SPRINGS (THE KRKONOŠE MOUNTAINS NATIONAL PARK, CZECH REPUBLIC): SPECIES DIVERSITY IN RELATION TO ENVIRONMENTAL FACTORS

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Abstract. The springs are unique ecotones that integrate ecological characteristics and human impacts associated with both underground and surface water as well as terrestrial ecosystems. A clear definition of the management of springs is a precursor to their effective protection and restoration. Species diversity of springs areas in the eastern part of the Krkonoše Mts. was investigated in eight various localities. By a cover-abundance scale species richness (plants and mosses) and habitat type (phytocenological survey) were evaluated. Statistical analyses were used to compare springs by main gradients with respect to environment determinants (Principal component analysis with environmental supplementary variables, Simpson's dominance index and Shannon's diversity index). A total of 59 vascular plants, 9 mosses and 4 communities were found, including 8 endangered taxa of them. The springs of Modry brook and Renner brook had the highest species diversity and the largest number of vascular plants were observed on the headwater area of Upa River. The fewest endangered species were determined on the springs of Suchy brook and Javori brook. The resulting species richness is a function of the combination of altitude and exposure, where the highest species richness values were recorded in the highest located subalpine headwater areas.
Keywords: *wetland vegetation; Montia fontana; plant communities; altitude; subalpine spring*

Introduction

Springs are ecosystems in which groundwater reaches the Earth's surface either at or near the land-atmosphere or land-water interface. At their sources (orifices, points of emergence), the physical geomorphic template allows some springs to support numerous microhabitats and large arrays of aquatic, wetland, and terrestrial plant and animal species. Yet, springs ecosystems, however, differ significantly from other aquatic, wetlands and riparian ecosystems (Stevens et al., 2005). They fundamentally contribute to the circulation of nutrients, soil formation, climate regulation, carbon accumulation, nutrient and water retention (Sorooshian and Whitaker, 2003). As wetland habitats are one of the most threatened in all of Europe, detailed knowledge of relationships between springs vegetation and environmental conditions is, among others, highly important for applications in nature conservation. This study is intended to fill a large gap in the knowledge of the springs vegetation diversity in Krkonoše high-mountain regions and its ecological determinants.

The Krkonoše was proclaimed as a government-protected area for water accumulation because of its significance as a headwater area. The collecting area of

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underground waters is shallow and has a relatively low springs discharge. The springs water maintains a year-around temperature between 4 - 6 °C, so the headwater areas do not freeze (Stursa et al., 2012). Thanks to various geologic and ecologic conditions, headwater areas include a wide range of locations (Danks and Williams, 1991).

Twelve springs types are recognized, not including paleo-springs (Springer and Stevens, 2009). In a recent study biology of springs widely used simple division into three basic types (according to the method of seepage of ground water and the intensity of its velocity: Limnocrene; Helocrene; Rheocrene), as aptly describes the nature of springs (Cantonati et al., 2006). This differentiation of communities is primarily conditioned by the ground water mode; water chemical composition, temperature, nutrition content, springs discharge, water flow rate and slope angle. The most significant species diversity is influenced by mineral richness and the reaction of springs water (Tahvanainen et al., 2002; Nekola, 2004; Novakova, 2007).

Earlier vegetation studies carried out by Czech and Poland researchers were mostly performed using the dominance approach (see Chumanova-Vavrova et al., 2015; Vacek et al., 2017). Moreover, springs have been investigated only marginally in these studies. Studies of springs vegetation that focus on the overall species composition of the vegetation are very rare in Czech Republic. A vegetation study from Czechoslovakia (Hadac, 1983) and the syntaxonomic evaluation of spring communities with *Montia fontana* (Hadac and Vana, 1971) represent the exceptions. In the present study, we describe the diversity of Krkonoše high-mountain springs with respect to major environmental factors measured directly in the field.

Vegetation of springs is widespread throughout Europe, and is more frequent at higher altitudes with humid climates. Spring represent azonal habitat, sometimes referred to as hydrological sub-climax (Hinterlang, 1992). The *Montio-Cardaminetea* class comprises vegetation developing in springs with cold and well oxygenated water. Cold water with low nutrient content reduces vascular plant productivity, while leading to increasing bryophyte cover. Enhanced input of nutrients can therefore quickly change the structure of springs vegetation to the benefit of vascular plants (Hajkova et al., 2006). Variability of this class is relatively large and therefore may occur in the springs ecologically distinct from foothills to alpine levels in deciduous and coniferous woods and on open sites (Zechmeister and Mucina, 1994). With increasing distance from a springs, flow rates and oxygenation decrease and springs vegetation is replaced by other communities, typically mire and fen vegetation of the class *Scheuchzerio palustris-Caricetea nigrae* (Økland et al., 2001).

By describing vegetation diversity, we examine the major ecological determinants of vegetation variation springs in a biogeographical context. Another objective is to evaluate the floristic elements in ecologically diverse springs vegetation types in the Krkonoše Mountains National Park, Czech Republic.

Materials and methods

Study area

A field survey was conducted at the The Krkonoše Mountains National Park (Czech Republic, official abbreviations KRNAP – KPN). Krkonoše is home to the highest mountains in the Czech Republic, but that is also true throughout Central Europe to the north of the Alps. In fact, the mountains form the northernmost montane border of Central Europe, stretching in length just over 50° of northern latitude, whilst their slopes

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protrude above the alpine tree line. Consequently, the Krkonoše Mountains represent a mighty and natural barrier on the perimeter of large open plains in Germany and Poland. They measure approximately 35 km in length, with their main ridges and valleys arranged in a direction from northwest to southeast. This significantly affects all the geographical, climatic and biological features of these European medium-sized mountains and their surroundings. Therefore, Krkonoše Mountains are a truly important area for geobiodiversity in Central Europe.

Vegetation samples were taken from representative springs, which we found in Krkonoše Mountains during our extensive research in vegetation seasons 2015 –2016. Eight springs were chosen:

L1 – Zeleny brook 50°42´42.704´´N 15°40´26.351´´E | L2 – Modry brook 50°43'21.799"N 15°41'23.273"E | L3 – Javori brook 50°39´30.148´´N 15°44´27.238´´E | L4 – Weber brook 50°40´33.614´´N 15°44´19.803´´E | L5 – Renner brook 50°43´45.719´´N 15°49´29.460´´E | L6 – Max brook 50°39´26.506´´N 15°50´58.014´´E | L7 – Suchy brook 50°39´45.649´´N 15°51´26.606´´E | L8 – Upa River (so called ´Deliquescent Rock´) 50°40´1.685´´N 15°47´321.445´´E – for more characteristics, see *Table 1* and *Fig. 1*.

Table 1. *Summary of different springs at different sites of the The Krkonoše Mountains National Park (Czech Republic)*

	Exposure	**Soil**	**Altitude** (m a.s.l.)	**Slope** (°)	**Coverage E_1** (%)	**Coverage E_0** (%)	**Springs type**
L1	East	Podsol	1 375	12	70	40	Limnocrene
L2	South	Podsol	1 350	39	70	50	Helocrene
L3	North	Podsol	1 220	14	15	90	Helocrene
L4	Northwest	Podsol	1 110	9,5	60	50	Helocrene
L5	West	Podsol	1 080	11,3	70	50	Helocrene
L6	West	Cambisol	965	54	90	15	Rheocrene
L7	West	Cambisol	940	10,5	60	20	Helocrene
L8	East	Podsol	625	69	80	5	Rheocrene

The phyto-sociological part was worked out with the help of the Zürich Montpellier School of Phytosociology and included analysis, synthesis and identifying vegetation. Sixteen phyto-sociological relevés were taken (Rosenthal, 2003). The vegetation plot size was delimited in such a way as to represent full floristic composition of the phyto-coenosis. It varied from 3.75 to 12 m^2 depending on plant density and the homogeneity of vegetation cover (Chytry and Otypkova, 2003).

Cover of vascular plants and bryophytes was estimated using the seven-grade Braun-Blanquet scale (van der Maarel, 1979). Vegetation and environmental data were simultaneously collected in submontane and lowland springs and from subalpine tall-form vegetation. The slope of the sample plot was subjectively estimated. Altitude and coordinates were measured by GPS Garmin Oregon 400t (WGS 84 system) with altimeter calibrated by current atmospheric pressure. Other environmental factors (soil types, aspect) were noted for each relevé.

The nomenclature of vascular plants follows Danihelka et al. (2012) and the bryophytes nomenclature follows Kucera et al. (2012). The vascular plant species were classified into five groups according to their threat status by Grulich (2012).

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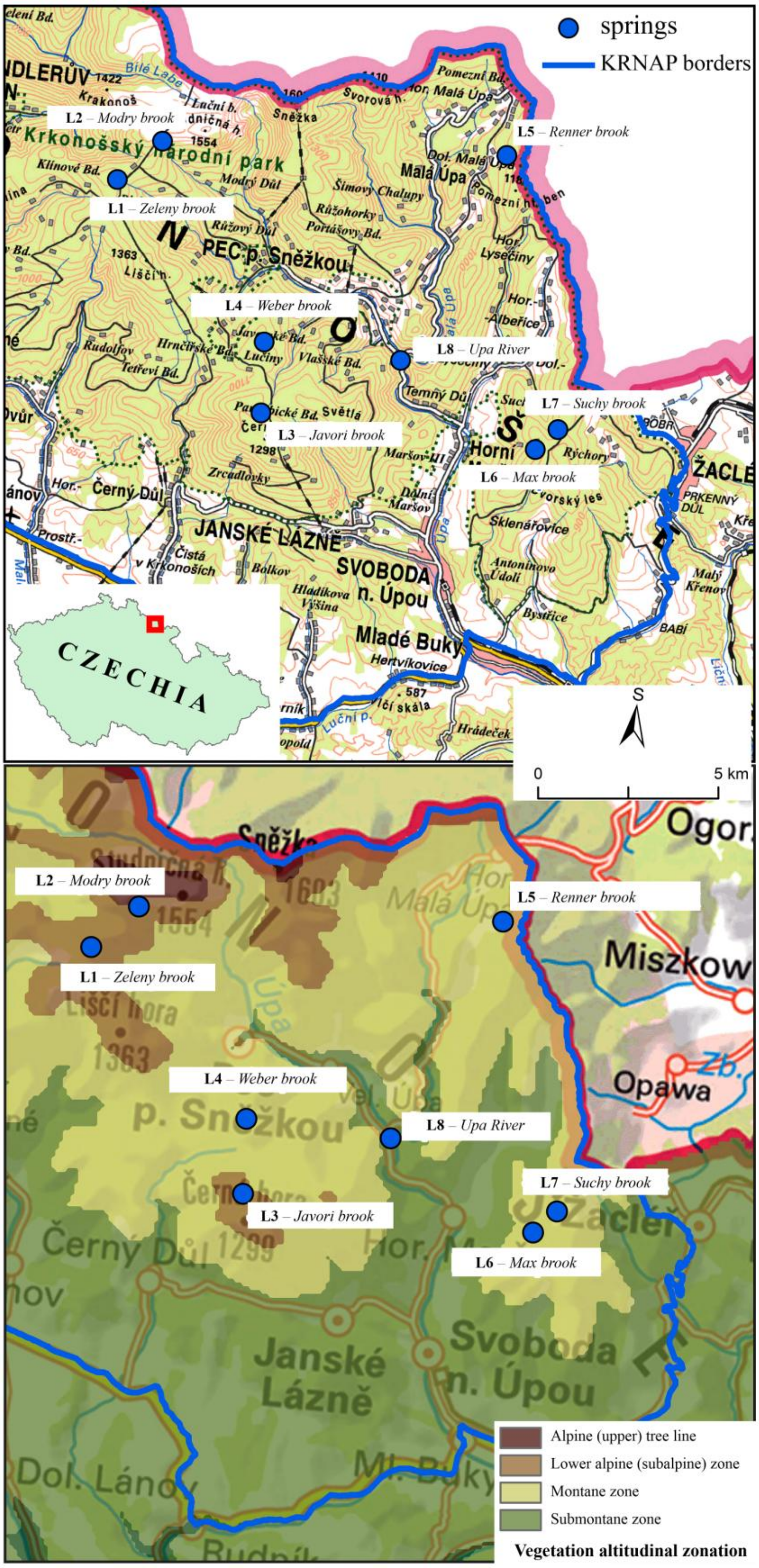

Figure 1. *Distribution map of studied high-mountain springs vegetation in The Krkonoše Mountains National Park (KRNAP – KPN), Czech Republic*

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Data analysis and statistical methods

The springs type was determined by analysing its groundwater environment. Simpson's dominance index and Shannon's diversity index was calculated for each individual location, using the PAST software (Hammer et al. 2001). A TWINSPAN analysis (Hill and Smilauer, 2005) was used to perform the preliminary classification of communities (cluster analysis). Principal component analysis (PCA) of species composition (relevé diversity is expressed as Shannon-Wiener index) with forward selection of environmental factors was analysed by CANOCO 5 software package (Smilauer and Leps, 2014).

Results and discussion

On selected springs, a total of 59 vascular plants and 9 mosses were determined, including 8 endangered taxa among them (*Table 2*, *Appendix I*). The highest occurrence of endangered species is represented by the springs L2, characterized by the continuous plant cover of *Cardamine amara* subsp. *opicii* (*Fig. 4*) with almost equal coverage of herbaceous and mosses layer. It is a newly discovered locality with this taxon, which is extremely rare and critically endangered. This subspecies is extended, among other things, in the highest mountains of the Western Carpathians (Marhold, 1995). It is a natural habitat without the necessary regular management; question is the occurrence of forest animals. There is also *Montia fontana*, which, according Grabherr and Mucina (1993), due to the overall eutrophication of the landscape and increased productivity of stands from the whole of Europe is receding.

Table 2. *Summary of threatened taxa determined at different springs*

	Statutes by Red List (Grulich 2012)	**Springs**	**Cover-abundance scale**
Cardamine amara subsp. *opicii*	C1 b - Critically threatened taxa	L2	3
Delphinium elatum	C2 r - Endangered taxa	L6	2
Epilobium alsinifolium	C3 - Vulnerable taxa	L2, L4, L8	2, +, 1
Epilobium palustre	C4 a - Lower risk – near threatened	L5	1
Chrysosplenium oppositifolium	C4 a - Lower risk – near threatened	L8	1
Montia fontana subsp. *fontana*	C1 b - Critically threatened taxa	L2	1
Swertia perennis	C2 r - Endangered taxa	L2	+
Viola biflora	C4 a - Lower risk – near threatened	L2, L3, L5	+, r, r

Cover-abundance 7-degree scale follows Braun-Blanquet | L1 – L8 see Materials and methods

Species richness

Fig. 2 (left side) shows highest species richness on L5 and L3 (with 19 vascular plants and 4 mosses, respectively 18 and 3). It is probably connected with this that the index is heavily dependent on the most numerous species and less sensitive to rare species. On the other hand, the lowest diversity was observed on L7 and L4 (5 vascular plants and 2 mosses) – which are closely similar. On right side of *Fig. 2* is a clear cluster with L1 and L2 (subalpine altitude) that also shows in other clusters, as well as springs. First cluster covers L6-L8, localities with lowest altitude (submontane zone).

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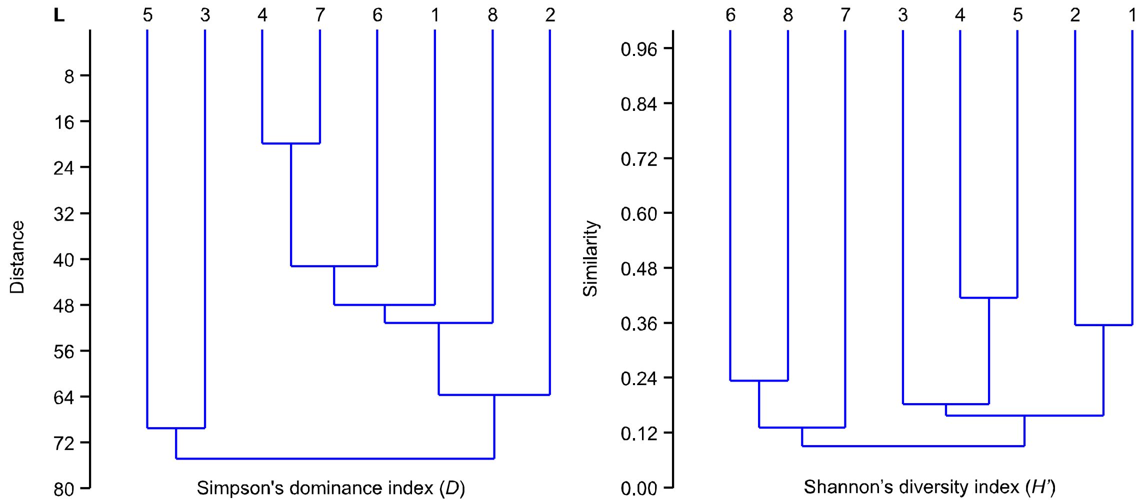

Figure 2. *Cluster analysis of species richness of different springs indicated by Simpson´s dominance index (D) and by Shannon's diversity index (H') - complete linkage (Euclidean distance) | L1 – L8 see Materials and methods*

The results of species diversity and phytocenological relevés show diverse types of communities in the springs. These are communities of the alliance *Swertio perennis-Dichodontion palustris* Hadač 1983 (L1-L4) and associations *Caricetum remotae* Kästner 1941 (L5, L6), *Cardamino-Chrysosplenietum alternifolii* Maas 1959 (L7) and *Pellio epiphyllae-Chrysosplenietum oppositifolii* Maas 1959 (L8).

According to Hajkova et al. (2006) the major species turnover in springs follows the variation in water pH and mineral content in water but altitude remains an important factor in all cases. Our results indicated that springs preserved in managed forests constitute biodiversity hotspots in the landscape because they provide habitat for many species of plants, including protected and endangered (Spalek and Prockow, 2011).

The first and second axis in PCA are explained in 24.62 and 23.72, respectively. *Fig. 3* shows both species abundance and richness by various springs in relation to their environmental gradient. First axis represents the effects of elevation and slope while the second illustrates aspect. The resulting species richness is a function of the combination of altitude and exposure, where the highest species richness values were recorded in the highest located subalpine headwater areas with southern exposures.

This contradicts the conclusions of some studies (Hajkova et al., 2006); that the plant species richness decreases significantly with increasing altitude. On the contrary, Krkonoše Mountains are specific due to rarity of calcareous bedrock. In such conditions, vegetation of the high-mountain springs (*Montio-Cardaminetea* class) is not diversified according to the gradient of mineral richness. Species composition is more influenced by the variation in altitude and also by succession advancing due to *Sphagnum* sp. expansion and peat accumulation (Hajek et al., 2005). As a general conclusion, our results show that subalpine springs vegetation should be analysed separately while searching for vegetation-environment relation.

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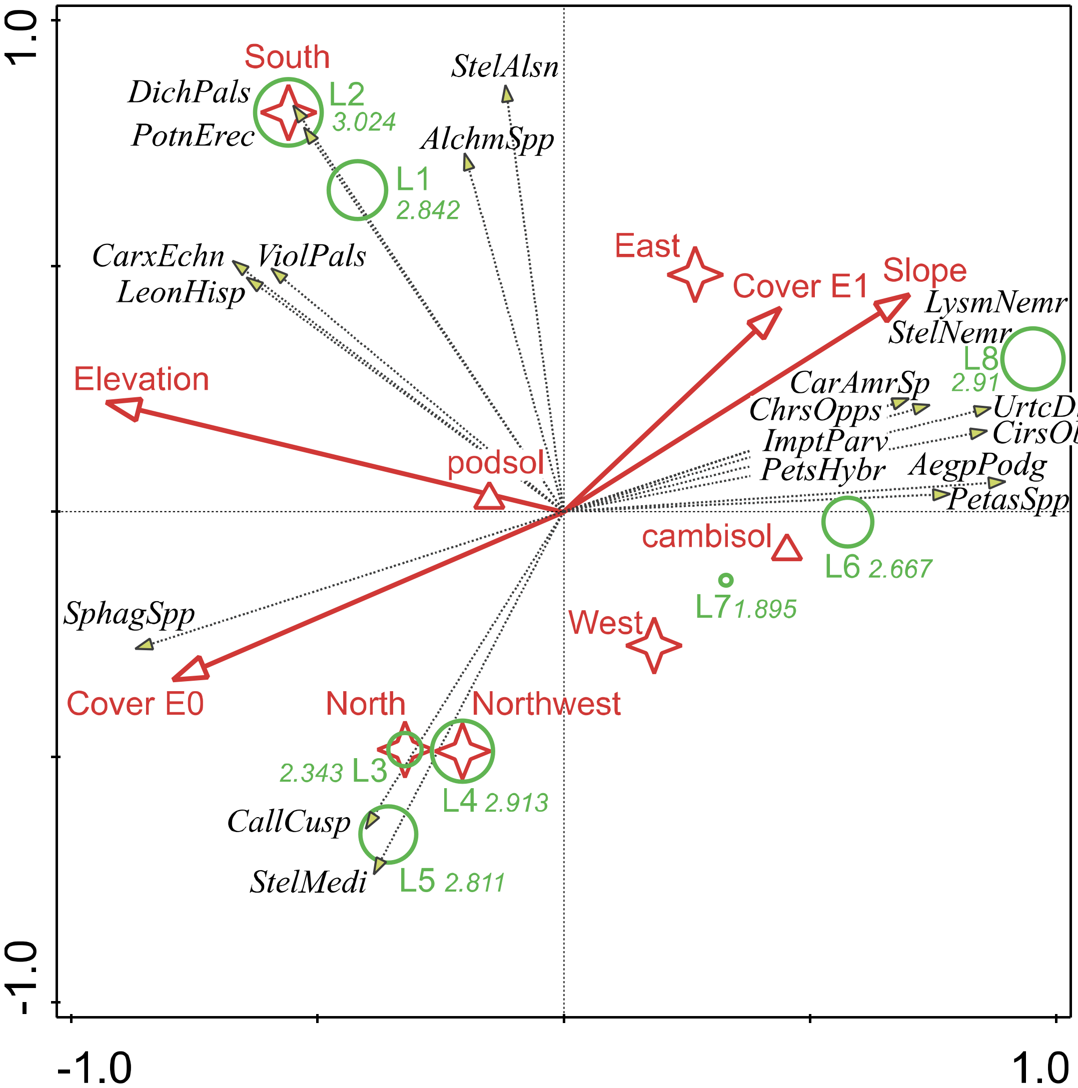

Figure 3. *An ordination diagram of PCA with environmental supplementary variables | red – supplementary variables; black - species; green – springs (L1 - L8) – point size and number correspond with Shannon-Wiener index | L1 – L8 see Materials and methods | AegpPodg - Aegopodium podagarium | AlchmSpp - Alchemilla spp. | CallCusp – Calliergonella cuspidata | CarAmrSp - Cardamine amara | CarxEchn - Carex echinata | ChrsOpps - Chrysosplenium oppositifolium | CirsOber - Cirsium oleraceum | DichPals - Dichodontium palustre | ImptParv - Impatiens parviflora | LeonHisp - Leontodon hispidus | PetasSpp - Petasites spp. | PetsHybr - Petasites hybridus | PotnErec - Potentila erecta | SphagSpp - Sphagnum spp. | StelAlsn - Stelaria alsine | StelMedi - Stelaria media | StelNemr - Stellaria nemorum | UrctDioi - Urtica dioica | ViolPals - Viola palustris | LysmNemr - Lysimachia nemorum*

Management of springs

In terms of the overall approach to management of habitats, springs are distinguished by two basic groups. The first involves the natural habitat (forest and subalpine springs as L1, L2 and L3; bogs and some types of transitional bogs), which should generally leave the spontaneous development with possible one-off interventions aimed primarily at restoring the natural water regime. This corresponds with Barquin and Scarsbrook (2008). The second group consists of semi-natural habitats – mainly springs L4 and L6.

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The existence of these semi-natural habitats is conditioned especially by human activities, including deforestation and subsequent traditional management in the past of non-forest springs, calcareous and non-calcareous moss springs and some types of transitional bogs. These habitats require more or less steady, albeit extensive management to replace the former traditional agricultural practices.

Conclusions

The springs are unique ecotones that integrate ecological characteristics and human impacts associated with both underground and surface water and terrestrial ecosystems. Spring vegetation occurs across a broad altitudinal range from lowlands to the subalpine belt, both in open places and under forest canopies. A clear definition of the management of springs, with the help of vegetation and environmental factors surveys, is a precursor to their effective protection and restoration. Our results suggest that subalpine springs vegetation should be analysed separately with respect to vegetation-environment correlations. Separate analysis of springs below and above timberline is quite appropriate.

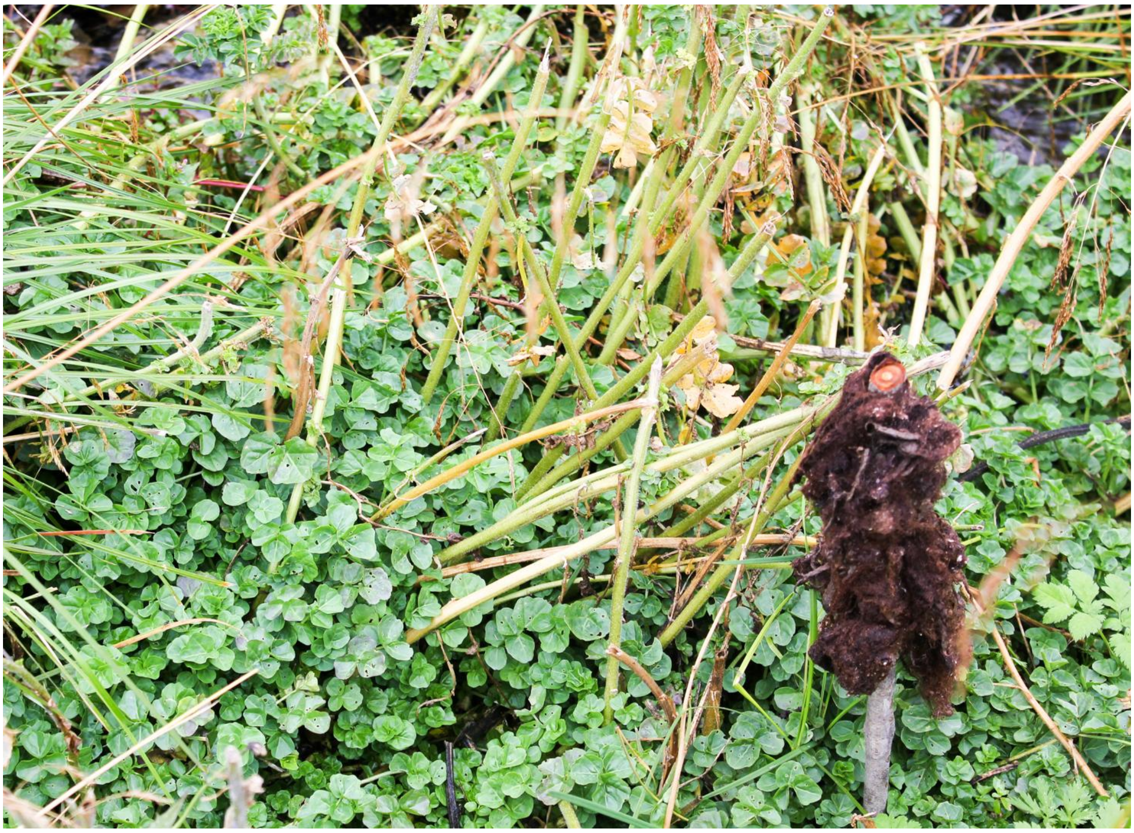

Figure 4. *The critically threatened plant Cardamine amara subsp. opicii (large bitter-cress) on subalpine springs Modry brook (L2 | 18. 9. 2015) with protection (fleece) against grazing forest animals*

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APPENDIX

Appendix I. *Shortened synoptic table with Braun-Blanquet scale values*

	Taxon	L1-8
E_1	*Aegopodium podagaria*	. . . . . 1 + +
	Agrostis canina	. . . + ...
	Agrostis capillaris	3 . . . .
	Agrostis stolonifera	. . . 1 + 1 . r
	Anthriscus sylvestris	. . . . . . 1 .
	Alchemilla spp.	+ + . . . + . .
	Athyrium filix femina	. . . . r . . +
	Cardamine amara spp.	. . . . . . r 3
	Cardamine amara subsp. *opicii*	. 3 . . . . . .
	Carex echinata	+ 2 . . + . . .
	Carex rostrata	. . . . 1 . . .
	Cirsium oleraceum	. . . . . + . +
	Crepis paludosa	+ 1 . 1 . . . .
	Dactylorhiza fuchsii	. + ...
	Delphinium elatum	. . . . . 2 . .
	Deschampsia cespitoza	. 1 . . . . . .
	Dryopteris dilatata	. . + ...
	Dryopteris filix- mas	. . 1 . . . . .
	Epilobium alsinifolium	. 2 . + . . . 2
	Epilobium angustifolium	. . . 2 . 1 . .
	Epilobium palustre	. . . . 1 . . .
	Equisetum sylvaticum	. . . + r . . .
	Eriophorum vaginatum	2 . . . .
	Galium palustre	. . . r r . . .
	Geranium palustre	. . . . . 1 . .
	Homogyne alpina	1 r 1 . . . . .
	Hypericum maculatum	+ . . . . 1 . .
	Chaerophilum hirsutum	2 1 . . 1 3 . 1
	Chrysosplenium alternifolii	r . . . .
	Chrysosplenium oppositifolium	 1
	Impatiens parviflora	 2
	Juncus effusus	. . . 1 + . . .
	Leontodon hispidus	+ + . + ...
	Lysimachia nemorum	 1
E_1	*Montia fontana*	. 1 . . . . . .
	Myosotis nemorosa	. . . 1 1 . . .
	Myostis palustris	. + ... r
	Nardus stricta	2 . . . .
	Oxalis acetosella	. . . . 2 . 1 +
	Petasites hybridus	 2
	Petasites spp.	. . . . . 3 + +
	Poa trivialis	. . 2 + . + . .
	Potentila erecta	1 1 . . . . . .
	Ranunculus acris	. + . + . + . .
	Rumex acetosa	. + . + r . . .
	Rumex alpinus	1 . . . .
	Sanguisorba officinalis	. . . . r . . .
	Senecio spp.	. . . 1 r . . r
	Stellaria alsine	2 1 . 2 4 . . 1
	Stellaria nemorum	 1
	Stellaria media	. . + ...
	Swertia perennis	. + ...
	Symphytum officinale	. . . . +
	Thelypteris limbosperma	. . . . r . . .
	Urtica dioica	. . . . . r . +
	Valeriana dioica	. . . r . . . +
	Vicia cracca	. . . . . + . .
	Viola biflora	. + r . r . . .
	Viola palustris	1 + . . + . . .
E_0	*Calliergonella cuspidata*	+ . + 1 1 . 1 .
	Dichodontium palustre	1 3 . . . . . .
	Isothecium alopecuroides	. . + . . 1 . +
	Pellia epiphyla	. . 1 . . . . .
	Philonotis fontana	. 2 . . . . . .
	Polytrichum commune	. 1 2 1 1 + . .
	Polytrichum formosum	1 . . . .
	Rhizomnium punctatum	. . 2 . . . + .
	Sphagnum spp.	2 2 4 2 3 . . .

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