Spring fen *Scheuchzerio-Caricetea nigrae* in the Polish Western Carpathians – vegetation diversity in relation to soil and feeding waters

Anna Koczur1*, Paweł Nicia2

1 Institute of Nature Conservation, Polish Academy of Sciences, Mickiewicza 33, 31-120 Cracow, Poland
2 Department of Soil Science and Soil Protection, Agricultural University of Cracow, Mickiewicza 21, 31-120 Cracow, Poland

Abstract

The species composition of vegetation associated with the Carpathian fens primarily depends on the type of water present and the hydrological feeding of the soils that occur there. These, in turn, shape the fertility of the fens. Those with typically formed *Carici-Agrostietum caninae* and *Valeriano-Caricetum flavae* fundamentally differ in the properties of their soils and feeding waters. These include differences in mineral content, pH, CaCO3, levels, degree of peat decomposition, electrical conductivity and oxygenation of the waters that feed the fens. *Carici-Agrostietum caninae* is a homogenous plant association adapted to extreme habitat conditions. It is characterized by a very narrow range of essential soil and feeding water parameters. *Valeriano-Caricetum flavae* is a highly diverse association. Considerable diversity both in terms of plant species and vegetation structure reflects very wide ranges in the properties of soil and feeding water. Vegetation patches of transitory character were also identified. These contained plant species characteristic of both associations. The character of the vegetation depends mainly on fen soil pH and the degree of mineralization of the feeding waters. It is only these parameters that allow intermediate patches to be clearly distinguished. The degree of peat decomposition, mineral content and water oxygenation all differ for *Carici-Agrostietum caninae* and *Valeriano-Caricetum flavae*, whereas the values for intermediate patches display a range of parameters typical of both investigated associations. Consequently, vegetation present in these patches reflects to a greater or lesser extent one of the two analyzed plant associations.

Keywords: *Carici-Agrostietum caninae*, *Valeriano-Caricetum flavae*, fens, soil and water properties, Western Carpathians, Poland

Introduction

The accumulation of organic matter derived from plants growing in fens results in the formation of peat in fen soils subjected to very wet conditions. Depending on the type of hydrological feeding present, fen waters vary greatly in terms of their mineral and ion composition [1,2]. As water flows through organic matter deposited during the formation of peat, it becomes enriched with minerals and thus, contributes to soil fertility. Fens of this kind can be divided into two groups, based on the type of hydrological feeding present. Firstly, soligenic fens are rich fens that form on a lime substratum, or moderately rich fens that develop on flysch bedrock of sub-Magura and mid-Magura layers, or on glacial deposits. The second group consists of poor fens that are fed by precipitation waters, and these develop on a matrix lacking in carbonate. In the Polish Western Carpathians these are usually colonized by vegetation characteristic of *Valeriano-Caricetum flavae* and *Agrostietum caninae* associations [3]. Rich soligenic fen soils are characterized by their high degree of mineralization and the proportion of calcium cations involved in general mineralization. The concentration of calcium cations and the degree of mineralization of poor fen waters that display an ombrogenic type of feeding is many times lower [2,4]. On the basis of field investigations, a third group of fens was identified. Physical and chemical properties of their soils and waters were described as intermediate. These fens are called mesotrophic fens by Kornaś and Medwecka-Kornaś [5].

The aim of this work is to demonstrate that differences in the floristic composition of these plant communities reflect the physicochemical properties of the soil on which they grow.

Investigated area

Detailed analyses conducted during the period 2001–2006 investigated 20 selected fens distributed throughout the area of the Western Carpathians (the Tatra Mountains, the Subtatra Trough, the Spisko-Gubalowskie Foothills, the Pieniny Mountains, the Orawa-Nowy Targ Basin, the Gorce Mountains, Dzialy Orawskie Mountains, and the Babia Góra Range; *Fig. 1*). These fens were located at altitudes of between 530 and 925 m a.s.l., which, based on vegetation type, corresponds to a lower
Material and methods

Between one and three soil pits were made on each of the fens selected for analysis, in order to determine the basic morphological, chemical and physical properties of their soils. Piezometers were installed at the site of the soil pits, and water was sampled every month throughout the period March–December. Rich fens were investigated during 2000–2001, poor fens during 2003–2004 and mesotrophic fens during 2005–2006. The following criteria were measured for soil samples taken from fens during 2003–2004 and mesotrophic fens during 2005–2006.

Plant communities of the analyzed fens

Vegetation overgrowing fens in the Polish Western Carpathians comprises the Scheuchzerio-Caricetum fuscae class and consists of low sedge waterlogged meadows abundant in bryophytes and immersive low and transitory peatbogs [3].

The investigated fens can be divided into two alliances: Caricion fuscae and Caricion davallianae, each belonging to the Caricetalia fuscae order [10]. Patches of intermediate character were often observed among rich spring fens (Caricion davallianae alliance) [12]. When water relations were disturbed (e.g. by an irrigation system) these associations became transformed into meadow communities, mainly wet meadows of the Molinietalia order.

The investigated patches were divided into three groups (Tab. 1), based on species composition:

1. Poor fens (Caricion fuscae alliance), represented by Carici-Agrostietum caninae association.

The mean number of species in the investigated patches was 25.6 (range = 15–33). The characteristic plants were Agrostis canina, Carex canescens and C. echinata. Species typical of the Caricion fuscae alliance – Viola palustris, Polyrhichium commune, Juncus filiformis and Ranunculus flammula were also very numerous. Of those species characteristic of the Caricetalia fuscae order and the Scheuchzerio-Caricetum fuscae class, the most frequently encountered were Carex nigra and Eriophorum angustifolium. Plants typical of other biotopes usually consisted of a small number of species. The moss layer was usually well formed (50–100% cover in the investigated patches) Polyrhichium commune and Sphagnum angustifolium were the most numerous species. Carici-Agrostietum, a homogenous plant association (Fig. 2), was clearly distinguishable from the surrounding plant communities.
(ii) Rich fens (Caricion davallianae alliance), were represented mainly by the Valeriano-Caricetum flavae association. One phytosociological relevé should be classified as Caricetum davalliae, two others as Eleocharitetum pauciflorae [11].

The vegetation of these fens was abundant in species, (mean number of species = 37; range = 19–48). Valeriano-Caricetum flavae characteristic species, which occur here quite permanently, are Valeriana simplicifolia, Eriohorham latifolium, Carex flava and the much rarer C. lepidoarpa. Carex davalliana dominated the patch classified as Caricetum davalliae. However, it was present in much smaller numbers in the remaining patches. Eleocharis quinqueflora and Triglochin palustris grew exclusively in Eleocharitetum pauciflorae patches. Species characteristic of the Caricion davalliae alliance, such as Epipactis palustris, Dactylorhiza majalis and Carex flacca were numerous. Of those species characteristic of the Caricetalia fuscae order and Scheuchzerio-Caricetea fuscae class, the most frequently encountered were Carex panicea and C. nigra. Plants primarily characteristic of meadow associations (Briza media, Calliergonella cuspidata, Calthula lutet, Cirsium palustre, C. rivulare, Climacium dendroides, Crepis paludosa, Crucia gabra, Equisetum palustre, Galium uliginosum, Linum catharticum, Myosotis palustris, Plagionmum elatum, Potentilla erecta, Ranunculus acris) were numerous represented and even dominated in many relevés. Some rushes species (Equisetum fluviatile, Carex paludicata) were also frequent in these associations. The moss layer was very well developed, and displayed 30–100% cover, depending on the degree of hydration. Species of wet habitats were the most frequent whereas species characteristic of the Scheuchzerio-Caricetea fuscae class appeared to abort in 50% of the investigated patches. A characteristic phenomenon indicating considerable water movement was the shared presence of both spring species (Montio-Cardaminetea class) and species characteristic of Caricion lasiocarpae (i.e., Calliergon giganteum, Tomentypnum nitens). These are indicators of local acid conditions and occurred only occasionally.

Dominant among rich fens, Valeriano-Caricetum flavae is a heterogeneous, strongly diversified association (Fig. 2), forming a number of variants. Different species dominated in individual patches, and plants recognized as characteristic for the described association, alliance, order, or some plants typical of wet meadows or rushes plants were often the main taxon.

(iii) Patches of transitional character with species characteristic of both identified groups. Patches classified as intermediate were among those which were most abundant in species, the mean number of species being 38.8, with individual phytosociological relevés displaying a range of 26–51. They are identified by the presence of species characteristic of the Carici-Agrostietea caninae association and the Caricion fuscae alliance (Agrostis canina, Carex echinata, Viola palustris), and those typical of the Valeriano-Caricetum flavae association, and the Carex davalliae alliance (Carex flava, Dactylorhiza majalis, Epipactis palustris, Eriohorham latifolium, Valeriana simplicifolia).

As in the case of Valeriano-Caricetum flavae, species typical of other communities, primarily meadow and rushes communities, were present in some numbers. The moss layer showed great diversity and displayed a cover range of 10–90%. Species characteristic of both moist and wet habitats were present here, including both species typical of rich fens and springs. A characteristic feature was the small overlap of species characteristic of the Caricion lasiocarpae alliance (Calliergon giganteum, Sphagnum teres, S. warnstorfi).

### Tab. 1 Plant communities of spring fens (Scheuchzerio-Caricetea nigrae).

<table>
<thead>
<tr>
<th>Number of relevés</th>
<th>I (1–9)</th>
<th>II (10–15)</th>
<th>III (16–28)</th>
<th>IV (28+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch. Caricion fuscae</td>
<td>Carex echinata</td>
<td>V (1–3)</td>
<td>V (1–3)</td>
<td>I (1–3)</td>
</tr>
<tr>
<td></td>
<td>Agrostis canina</td>
<td>V (1–3)</td>
<td>I (1)</td>
<td>I (1–3)</td>
</tr>
<tr>
<td></td>
<td>Viola palustris</td>
<td>IV (1–3)</td>
<td>I (1–3)</td>
<td>II (1–3)</td>
</tr>
<tr>
<td></td>
<td>Carex canecens</td>
<td>IV (1–3)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Polytrichum commune</td>
<td>III (1–3)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Juncus filiformis</td>
<td>III (1–3)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ranunculus flammula</td>
<td>III (1–3)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

| Ch. Caricion davalliae | Valeriana simplicifolia | I (1–3) | IV (1–3) | V (1–3) | IV (1–3) |
|                       | Dactylorhiza majalis | I (1–3) | IV (1–3) | II (1–3) | II (1–3) |
|                       | Epipactis palustris | - | I (1) | V (1–3) | III (1–3) |
|                       | Eriohorham latifolium | - | III (1–3) | IV (1–3) | III (1–3) |
|                       | Carex flava | - | III (1–3) | III (1–3) | I (1–3) |
|                       | Carex flacca | - | - | IV (1–3) | II (1–3) |
|                       | Carex lepidoarpa | II (1–3) | - | - | I (1–3) |
|                       | Pinguicula vulgaris | I (1) | II (1–3) | I (1–3) | I (1–3) |
|                       | Brynum pseudotriquetrum | I (1) | - | - | I (1–3) |
|                       | Parnassia palustris | I (1) | - | - | I (1–3) |
|                       | Carex davalliana | - | - | II (1–3) | I (1–3) |
|                       | Eleocharis quinqueflora | - | - | II (1–3) | I (1–3) |
|                       | Triglochin palustre | - | - | II (1–3) | I (1–3) |
|                       | Dactylorhiza incarnata | - | - | I (1–3) | I (1–3) |
|                       | Polygala amarella | - | - | I (1–3) | I (1–3) |

| Ch. Caricetalia fuscae | Carex nigra | V (1–3) | V (1–3) | III (1–3) | IV (1–3) |
|                       | Carex panicea | II (1–3) | V (1–3) | V (1–3) | IV (1–3) |
|                       | Epipactis palustris | II (1–3) | III (1–3) | I (1) | II (1–3) |
|                       | Juncus articulatus | I (1–3) | III (1–3) | II (1–3) | II (1–3) |
|                       | Pedicularis palustris | - | I (1–3) | - | I (1–3) |
|                       | Drepanocladus aduncus | - | - | I (1–3) | I (1–3) |
|                       | Veronica scutellata | I (1–3) | - | - | I (1–3) |

| Ch. Caricion lasiocarpae | Calliergon giganteum | - | II (1–3) | I (1–3) | I (1–3) |
|                         | Sphagnum teres | - | I (1) | - | I (1–3) |
|                         | Sphagnum warnstorfi | - | I (1) | - | I (1–3) |
|                         | Tomentypnum nitens | - | - | II (1–3) | I (1–3) |

| Ch. Scheuchzerietalia palustris | Sphagnum angustifolium | III (1–3) | I (1–3) | - | - |
|                               | Straminergon stramineum | II (1–3) | I (1) | - | I (1–3) |
|                               | Sphagnum fallax | II (1–3) | - | - | I (1–3) |

| Ch. Scheuchzerio-Caricetea nigrae | Hamataculis vernicosus | II (1–3) | II (1–3) | - | I (1–3) |
|                                   | Eriohorham angustifolium | III (1–3) | I (1) | - | I (1–3) |
|                                   | Limprichtia revolvens | - | - | II (1–3) | I (1–3) |

| Ch. Montio-Cardaminetea | Cardamine amara | - | II (1–3) | I (1–3) | I (1–3) |
|                        | Paludriella decipiens | - | III (1–3) | I (1–3) | I (1–3) |

| Ch. Phragmitetea | Galium palustre | IV (1–3) | III (1–3) | I (1–3) | I (1–3) |

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Relationship between spring fen vegetation, the soil reaction, and electric conductivity of feeding waters

Analysis of the acquired data revealed that both described groups of plant associations, identified on the basis of differences in their floristic composition, occurred in biotopes differing in pH. They also differed in the degree of mineralization of feeding water, as shown by electric conductivity measurements (Fig. 3). These differences were statistically significant (Tab. 2).

Soils bearing patches of Carici-Agrostietum caninae were characterized by low pH values (Fig. 3) in KCl (mean = 3.73; range = 3.29–4.73), whereas their feeding waters displayed low mineralization, as indicated by their electric conductivity.

### Tab. 1 (continued)

<table>
<thead>
<tr>
<th>Number of relevés</th>
<th>I 1–9</th>
<th>II 10–15</th>
<th>III 16–28</th>
<th>IV 1–28</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equisetum fluviatile</strong></td>
<td>II (+–2)</td>
<td>III (+–2)</td>
<td>III (+–3)</td>
<td>II</td>
</tr>
<tr>
<td><strong>Poa palustris</strong></td>
<td>-</td>
<td>II (+)</td>
<td>II (+–1)</td>
<td>II</td>
</tr>
<tr>
<td><strong>Carex paniculata</strong></td>
<td>-</td>
<td>-</td>
<td>III (+)</td>
<td>I</td>
</tr>
<tr>
<td><strong>Carex rostrata</strong></td>
<td>-</td>
<td>I (+)</td>
<td>II (+–2)</td>
<td>I</td>
</tr>
</tbody>
</table>

### Ch. Molinietalia

Equisetum palustre

Cirsium rivulare

Calathia laeta

Myosotis palustris

Cirsium palustre

Carex paludosa

Lychnis flos-cuculi

Juncus effusus

Gallium alpinum

Deschampsia caespitosa

Juncus conglomeratus

Scripus sylvaticus

Climacium dendroides

Lychnis flos-cuculi

Lotus corniculatus

Gallium mollugo

### Ch. Molino-Arrhenatheretalia

Ranunculus acris

Rumex acetosa

Lathyrus pratensis

Prunella vulgaris

Vicia cracca

Holcus lanatus

Juncus inflexus

Trifolium pratense

Lysimachia vulgaris

Angelica sylvestris

Calathia palustris

Carex cespitosa

### Ch. Nardo-Callunetea

Potentilla erecta

Nardus stricta

Luzula campestris

### Others

Briza media

Calamagrostis canadensis

Cruciata glabra

Anthoxanthum odorum

Picea abies

Rhytidiadelphus squarrosus

Trifolium medium

Linum catharticum

Gesneria rivale

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I – poor fens (including Carici-Agrostietum caninae); II – moderately rich fens; III – rich fens (include Valeriano-Caricetum flavae, Caricetum davallianae and Eleocharitacetum pauciflorae).

(mean = 45.0; range = 36–53 μS cm⁻¹). Such extreme biotopic conditions result in the formation of a distinctive flora in poor fens, and a small degree of penetration of the association by alien species. They also result in a visible difference that enables a distinction to be made between this and neighboring associations that are already present on mineral soils. Hierarchical analysis of phytosociological relevés of Carici-Agrostietum caninae revealed the presence of a close group, that is particularly obvious in dendrogram II, based on species coverage (Fig. 2). It corroborates a small degree of differentiation of the analyzed patches and the considerable floristic distinctness of the association.

Soils colonized by Valeriano-Caricetum flavae, Caricetum davallianae and Eleocharitacetum pauciflorae associations displayed higher pH values (Fig. 3) within the 6.1–7.6 range in KCl (mean 6.77) and considerable mineralization of their feeding waters (range = 5.42–5.85) in KCl (Fig. 3), and their feeding waters are moderately abundant in mineral compounds, as indicated by their mean electric conductivity of 261.2 (range = 201–281 μS cm⁻¹). The ranges of pH values typical for this fen group fall exactly between those ranges typical of the two described plant communities. Whereas the upper limit of electrical conductivity is clearly visible, the lower limit does not conform to that on other patches. Together with the adjoining patch, it inclined towards intermediate fens (Fig. 2). However, the combination of characteristic species associated with this patch, and the predominance of plants typical of Valeriano-Caricetum flavae, made it possible to classify it as this association.

Fen soils having transitory vegetation features are characterized by their possession of intermediate parameters. They belong to weakly acid soils, with a mean pH value of 5.59 (range = 5.42–5.85) in KCl (Fig. 3), and their feeding waters are moderately abundant in mineral compounds, as indicated by their mean electric conductivity of 261.2 (range = 201–281 μS cm⁻¹). The ranges of pH values typical for this fen group fall exactly between those ranges typical of the two described plant communities. Whereas the upper limit of electrical conductivity is clearly visible, the lower limit does not conform to that considered typical of Carici-Agrostietum caninae. This is important, since typical patches of poor fens are characterized by a unique homogeneity with regard to water electrical conductivity.

The narrow range given here contains those patches with species typical of both poor and rich fens in almost equal

Tab. 1 (continued)

<table>
<thead>
<tr>
<th>Number of relevés</th>
<th>I 1–9</th>
<th>I 10–15</th>
<th>I 16–28</th>
<th>I 1–28</th>
</tr>
</thead>
<tbody>
<tr>
<td>Listera ovata</td>
<td>-</td>
<td>III (+1)</td>
<td>II (+1)</td>
<td>II</td>
</tr>
<tr>
<td>Plagiommium elatum</td>
<td>-</td>
<td>I (2)</td>
<td>IV (+4)</td>
<td>II</td>
</tr>
<tr>
<td>Plagiommium rostratum</td>
<td>-</td>
<td>II (1–2)</td>
<td>II (1–2)</td>
<td>II</td>
</tr>
<tr>
<td>Rhytidolepitis triquetras</td>
<td>-</td>
<td>III (+2)</td>
<td>II (1–2)</td>
<td>II</td>
</tr>
<tr>
<td>Tussilago farfara</td>
<td>-</td>
<td>-</td>
<td>III (1–3)</td>
<td>II</td>
</tr>
<tr>
<td>Aulacomnium palustre</td>
<td>I (+)</td>
<td>I (0)</td>
<td>I (0)</td>
<td>I</td>
</tr>
<tr>
<td>Ranunculus auricom</td>
<td>II (+)</td>
<td>I (+)</td>
<td>I (+)</td>
<td>I</td>
</tr>
<tr>
<td>Rhinanthus serotinus</td>
<td>I (0)</td>
<td>II (1–0)</td>
<td>I (1–1)</td>
<td>I</td>
</tr>
<tr>
<td>Salix aspera</td>
<td>I (1)</td>
<td>I (0)</td>
<td>I (+)</td>
<td>I</td>
</tr>
<tr>
<td>Salix silesica</td>
<td>II (+)</td>
<td>I (0)</td>
<td>I (+)</td>
<td>I</td>
</tr>
<tr>
<td>Equisetum sylvaticum</td>
<td>II (+)</td>
<td>III (1–2)</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>Senecio subalpinus</td>
<td>II (0–1)</td>
<td>II (0)</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>Chaerophyllum hirsutum</td>
<td>-</td>
<td>III (1–1)</td>
<td>I (1–2)</td>
<td>I</td>
</tr>
<tr>
<td>Equisetum variegatum</td>
<td>-</td>
<td>II (1–2)</td>
<td>II (1–1)</td>
<td>I</td>
</tr>
<tr>
<td>Festuca ovina</td>
<td>III (1–1)</td>
<td>-</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>Gymnadenia conopsea</td>
<td>-</td>
<td>-</td>
<td>II (1–1)</td>
<td>I</td>
</tr>
<tr>
<td>Eupatorium cannabinum</td>
<td>-</td>
<td>-</td>
<td>II (1–1)</td>
<td>I</td>
</tr>
</tbody>
</table>

Tab. 2 Changes to essential properties of surface horizon soils and feeding waters, proposed initially as typical of the investigated plant communities, and that allow them to be distinguished from each other.

<table>
<thead>
<tr>
<th>Essential properties of soils and waters</th>
<th>Carici-Agrostietum caninae</th>
<th>Intermediate fens</th>
<th>Valeriano-Caricetum flavae</th>
<th>x²</th>
<th>df</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>3–5</td>
<td>5–6</td>
<td>6–8</td>
<td>24.67</td>
<td>2</td>
<td>0.0000</td>
</tr>
<tr>
<td>Electrical conductivity (μS cm⁻¹)</td>
<td>30–60</td>
<td>200–300</td>
<td>300–900</td>
<td>24.67</td>
<td>2</td>
<td>0.0000</td>
</tr>
<tr>
<td>CaCO₃ concentration (g kg⁻¹)</td>
<td>0</td>
<td>0</td>
<td>0–700</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mineral content (%)</td>
<td>6–33</td>
<td>(22–73)</td>
<td>34–75</td>
<td>15.237</td>
<td>2</td>
<td>0.0005</td>
</tr>
<tr>
<td>Water oxygenation (mg O₂ dm⁻³)</td>
<td>0.1–0.3</td>
<td>[0.15–2.3]</td>
<td>0.5–5</td>
<td>14.857</td>
<td>2</td>
<td>0.0006</td>
</tr>
<tr>
<td>Peat decomposition</td>
<td>H₂–H₄</td>
<td>[H₅–H₇]</td>
<td>H₆–H₉</td>
<td>12.697</td>
<td>2</td>
<td>0.0018</td>
</tr>
</tbody>
</table>

Values which do not allow distinction between individual fen groups (overlapping ranges typical of other groups) are given in curly brackets.
measure. However, a degree of diversification was observed in this small group, indicating a slight prevalence of species characteristic of one of the associations. Hierarchical numerical analysis (Fig. 2) demonstrated that when dendrogram II was based on species abundance, these patches became segregated into two different groups containing relevés from poor and rich fens. This diversification can be correlated with variation in other soil parameters, such as mineral content, degree of peat decomposition and differences in the oxygenation of waters feeding individual patches (Fig. 4).

Moreover, one of these investigated patches differed from all the rest and was distinguished by its extremely high electric conductivity value (1337 μS cm⁻¹). Such elevated values were due to exceptionally high concentrations of chlorides resulting from disturbance of the natural environment by anthropogenic factors. This particular patch is located on a slope below and at a distance of approx. 100 m from the Cracow to Zakopane national road. Despite these considerable changes to the natural environment, the vegetation present on the aforementioned fen did not differ much from that found on the others. Possibly, in future, the situation will change as increased salting adversely affects some of the more sensitive species, eventually causing them to vanish. Mainly facultative halophytes (inter alia: Carex nigra, C. panicea, Equisetum palustre, Juncus articulatus) will tend to survive, together with some of the meadow species [23]. Currently they constitute about 30% of vascular plants present on this spot, however in future these proportions may change.

**Calcium carbonate content in spring fen soils**

Carici-Agrostietum caninae association and patches bearing transitory vegetation occur on soils lacking carbonate. The presence of calcium carbonate was found only in the soils of rich fens (Fig. 5). However, even here, it was not present in all investigated patches.

The CaCO₃ concentrations of analyzed rich fen soils showed great diversity. However, the results obtained were not unanimous but fell into three ranges or groups, as shown below (Fig. 5):

(i) Fens where calcium carbonate is high or very high (range = 351–653 g kg⁻¹) – Valeriano-Caricetum flavae and Caricetum davallianae patches as well as one patch of Eleocharitetum pauciflorae belong here.

(ii) Fens with low concentrations of CaCO₃ (range = 50–85 g kg⁻¹) – Valeriano-Caricetum flavae patches belong here.

(iii) Fens lacking carbonate or containing trace amounts of CaCO₃ (range = 0–0.1 g kg⁻¹) – Valeriano-Caricetum flavae patches and one patch of Eleocharitetum pauciflorae belong here.

Contrary to expectations, these enormous differences in the calcium carbonate content of the soil did not significantly affect the species composition and structure of plant communities. Patches lacking carbonate, and those containing only trace amounts of CaCO₃, can be distinguished by a slightly greater amount of Carex nigra. It would also seem that Eriophorum latifolium is more characteristic of habitats with lower concentrations of calcium carbonate. Conversely, Pinguicula vulgaris and Triglochin palustre prefer habitats containing large amounts of CaCO₃. Differences between patches lacking carbonate and others are more obvious, in that they more closely resemble intermediate patches, as has been shown by hierarchical numerical analysis (Fig. 2).
Other properties of soils and their influence on the vegetation of spring fens

The described plant associations, identified on the basis of differences in their floristic composition, are the result of not only differences in the acidity and CaCO₃ concentrations of the soils in which they grow, and the electrical conductance of their feeding waters, but also, the degree of peat decomposition, mineral content and oxygenation level of the feeding water. These differences are statistically significant (Tab. 2).

Carici-Agrostietum caninae association grows on peat exhibiting a low degree of decomposition (H2–H4) and having a low mean mineral content of 13.1% (range = 6.0–33.3%). Its feeding waters are extremely poorly oxygenated, having a mean value of 0.17 (range = 0.10–0.26 mg O₂ dm⁻³; Fig. 4).

Valeriano-Caricetum flavae, Caricetum davallianae and Eleocharitetum pauciflorae associations grow on peat exhibiting a high degree of decomposition (H6–H9) and having a higher mean mineral content of 56.77 (range = 34.6–74.1%). The feeding waters show great diversity in terms of their oxygenation levels, which vary widely (mean = 1.99; range = 0.55–4.85 mg O₂ dm⁻³; Fig. 4). Despite these large differences, in the degree of water oxygenation, this factor did not have any significant effect on plant species composition (compare Fig. 2, Fig. 4).

Peat exhibiting a low or medium degree of decomposition (H5–H7) occurs in the substratum of fens covered by transitional type of vegetation, the degree of decomposition depending on its floristic composition. Mineral content fluctuates widely from 22.3 to 72.5% (mean = 42.12; Fig. 4), and enters the ranges typical for both Carici-Agrostietum caninae and Valeriano-Caricetum flavae. The values of fen-feeding water oxygenation are similar, and fluctuate from 0.15 to 2.21 mg O₂ dm⁻³ (mean = 1.23). It would seem that the boundaries between the ranges for mineral content and water oxygenation typical for both investigated associations, are crucial for their vegetation structure. Fens with vegetation of intermediate characteristics are closer to Carici-Agrostietum caninae, or to Valeriano-Caricetum flavae, depending on the values of the described parameters (compare Fig. 2, Fig. 4).

Discussion

Fens bearing typically formed Carici-Agrostietum caninae and Valeriano-Caricetum flavae associations differ fundamentally in relation to the properties of their soils and feeding waters. Mineral content, pH, CaCO₃ concentration and the degree of peat decomposition, as well as electrical conductivity and the oxygenation of fen-feeding waters do not tally. Parameter ranges typical for each of these two associations can easily be determined as an initial step in their characterization (Tab. 2). Carici-Agrostietum caninae is a uniform association adapted to extreme biotic conditions. It is characterized by its very narrow range of soils and feeding-water parameter values. Valeriano-Caricetum flavae is a more diverse association. The considerable diversity of its species composition and plant structure reflects a very wide range of basic soil and feeding water parameters. The character of its vegetation depends mostly on fen soil pH and the degree of mineralization of its feeding water. It is only these parameters that seemingly distinguish patches that bear vegetation of intermediate character. They cannot be identified easily based on the degree of peat decomposition, mineral content and level of water oxygenation. These parameters are different for Carici-Agrostietum caninae and Valeriano-Caricetum flavae, whereas intermediate patches are able to grow in the typical ranges characteristic of both investigated associations. Moreover, the vegetation of these patches is able to diversify to such an extent that the latter resembles one of the two investigated associations.

The results obtained in this study generally agree with those obtained for other studies of spring fens in the Carpathians [24,25], although we identified fewer plant communities. The chemical properties of both soil and water in Carici-Agrostietum caninae correspond with those typical of Carici echinatae-Sphagnetum sphagnetosum fallacies, a community identified in the Czech Republic and Slovakia [11,24]. The parameters exhibited by Valeriano-Caricetum flavae are also similar. Patches of intermediate pH represent Carici echinatae-Sphagnetum sphagnetosum flexusi, but their electrical conductivity is typical of Valeriano-Caricetum flavae [24].

The concentration of calcium carbonate in some spring fens was found to be very high and considerably exceeded those concentrations reported from spring fens for other areas of the Western Carpathians [25]. These differences were due to two factors. Firstly, in our study, the concentration of calcium carbonate was determined for soil, whereas other authors based their results on the analysis of water. Secondly, our study included fens located both on fylsah and on calcareous substrate. However, earlier studies were restricted to fens of the fylsah region.

Plant species characteristic of Sphagno warnstorffii-Eriohoretum latifolii and Caricion lasiocarpeae alliances (Sphagnum teres, S. warnstorffii and Tomentypnum nitens) represented only a small proportion of plants from both the Valeriano-Caricetum flavae and fens with the intermediate type of vegetation. Sphagno warnstorffii-Eriohoretum latifolii occurs in the investigated area [17], but was not present in those fens selected for this study. None of the conductivity values obtained fell within the range characteristic of this plant association [24].

Some characteristics discovered in our study have previously been reported from the Western Carpathians [24], e.g., the wide tolerance of Eleocharitetum pauciflorae to the CaCO₃ content of soil, its floristic similarity to Valeriano-Caricetum flavae and the similar ranges of basic soil parameters. We also demonstrated that a high proportion of spring species present in the moss layer is typical of fens located on slopes with running water.

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Authors’ contributions

The following declarations about authors’ contributions to the research have been made: collecting data (vegetation sampling), data analyzes and interpretation, writing the manuscript, table and figures arrangement: AK; research designing, collecting data (soil and water sampling, chemical analyzes), writing the manuscript: PN.

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