species of the *Molinietalia* order, which accounted for 58.3% (Fig. 2b). Among these, species of the *Molinion caerulae* alliance were particularly prevalent, representing 48.6% (Fig. 2c). ANKPA was most frequently (frequency >70%) accompanied by the following species: *Molinia caerulea*, *Galium verum*, *Briza media*, *Centaurea jacea*, *Potentilla erecta*, *Selinum carvifolia*, *Carex flacca*, *Succisa pratensis*, *Deschampsia caespitosa* (Tab. S1).

The findings of our research were compared with the existing literature on the identified habitats of ANKPA, and are presented in a synthesis in Table S2.

DISSCUSSION

In the Natura 2000 area, PLB 060001 Bagno Bubnów, ANKPA was recorded primarily in phytocoenoses of meadows belonging to the *Molinion* alliance. This observation aligns with the findings of numerous other documented locations in Poland and other countries, including Grynia (1962), Kępczyński and Załuski (1991), Dittbrenner, Partzsch and Hensen (2005), Nobis, Nobis and Kozak (2008), Nobis and Piwowarczyk (2008), Michalska-Hejduk and Kopeć (2010), Bliz (2011), Krasicka-Korczyńska, Stosik and Korczyński (2014), Chusova *et al.* (2022), and Ćušterevska and Stojchevska (2024). Nevertheless, a synthesis of the available literature reveals that ANKPA demonstrates a much wider ecological spectrum (Tab. 2). It occurs in a wide variety of phytocoenoses, including fresh meadows and pastures belonging to the *Arrhenatheretalia* order (as documented by: Załuski (2004), Dittbrenner, Partzsch and Hensen (2005),

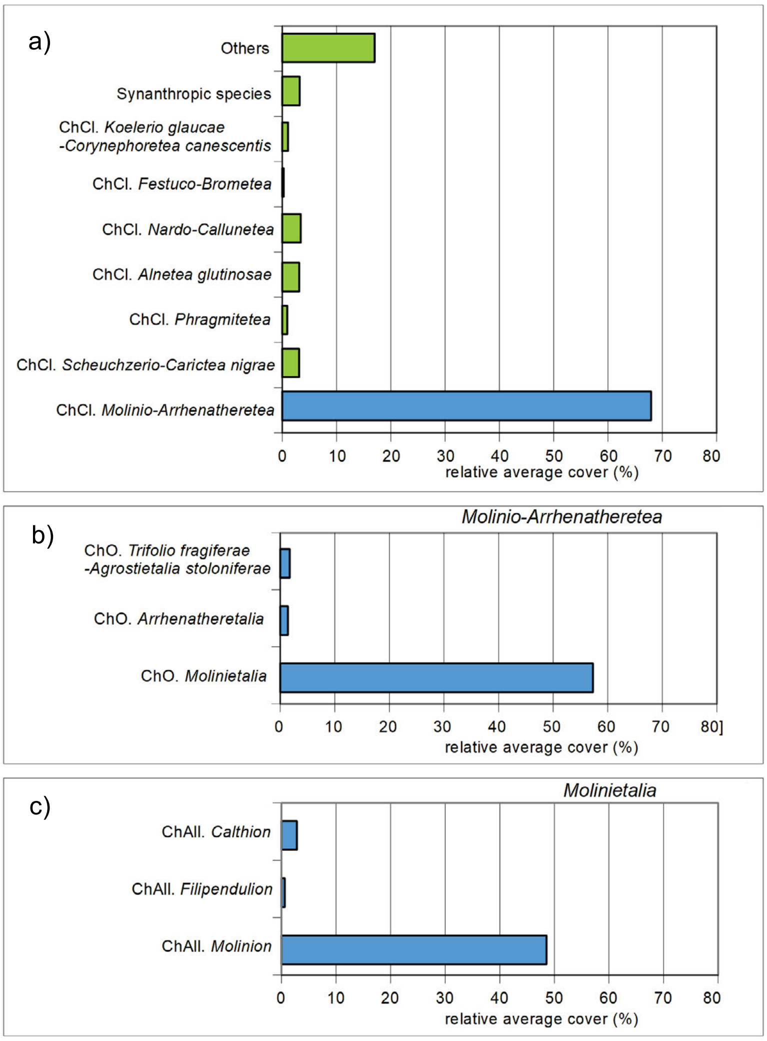

Fig. 2. Syntaxonomic structure of the analysed plant communities with *Ostericum palustre* in the PLB 060001 Bagno Bubnów: a) species characteristic of the classes occurring, b) species characteristic of the orders belonging to *Molinio-Arrhenatheretea* class, c) species characteristic of the alliances belonging to *Molinietalia* order; ChCl = species characteristic for class, ChO = species characteristic for order, ChAll = species characteristic for alliance, synathropic species – sum of species from *Agropyretea intermedio-repentis*, *Epilobietea angustifolii* and *Artemisietea vulgaris* classes; others = species not designated as characteristic for syntaxa or species with a very low frequency; source: own study

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

Krasicka-Korczyńska, Stosik and Korczyński (2014)), through the variable humidity meadows of the *Molinion* alliance (Grynia, 1962; Nobis, Nobis and Kozak, 2008; Michalska-Hejduk and Kopeć, 2010; Krasicka-Korczyńska, Stosik and Korczyński, 2014), then, wet meadows of *Calthion* alliance (Grynia, 1962; Dittbrenner, Partzsch and Hensen, 2005; Bróż and Podgórska, 2006; Nobis, Nobis and Kozak, 2008; Kostrakiewicz-Gierałt, Stachurska-Swakoń and Towpasz, 2018) and *Filipendulion* (Michalska-Hejduk and Kopeć, 2010), communities of the *Phragmitetea* class (Dittbrenner, Partzsch and Hensen, 2005; Nobis, Nobis and Kozak, 2008; Michalska-Hejduk and Kopeć, 2010; Krasicka-Korczyńska, Stosik and Korczyński, 2014) to the peatlands of *Scheuchzerio-Caricetea nigrae* class (Michalska-Hejduk and Kopeć, 2010; Nobis, 2012; Krasicka-Korczyńska, Stosik and Korczyński, 2014).

The presented research, although conducted on a relatively limited scale, also indicates the wide ecological spectrum of ANKPA. This conclusion is supported by the findings of the soil physicochemical property analyses, which demonstrate considerable variability in several features (Tab. 1). The data indicate that ANKPA grew on mineral, mineral-organic, and organic soils (PTG, 2019) with mineral soils being the most common. Only two of the sites had $C_{org.}$ content greater than 12% (PTG, 2019). The pH (H_2O) of the soils ranged from slightly acidic to neutral and alkaline, with neutral soils predominating (found at 8 out of 12 sites). The degree of soil complex saturation with alkaline cations (Na^+, K^+, Mg^{+2}, Ca^{+2}) was found to be greater than 15 $cmol(+)\cdot kg^{-1}$ in almost all samples, with the lowest value recorded being 13.4 $cmol(+)\cdot kg^{-1}$. This indicates that the habitats can be classified as eutrophic. The examined sites exhibited a relatively constant carbon-to-nitrogen (C:N) ratio, ranging from 10.6 to 14.6. This suggest soils with advanced humification of organic matter. This implies that these habitats may share similar properties with those in Slovakia, where ANKPA occurs on wet fen meadows. These meadows are characterised by neutral to moderately alkaline, mineral-rich soils, with high organic carbon and calcium content (Ćušterevska and Stojchevska, 2024).

In the recorded locations within the PLB 060001 Bagno Bubnów, ANKPA was observed in areas subjected to mowing. In the context of protection methods for ANKPA, it is known that habitat alterations occur as a result of drainage and intensification, or abandonment of grassland management. These changes are difficult to mitigate on a large scale due to the low profitability of extensive agricultural practices. Comprehensive protection strategies have established that regular mowing of meadows is a crucial measure for sustaining the populations of ANKPA (Kostrakiewicz-Gierałt, Stachurska-Swakoń and Towpasz, 2018).

Additionally, the frequency of mowing is a topic of particular interest. According to Ćušterevska and Stojchevska (2024), meadows where ANKPA grows are typically mowed once or twice a year, depending on traditional practices. As reported by these authors, the first mowing typically takes place in May–June, while the second in August–September. In light of the available literature and our investigations, it is worth considering limiting the mowing to one cut per year or even perform cuts irregularly. One cut per year enables this species to bear fruit each year, which seems to be very important to maintain the population size.

Investigations conducted in a wet meadow belonging to the *Calthion palustris* alliance and in a swamp phytocoenosis of the *Phragmition australis* association revealed that the height of the generative shoots of ANKPA depends on the type of phytocoenosis in which ANKPA occurs, as well as on grassland management practices (Kostrakiewicz-Gierałt *et al.*, 2018). When the co-occurring species in the community are taller, for example due to the reduced number of cuts, the ANKPA shoots also grow longer. This is likely due to competition for both light and pollinators, as taller shots improve visibility of inflorescences. Interestingly, in abandoned meadows, ANKPA formed higher generative shoots with a larger number of inflorescences and infructescences. This adaptation may enhance seed dispersal and help the species escape unfavourable sites. Nevertheless, it is evident that the cessation of mowing is not an effective method for conserving ANKPA habitats. Secondary succession would rapidly lead to the overgrowth of abandoned meadows. Therefore, determining the optimal timing and frequency of cuts is crucial. This depends on the habitat conditions and the type of phytocoenosis in which ANKPA occurs. Such management practices will certainly require regular monitoring of the studied populations.

In the locations described in this paper with the PLB Bagno Bubnów, the timing and frequency of mowing aligned with the recommended methodology for protecting the habitats of *Molinia* meadows in Natura 2000 sites. This involved annual late-summer mowing, excluding some fragments of the meadow each year. However, Dittbrenner, Partzsch and Hensen (2005) postulated that mowing once a year in early summer could make ANKPA more competitive in comparison to other species.

In conclusion, it is important to emphasise that comprehensive research, comprising a more detailed recording of ANKPA's population size and distribution in the study area, along with subsequent morphological studies conducted on a representative sample of sites, may help to ascertain the strategy of this species in the identified locations. This, in turn, would enhance the ability to forecast population changes more accurately in the future. Endangered species are often protected as part of the habitat with which they are associated. The principal objective is to protect entire plant communities to maintain their optimal ecological condition. This is indicated, among other factors, by the presence of a considerable number of diagnostic species within protected phytocoenoses. Nevertheless, this approach entails protecting different species with varying phenological requirements. Therefore, the key to successful conservation lies in the knowledge of the genesis and habitat conditions of the phytocoenosis being protected.

As underlined by Ćušterevska and Stojchevska (2024, p. 16): "Although *Angelica palustris* is a widespread species, due to habitat loss, its populations are generally small, fragmented and isolated, and with reduced biological vitality. Similarly, Bliz (2011) states that the population trend of ANKPA is currently unknown but it is suspected to be decreasing. This is supported by its classification as an endangered species on numerous national red lists. Furthermore, no evidence suggests the existence of robust and expansive populations of this species in any given region. It is highly probable that the current data on the global population size and distribution of ANKPA are incomplete. However, the data provide some insights into general trends in the status and development prospects of ANKPA populations within its geographical range. Official

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

European data indicate that the majority of ANKPA locations are in Poland, which underscores the importance of expanding ongoing research and implementing continuous monitoring of this species (EEA, 2024).

A review of the existing literature suggests that ANKPA is most frequently observed in phytocoenoses of the *Molinietalia* order. These communities are extensively utilised, eutrophic, and exhibit a broad pH range. They are characterised by high moisture levels and a lack of prolonged flooding. Based on this, it can be concluded that ANKPA finds favourable conditions for its occurrence in the PLB Bagno Bubnów, supported by both edaphic conditions and grassland management. The fact that this species grows within a formal protection area ensures the continuation of meadow management. This addresses one of the most frequently raised issues in the literature concerning the protection of endangered species associated with semi-natural ecosystems (Nobis, Nobis and Kozak, 2008; Kostrakiewicz-Gierałt, Stachurska-Swakoń and Towpasz, 2018; Sienkiewicz-Paderewska *et al.*, 2019; Ćušterevska and. Stojchevska, 2024).

Hydrological factors strongly influence the conservation of the ANKPA habitats, as highlighted by various authors (Bróż and Podgórska, 2006; Towpasz, Stachurska-Swakoń and Kostrakiewicz, 2011; Krasicka-Korczyńska, Stosik and Korczyński, 2014; Czarna *et al.*, 2014). In the PLB 060001 Bagno Bubnów area, the probability of ANKPA's survival is high, provided appropriate grassland management is combined with adequate water regime. It is important to highlight that the presence of *Molinia* meadows within the Bagno Bubnów results from succession processes linked to the drying out of carbonate peat bogs. These peatbogs are a valuable natural resource, currently threatened by unfavourable hydrological changes (Urban *et al.,* 2020). The continued existence of both carbonate peat bog communities (7210) and *Molinia* meadow communities (6410) in this location may be at risk due to the unsteady level of groundwater. As observed by Krasicka-Korczyńska, Stosik, and Korczyński (2014), the range of habitats occupied by ANKPA is frequently limited by reduced moisture in the topsoil layer. Nevertheless, the positive effects of the activities conducted within the Polesie National Park, aimed at enhancing water retention, coupled with the sustained proper management of meadows, bode well for the conservation of these highly valuable habitats and the species associated with them (Urban *et al.*, 2020).

CONCLUSIONS

1. The Natura 2000 site PLB 060001 Bagno Bubnów constitutes an important refuge for *Ostericum palustre* (ANKPA).
2. ANKPA occurs in the PLB 060001 Bagno Bubnów area within habitats that can be considered optimal for this species.
3. In the study area, ANKPA was primarily found in the phytocoenoses of *Molinion* alliance meadows.
4. In the studied locations, ANKPA was most frequently observed in eutrophic habitats, on mineral soils, with advanced humification and a neutral pH.
5. Effective protection of the ANKPA is possible by maintaining an appropriate hydrological regime and implementing proper grassland management. This should take into account the phenology of ANKPA, the characteristics of its habitat, and the type of phytocenosis to which it belongs.

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at: https://www.jwld.pl/files/Supplementary_material_Sienkiewicz.pdf

FUNDING

This article was created as a result of the NCN (National Science Center) Miniatura 5 project 2021/05/X/NZ9/01141: "Habitat requirements and conservation practices of rare and endangered vascular plant species in the Bagno Bubnów in the Polesie National Park".

CONFLICT OF INTEREST

All authors declare that they have no conflict of interests.

REFERENCES

Bilz, M. (2011) *Angelica palustris (Europe assessment)*. The IUCN Red List of Threatened Species 2011:e.T162030A5535896. Available at: https://www.iucnredlist.org/species/162030/5535896 (Accessed: August 12, 2024).

Braun-Blanquet, J. (1964) *Pflanzensoziologie. Grundzüge der Vegetationskunde [Plant sociology. Basics of vegetation science]*. Wien–New York: Springer Verlag.

Bróż, E. and Podórska, M. (2006) "Starodub łąkowy *Ostericum palustre* Besser na Wyżynie Małopolskiej [*Ostericum palustre* Besser in the Małopolska Upland]," *Chrońmy Przyrodę Ojczystą*, 62(3), pp. 3–12.

Chusova, O.O. *et al.* (2022) "Protected species in grassland habitats of Ukraine," *Ukrainian Botanical Journal*, 79(5). Available at: https://doi.org/10.15407/ukrbotj79.05.290.

Ćušterevska, R. and Stojchevska, C. (2024) "General guidelines for *Angelica palustris* conservation," in H. Pánková (ed.) *Guidelines for species conservation*. Průhonice: Institute of Botany, Czech Academy of Sciences, pp. 4–30.

Czarna, A. *et al.* (2014) "*Ostericum palustre* starodub łąkowy [*Ostericum palustre* marsh angelica]," in R. Kaźmierczakowa, K. Zarzycki and Z. Mirek (eds.) *Polska czerwona księga roślin [Polish red data book of plants]*. Kraków: Instytut Ochrony Przyrody PAN, pp. 365–368.

Convention (1979) "Convention on the conservation of European wildlife and natural habitats," *European Treaty Series*, 104. Available at: https://rm.coe.int/1680078aff (Accessed: August 12, 2024).

Council Directive (1992) "Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora," *Official Journal*, L 206, Consolidated version 1.1.2007.

Dittbrenner, A., Partzsch, M. and Hensen, I. (2005) "Beiträge zur Populationsbiologie und Vergesellschaftung von *Angelica palustris* (Besser) Hoffm.) [Contributions to the population biology and association of *Angelica palustris* (Besser) Hoffm.]," *Hercynia N.F.*, 38, pp. 59–87. Available at: http://dx.doi.org/10.25673/93320.

Dobrowolski, R. and Pietruczuk, J. (2020) "Budowa geologiczna i rzeźba terenu [Geological structure and topography]," in T.J. Chmielewski, J. Szymański and A. Weigle (eds.) *Poleski Park Narodowy. Dziedzictwo i przyszłość [Polesie National Park. Heritage and Future]*. Lublin: Wyd. UMSC, pp. 55–84.

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

Dobrowolski, R. *et al.* (2021) "Polesie Zachodnie 845.1. [West Polesie 845.1.]," in A. Richling *et al.* (eds.) *Regionalna geografia fizyczna Polski [Regional physical geography of Poland]*. Poznań: Bogucki Wyd. Naukowe, pp. 577–584.

EEA (2024) *Angelica palustris (Besser) Hoffm. – Synonym of Ostericum palustre*. European Environment Agency. Available at: https://eunis.eea.europa.eu/species/151518 (Available at: August 12, 2024).

Ellenberg, H. *et al.* (1991) "Zeigerwerte von Pflanzen in Mitteleuropa [Indicator values of plants in Central Europe]," *Scripta Geobotanica*, 18.

EPPO Global Database (no date) *Angelica palustris (ANKPA)*. EPPO Global Database. Available at: https://gd.eppo.int/taxon/ANKPA (Accessed: October 24, 2024).

Fijałkowski, D. (1994) *Flora roślin naczyniowych Lubelszczyzny [The vascular plants in the Lublin District]*. Vol. 1. Lublin: Lubelskie Towarzystwo Naukowe.

GDOŚ (no date) *Geoserwis mapy [Geoservis maps]*. Warszawa: Generalna Dyrekcja Ochrony Środowiska. Available at: https://geoserwis.gdos.gov.pl/mapy/?showExternalObject=50EE7EB8130C2C92FD74E7818DB899E2 (Accessed: August 12, 2024).

Grynia, M. (1962) "Łąki trzęślicowe Wielkopolski [*Molinia caerulea* meadow types in Great Poland Region]," *Prace Komisji Nauk Rolniczych i Komisji Nauk Leśnych PTPN*, 13(2), pp. 145–269.

Kaźmierczakowa, R. *et al.* (2016) *Polska czerwona lista paprotników i roślin kwiatowych [Polish red list of pteridophytes and flowering plants]*. Kraków: Instytut Ochrony Przyrody Polskiej Akademii Nauk.

Kępczyński, K. and Załuski, T. (1991) "Zróżnicowanie roślinności łąk trzęślicowych w dolnym odcinku doliny Rakutówki [Diversity of vegetation of *Molinia* meadows in the lower section of the Rakutówka valley]," *Acta Universitatis Nicolai Copernici*, *Biologia*, 36, pp. 41–55.

Kostrakiewicz-Gierałt, K., Stachurska-Swakoń, A. and Towpasz, K. (2018) "Variability of morphological traits of the rare plant species *Angelica palustris* (*Apiaceae*) in managed and abandoned meadows: Effect of mowing," *Polish Journal of Ecology*, 66, pp. 36–47. Available at: https://doi.org/10.3161/15052249PJE2018.66.1.004.

Krasicka-Korczyńska, E., Stosik, T. and Korczyński, M. (2014) "Habitat and phytocenosis conditions of the occurrence of *Ostericum palustre* in the Natura 2000 "Lisi Kąt" site", *Steciana*, 18, pp. 3–11. Available at: https://doi.org/10.12657/steciana.018.001.

Matuszkiewicz, W. (2008) *Przewodnik do oznaczania zbiorowisk roślinnych Polski [Polish plant communities' guidebook]*. Warszawa: Wydaw. Nauk. PWN.

Michalska-Hejduk, D. and Kopeć, D. (2010) "Ecological and sociological spectrum of *Ostericum palustre* at new localities in central Poland," *Biodiversity Research Conservation,* 17, pp. 63–71. Available at: http://dx.doi.org/10.2478/v10119-010-0008-0.

Mirek, Z. *et al.* (2002) *Vascular plants of Poland. A checklist.* Available at: http://bomax.botany.pl/ib-db/check/ (Accessed: August 12, 2024).

Mirek, Z. *et al.* (eds.) (2006) *Red list of plants and fungi in Poland.* Kraków: Instytut Botaniki im. W. Szafera, Polska Akademia Nauk.

Nobis, M. (2012) "1617: "*Ostericum palustre* Besser – starodub łąkowy [*Ostericum plaustre* Besser – marsh angelica]," in J. Perzanowska (ed.) *Monitoring gatunków roślin: przewodnik metodyczny: opracowanie zbiorowe. Biblioteka Monitoringu Środowiska [A methodological guide to the monitoring of plant species: A collective work]*. Warszawa: GIOŚ. Available at: https://siedliska.gios.gov.pl/images/pliki_pdf/wyniki/2009-2011/dla_roslin/Starodub-kowy-Ostericum-palustre.pdf (Accessed: August 12, 2024).

Nobis, M., Nobis, A. and Kozak, M. (2008) "Występowanie *Ostericum palustre* (*Apiaceae*) w południowej Polsce [Occurrence of *Ostericum palustre* (*Apiaceae*) in southern Poland]," *Fragmenta Floristica et Geobotanica Polonica*, 15(1), pp. 3–9. Available at: http://bomax.botany.pl/pubs/#article-2183 (Accessed: August 12, 2024).

Nobis, M. and Piwowarczyk, R. (2008) "The distribution, habitat preferences and size of population of *Ostericum palustre* Besser on the south-western limit of its occurrence in Poland," *Nature Conservation*, 65, pp. 43–49. Available at: https://panel.iop.krakow.pl/uploads/wydawnictwa_artykuly/482414799da80cec783366cd18690fe3000e3e18.pdf (Accessed: August 12, 2024).

Programme of the European Union, Copernicus, EESA (no date) *Sentinel-2*. Available at: https://dataspace.copernicus.eu/explore-data/data-collections/sentinel-data/sentinel-2 (Accessed: August 12, 2024).

PTG (2019) *Systematyka gleb Polski [Systematics of Polish soils].* Wrocław–Warszawa: Polskie Towarzystwo Gleboznawcze, Komisja Genezy Klasyfikacji i Kartografii Gleb. Wydawnictwo Uniwersytetu Przyrodniczego we Wrocławiu, Polskie Towarzystwo Gleboznawcze.

Reeuwijk van, L.P. (ed.) (2002) "Procedures for soil analysis," *Technical Paper*, 9. 6th edn. Wageningen: ISRIC. Available at: https://www.isric.org/sites/default/files/ISRIC_TechPap09.pdf (Accessed: August 12, 2024).

Rozporządzenie (2001) "Rozporządzenie Ministra Środowiska z dnia 11 września 2001 r. w sprawie listy gatunków roślin rodzimych dziko występujących objętych ochroną gatunkową ścisłą częściową oraz zakazów właściwych dla tych gatunków i odstępstw od tych zakazów [Regulation of the Minister of Environment of the 11 September 2001on the list of species of native wild plants under strict and partial protection, prohibitions applicable to these species and exceptions to these prohibitions. *Dz.U.*, 2001, nr 106, poz. 1167.

Rozporządzenie (2014a) "Rozporządzenie Ministra Środowiska z dnia 9 października 2014 r. w sprawie ochrony gatunkowej roślin [Regulation of the Minister of Environment of 9 October 2014 on conservation of plant species]," *Dz.U.*, 2014, nr 106, poz. 1409.

Rozporządzenie (2014b) "Rozporządzenie Ministra Środowiska z dnia 4 grudnia 2014 r. w sprawie siedlisk przyrodniczych oraz gatunków będących przedmiotem zainteresowania Wspólnoty, a także kryteriów wyboru obszarów kwalifikujących się do uznania lub wyznaczenia jako obszary Natura 2000 [Regulation of the Minister of Environment of 4 December 2014 on natural habitats, species of Community interest and selection criteria for areas qualifying for being classified or designated as Natura 2000 areas]," *Dz.U.*, 2014, poz. 1713.

Sienkiewicz-Paderewska, D. *et al.* (2019) "Effect of different land-use on occurrence and morphological traits of *Carex buxbaumii* (study from Biebrza National Park, Poland)," *Global Ecology and Conservation*, 20, pp. 1–11. Available at: https://doi.org/10.1016/j.gecco.2019.e00802.

Szafer, W., Kulczyński, S. and Pawłowski, B. (1953) *Rośliny polskie [Polish plants]*. Warszawa: PWN.

Towpasz, K., Stachurska-Swakoń, A. and Kostrakiewicz, K. (2011) "*Ostericum palustre* (*Apiaceae*) – a new species in the Proszowice Plateau (S Poland)," *Fragmenta Floristica et Geobotanica Polonica*, 18, pp. 169–171.

Urban, D. *et al.* (2020) "Torfowiska [Peatlands]," in T.J. Chmielewski, J. Szymański and A. Weigle (eds.) *Poleski Park Narodowy.*

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

Dziedzictwo i przyszłość [Polesie National Park. Heritage and Future]. Lublin: Wyd. UMSC, pp. 157–186.

Ustawa (2004) "Ustawa z dnia 16 kwietnia 2004 r. o ochronie przyrody [Act on nature conservation of 16 April 2004]," *Dz.U.*, 2004, nr 92, poz. 880.

Wołkowycki, D. (2012) "Materiały do flory Wzgórz Sokólskich [Data on the flora of the Sokólskie Hills]," *Fragmenta Floristica et Geobotanica Polonica*, 19(2), pp. 379–688.

Wójcik, T. *et al.* (2021) "Nowe stanowiska roślin naczyniowych Polski, 2 [New localities of vascular plants occurring in Poland, 2]," *Wiadomości Botaniczne*, 65, pp. 1–20. Available at: https://doi.org/10.5586/wb.656.

Załuski, T. (2004) "*Ostericum palustre* Besser," in B. Sudnik-Wójcikowska and H. Werblan-Jakubiec (eds.) *Poradnik ochrony siedlisk i gatunków Natura 2000 – podręcznik metodyczny. T. 9. Gatunki roślin [Natura 2000 habitat and species protection guide – methodological manual. Vol. 9. Plant species]*. Warszawa: Ministerstwo Środowiska, pp. 160–165.

Zarzycki, K. (2002) "*Ekologiczne liczby wskaźnikowe roślin naczyniowych Polski [Indicator values of vascular plants of Poland*]," Kraków: Instytut Botaniki im. W. Szafera PAN.

Zarzycki, K. and Kaźmierczakowa, R. (eds.) (2001) *Polska czerwona księga roślin. Paprotniki i rośliny kwiatowe [Polish Red Data Book of Plants. Ferns and flowering plants]*. Kraków: Instytut Botaniki im. W. Szafera PAN.

Zarzycki, K., Kaźmierczakowa, R. and Mirek, Z. (2014) *Polska Czerwona Księga Roślin. Paprotniki i rośliny kwiatowe [Polish Red Data Book of Plants. Ferns and flowering plants]*. Kraków: Instytut Ochrony Przyrody PAN.

Zych, M., Michalska, B. and Krasicka-Korczyńska, E. (2014) "Myophily in a critically endangered umbelliferous plant *Ostericum palustre* Besser (*Apiaceae*)," *Plant Systematics and Evolution*, 300, pp. 187–196.

© 2024. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)