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Challenges to the conservation of threatened species in alkaline fens: Study of Bagno Bubnów PLB060001

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Highlights
- Plant specialists of alkaline fens are disappearing along with their habitats.
- PLB060001 Bagno Bubnów constitutes a mosaic of unique phytocoenoses.
- Six protected plants species diagnostic for alkaline fens were identified there.
- Syntaxonomic structure of their phytocoenoses is disturbed and soils of their sites are humified.
- Continued habitat drying poses a threat to the survival of these endangered species.

Abstract: The objective of the present study is to draw attention to the problem of protecting alkaline fens (EU habitat 7230) and related plant species. The distribution, habitat conditions and vegetation structure of the phytocoenoses in which protected species diagnostic of eutrophic low-sedge alkaline fens of the *Caricion davallianae* alliance occurred in the area of PLB060001 Bagno Bubnów were therefore described. The findings of the research conducted in the years 2021–2022 enabled the identification of factors that pose a threat to their occurrence. The following species were documented: *Epipactis palustris* (44 locations), *Carex davalliana* (25), *Pedicularis sceptrum-carolinum* (3), *Pedicularis palustris* (1), *Pinguicula vulgaris subsp. bicolor* (1), *Tofieldia calyculata* (1). The species under study exhibit a diverse ecological spectrum. They occurred in diverse phytocoenoses, usually in *Molinion* meadows or *Scheuchzerio-Carcietea nigrae* low-sedge alkaline fens and were predominantly recorded on eutrophic, organic or mineral-organic, neutral or alkaline soils. The C:N ratio ranging from 12.20 to 13.55 on average, with high calcium content, and high level of base saturation which indicates eutrophic soils with advanced mineralisation and humification of organic matter. An analysis of the syntaxonomic structure of the examined phytocoenoses and soil conditions has revealed a potential risk of habitat loss due to drying out. The PCA revealed that moisture is a key element in maintaining protected species of alkaline fens and exerts a fundamental influence on the phytosociological variability of the investigated phytocoenoses of PLB060001 Bagno Bubnów site.

Keywords: Bagno Staw, calcareous fens, *Caricion davallianae*, drying out of peatlands, EU Habitat 7230, habitat loss, wetland biodiversity

INTRODUCTION

Alkaline fens (Council Directive, 1992, Annex 1) are eutrophic fens with low sedge and bryophyte communities that occur on permanently waterlogged soils with calcareous water supply, slight water level fluctuations and peat substrate (Matuszkiewicz, 2001; Šefferová Stanová, Šeffer and Janák, 2008; EC DG Environment, 2013; Koczur, 2017).

The presence of alkaline fens (7230) has been recorded in the majority of biogeographical regions across Europe. According to Šefferová Stanová (2008) the largest area designated for protection within the European Natura 2000 network (exceeding 60%) is located in the boreal and continental regions. The highest number of sites is located in Germany, Sweden and Finland. Nevertheless, the most substantial area is in Poland (24,233 ha) and Estonia (20,122 ha), which account for 30% of the total designated area. In Poland, the distribution of alkaline fens is uneven. Their occurrence is observed in both the mountainous regions, situated in the southern part of the country, and the lowlands, predominantly in the northern and eastern parts of Poland (Koczur, 2017).

Peatlands, including alkaline fens 7230, are among the most valuable types of ecosystem on the planet, as they provide a wide range of vital ecosystem services, primarily for the storage and purification of water and the sequestration of organic carbon, climate change mitigation and being a habitat for various organisms, including numerous rare and protected species (Šefferová Stanová, Šeffer and Janák, 2008; Barthelmes *et al.*, 2015; Urák *et al.*, 2017; Štokmane and Cera, 2018). This also applies to the vegetation, which is the reason why these habitats are of great botanical interest.

Alkaline fen habitats have declined most significantly in comparison to other habitats, and are now classified as being seriously endangered in the majority of regions (EC DG Environment, 2013). The most important factor determining the formation and maintenance of alkaline fens is appropriate water conditions (Wołejko *et al.*, 2018). In Poland, the substantial drainage of wetlands with the aim of increasing agricultural productivity has led to the loss of approximately 90% of alkaline fens. Over 80% of this loss occurred during the second half of the 20th century (Wołejko *et al.*, 2018; KP, no date).

Alkaline fens have undergone a degradation process in recent decades, resulting from alterations to hydrology, eutrophication, overgrowth by shrubs and trees due to a lack of management practices such as grazing or mowing, and habitat fragmentation (Hochegger *et al.*, 2013; Wołejko, Pawlaczyk and Stańko, 2019; Grzybowski and Glińska-Lewczuk, 2020). As a hydrogenic habitat, alkaline fens are particularly sensitive to alterations to hydrology that are often associated with dredging and maintenance of ditches, maintenance works in water courses, groundwater abstraction within the site or nearby, and draining of the fen area due to the removal of trees. In certain cases, indirect threats have been observed to be associated with the exploitation of other adjacent ecosystems. As highlighted Wołejko, Pawlaczyk and Stańko (2019), the Polesie fens, including Bagno Bubnów, are under threat from industrial activities related to hard coal mining which is associated with disturbances in the hydrological conditions.

As Hochegger *et al.* (2013) underline, historically, alkaline fens were often managed as meadows or pastures. Therefore, in accordance with their genesis, it is sometimes necessary to manage them in a proper way, in the form of grazing, mowing or manual removal of trees and shrubs.

The classification and diagnostic species of alkaline fens (7230) given in the "Interpretation Manual of European Union Habitats" (EC DG Environment, 2013) are largely consistent with the Polish phytosociological classification (Matuszkiewicz, 2001). According to Matuszkiewicz (2001) phytosociological system, the following classification is employed:

Class: *Scheuchzerio-Caricetea nigrae* (Nordh. 1937) R. Rx. 1937
  Order: *Caricetalia davallianae* Br.-Bl. 1949
    Alliance: *Caricion davallianae* Klika 1934
      Association: *Valeriano-Caricetum flavae* Pawł. (1949 n.n.)1960
        Caricetum davallianae Dutoit 1924 em. Görs 1963
        Orchido-Schoenetum nigricantisi Oberd. 1957
      Community: *Schoenus ferrugineus* (Fijałk. 1960) Pałcz. 1964.

In the given system, the following species are characteristic of the *Caricetalia davallianae* order and the *Caricion davallianae* alliance: *Bryum bimum*, *Campylium stellatum*, *Carex capillaris*, *C. davalliana, C. dioica*, *C. flava*, *C. hostiana*, *C. lepidocarpa, C. pulicaris, Drepanocladus intermedium*, *Eleocharis quinqueflora*, *Epipactis palustris*, *Eriophorum latifolium*, *Liparis loeselii*, *Orchis palustris*, *Parnassia palustris*, *Pinguicula vulgaris*, *Primula farinosa*, *Scorpidium scorpioides*, *Swertia perennis*, and *Tofieldia calyculata.* Some authors highlighted that among the species frequently occurring within the akaline fens from *Caricion davallianae* alliance are also *Pedicularis palustris* and *Pedicularis sceptrum-carolinum* (Koczur, 2017), which Matuszkiewicz (2001) treats as diagnostic for the whole class *Scheuchzerio-Caricetea nigrae*. However, Matuszkiewicz (2001) and other authors (e.g., Koczur (2017)) emphasise the need for further research and revision in the classification of these communities. Consequently, the species composition of the described communities is typically provided without the application of a strict positioning in the phytosociological system.

Bagno Bubnów (PLB060001) is situated within the Polesie National Park (51°19'–51°23'N, 23°15'–23°21'E). As well as being a Natura 2000 site, Bagno Bubnów is part of a Ramsar site, a UNESCO Transboundary Biosphere Reserve (covering Poland, Belarus and Ukraine) and an Important Bird and Biodiversity Area (IBBA).

PLB060001 Bagno Bubnów is one of the largest areas of eutrophic low carbonate peatlands in eastern Poland covering 2,344 ha. It 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). PLB060001 Bagno Bubnów is a complex of two peat bogs: Bagno Bubnów and Bagno Staw. Physiographically, Bagno Bubnów is located in the Western Polesie, while Bagno Staw is located in the Volyn Polesie (Dobrowolski *et al.*, 2021).

In the area of PLB060001 Bagno Bubnów, the habitat (7230) is characterised by plant communities belonging to the *Caricion davallianae* alliance, including the *Caricetum davallianae* association and the *Schoenenus ferrugineus* community (Urban *et al.*, 2020). These phytocenoses contain legally protected vascular plants: *Carex davalliana*, *Epipactis palustris*, *Liparis loeselii*, *Schoenus ferrugineus*, and *Tofieldia calyculata* (Urban *et al.*, 2020).

Many species related to alkaline fens (7230) are very rare (for example, *Pinguicula vulgaris subsp. bicolor*) or show a clear decreasing trend (Różycki, 2014; Urban *et al.*, 2020). Furthermore, the existing knowledge on their ecology is limited. Most reports on new locations are rarely supported by soil research results. In the absence of comprehensive data, it remains challenging to draw definitive conclusions regarding their habitat requirements and the factors that may positively influence the effectiveness of their conservation methods.

The objective of the present study is to draw attention to the problem of protecting alkaline fens (EU habitat 7230) and related protected plant species. The habitat conditions and characteristics of the phytocoenoses in which protected species diagnostic of eutrophic low-sedge fens of the *Caricion davallianae* alliance occurred in the area of PLB060001 Bagno Bubnów were therefore examined. The findings of the research enabled the determination of the spectrum of occurrence of the species under study in the area of PLB060001 Bagno Bubnów. Moreover, the research results allowed to determine the factors threatening the studied species and formulation of conclusions aimed at increasing the effectiveness of their protection.

MATERIALS AND METHODS

LOCATION

The locations of plant species typical of calcareous fens (7230), currently protected by law in Poland, were recorded during geobotanical surveys carried out in PLB060001 Bagno Bubnów in the period from June to August of 2021 and 2022. In the locations where their occurrence was confirmed, soil samples were taken and the phytosociological relevés were made using the Braun-Blanquet method (Braun-Blanquet, 1964). The mean air temperature and annual precipitation at the Włodawa weather station located 27 km from the study area are presented in the Table 1.

Table 1. The mean air temperature and annual precipitation at the Włodawa weather station

Parameter	Year				
	2018	2019	2020	2021	2022
Mean air temperature (°C)	9.4	10.0	9.8	8.3	9.0
Total rainfall (mm)	519.6	522.0	698.1	630.4	649.1

Source: own elaboration, based on GUS (2025).

BOTANICAL AND PHYTOSOCIOLOGICAL RESEARCH

The 62 phytosociological relevès with an area of 100 m^2 each were sampled using the Braun-Blanquet (1964) method. Species identification was based on Szafer, Kulczyński and Pawłowski (1953), Mądalski (1968), and Sikorski *et al.* (2020). The abundance of species was estimated using Braun-Blanquet 7-degree cover-abundance scale values of which were transformed as follows: r (rare) = 0.1%; + (sparse) = 0.5%; 1 = 2.5%; 2 = 15.0%; 3 = 37.5%; 4 = 62.5%; 5 = 87.5% in order to calculate the cover of species. Next, the frequency, mean cover, and relative mean cover were calculated for each species included in the phytocoenosis. Calculations were made as follows: (i) average cover – the cover of each species per one phytosociological relevé, (ii) relative average cover – the percentage of the average cover of one species in relation to the sum of the average covers of all species.

The height of the plant sward was measured at three points in each phytosociological relevé using a centimetre scale with an accuracy of 1 centimetre (1 cm). The results of the measurements were then averaged for each phytosociological relevé.

Based on phytosociological relevés, it was described syntaxonomic structure of communities of which protected species (Ustawa, 2004; Rozporządzenie, 2014) diagnostic of alkaline fens of the *Caricion davallianae* were a component. The affiliation to syntaxa was based on Matuszkiewicz (2001), while the species nomenclature was given after Mirek *et al.* (2002).

SOIL PROPERTIES RESEARCH

The material included soil samples representing some of the phytosociological relevés. The samples of soil were taken in duplicate (64 samples in total) from the topsoil layer, with a depth of 0–30 cm, and then air-dried and ground. Next, the following laboratory analyses were performed with the use of standard methods (Reeuwijk van, 2002): pH in water (pH (H_2O)) using a potentiometric method with an Elmetron IP67 pH meter with a GPX-105 electrode, total organic carbon and total nitrogen content by dry combustion using the VarioMAX CNS apparatus, calcium carbonate equivalent content by volumetric method using Scheibler's apparatus, organic matter content was determined on the basis of loss on ignition by burning the sample in a muffle furnace at 550°C, the content of exchangeable cations: calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+) – after extraction of samples in 1M ammonium acetate solution at pH = 7.0, by atomic absorption spectrometry using an AA 220 FS spectrometer (Varian), and hydrolytic acidity using the Kappen method.

RESULTS ANALYSES

The total relative coverage of species from the classes *Scheuchzerio-Caricetea nigrae*, *Phragmitetea*, *Molinio-Arrhenatheretea*, *Alnetea glutinosae*, *Koelerio glaucae-Corynephoretea canescentis* and *Festuco-Brometea*, as well as the total relative coverage of synanthropic species (sum of species from the classes *Artemisietea vulgaris*, *Stellarietea mediae* and *Epilobietea angustifolii*), tree and shrub species in phytosociological relevés, was determined and used as an index of habitat conditions. The Shannon-Wiener *H*' index (Maggurran, 2004), the Ellenberg *F* index (Hill *et al.*, 1999), and the average sward height from three measurements per phytosociological relevé were also calculated. The relationships between these variables were described using principal component analysis (PCA) with variable standardisation.

Statistical analyses were conducted in the R environment (R Core Team, 2024). The distribution of soil parameters is illustrated in a series of boxplots made using the boxplot function. The syntaxonomic structure for the phytosociological relevés containing the protected species under consideration is presented in a bar chart. The PCA analysis was conducted using the 'vegan' package (Oksanen *et al.*, 2022), with the results presented in the form of a biplot.

RESULTS

SPECIES AND PHYTOCOENOSES

The results of geobotanical research conducted in the Natura 2000 site Bagno Bubnów (PLB060001) in the years 2021 and 2022 revealed the presence of six vascular plant species representing alkaline fens 7230 of *Caricion davallianae* alliance (Matuszkiewicz, 2001) and that are currently subject to legal protection in Poland (Ustawa, 2004; Rozporządzenie, 2014). In the studied patches, the most frequently occurring were: *Epipactis palustris* (L.) Crantz (44 locations) and *Carex davalliana* Sm. (25). Less frequent were: *Pedicularis sceptrum-carolinum* L. (3), *Pedicularis palustris* L. (1), *Pinguicula vulgaris subsp. bicolor* Á. Löve & D. Löve (1), and *Tofieldia calyculata* (L.) Wahlenb. (1). The species identified were predominantly located at the peripheries of the peat bogs Bagno Bubnów and Bagno Staw (Fig. 1).

In the examined phytocoenoses, the presence of plants diagnostic for 19 phytosociological classes and species without phytosociological affiliation was indicated. A total of 200 plant species were identified, which belonged to 42 different botanical families. However, analysis showed that all phytocoenoses were dominated by species from the *Cyperaceae* and *Poaceae* families. The relative cover of species from these two families accounted for an average of between 60.13% (phytocoenoses with *Pedicularis sceptrum-carolinum*) and 88.56% (phytocoenosis with *Pedicularis palustris*).

The protected species diagnostic for alkaline fens from the *Caricion davallianae* alliance were recorded in phytocoenoses characterised by a diverse phytosociological structure (Fig. 2a–f). Most frequently, they occurred within meadow phytocoenoses of the *Molinion* alliance or low-sedge fens of the *Scheuchzerio-Caricetea nigrae* class (Fig. 2a–f). In most cases, >70% of the relative cover were species from the classes: *Scheuchzerio-Caricetea nigrae*, *Molinio-Arrhenatheretea* and *Phragmitetea* (Fig. 2a). An exception to this rule was observed in the phytosociologically heterogeneous patch with *Pinguicula vulgaris subsp. bicolor*, in which species without syntaxonomic affiliation predominated, constituting as much as 88.4% (Fig. 2a).

The largest number of species characteristic of *Caricion davallianae* occurred in the patches with *Carex davalliana*, followed by the patches with *Pedicularis sceptrum-carolinum* and the patch with *Pedicularis palustris* (Fig. 2b). Nevertheless, these species never constituted the majority. In the patches with *Carex davalliana*, *Epipactis palustris*, *Tofieldia calyculata* and *Pedicularis sceptrum-carolinum*, species from wet meadows of the alliance *Molinion* were the most prevalent (Fig. 2d) while, the *Pedicularis palustris* patch was dominated by species from the class *Phragmitetea*, alliance *Magnocaricion* (Fig. 2a, e). These were: *Carex acutiformis* and *Carex appropinquata*.

The PCA analysis was performed to describe the relationship between phytosociological structure and phytocoenosis features (presence of shrubs, trees and synanthropic species, species diversity, sward height), as well as habitat moisture. The first two principal components of the PCA analysis accounted for 54.4% of the variability in the standardised habitat parameters (Fig. 3).

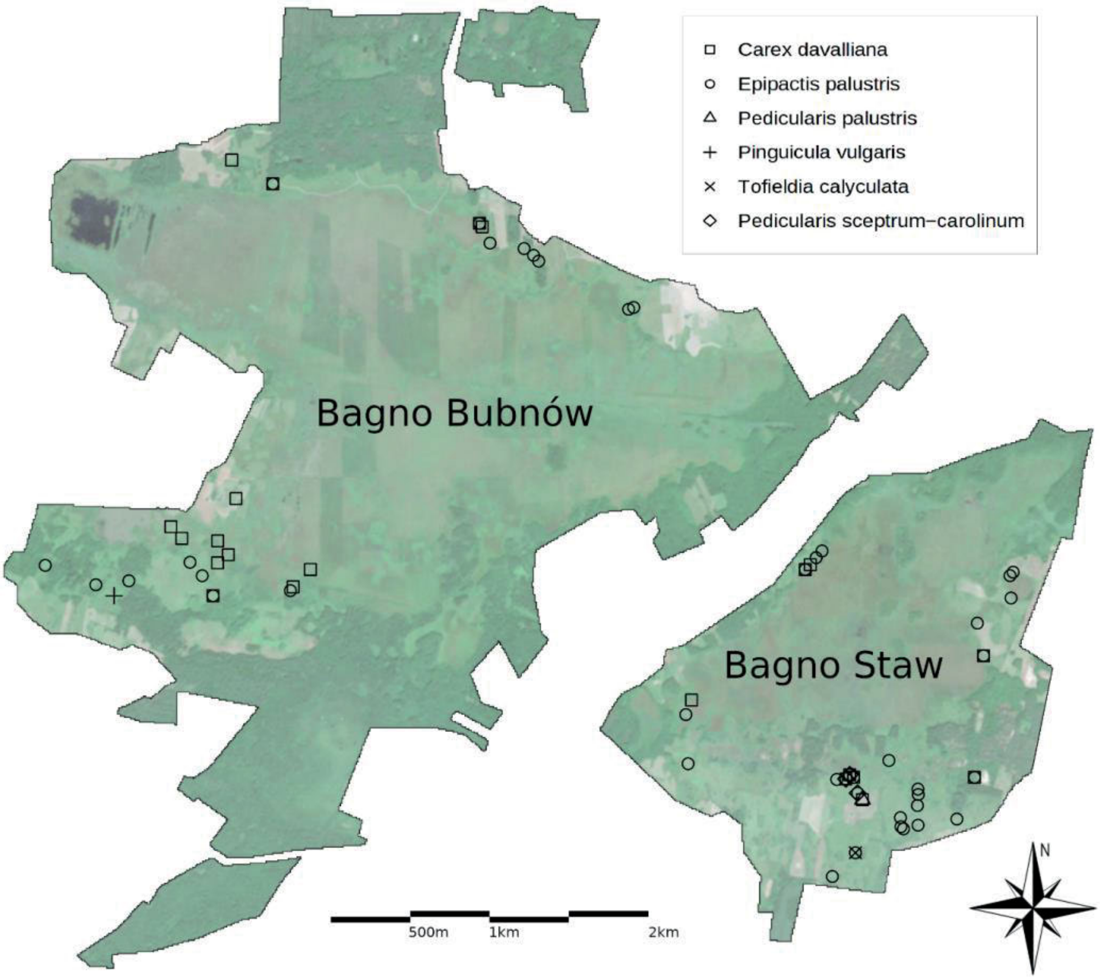

Fig. 1. The identified locations of the examined species; source: own elaboration with the use of the satellite Sentinel-2 Imagery 2020 06 25 (https://eos.com/find-satellite/)

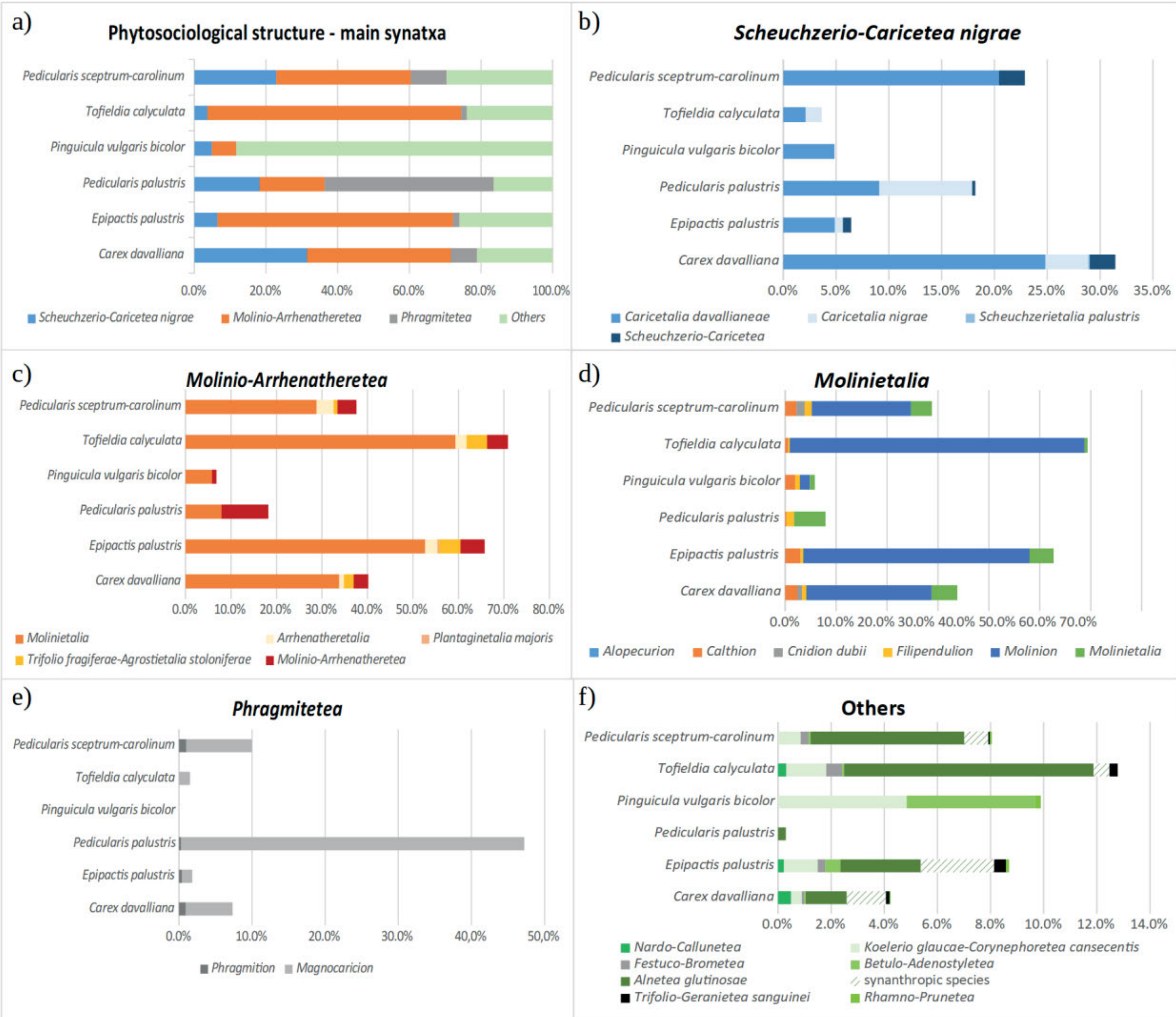

Fig. 2. The syntaxonomic structure of the analysed plant communities in which protected species diagnostic for alkaline fens occurred in the PLB 060001 Bagno Bubnów – species characteristic of the synatxa of: a) main syntaxa (classes), b) *Scheuchzerio-Caricetea nigrae* class c) *Molinio-Arrhenatheretea* class, d) *Molinietalia* order; e) *Phragmitetea* class; f) species characteristic of other classes; synathropic species = sum of species from *Artemisietea vulgaris*, *Stellarietea mediae* and *Epilobietea angustifolii* classes; others = species without affiliation or species with a very low frequency; affiliation to syntaxa acc. to Matuszkiewicz (2001); source: own study

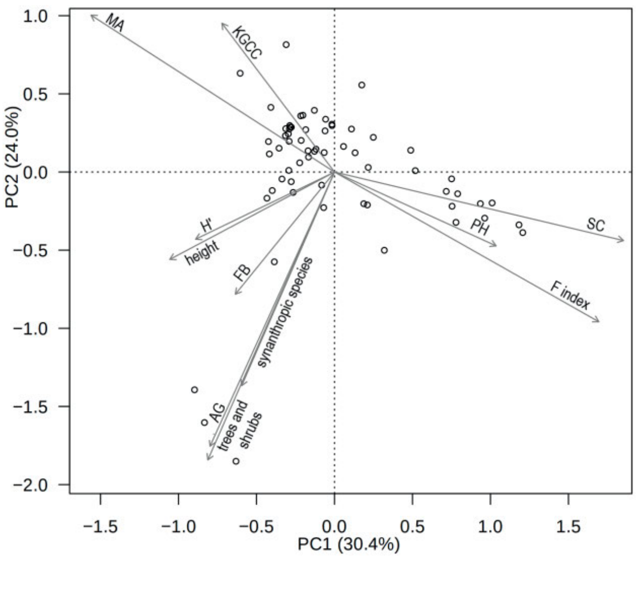

Fig. 3. The relationships between standardised habitat parameters in the set of phytosociological relevés described by the principal component analysis (PCA); explanations: ○ = phytosociological relevés, → = habitat conditions; SC = *Scheuchzerio-Caricetea nigrae*, PH = *Phragmitetea*, MA = *Molinio-Arrhenatheretea*, AG = *Alnetea glutinosae*, KGCC = *Koelerio glaucae-Corynephoretea canescentis*, FB = *Festuco-Brometea*, *H'* = Shannon–Wiener index, *F* index = moisture index; affiliation to syntaxa acc. to Matuszkiewicz (2001); source: own study

The PCA biplot showed an area with a high concentration of phytosociological relevés (Fig. 3). Only two relevés clearly diverged towards phytosociological classes associated with drier areas, i.e. towards *Koelerio glaucae-Corynephoretea canescentis* and *Molinio-Arrhenatheretea* (upper-left direction). Furthermore, four relevés diverged towards components related to the extensification of utilisation (sward height, shrubs, synanthropic species). This means that habitat changes in these directions will strongly influence the reduction in the occurrence of the species under study.

The distribution of coordinates of relevés (Fig. 3) indicates that humidity is a parameter with key environmental role in on the phytosociological variability of the analysed phytocoenoses. The large number of outlier relevés in the direction of increased habitat moisture implies that increasing humidity will support the conservation of endangered species under study. Additionally, no correlation was observed between humidity levels and either *H*' or sward height.

In the majority of patches, the vegetation of the *Molinia* meadows was observed, which occurred concurrently with lower site humidity (Fig. 3). This lower humidity is likely associated with the drying out of soil and mineralisation and humification processes, as evidenced by the results of soil analyses (Fig. 4). The stated encroachment of shrubs and trees from the *Alnetea glutinosae* class (Fig. 3) was obviously not related to drying out, but this process was accompanied by an increase in the share of synanthropic species. The results of the PCA shows that higher humidity favours low-sedge vegetation of alkaline fens from the *Scheuchzerio-Caricetea nigrae* class and leads to increased diversity in the studied phytocenoses (Fig. 3).

SOIL PROPERTIES

The species found occurred most frequently on organic (predominantly) or mineral-organic soils, rarely appearing on mineral soils (some patches with *Epipactis palustris*) – Figure 4. The C:N ratio was relatively stable ranging from 12.2 to 13.55 on average, with high calcium content, and high level of base saturation. The soils were generally neutral or alkaline, with only occasional instances of slight acidity. The observed high pH is due to the high saturation of the sorption complex with alkaline cations, predominantly calcium cations (Fig. 4).

A certain similarity was observed between the locations where *Carex davalliana*, *Pedicularis palustris* and *Pinguicula vulgaris subsp. bicolor* were present. The analysis revealed that these were sites with high, alkaline pH, high organic matter content, and high concentrations of organic carbon, total nitrogen, and calcium (Fig. 4).

DISSCUSSION

PHYTOCOENOSES

The studied protected species of alkaline fens from the *Caricion davallianae* alliance occurred in phytocoenoses with a diverse phytosociological structure, most often in the meadows of the *Molinion* alliance or low-sedge fens of the *Scheuchzerio-Carcietea nigrae* class. An analysis of the syntaxonomic structure of the examined phytocoenoses and soil conditions has revealed a potential risk of habitat loss due to drying out. These results were supported by PCA analysis which revealed that moisture is a key element in maintaining protected species of alkaline fens and exerts a fundamental influence on the phytosociological variability of the investigated phytocoenoses of PLB060001 Bagno Bubnów site.

This is consistent with the conclusions of Urban *et al.* (2020), who emphasised that the most significant threat to alkaline fens (7230), in the entire Polesie National Park and its buffer zone is alterations in water conditions (land drainage). Nevertheless, Urban *et al.* (2020) observed that in 2013, the examined fragments of habitat 7230 exhibited optimal structure and moisture. In view of the aforementioned results, it is imperative to emphasise the necessity of monitoring the level of habitat moisture, the structure of their vegetation, and the status of the populations of key species. As stated by Stańko *et al.* (2015), well-preserved patches of alkaline fens do not require active protection. However, in the event of disturbed water conditions within the facility, measures must be implemented to restore the optimal level of groundwater and to slow down its outflow.

According to the Manual of the European Commission (EC DG Environment 2013), both mire communities in the strict sense (*Caricion davallianae*) and their transitional forms corresponding to the communities of the *Molinion* alliance are considered to be of significant natural value. For this reason, the identified plant patches of *Molinion* meadows should be considered as a valuable refuge for species typical of alkaline fens. Furthermore, the presence of diagnostic species for the *Caricion davallianae* alliance within them should be regarded as a valuable premise for further phytosociological studies on characteristic combinations of species and on the ecological spectra of plants.

In many places in the PLB060001 Bagno Bubnów a mosaic of different habitats can be observed, ranging from peat bogs, through wet or fresh meadows, inland dunes, and xeric and calcareous grasslands (Kulik *et al*., 2020). For this reason, even in the described communities a small share of species of *Koelerio glaucae-Corynephoretea canescentis* and *Festuco-Brometea* classes was sometimes observed (Fig. 2). It was also found that the presence of diagnostic species for xerothermic grasslands from the *Festuco-Brometea* class was not associated with habitat drying, suggesting that their presence is rather related to the carbonate substrate.

On the PCA biplot (Fig. 3) it is clearly visible that in the examined sites, secondary succession and synathropisation occurred at the same time and were not caused by drying out of soils. Furthermore, secondary succession in the studied phytocoenoses was not advanced and led towards alder woodlands vegetation from the *Alnetea glutinosae* class. In the case of the studied phytocenoses, the *H*' index was found to be positively correlated with synatropisation and secondary succession. The *H*' index should not be regarded as an independent indicator of the ecological condition of plant communities; rather, it should be regarded as a constituent element of a broader assessment which is in accordance in some previous studies (Sienkiewicz-Paderewska *et al*., 2021).

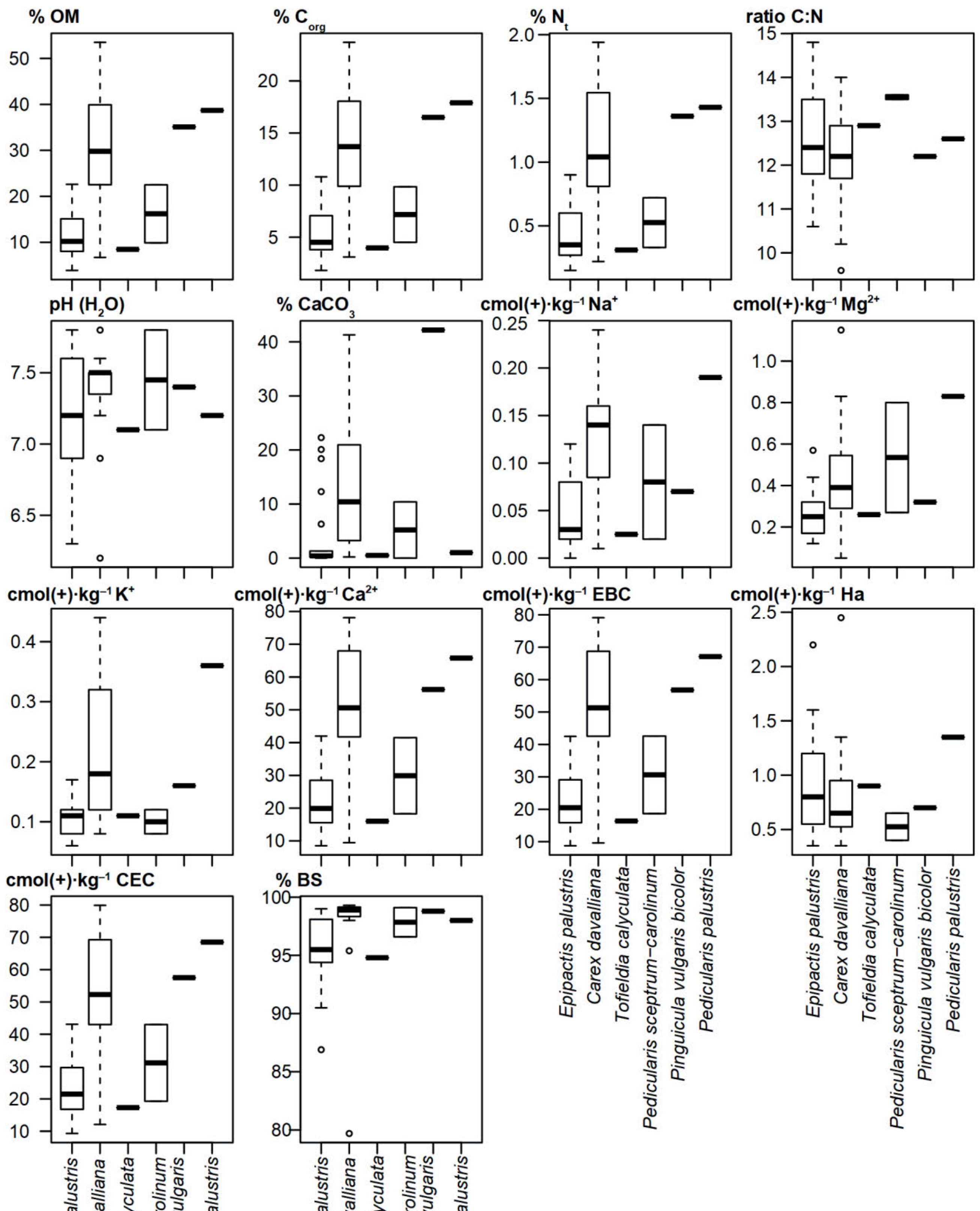

Fig. 4. Boxplots of soil parameters for phytocoenoses representing six studied species; OM = organic matter, Corg = organic carbon, N_t = total nitrogen content, $CaCO_3$ = calcium carbonate content, Na^+ = sodium content, K^+ = potassium content, Mg^{2+} = magnesium content, Ca^{2+} = calcium content, *EBC* = exchangeable base cations, *Ha* = hydrolytic acidity, *CEC* = cation exchange capacity, *BS* = base saturation; source: own study

SOIL PROPERTIES

The results of the conducted phytosociological studies are in accordance with the results of soil analyses. The examined endangered plant species most often occurred on organic or mineral-organic soils, usually with a neutral or alkaline pH. The C_{org}:N_t ratio ranged on average from 12.2 to 13.55 (Fig. 3). Following Becher *et al.* (2013), C_{org}:N_t values ranging from 11.4 to 16.4 are typical for eutrophic soils on low-moor peatlands and indicate excessive drying, a high level of biological activity and a significant degree of organic matter processing, caused by the mineralisation and humification. Persistent water shortages may therefore cause gradual degradation of the peat bog in the future. This, in turn, may result in the disappearance of endangered species typical of alkaline fens.

The sorption complex has been shown to be substantially saturated with alkaline cations, predominantly calcium cations (Ca^{2+}), which results in a high pH level (Fig. 3). As Pietruczuk (2016) stated, Bagno Bubnów and Bagno Staw developed in the carbonate substrate, which appears to be the main source of Ca^{2+} ions in the soil.

ECOLOGICAL SPECTRA

The findings of this study indicated that within the designated area of PLB060001 Bagno Bubnów, the species under investigation exhibited a diverse ecological spectrum in relation to various habitat parameters. The largest number of sites was recorded for *Carex davalliana* and *Epipactis palustris*. The analysis of the collected data concerning these two species showed that *Carex davalliana* presents a wider range for concentration of organic matter, organic carbon, and total nitrogen content. However, the C:N ratio was similar for both species (Fig. 4). In contrast, *Carex davalliana* exhibited a preference for alkaline substrates characterised by a high concentration of calcium carbonate and Ca^{2+} cations.

The analysis of syntaxonomic structure of phytocoenoses showed that *Epipactis palustris* is probably less sensitive to drying out and willingly occurs in phytocoenoses that correspond to wet *Molinion* meadows (Fig. 2). On the basis of the above results, *Epipactis palustris* appears to be less threatened than *Carex davalliana* in the Bagno Bubnów site. The research carried out may suggest a direction for revising the position of some species in the phytosociological system. It can be hypothesised that *Epipactis palustris* is less closely related to the phytocenoses of the *Caricion davallianae* alliance than *Carex davalliana* or *Pedicularis sceptrum-carolinum*.

The researchers of the flora of the Polesie National Park have classified *Pedicularis sceptrum carolinum* and *Pinguicula vulgaris subsp. bicolor* as species exhibiting a marked declining tendency and stated that the primary threat to these species is secondary succession, which results in the shading of sites (Urban *et al.*, 2020). During the research conducted, it was found that the stated populations of *Pedicularis sceptrum-carolinum* are in very good condition, numerous, with healthy and large leaf rosettes.

In the case of *Pedicularis palustris*, only one site with several individuals was found. Although the conservation status of this species has changed and *P. palustris* has been partially protected since 2014, it appears that due to the loss and fragmentation of wetland habitats, populations of this species are seriously threatened. This is a particular concern given that certain researchers regard this hemiparasite as a key species for the maintenance of a good condition, or even the restoration of fen-meadow ecosystems, which are under threat from colonisation by expanding *Carex* species, among others, such as *Carex acuta* (Decleer, Bonte and Diggelen Van, 2013).

The most endangered species identified in the present study (CR category in the Polish Red Data Book of Plants (Różycki, 2014)) and a highly rare taxon is *Pinguicula vulgaris subsp. bicolor*. Recent monitoring of selected continental sites in Poland has revealed a decline in the population size of the species *P. vulgaris subsp. bicolor* in most locations (Czerny and Piątek, 2022). According to Różycki (2014) and Bielecki (2016) the main centre in Poland of its lowland population is the Lublin region. The research by Majeský *et al.* (2022) indicates that the populations of *P. vulgaris subsp. bicolor* in Central Europe are genetically distinct from those found in the mountains of the Czech Republic and Poland. Therefore, each lowland location appears to be of particular value as an important genetic resource.

A tiny *Tofieldia calyculata*, which is typically regarded as a mountain species of the Alps and Western Carpathians (Vlasta *et al.*, 2020). It has also been recorded in the lowlands of Central Europe, particularly on calcareous fens, with the Polesie National Park being a noteworthy example. The lowland populations of Central Europe are considered to be most at risk of extinction due to a variety of factors, including drought, changes in vegetation structure, and ongoing secondary succession (Vlasta *et al.*, 2020).

Few scientific publications address the habitat requirements of diagnostic species for alkaline low-sedge fens of the *Caricion davallianae* alliance. The research presented contributes to the existing body of knowledge. This appears to be of significant importance, given that our understanding of the capacity of plant species specialists to inhabit a broader range of habitats or microhabitats is likely incomplete and requires verification (Monks and Burrows, 2014). This is also seen in the results of research conducted on, among others, *Epipactis palustris* and *Carex davalliana*. Nevertheless, this certainly requires further, larger-scale research.

The research also has implications for the practice of protecting endangered species. The knowledge of the ecological spectra of species is very helpful in selecting appropriate methods for protecting endangered ones and in determining the degree to which they are threatened with extinction. The conducted study confirms this, as we note a clear differentiation in the ecological spectra of the species studied. The potential drying of the Bagno Bubnów area will likely result in the first elimination of species more closely associated with low-sedge fens: *Carex davalliana*, *Pedicularis sceptrum-carolinum* and *Pedicularis palustris*, while species with a wider spectrum, such as *Epipactis palustris*, will probably have a greater chance of survival.

In view the results obtained, it appears necessary to ensure appropriate hydrological regimes by monitoring humidity levels in habitats where endangered species occur, identifying humidity fluctuations and their causes, and then developing methods to prevent water loss. The measures undertaken should be oriented towards raising the groundwater level in areas of alkaline fens and preventing excessive drainage, in order to inhibit the mineralisation and eutrophication of the surface layer of peat.

CONCLUSIONS

1. The Natura 2000 site PLB060001 Bagno Bubnów is of significant importance as a refuge for endangered plant species diagnostic for alkaline fens.
2. In the Natura 2000 site Bagno Bubnów (PLB060001) in the years 2021 and 2022 revealed the presence of six vascular protected plant species representing alkaline fens 7230 of *Caricion davallianae* alliance: *Epipactis palustris* (44 locations), *Carex davalliana* (25), *Pedicularis sceptrum-carolinum* (3), *Pedicularis palustris* (1), *Pinguicula vulgaris subsp. bicolor* (1), *Tofieldia calyculata* (1).
3. The studied protected species of alkaline fens from the *Caricion davallianae* alliance occurred in phytocoenoses with a diverse phytosociological structure, most often in phytocoenoses of the meadows of the *Molinion* alliance or low-sedge fens of the *Scheuchzerio-Carcietea nigrae*
4. These species occurred most frequently on organic or mineral-organic soils, predominantly neutral or alkaline. The C_{org}:N_t ratio ranging from 12.2 to 13.55 on average, with high calcium content, and high level of base saturation which indicates eutrophic soils with advanced mineralisation and humification of organic matter.
5. The occurrence of the *Molinion* meadows was connected with drying out of soils.
6. The species under study exhibit a diverse ecological spectrum. The potential drying of the Bagno Bubnów will likely result in the first elimination of species more closely associated with low-sedge fens: *Carex davalliana, Pedicularis sceptrum-carolinum* and *Pedicularis palustris*, while species with a wider spectrum, such as *Epipactis palustris*, will have a greater chance of survival.
7. Since moisture is a key element in maintaining endangered species of alkaline fens, every effort should be made to ensure an optimal hydrological regime in the examined area of the PLB060001 Bagno Bubnów.

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CONFLICT OF INTEREST

All authors declare that they have no conflict of interests.

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