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Original scientific paper

NEW ACIDOPHILOUS *NARDO-AGROSTION TENUIS* PLANT COMMUNITIES IN SLOVENIA

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Acidophilic vegetation on silicate rock is relatively rare in Slovenia, where carbonate rocks predominate, and some plant communities remain undocumented. In this study, we examined herbaceous acidophilous vegetation on Smrekovec Mountain in northern Slovenia. Based on numerical classification and ordination of available relevé data, we conducted 13 relevés and described a new association, *Avenello flexuosae-Caricetum brizoidis* ass. nova, along with a newly identified plant community featuring *Calamagrostis villosa* in Slovenia. We compared our findings with other vegetation types in the study area and with similar syntaxa from Central and Southeastern Europe. Both newly identified syntaxa were classified within the *Nardio-Agrostion tenuis* alliance and the *Nardetea strictae* class.

Key words: vegetation; Smrekovec; Slovenia; acidophilous

INTRODUCTION

Acidophilic vegetation on silicate rock is relatively uncommon in Slovenia, where carbonate sediments predominate [1]. Although the vegetation has been well researched [2] and described [3], some plant communities, particularly in marginal habitats, remain undocumented by relevés.

Carex brizoides L. (Quaking-grass Sedge) is a calciphobic forest sedge that thrives in both forests and forest openings across a wide altitudinal and geographical range [4, 5]. Its native distribution extends from Central and Southern Europe to Central Ukraine and northwestern Türkiye [6]. It is a perennial, rhizomatous geophyte [7].

In most cases, stands dominated by *Carex brizoides* have been classified within previously described associations as degradation phases without distinct names [8, 9]. However, three syntaxa with dominant *Carex brizoides* have been identified in Europe: *Scirpo sylvatici-Caricetum brizoidis* (Czech Republic, *Calthion palustris*, [10]), *Cirsio heterophylli-Caricetum brizoidis* (Czech Republic, *Calthion palustris*, [8]), and *Caricetum brizoides* (Romania, *Calamagrostion villosae*, [5]). These syntaxa have been classified into different higher syntaxonomic units, reflecting the species' ecological plasticity.

In Slovenia, *Carex brizoides* is found in vegetation stands classified into 16 different classes [11], with the highest abundance in *Molinio-Arrhenatheretea*, *Carpino-Fagetea*, *Vaccinio-Piceetea*, *Populetea albae*, and *Alnetea glutinosae*.

Calamagrostis villosa (hairy reed grass) is a perennial species that grows optimally in spruce forests and spruce bogs [12]. Its natural range spans the temperate biome from France to Ukraine [7]. It is a characteristic species of multiple syntaxa [13, 14] and occurs in various natural and secondary plant communities [15]. In Slovenia, *Calamagrostis villosa* is present in 13 vegetation classes, predominantly in *Carpino-Fagetea*, *Vaccinio-Piceetea*, and *Roso pendulinae-Pinetea mugo* [11].
The aim of this study is to analyze the acidophilous herbaceous vegetation of the Smrekovec region in Slovenia and to describe new syntaxa dominated by *Carex brizoides* and *Calamagrostis villosa*.

METHODS

Study site

The Smrekovec Mountains (*Smrekovško pogorje*) are located in northeastern Slovenia, forming the eastern part of the Kamnik-Savinja Alps, east of the Raduha peak (Figure 1). The range extends in a west-east direction and comprises three main peaks: Smrekovec (1,577 m), Krnes (1,613 m), and Komen (1,684 m). While most of the rock is covered by soil, the summit of Komen remains rocky [16].

The bedrock consists primarily of Mesozoic carbonate rocks, with occurrences of Upper Oligocene marls and siltstones. The Smrekovec range was formed by volcanic activity during the Upper Oligocene, giving rise to a stratovolcanic massif that developed in a marine environment. The composition of the magma changed during this period, resulting in a variety of volcanic rocks, including andesite, andesite tuff, and tuffites, which dominate the mountain range. Tonalite is found on the northern slopes [17, 18].

The forest vegetation along the Smrekovec ridge includes spruce-dominated communities such as *Rhytidiadelpho lorei–Piceetum*, *Avenello flexuosae-Piceetum*, and *Luzulo sylvaticae-Piceetum*, as well as beech forests (*Luzulo sylvaticae-Fagetum*) [19-21]. Large areas are covered by acidophilic grasslands and pastures dominated by *Nardus stricta* (*Homogyno alpinae-Nardetum strictae*) [22]. Additionally, Smrekovec hosts unique plant associations, including *Woodsio ilvensis-Asplenietum septentrionalis* and *Campanulo cochleariifoliae-Primuletum villosae*, which are found exclusively on outcrops of acidic rock in Slovenia [23].

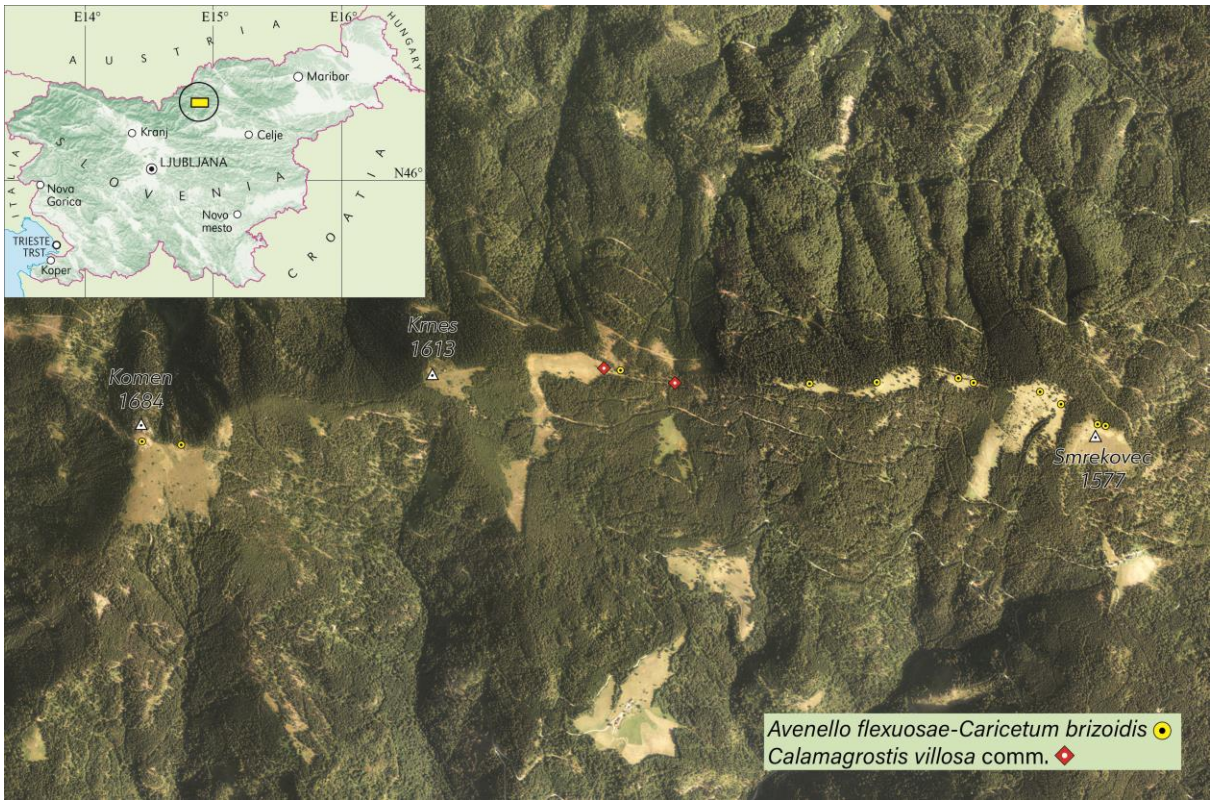

Figure 1. Study area on Smrekovec mountain ridge

Sampling and statistical analysis

Vegetation sampling followed the method described by [24]. Relevés were conducted in the most characteristic vegetation types, and the collected data from Slovenia were stored in the Vegetation of Slovenia database [11] using Turboveg software [25].

To classify the collected relevés and compare them with existing syntaxa, we applied hierarchical classification using PC-ORD software [26]. For ecological interpretation, we calculated non-weighted mean ecological indicator values for each relevé. To compare vegetation plots within the Smrekovec region, we used indicator values from

[27], while for broader European comparisons, we followed [28].

We employed non-metric multidimensional scaling (NMDS**)** to visualize relationships among vegetation types. Ecological indicator values were passively plotted within the ordination diagram to illustrate ecological relationships among vegetation types. The analyses were conducted using JUICE software [29], while ordination was performed in R with the *vegan* package [30].

Plant species nomenclature follows Plants of the World Online [7], while moss nomenclature follows [31]. Syntaxonomic nomenclature is based on [3] and [13].

RESULTS

Classification

We conducted eleven relevés in monodominant stands of *Carex brizoides* and two additional relevés in stands dominated by *Calamagrostis villosa*. In total, 43 plant species were recorded. To analyze vegetation patterns, we combined these newly sampled relevés with 27 previously published grassland relevés of *Homogyno-Nardetum* from Smrekovec [22] and performed a hierarchical classification (Figure 2).

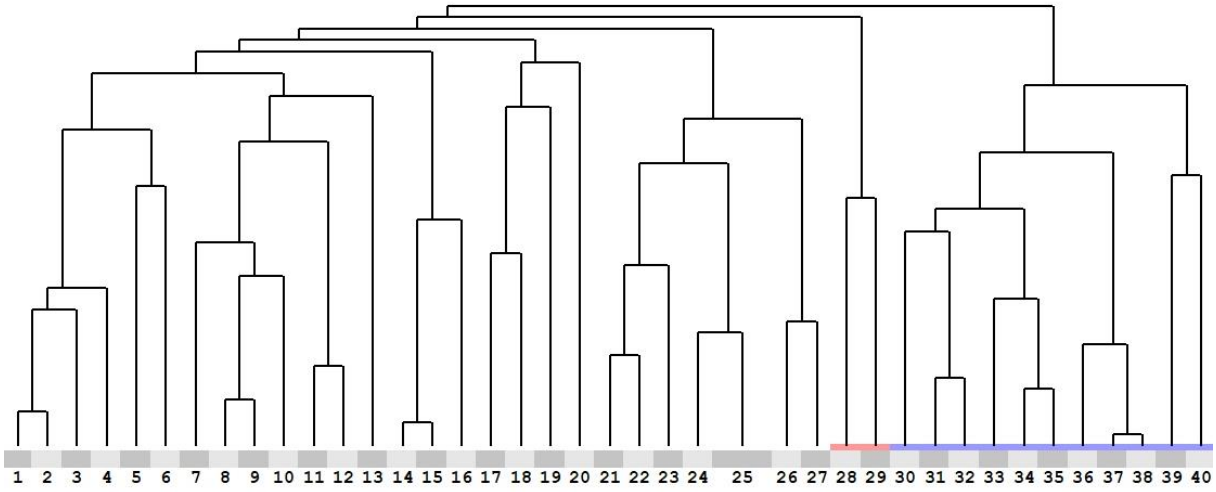

Figure 2. Classification of the relevés from the Smrekovec Mts. White-*Homogyno-Nardetum*, red-*Calamagrostis villosa* community, blue-*Avenello flexuosae-Caricetum brizoidis*

The dendrogram revealed three distinct clusters at a higher level. The largest cluster (Figure 2, relevés 1-27) represents grasslands dominated by *Nardus stricta* (classified as *Homogyno alpinae-Nardetum strictae*), alongside two stands dominated by *Calamagrostis villosa* (relevés 28-29). The third cluster (relevés 30-40), which is the most floristically distinct, includes stands with *Carex brizoides* as the dominant species. Based on the classification and the synoptic table (not shown), we classified these two plant communities into the association *Avenello flexuosae-Caricetum brizoidis* and the *Calamagrostis villosa* community.

***Avenello flexuosae-Caricetum brizoidis* ass. nova**

The stands are species-poor and dominated by *Carex brizoides*, which limits the growth of other species within the community (Figure 6). The moss layer is poorly developed due to the accumulation of litter, with a high cover beneath the sedge (averaging 90%). The most frequent species are *Deschampsia cespitosa*, *Avenella flexuosa*, *Potentilla erecta*, *Nardus stricta*, and *Vaccinium myrtillus*.

Upon comparison with other plant communities dominated by *Carex brizoides* (Figure 4), we identified several diagnostic species: *Melampyrum pratense*, *Avenella flexuosa*, and *Veratrum album*. A key differential species from *Nardus stricta* grassland is *Deschampsia cespitosa*. Based on the presence of these diagnostic species, we have described this new association as *Avenello flexuosae-Caricetum brizoidis*.

These stands develop on deeper soils with higher water retention, though they can also be found on slopes. The soils are typically acidic, distric brown soils, sometimes pseudogleyic. The altitude range is between 1,520-1,670 m above sea level. In Slovenia, this community is known only from the Smrekovec area, although [22] mention

similar stands above Komen (Smrekovec Mts.) and in the Pohorje Mountains.

***Calamagrostis villosa* community**

The stands dominated by *Calamagrostis villosa* are more species-rich than those dominated by *Carex brizoides*, with more species from the *Nardetea strictae* class, such as *Carex pilulifera*, *Carex pallescens*, and *Agrostis capillaris*.

These stands develop either as patches within *Nardus stricta* grasslands (Figure 7) or at the edges of *Picea abies* forests. The soils in these stands are generally deeper than those in the *Nardus* grasslands. These communities are rare in the studied area and have not been previously reported in Slovenia, although similar stands have been observed in the Pohorje Mountains.

Since only two relevés of *Calamagrostis villosa* were made, we classified them as a plant community without the rank of association. Both new syntaxa were classified within the *Agrostio tenuis-Nardion strictae* alliance, as the characteristic species of this alliance and the corresponding class are the most abundant. Both studied syntaxa are also successionally and ecologically linked to the predominant *Nardus stricta* grasslands in the region.

Using the previously analyzed data set from the Smrekovec Mts., we performed NMDS ordination to identify floristic and ecological differences between the stands. The comparison revealed high variability within *Homogyno-Nardetum* and a floristic similarity among all three communities (Figure 3). However, the *Avenello flexuosae-Caricetum brizoidis* and *Calamagrostis villosa* communities cluster in the right part of the ordination diagram, indicating they occupy wetter and more nutrient-rich sites compared to the *Nardus* grassland.

We also compared *Carex brizoides*-dominated communities with similar syntaxa from the Czech Republic [8, 10] and Romania [5]. The classification revealed a clear distinction between the relevés from the Czech Republic and those from the southeastern regions of Slovenia and Romania (Figure 4).

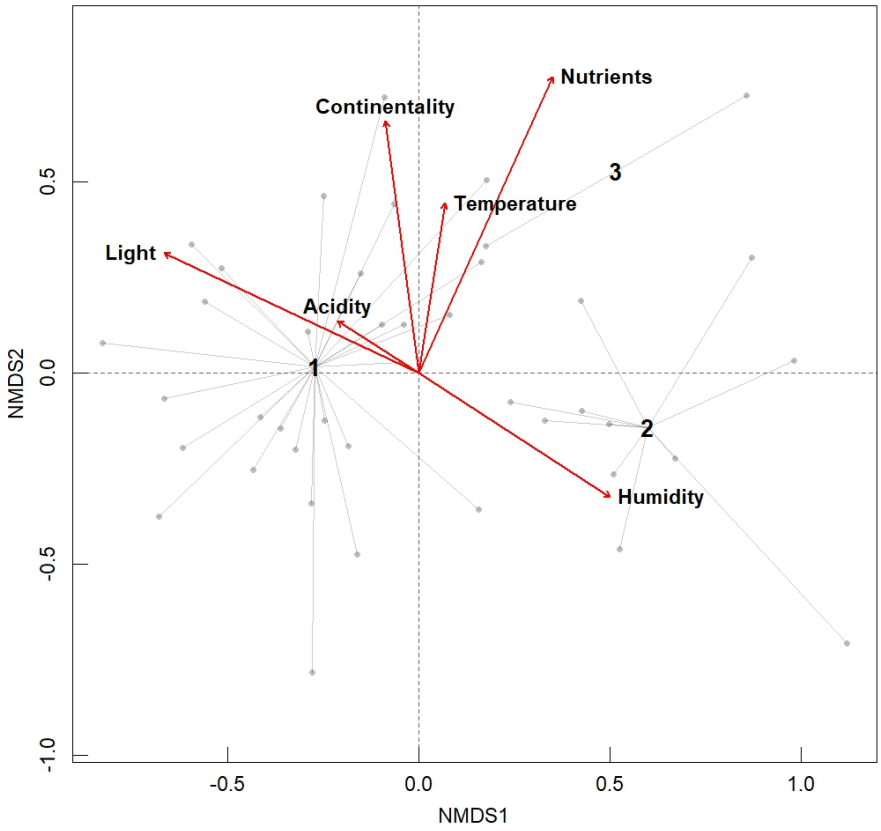

Figure 3. NMDS ordination of the grasslands of Smrekovec Mt. Legend: 1- *Homogyno alpinae-Nardetum*, 2- *Avenello flexuosae-Caricetum brizoidis*, 3- *Calamagrostis villosa* comm.

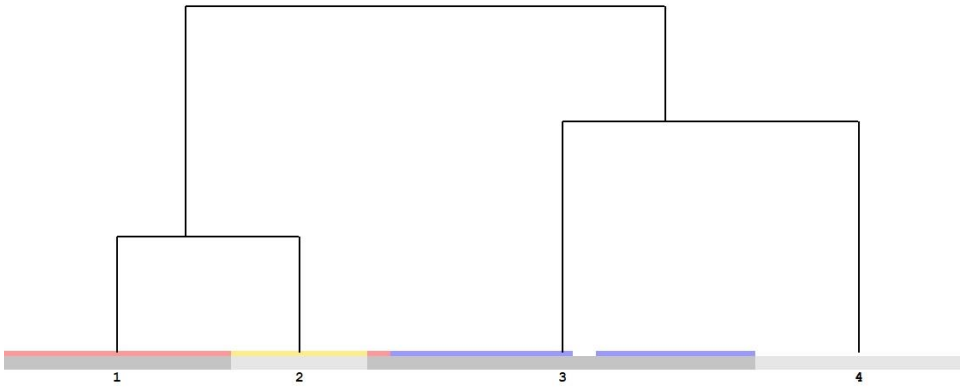

Figure 4. Hierarchical classification of stands dominated by *Carex brizoides* in Slovenia, the Czech Republic and Romania. Legend: 1- *Avenello flexuosae-Caricetum brizoidis* (Slovenia), 2- *Caricetum brizoidis* (Romania), 3- *Scirpo sylvatici-Caricetum brizoidis* (Czech Republic), 4- *Cirsio heterophylli-Caricetum brizoidis* (Czech Republic).

Similar results were obtained from the NMDS ordination, where we used the authors' original classification for group delimitation (Figure 5). The southeastern relevés cluster in the left part of the diagram, while the Central European ones are positioned on the right. The ecological indicator values clearly show that the Central European communities are wetter, richer in nutrients, and have a higher pH. *Carex brizoides* stands are also found at higher altitudes in southeastern Europe.

Syntaxnomical scheme of acidophilous grassland syntaxa in the studied area:

Nardetea strictae Rivas Goday et Borja Carbonell in Rivas Goday et Mayor Lopez 1966 nom. conserv. propos.

Nardetalia strictae Preising 1950

Nardo-Agrostion tenuis Sillinger 1933

Homogyno alpinae-Nardetum Mráz 1956

Avenello flexuosae-Caricetum brizoidis ass. nova

(Holotypus Table 1, relevé 2)

Calamagrostis villosa comm.

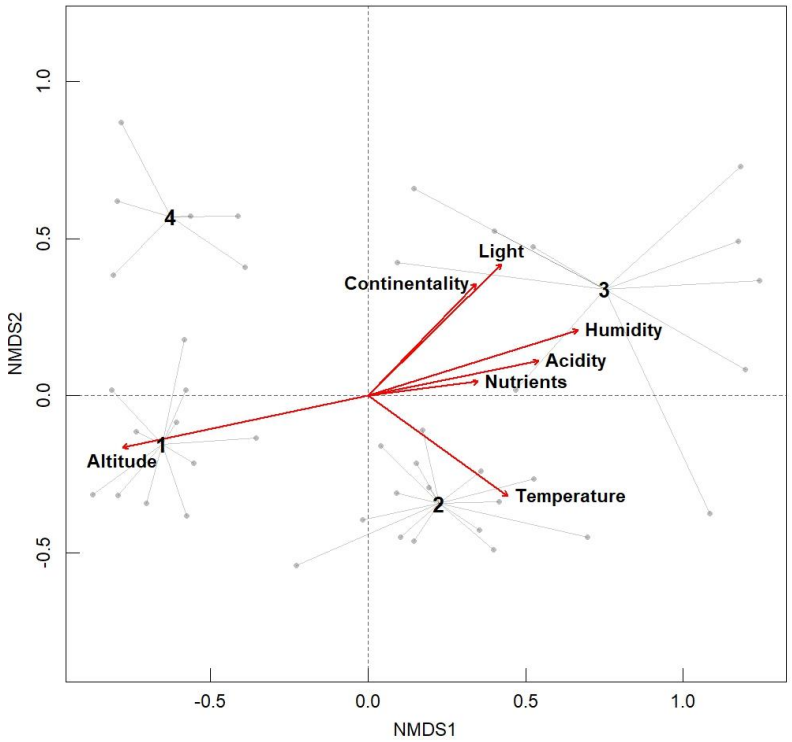

Figure 5. NMDS ordination of *Carex brizoides* relevés from Slovenia, Czech Republic and Romania. Legend: 1- *Avenello flexuosae-Caricetum brizoidis* (Slovenia), 2- *Scirpo sylvatici-Caricetum brizoidis* (Czech Republic), 3- *Cirsio heterophylli-Caricetum brizoidis* (Czech Republic), 4- *Caricetum brizoidis* (Romania).

Table 1: *Avenello flexuosae-Caricetum brizoidis* and *Calamagrostis villosa* community on the Smrekovec Mt. (Slovenia).

	Relevé number		1	2*	3	4	5	6	7	8	9	10	11	12	13	
	Relevé area (m^2)		25	25	25	25	100	25	25	100	25	25	100	9	25	
	Altitude (m)		1577	1578	1551	1524	1521	1564	1516	1507	1525	1654	1674	1531	1493	
	Aspect (degrees)		245	45	180	260	210	165	90	130	-	360	120	180	180	
	Slope (degrees)		10	15	15	15	10	10	5	5	-	10	10	15	15	
	Cover herb layer (%)		98	95	100	60	98	98	98	98	95	90	95	90	90	
	Cover moss layer (%)		0	0	0	0	0	0	1	1	1	0	0	50	0	
Class according to Mucina et al. (2016)	Cover litter (%)		70	70	90	90	90	85	90	80	90	90	90	30	60	Freq.
	Diagnostic species of the association															
MOL, POP	Carex brizoides	C	5	5	5	4	5	5	5	5	5	5	5	.	.	11
EPI, NAR, PIL, QUE,	Avenella flexuosa		+	1	+	+	.	+	.	+	.	1	+	+	.	9
GER, PIC, QUE	Melampyrum pratense subsp. pratense		.	+	+	2	+	.	+	+	.	1	.	1	2	9
MUL	Veratrum album		+	.	+	.	.	.	+	+	.	2	.	.	.	5
MUL	Calamagrostis villosa		.	1	.	.	.	.	.	.	+	.	1	4	5	5
	Nardetea strictae															
ALN, NAR	Potentilla erecta		+	+	.	+	.	+	+	1	1	+	.	1	.	9
NAR, PIL, ULI, TRI	Nardus stricta		+	.	+	+	.	+	+	+	.	+	.	+	.	8
NAR, PIC, QUE, ULI	Vaccinium myrtillus		.	2	.	+	.	.	+	+	.	1	+	1	+	8
MUL, NAR	Hypericum maculatum		+	.	.	.	.	.	.	.	+	.	+	2	+	5
MOL, NAR	Carex leporina		.	.	.	+	.	.	+	.	+	.	.	+	+	5
MOL, NAR	Stellaria graminea		.	.	.	.	.	.	.	.	.	+	+	+	.	3
NAR, QUE	Veronica officinalis		.	.	.	.	.	.	.	+	.	.	.	1	+	3
NAR	Carex pilulifera		.	.	.	+	.	.	.	.	.	.	.	+	.	2
GER, MOL, NAR	Agrostis capil-laris		.	.	.	.	.	.	.	+	.	.	.	2	.	2
MOL, NAR	Carex pallescens		.	.	.	.	.	.	.	.	+	.	.	+	.	2
NAR, TRI	Solidago virgaurea subsp. minuta		.	.	.	.	.	.	.	.	.	+	1	.	.	2

Table 1 Continued

NAR, TRI, ULI	Luzula multiflora		.	.	.	.	.	.	.	.	+	.	.	.	.	1
FES, NAR, SAC, ULI	Luzula campestris		.	.	.	.	.	.	.	.	.	.	.	1	.	1
	Other species															
FAG, QUE	Luzula luzuloides		.	+	.	+	.	.	.	+	+	+	.	+	1	7
MOL, MON	Deschampsia cespitosa		.	.	+	.	+	1	.	+	1	1	2	.	.	7
PIC	Picea abies		.	.	.	+	.	+	+	+	+	+	.	.	.	6
MOL	Festuca rubra		+	.	.	.	.	+	.	+	.	1	.	1	.	5
FAG	Luzula sylvatica		.	.	.	.	.	+	.	.	.	+	+	.	+	4
MOL	Crocus vernus		+	.	+	.	.	.	.	.	.	.	.	+	.	3
LON, ROB	Rubus idaeus		.	.	.	.	.	.	.	+	.	.	1	.	+	3
FAG	Anemone nemorosa		.	.	+	.	.	.	.	.	.	.	.	.	+	2
ASA, FAG, PIC	Oxalis acetosella		.	.	.	.	.	.	.	.	.	+	.	.	+	2
BRA, MOL, GER	Veronica chamaedrys		+	.	.	.	.	.	.	.	.	.	.	.	.	1
FAG, QUE, VIR	Polygonatum verticillatum		+	.	.	.	.	.	.	.	.	.	.	.	.	1
EPI, POP, ROB	Urtica dioica		+	.	.	.	.	.	.	.	.	.	.	.	.	1
MOL	Cerastium holosteoides		+	.	.	.	.	.	.	.	.	.	.	.	.	1
BRA, LON, RHA	Sorbus aucuparia		.	+	.	.	.	.	.	.	.	.	.	.	.	1
	Festuca pulchra		.	.	+	.	.	.	.	.	.	.	.	.	.	1
	Luzula sp.		.	.	.	+	.	.	.	.	.	.	.	.	.	1
FES, GER	Cruciata glabra		.	.	.	.	.	+	.	.	.	.	.	.	.	1
EPI, MOL, MUL	Melandrium rubrum		.	.	.	.	.	.	.	+	.	.	.	.	.	1
FAG, PIC	Homogyne alpina		.	.	.	.	.	.	.	.	.	1	.	.	.	1
	Galeopsis sp.		.	.	.	.	.	.	.	.	.	.	+	.	.	1
MUL	Senecio cacaliaster		.	.	.	.	.	.	.	.	.	.	.	.	+	1
ASA, AZO, FAG, LAU	Athyrium filix-femina		.	.	.	.	.	.	.	.	.	.	.	.	+	1
	Mosses and lichens															
	Cladonia rangiferina	D	.	.	.	+	.	.	.	.	.	.	.	.	.	1
	Dicranum sp.		.	.	.	+	.	.	.	.	.	.	.	.	.	1
	Polytrichum formosum		.	.	.	.	.	+	.	.	+	.	.	.	.	2
	Polytrichum sp.		.	.	.	.	.	.	+	.	.	.	.	.	.	1

DISCUSSION

Based on the comparison of available relevé material, we have described a new association, *Avenello flexuosae-Caricetum brizoidis* ass. nova, and a plant community with *Calamagrostis villosa* occurring on non-carbonate bedrock in Slovenia.

Plant communities dominated by *Carex brizoides* have previously been reported from the Czech Republic, Romania, and Slovenia. However, it is likely that they are more widespread across Europe. In Central Europe, they are found at middle altitudes (500-1000 m above sea level) and classified under the *Calthion palustris* alliance [8, 10], as many species characteristic of wet meadows (e.g., *Lotus uliginosus*, *Scirpus sylvaticus*, *Cirsium oleraceum*) are found in these stands. The two associations, *Scirpo sylvatici-Caricetum brizoidis* and *Cirsio heterophylli-Caricetum brizoidis*, are ecologically similar and could represent altitudinal variants.

The association from Romania, which occurs at higher altitudes (1100–1300 m above sea level), differs significantly. These stands have been classified under the *Deschampsion caespitosae* Borza 1943 (a valid synonym, *Trisetion fusci* according to [13]) or even the *Deschampsion caespitosae* Horvatić 1930 [5, 32, 33]. This classification has caused confusion, as it was initially placed in the *Mulgedio-Aconitetea* [5], but more recently [33] has been assigned to the *Molinio-Arrhenatheretea*. Our results show similarities between the Romanian stands and those from Slovenia, but a lack of characteristic species from the *Nardetea strictae* class in the Romanian *Caricetum brizoidis*. The classification into one of the two proposed classes appears correct [5, 33], but further analysis of a larger dataset from Romania is needed. On the other hand, species such as *Nardus stricta*, *Avenella flexuosa*, and *Carex leporina* support the classification of *Avenello flexuosae-Caricetum brizoidis* from Slovenia within the *Nardetea strictae* class.

Calamagrostis villosa is a characteristic species of the *Calamagrostion villosae* alliance, which comprises tall-herb and herb-rich vegetation on acidic, deep-leached soils in the subalpine and alpine belts of the Alps, Carpathians, and Hercynicum [13]. This alliance is not mentioned in the Slovenian literature [3]. [14] described *Calamagrostis villosa* stands that cannot be classified as *Campanulo scheuzeri-Calamagrostietum villosae* because they lack characteristic tall perennials. [15] lists its occurrence in various habitat types, including natural occurrences above the timberline, within natural (climax) forest communities, and in secondary communities after deforestation.

Carex brizoides is a perennial herbaceous species found in both herbaceous and forest communities, where it can be dominant or characteristic. In Slovenia, the species is primarily known as a key characteristic species of the *Carici brizoidis-Alnetum glutinosae*, which occurs as a secondary plant community on sites formerly occupied by various flooded forest communities (*Piceo abietis-Quercetum roboris*, *Pseudostellario europeae-Carpinetum betuli*, and *Pseudostellario europeae-Quercetum roboris*) [34]. This suggests a clear association of the Alpine grass with wet, mineral-rich sites and highlights its role in the succession from wet meadows to forests in the lowlands. A similar successional process is reported for *Carex brizoides* stands in the Czech Republic [10, 35].

Nevertheless, the Smrekovec ridge stands out as one of the few acidophilic mountain regions on silicate rock in Slovenia, as sedimentary carbonate rock predominates in most of the country [1]. On the Smrekovec ridge, *Carex brizoides* is found on acidic, mineral-poor, sometimes pseudogleyic soils. Succession in this region, following centuries of exploitation, follows a pattern: acidic grasslands with *Nardus stricta* → *Carex brizoides* swards → *Avenello flexuosae-Piceetum* → potential vegetation of acidophilic beech forests [36]. The successional process in Romania, where *Carex brizoides* stands are related to spruce forests (*Piceetum montanum*) [5], appears to follow a similar trajectory.

Succession in these communities is slow, likely due to the degraded soils and the fact that *Carex brizoides* can form long-lasting successional stages with high cover and accumulation of litter. This accumulation impedes the successful growth of other species, particularly the seedlings of woody species. This pattern is consistent across all *Carex brizoides* communities, irrespective of their ecological context (wet or acidic). *Carex brizoides* inhibits succession toward forest stages after the abandonment of mowing or grazing [37], and only intensive management (e.g., two harvests per year and fertilization) can restore the community to a meadow-like state [8]. *Carex brizoides* stands are one of the least productive grasslands [38], and several methods of converting these communities into meadows have been studied [8, 37, 39].

Carex brizoides and *Calamagrostis villosa* communities are not included in Slovenia's Habitat typology [40] nor the Catalogue of semi-natural grasslands of Slovenia [41]. While they are not of significant concern from a nature conservation per-

spective, they may play an important role in regional biodiversity. However, it is equally crucial to prevent these stands from spreading and encroaching on neighboring grassland areas, as they can threaten biodiversity by disrupting successional processes.

Figure 6. *Carex brizoides* swards are sometimes also grazed

Figure 7. Patch of *Calamagrostis villosa* community surrounded by *Nardus stricta* acidophilous grassland

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Appendix

Location, WGS84 coordinates, all relevés were made on 25. 7. 2024

1. Smrekovec, the Smrekovec peak, mosaic stand of *Nardus stricta*, *Avenella flexuosa*, *Vaccinium myrtilus*; 14.8985475; 46.4183001
2. Smrekovec, under the top of Smrekovec; 14.8988467; 46.4183093
3. Smrekovec, from the top of Smrekovec towards Krnes; 14.8964385; 46.4191349
4. Smrekovec, degraded; 14.8917146; 46.4198953
5. Smrekovec; 14.8908816; 46.4200835
6. Smrekovec, between Smrekovec and Krnes; 14.8953449; 46.4195388
7. Smrekovec; 14.8864327; 46.4199353
8. Smrekovec; 14.8827901; 46.4198777
9. Smrekovec, in front of Krnes; 14.8724464; 46.4203796
10. Smrekovec, in front of Kamen (Komen), pasture (trampled, cow faeces); 14.8485164; 46.4175347
11. Smrekovec; 14.8463305; 46.4176938
12. Smrekovec, patch of *Calamagrostis villosa* in *Arnico-Nardetum*, along the path; 14.8715617; 46.4203787
13. Smrekovec, forest clearing, non-developed stand; 14.8754397; 46.4199150

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НОВИ АЦИДОФИЛНИ *NARDO-AGROSTION TENUIS* ЗАЕДНИЦИ ВО СЛОВЕНИЈА

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Ацидофилната вегетација на силикатни карпи е поретка во Словенија, бидејќи доминира карбонати, така што некои растителни заедници сèуште не се документирани. Во трудот се презентирани резултатите од проучуваната тревеста ацидофилна вегетација на планината Смрековец во северна Словенија. Направени се 13 вегетациски снимки и опишана е нова асоцијација *Avenello flexuosae-Caricetum brizoidis* ass. nova и нова растителна заедница со *Calamagrostis villosa* во Словенија, врз основа на нумеричка класификација и ординација на достапните вегетациски снимки. Авторите ги споредуваат нивните податоци со другите вегетациски типови во областа на проучување и со слични синтаксони од Централна и Југоисточна Европа. Двата нови синтаксони класифицирани се во сојузот *Nardio-Agrostion tenuis* и класата *Nardetea strictae*.

Клучни зборови: вегетација; Смрековец; Словенија; ацидофилна