

The primary grasslands of the northern Apennine summits (N-Italy): a phytosociological and ecological survey

Die primären Rasengesellschaften der Gipfel der nördlichen Apenninen (N-Italien): eine pflanzensoziologische und ökologische Untersuchung

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Abstract

This paper provides a comprehensive phytosociological survey on the alpine grasslands occurring on the northern Apennine summits (N-Italy). The study area represents a crucial phytogeographic joint between the Alps and the Apennines and its summit grassland vegetation was only partially documented at the time. Research was based on 219 relevés classified combining a preliminary manual procedure with a cluster analysis that was performed with the Ward's minimum variance method on the chord distance matrix. In such a way, six different plant associations were identified and allocated to three different phytosociological classes (*Juncetea trifidi*, *Elyno-Seslerietea*, *Carici rupestris-Kobresietea bellardii*). All the six associations could be regarded as endemic because occurring only in the study area. Four of them were described here for the first time and typified according to the rules of the International Code of Phytosociological Nomenclature. The relevés corresponding to calcium-poor grasslands (*Juncetea trifidi*) were assigned to three different associations allocated to the suballiance *Festucion riccerii*, here newly described. The relevés corresponding to calcium-rich grasslands (*Elyno-Seslerietea*) were assigned to two associations, respectively, belonging to the alliance *Caricion ferrugineae* and to a new alliance described here under the name *Caricion sempervirentis-Seslerion apenninae*. Finally, a graminoid tundra association was firstly documented for the northern Apennines and assigned to the alliance *Oxytropido-Elynon myosuroidis*. The extent and quality of species fidelity to the different plant associations was detected by developing a metric named "Retention Index" (RIN). Calculation of RIN values showed that calcium-rich grasslands retained a higher floristic distinctiveness with respect to the calcium-poor ones. The analysis of environmental gradients within the grassland vegetation was performed through Principal Component Analysis (PCA), adopting Ellenberg indicator values as indirect environmental factors. The first ordination axis of PCA was primarily positively correlated with soil reaction and, secondarily, with temperature. The primary grasslands in the alpine life zone of the northern Apennines showed a fine floristic variation along the gradient from calcium-poor to calcium-rich substrates.

Keywords: arctic-alpine grasslands, *Carici rupestris-Kobresietea bellardii*, Ellenberg indicator values, *Elyno-Seslerietea*, *Juncetea trifidi*, northern Apennines, syntaxonomy

Erweiterte deutsche Zusammenfassung am Ende des Artikels

1. Introduction

Palaeartic grasslands are herbaceous communities dominated by graminoids (including grasses, sedges and rushes), having a relatively dense vegetation cover (usually > 25%) and occurring in the Palaeartic biogeographic realm (DENGLER et al. 2014). They can be subdivided into four major types based on their origin and ecology. Among them, the zonal climatogenic grasslands occurring at high elevations or latitudes, where climate is too cold to support forests, are classified as arctic-alpine grasslands. The arctic-alpine grasslands occurring at high elevations (alpine grasslands) represent an important fraction of the vegetation in the alpine life zone as defined by KÖRNER (2003). When they persist in a natural state or are near-natural because subject to moderate level of grazing by wild animals or domestic livestock, their floristic composition and structure correspond or do not significantly diverge from the original state. These alpine primary grasslands provide many essential ecosystem services such as, for instance, nutrient cycling and carbon sequestration and storage, biomass production, pollination services as habitat for insect pollinators, soil formation and protection, erosion control, regulation of water flow, climate regulation and recreation opportunities among others.

The main source of diversity in the primary alpine grasslands in the nemoral European orosystems is parent rock type, as punctually reflected at the highest rank of the phytosociological hierarchy where the grasslands occurring on calcium-poor substrates are allocated in the class *Juncetea trifidi* and those on calcium-rich ones in the class *Elyno-Seslerietea* (see MUCINA et al. 2016). The subdivision of both the classes in different orders and alliances is mostly based on latitudinal and elevational gradients reflecting climatic differences and biogeographic reasons (see again MUCINA et al. 2016). The syntaxonomic framework of calcium-poor and calcium-rich primary grasslands has long been defined in the Alps (see GRABHERR & MUCINA 1993, THEURILLAT et al. 1995, PIGNATTI & PIGNATTI 2014). Nevertheless, there is still some way to go for a better definition of the distribution range of several alliances. In particular, the southern border of several Alpine alliances needs a clearer definition and the cut off between Alpine and Apennine primary grassland communities along the Apennine chain must be precisely located also considering the recent syntaxonomic proposal of the order *Gentianello columnae-Festucetalia italicae* including the acidophytic summit primary grasslands of the central and southern Apennines (see DI PIETRO et al. 2017). A further unresolved question concerns the gap occurring within the graminoid tundra vegetation belonging to the class *Carici rupestris-Kobresietea bellardii* between the Alps and the central Apennines.

In the light of the above considerations, we undertook a research focused on the primary alpine grasslands occurring at the summits or strictly close to them in the northern Apennines (Italy). We chose this study area because it represents: i) a zone of phytogeographic and ecologic transition between the Alps and the central Apennines; ii) a major refuge area for boreal species; iii) a centre of endemism (FOGGI 1990, PIGNATTI 1994). Moreover, it is also characterized by a high diversity of geological substrates (TOMASELLI et al. 2019). For these reasons, it could be a very powerful area in order to detect vegetation transitions within summit primary grasslands on the the Italian mountains.

In the northern Apennines, the primary alpine grasslands occur typically close to the summits terminating an elevational sequence of primary heaths and secondary grasslands occurring above timberline (see PIGNATTI 1994, TOMASELLI 1994). Their habitats include windswept ridges, plateaus and steep slopes exposed to frequent strong winds blowing away the snow cover and enhancing the risk of severe frosts (TOMASELLI & ROSSI 1994). These factors affect vegetation, both directly and through their impact on the substrate, limiting the extent of vegetation cover and excluding from colonization the species more vulnerable to their combined effects.

The paper represents an attempt to fill a gap of phytosociological knowledges within the vegetation of the alpine life zone of the northern Apennines through a comprehensive study enlarging the scarce documentation available up to now (TOMASELLI 1994, TOMASELLI & ROSSI 1994). We expect that the grasslands, when treated in phytosociological terms, could hypothetically belong to the classes *Juncetea trifidi*, *Carici rupestris-Kobresietea bellardii* and *Elyno-Seslerietea*. On the Italian mountains, the first two classes have their distribution centre in the Alps and their communities become increasingly rarer moving from the Alps southwards, differently from the class *Elyno-Seslerietea* whose communities are widespread also along the Apennine chain from North to South (GERDOL et al. 2008).

2. Study area

The study area includes the northern Apennines that form a 250 km long mountain barrier running in a NW-SE direction and separating the Po plain in the North from the Italian peninsula in the South at latitude about 44° N. Our study sites are located in the Tuscan-Emilian district, representing the core of this mountain system, and in the Apuan Alps bordering it to South-West (Fig. 1). The highest peaks in the study area are Mt. Cimone (2165 m a.s.l.) in the Tuscan-Emilian Apennines and Mt. Pisanino (1946 m) in the Apuan Alps.

The geology of the summits in the study area is extremely variable. In the Tuscan-Emilian Apennines, geology is mostly given by sandstone belonging to the Macigno Formation, by medium- to coarse-grained sandstone alternating with fine-grained sandstone and siltstone (Mt. Modino Formation) and by fine-grained sandstone alternating with shaly marl ascribed to the Mt. Cervarola Formation (BRUNI et al. 1994, DINELLI et al. 1999). In the Apuan Alps, bedrock is more heterogeneous including carbonate rocks (limestones, dolomites, marbles) largely prevailing on the siliceous ones (mostly sandstone and jasper) (DALLAN NARDI & NARDI 1974).

Climate is temperate with an average annual rainfall exceeding 2000 mm in the Apuan Alps and on the south-western (Tuscan) slope of the Tuscan-Emilian Apennines, both lying close to the

Ligurian Sea. Along the Emilian slope of the Tuscan-Emilian Apennines the average annual rainfall is around 1500 mm (RAPETTI & VITTORINI 1989, GIANNECCHINI 2006). In both areas, rainfall is irregularly distributed over the year with a peak during the autumn and a minimum over the summer.

Vegetation in the summit areas of the Tuscan-Emilian Apennines is dominated by primary *Vaccinium* dwarf shrub heathlands overlying a montane belt represented by different types of beech woodlands (UBALDI et al. 1993). The present limit of the montane belt ranges between 1600 and 1700 m and it is strongly dependent upon geomorphological and land use

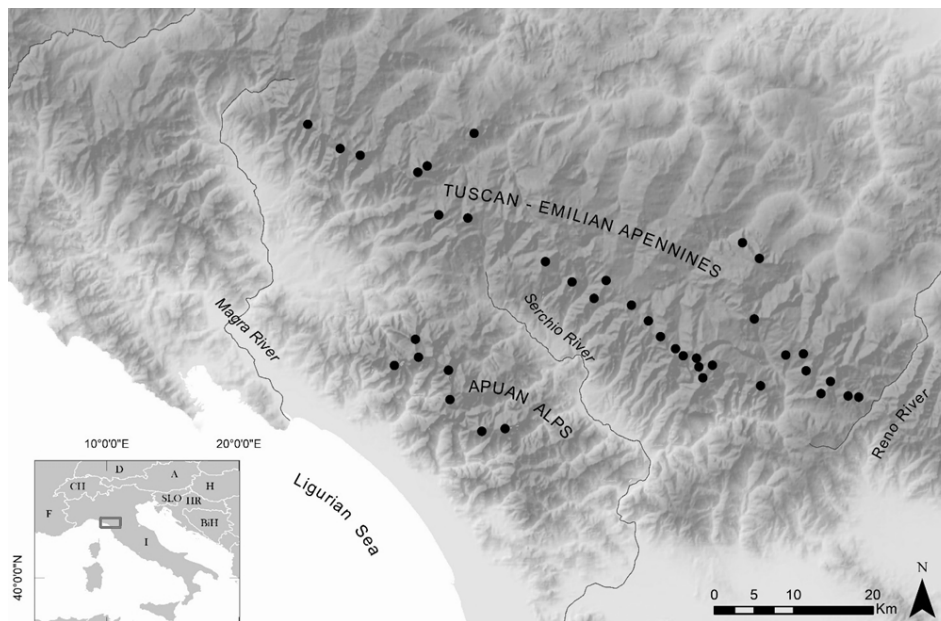


Fig. 1. Schematic map of the study area with locations of relevé sites.

Abb. 1. Schematische Übersichtskarte des Untersuchungsgebiets mit der geographischen Lage der Untersuchungsflächen.

conditions. Heathlands mostly occur on the northern slopes, whereas on the southern ones they are replaced by secondary grasslands dominated by the grass *Brachypodium genuense* (PIGNATTI 1994, FERRARI & PICCOLI 1997). Primary grasslands are confined to the summit ridges (TOMASELLI 1994). On the summit areas of the Apuan Alps, vegetation includes a mosaic of primary grasslands with *Sesleria apennina* and *Carex sempervirens* and of secondary grasslands dominated by *Brachypodium genuense* (TOMASELLI 1994) overlying beech woodlands.

3. Methods

3.1 Vegetation data collection

The vegetation was surveyed following the classical approach of the Zürich-Montpellier school (BRAUN-BLANQUET 1964), but updating the fundamental concepts according to DENGLER et al. (2005, 2008). We performed 219 relevés strictly according to the principle of the floristic and structural homogeneity within the sampled vegetation stands and providing a reasonable cover of the whole study area. The original relevés were integrated with 69 relevés taken between 1990 and 1994 and already introduced within synoptic or phytosociological tables by TOMASELLI (1994) and TOMASELLI & ROSSI (1994). Cover-abundance estimates for all species in every relevé were given according to the modified Braun-Blanquet scale as suggested by PIGNATTI & MENGARDA (1962): r < 0.01%, + = 0.01–1%, 1 = 1.1–20%, 2 = 21–40%, 3 = 41–60%, 4 = 61–80%, 5 = 81–100%. The list of the sampling sites was reported in the Supplement E1. The size of sample plots showed a considerable range of variation from 1 to 80 m². This can be justified considering that: i) many relevés were taken before possible standards for different vegetation classes were suggested (see CHYTRÝ & OTÝPKOVÁ 2003); ii) the size of plots

varied according to the habitat where relevés were taken and the vegetation types to which they were assigned; iii) some vegetation types occurred also or exclusively with small and fragmentary stands, sometimes confined to sharp summits.

For each relevé, the topographic variables (elevation, aspect and slope angle) were directly measured in the field. The bedrock type underlying the sampled vegetation was identified during the field surveys. Additional climatic and pedologic variables were indirectly defined using Ellenberg's indicator values (EIVs), adapted to the Italian flora by PIGNATTI et al. (2005). In particular, we considered the following ecological indicators: light (L), temperature (T), moisture (U), nutrients (N), continentality (K) and soil reaction (R). For each relevé, EIVs were obtained by calculating the average of all values of the species occurring in a relevé weighted by their transformed cover-abundance values (DIEKMANN 2003). The scale adopted for the transformation was that proposed by VAN DER MAAREL (1979): $r = 1$, $+ = 2$, $1 = 3$, $2 = 5$, $3 = 7$, $4 = 8$, $5 = 9$.

3.2 Vegetation data analysis

We followed a stepwise procedure for the analysis of vegetation data. The first step was manual and represented a preliminary requirement to the subsequent analysis. It led to assign relevés to phytosociological classes based on the prevailing combination of their diagnostic species after the calculation of the sums of the transformed cover-abundance values of the diagnostic species of each class in each relevé (see DENGLER et al. 2006, MICHL et al. 2010) (Table 1). The species diagnostic of different classes, including also those of their orders and alliances, were defined starting from the current literature. The main references were CHIAPPELLA FEOLI & POLDINI (1993), GRABHERR & MUCINA (1993), THEURILLAT (1996), AESCHIMANN et al. (2004), GENNAI et al. (2014). In the second step, an automatic classification of cluster analysis was applied to the 214 phytosociological relevés, subdivided into two classes during the previous step. It was not necessary to submit to the automatic procedure the residual five relevés assigned to a third class (*Carici rupestris-Kobresietea bellardii*) during the manual step owing to their very limited number and floristic homogeneity. For both calculations, the Braun-Blanquet cover abundance visual estimates were transformed according to the above reported van der Maarel scale. Cluster analysis was performed with the Ward's minimum variance method on the chord distance matrix. Relevés were grouped into clusters according to the criterion for the interpretation and validation of cluster analysis results proposed by ROUSSEEUW (1987) (Supplement E2). Computations were performed with the "vegan" package of R version 3.5.1 (R CORE TEAM 2018).

The clusters obtained were interpreted as distinct vegetation types and analysed in their floristic composition taking into account the occurrence of the diagnostic species defined in the first step of the classification process. In order to refine the interpretation, the incidence of phytosociological classes within the different vegetation types was analysed by non-parametric Kruskal-Wallis test followed by the Conover pairwise test for multiple comparisons of mean rank sums using the R package "PMCMR". The incidence of subordinate phytosociological classes was evaluated when helpful for interpreting compositional differences between the vegetation types.

Subsequently, within each vegetation type, we defined the character and differential species for syntaxa from the alliance to the variant level according to the principle of species fidelity, based on the phi coefficient of association (CHYTRÝ et al. 2002). For the alliances, the statistical approach was introduced whenever literature references were insufficient or lacking at all or to detect regional character or differential species. The phi values were computed based on the actual relevé tables by means of the software JUICE 7 (TICHÝ 2002). The fidelity of species to vegetation types was calculated with presence/absence data, with the phi coefficient applied to clusters of equalized size (TICHÝ & CHYTRÝ 2006). These values are independent of the statistical significance of species occurrence concentration in the different vegetation types, but in JUICE significance is obtained by a simultaneous calculation of Fisher's exact test. We choose as significance thresholds $p < 0.001$ for the alliance and association level, $p < 0.01$ for the subassociation level and $p < 0.05$ for the variant level. These values were chosen because they yielded lists of diagnostic species neither too long nor too short for the different vegetation subunits (see ILLYÉS et al. 2007). The diagnostic species were divided into character species (C), transgressive character species (TR), that is species also characteristic of a superior syntaxon, and

Table 1. Incidence of phytosociological classes in the main six vegetation types. Values are means (\pm SD) of the cover-abundance data, expressed as percentage of the total species cover of the relevés. For each class, p -value refers to Kruskal-Wallis test, whereas different letters indicate significant differences among associations (Conover pairwise test for multiple comparisons < 0.05). Acronyms of associations and highest values of percentage values for each column in bold types. SB-TA = *Sileno bryoidis-Trifolietum alpini*, TP-FR = *Thymo polytrichi-Festucetum riccerii*, CS-SP = *Cerasatio suffruticosi-Seslerietum pichiana*, AL-AN = *Aquilegio lucensis-Anemonastrum narcissiflorae*, CA-SA = *Caro appunian-Seslerietum apenninae*, GA-CR = *Geranio argentei-Caricetum rupestris*.

Tabelle 1. Häufigkeit pflanzensoziologischer Klassen in den sechs Hauptvegetationstypen. Die Werte sind Mittelwerte (\pm 1SD) der Deckung-Abundanz-Daten, dargestellt als Prozentsatz der gesamten Artendeckung der Aufnahmen. Für jede Klasse bezieht sich der p -Wert auf den Kruskal-Wallis-Test, wohingegen verschiedene Buchstaben signifikante Unterschiede zwischen pflanzensoziologischen Klassen anzeigen (paarweiser Conover-Test für Mehrfachvergleiche $< 0,05$). Akronyme der Assoziationen und die höchsten Werte der Prozentwerte für jede Spalte in Fettdruck. Namen der Assoziationen siehe oben.

	SB-TA	TP-FR	CS-SP	AL-AN	CA-SA	GA-CR	p -value
<i>Juncetea trifidi</i>	56.46 \pm 12.64 ^a	42.55 \pm 13.39 ^b	17.23 \pm 7.13 ^c	13.53 \pm 7.52 ^c	1.17 \pm 1.54 ^d	30.07 \pm 5.72 ^c	< 0.001
<i>Nardetea strictae</i>	6.63 \pm 5.91 ^a	6.03 \pm 5.22 ^a	2.19 \pm 2.70 ^b	2.03 \pm 2.88 ^b	0.30 \pm 0.94 ^b	0.67 \pm 1.49 ^b	< 0.001
<i>Acidophilous species</i>	3.56 \pm 3.46 ^a	1.30 \pm 2.41 ^b	1.82 \pm 3.20 ^b	0.42 \pm 1.15 ^b	.	.	< 0.001
<i>Elymo-Seslerietea</i>	4.11 \pm 3.95 ^d	12.19 \pm 7.10 ^c	15.15 \pm 8.61 ^{bc}	45.47 \pm 11.96 ^a	41.29 \pm 9.98 ^a	19.87 \pm 5.33 ^b	< 0.001
<i>Carici rupestris-Kobresietea bellardii</i>	0.24 \pm 0.92 ^c	0.79 \pm 1.87 ^c	0.39 \pm 1.77 ^c	0.26 \pm 1.04 ^c	5.57 \pm 6.59 ^b	29.00 \pm 8.56 ^a	< 0.001
<i>Amphoterie species</i>	2.08 \pm 2.77 ^d	4.46 \pm 3.97 ^c	24.74 \pm 8.05 ^a	5.50 \pm 4.71 ^c	11.38 \pm 5.74 ^b	.	< 0.001
<i>Molinio-Arrhenatheretea</i>	5.17 \pm 4.40 ^{ab}	8.07 \pm 6.85 ^a	6.77 \pm 6.97 ^{ab}	5.80 \pm 4.95 ^{ab}	3.93 \pm 4.42 ^b	2.39 \pm 3.30 ^{ab}	0.006
<i>Mulgedio-Aconitetea</i>	.	0.35 \pm 1.11 ^b	.	7.09 \pm 6.76 ^a	0.14 \pm 1.01 ^b	.	< 0.001
<i>Sedo-Scleranthetea</i>	5.96 \pm 4.06 ^b	9.66 \pm 5.11 ^a	8.51 \pm 5.97 ^{ab}	.	2.48 \pm 3.47 ^c	8.00 \pm 4.72 ^{ab}	< 0.001
<i>Festuco-Brometea</i>	0.82 \pm 1.93 ^c	7.01 \pm 6.13 ^b	12.46 \pm 6.62 ^a	0.60 \pm 1.74 ^c	11.92 \pm 8.80 ^a	2.26 \pm 3.11 ^{bc}	< 0.001
<i>Trifolio-Geranietea sanguinei</i>	.	0.61 \pm 2.27	.	.	.	.	.
<i>Carpino-Fagetea sylvatica</i>	.	0.06 \pm 0.48 ^b	0.21 \pm 0.97 ^b	2.50 \pm 3.89 ^a	0.18 \pm 0.75 ^b	.	< 0.001
<i>Erico-Pinetea</i>	0.19 \pm 1.06 ^b	.	.	.	1.91 \pm 2.84 ^a	.	< 0.001
<i>Vaccinio-Piceetea</i>	2.42 \pm 3.34 ^{ab}	1.09 \pm 2.33 ^c	0.93 \pm 2.03 ^{bc}	4.01 \pm 4.18 ^a	.	.	0.003
<i>Loiseleurio procumbentis-Vaccinietea</i>	6.77 \pm 7.39 ^a	2.62 \pm 4.58 ^b	0.77 \pm 2.61 ^b	3.86 \pm 4.66 ^{ab}	2.48 \pm 2.71 ^{ab}	.	< 0.001
<i>Asplenietea trichomanis</i>	0.61 \pm 1.55 ^d	0.79 \pm 1.93 ^{cd}	2.13 \pm 2.76 ^{bc}	3.14 \pm 4.30 ^b	8.26 \pm 4.35 ^a	5.36 \pm 3.90 ^{ab}	< 0.001
<i>Thlaspietea rotundifolii</i>	0.63 \pm 1.56 ^c	2.24 \pm 6.06 ^c	6.70 \pm 6.49 ^{ab}	2.50 \pm 3.35 ^{bc}	8.34 \pm 6.94 ^a	2.39 \pm 3.30 ^{abc}	< 0.001
<i>Salicetea herbaceae</i>	3.10 \pm 4.22	.	.	1.04 \pm 2.36	.	.	0.062
<i>Montio-Cardaminetea</i>	.	.	.	0.18 \pm 0.74	0.52 \pm 1.33	.	0.377
<i>Scheuchzerio palustris-Caricetea fuscae</i>	.	0.05 \pm 0.41 ^b	.	2.06 \pm 2.63 ^a	0.12 \pm 0.62 ^b	.	< 0.001

differential species (D) according to the definitions of DENGLER et al. (2005). Among them, we introduced also the so-called “klasseneigene Trennarten” *sensu* GRABHERR & MUCINA (1993). They include character species of a class that can be used also for differentiating subordinate syntaxa because of uneven occurrence within the class (OCD = own class differential species). We also distinguished regional character (RC) and regional differential (RD) species according to GRABHERR & MUCINA (1993). We considered as constant those species occurring with a frequency > 80% inside the vegetation units and dominant species those occurring with a cover value $\geq 40\%$ in at least 70% of relevés. Moreover, we designed as “amphoteric”, the species indifferently occurring from calcium-deficient to calcium-rich substrates.

As result of the classification procedure, we could interpret the vegetation types as plant associations in the sense of BRAUN-BLANQUET (1964). Associations were documented by synoptic tables with species frequencies. Species occurring only once in a vegetation type were excluded and listed separately at the bottom of each synoptic table. The original phytosociological tables concerning single associations, except two, were made available as individual tables as Supplements E3–E6. The average values of elevation, relevé area, vegetation cover and species richness of each association were reported in the headings of phytosociological tables. Species occurring only once in the original phytosociological tables (sporadic species) were listed separately at the bottom of each table in the Supplements E3–E6.

The floristic distinctiveness of the associations was subsequently analysed by comparing the fidelity patterns within the associations represented by a significant number of relevés.

To the aim, the quantity and quality of species fidelity were shown by developing a new metric named “Retention Index” (RIN). For each relevé, this index was computed by multiplying the proportion of faithful species out of the total number of species (i.e. quantity factor) by the average phi coefficient of faithful species (i.e. quality factor). Then, the retention index was represented by means of a “retention profile” calculated by varying a scale parameter (exponent, ranging from 0 to 1) applied to the two factors. These profiles allowed understanding different aspects of species fidelity to associations in a single graphical representation, disentangling the influences of the different components of species fidelity to associations. In particular, the two components have the same weight in influencing the RIN if the difference in scale parameters is zero, whereas at both ends of the profile, corresponding to differences in scale parameters of -1 and +1, only one of the two components influences the RIN.

Finally, we used a Principal Component Analysis (PCA) applied to species cover data transformed according to VAN DER MAAREL (1979) to extract the main trends in the floristic composition of relevés along a reduced number of axes. Prior to analysis, performed with the R package “vegan”, species abundances were standardized by means of the Hellinger distance (LEGENDRE & GALLAGHER 2001). Then, post hoc interpretation of the first two ordination axes was performed by projecting the EIVs into the ordination diagram. The permutation tests proposed by ZELENÝ & SCHAFFERS (2012) was used to assess the significance of the R^2 of the regressions between EIVs and the first two ordination axes.

Nomenclature of plant taxa is according to BARTOLUCCI et al. (2018), that of syntaxa is in accordance with the rules defined by the International Code of Phytosociological Nomenclature (ICPN; WEBER et al. 2000). The syntaxonomic reference for all syntaxa from the alliance level is MUCINA et al. (2016). All syntaxa were arranged into a syntaxonomic scheme reported at the end of the discussion. The nomenclaturally relevant decisions and proposals were reported in the Supplement S1, the type relevés of new syntaxa in the Supplement S2.

4. Results

4.1 Vegetation description

The phytosociological relevés were allocated to three different vegetation classes: i) *Juncetea trifidi* Hadač in Klika et Hadač 1944; ii) *Elyno-Seslerietea* Br.-Bl. 1948; iii) *Carici rupestris-Kobresietea bellardii* Ohba 1974 according to MUCINA et al. (2016). We refer to this paper also for the verbal diagnoses concerning these syntaxa.

Class *Juncetea trifidi*

The 148 relevés assigned to the class were subdivided into three main clusters corresponding to different associations. Each cluster was marked with four capital letters; sub-clusters, corresponding to subassociations were distinguished with couples of lowercase letters (Fig. 2a: SB-TAty, SB-TAad, SB-TAAs, TP-FRty, TP-FRcs, CS-SP). The floristic assessment of associations is shown in the synoptic Table 2.

Suballiance *Festucion riccerii* suball. nova hoc loco (Table 2)

Diagnostic species: *Festuca riccerii* (C), *Armeria marginata* (C), *Alchemilla flabellata* (RC), *A. transiens* (RC), *Gentianella campestris* (RC), *Minuartia verna* (RD)

The studied associations were assigned to the order *Caricetalia curvulae* Br.-Bl. in Br.-Bl. et Jenny 1926, because the diagnostic species of this order prevailed on those of the order *Festucetalia spadiceae* Barbero 1970. Despite the scarcity of *Caricion curvulae* species in our associations, the allocation of them to this alliance was inescapable. The alternative option (*Juncion trifidi*) was, indeed, not feasible because this alliance has a distribution range including the Carpathians and the Eastern Alps. The below described associations retained their floristic distinctiveness within the class *Juncetea trifidi*. Accordingly, we proposed here to include them within a new suballiance named *Festucion riccerii*. The complete list of the diagnostic species of the suballiance, including among the others the northern Apennine endemic *Armeria marginata*, is reported above. Differently from ARRIGONI (2015), we considered the Tuscan-Emilian Apennines populations as all belonging to *Armeria marginata* (including *Armeria arenaria* subsp. *apennina* Arrigoni) since, in our opinion, the taxonomic treatment proposed by this author was not satisfactory and needs further investigations.

Sileno bryoidis-Trifolietum alpini Tomaselli et Rossi 1994 nom. corr.

for *Sileno exscapae-Trifolietum alpini* Tomaselli & Rossi 1994 (Table 2, Supplement E3)

(Type relevé of the subassociation *antennarietosum dioicae*: rel. 40 in Supplement E3 and S2, *holotypus*; type relevé of the subassociation *sedetosum alpestris* rel. 62 in Supplement E3 and S2, *holotypus*)

Dominant species: None throughout the association, but *Alchemilla transiens*, *Festuca riccerii*, *Trifolium alpinum* and *Vaccinium uliginosum* subsp. *microphyllum* were alternatively prominent in most stands.

Constant species: *Agrostis rupestris*, *Alchemilla transiens*, *Festuca riccerii*, *Oreojuncus trifidus*, *Phyteuma hemisphaericum*

Diagnostic species of the association: *Agrostis rupestris* (TR), *Euphrasia minima* (TR), *Oreojuncus trifidus* (TR), *Phyteuma hemisphaericum* (TR), *Pilosella lactucella* (D), *Silene acaulis* subsp. *bryoides* (TR), *Trifolium alpinum* (TR); differential species of the subassociation *antennarietosum dioicae*: *Antennaria dioica*, *Juniperus communis* subsp. *nana*, *Vaccinium uliginosum* subsp. *microphyllum*; differential species of the subassociation *sedetosum alpestris*: *Cardamine resedifolia*, *Luzula spicata* subsp. *conglomerata*, *Omalotheca supina*, *Sedum alpestre*, *Trifolium thalii*

Structure: Relatively open and species-poor to fairly rich stands ranging from 10 to 60 m². Physiognomy is somewhat heterogeneous given by a mixture of rosulate hemicryptophytes, cushion plants, forbs, tussock grasses and ericoid sub-shrubs.

Table 2. Synoptic table of associations of the *Juncetea trifidi*. Abbreviations of associations: SB-TA: *Sileno bryoidis-Trifolietum alpini*, TP-FR: *Thymo polytrichi-Festucetum riccerii*, CS-SP: *Cerastio suffruticosi-Seslerietum pichianae*. Values in the columns are percentage frequencies, phi coefficient value $\times 100$ is given in brackets for species with Fisher's exact test value < 0.01 . RD: regional differential species.

Tabelle 2. Synoptische Tabelle der Assoziationen der *Juncetea trifidi*. Die Werte in den Spalten sind prozentuale Häufigkeiten, der Phi Koeffizientwert $\times 100$ ist in Klammern für Arten mit Exact-Fisher's exaktem Testwert $< 0,01$ angegeben. Abkürzungen der Namen der Assoziationen siehe oben. RD: regional Trennart.

Vegetation type	SB-TA	TP-FR	CS-SP	Vegetation type	SB-TA	TP-FR	CS-SP
No. of relevés	64	63	21	No. of relevés	64	63	21
<i>Juncetea trifidi</i>				<i>Acidophilous species</i>			
<i>Festuca riccerii</i>	88	100 (26)	76	<i>Avenella flexuosa</i>	61 (31)	24	33
<i>Alchemilla transiens</i>	94	89	62	<i>Calluna vulgaris</i>	3	-	5
<i>Phyteuma hemisphaericum</i>	84 (54)	49	5	<i>Elyno-Seslerietea</i>			
<i>Viola ferrarinii</i>	45	52	29	<i>Trifolium thalii</i>	13	41	48
<i>Oreojuncus trifidus</i>	83 (59)	37	5	<i>Galium anisophyllum</i>	2	40 (35)	19
<i>Minuartia verna</i> (RD)	45	22	57	<i>Pimpinella saxifraga</i> subsp.	8	29	24
<i>Alchemilla flabellata</i>	48	57	5	<i>alpina</i>			
<i>Euphrasia minima</i>	58 (61)	3	5	<i>Aster alpinus</i>	8	6	24
<i>Anthoxanthum nipponicum</i>	9	32	14	<i>Lotus corniculatus</i> subsp.	2	24 (32)	5
<i>Gentianella campestris</i>	36 (36)	5	9	<i>alpinus</i>			
<i>Botrychium lunaria</i>	2	14	9	<i>Hieracium villosum</i>	3	3	9
<i>Pedicularis tuberosa</i>	5	3	9	<i>Pulsatilla alpina</i> subsp.	13	5	-
<i>Gentiana acaulis</i>	8	3	5	<i>millefoliata</i>			
<i>Agrostis rupestris</i>	88 (76)	21	-	<i>Clinopodium alpinum</i>	-	24	57 (48)
<i>Luzula spicata</i> subsp.	52 (45)	21	-	<i>Bellidiastrum michelii</i>	17	10	-
<i>conglomerata</i>				<i>Crepis aurea</i> subsp.	20 (33)	3	-
<i>Luzula lutea</i>	47 (42)	19	-	<i>glabrescens</i>			
<i>Trifolium alpinum</i>	59 (64)	6	-	<i>Gentiana verna</i>	2	21 (36)	-
<i>Plantago alpina</i>	44 (50)	8	-	<i>Carduus carlinifolius</i>	-	13	9
<i>Silene acaulis</i> subsp. <i>bryoides</i>	38 (48)	5	-	<i>Phyteuma orbiculare</i>	-	3	9
<i>Geum montanum</i>	9	25	-	<i>Festuca violacea</i> subsp.	2	-	9
<i>Euphrasia alpina</i>	28	3	-	<i>puccinellii</i>			
<i>Armeria marginata</i>	8	13	-	<i>Linum alpinum</i>	-	5	5
<i>Helictochloa versicolor</i>	-	6	9	<i>Bupleurum ranunculoides</i>	5	3	-
<i>Scorzonerooides helvetica</i>	5	5	-	<i>Leucanthemum adustum</i>	-	3	5
<i>Veronica fruticans</i>	-	5	5	<i>Polygala alpestris</i>	-	14 (32)	-
<i>Jacobaea incana</i>	14 (31)	-	-	<i>Taraxacum aemilianum</i>	-	13 (30)	-
<i>Solidago virgaurea</i> subsp.	5	-	-	<i>Senecio doronicum</i>	-	-	9
<i>minuta</i>				<i>Gentiana nivalis</i>	3	-	-
<i>Potentilla aurea</i>	3	-	-	<i>Scabiosa lucida</i>	-	3	-
<i>Viscaria alpina</i>	3	-	-				
<i>Nardetea strictae</i>				<i>Carici-Kobresietea</i>			
<i>Luzula multiflora</i>	2	36	43	<i>Potentilla crantzii</i>	3	8	5
<i>Festuca rubra</i> subsp.	9	11	5	<i>Arenaria gothica</i> subsp.	3	10	-
<i>commutata</i>				<i>moehringioides</i>			
<i>Antennaria dioica</i>	48 (54)	8	-	<i>Amphoterie species</i>			
<i>Pilosella lactucella</i>	39 (41)	13	-	<i>Carex sempervirens</i>	41	41	19
<i>Pilosella officinarum</i>	17	22	-	<i>Brachypodium genuense</i>	-	25	57 (47)
<i>Genista tinctoria</i>	6	8	-	<i>Campanula scheuchzeri</i>	-	17	24
<i>Nardus stricta</i>	8	5	-	<i>Sesleria pichiana</i>	-	-	100 (100)
<i>Dianthus deltooides</i>	-	21 (38)	-	<i>Erigeron alpinus</i>	2	5	-
<i>Ranunculus apenninus</i>	-	11	-				
<i>Meum athamanticum</i>	5	-	-				
<i>Potentilla erecta</i>	-	5	-				
<i>Carex pilulifera</i>	3	-	-				

Vegetation type	SB-TA	TP-FR	CS-SP	Vegetation type	SB-TA	TP-FR	CS-SP
No. of relevés	64	63	21	No. of relevés	64	63	21
<i>Acidophilous species</i>				<i>Festuca violacea</i> subsp.	2	-	9
<i>Avenella flexuosa</i>	61 (31)	24	33	<i>puccinellii</i>	-	5	5
<i>Calluna vulgaris</i>	3	-	5	<i>Linum alpinum</i>	-	3	-
<i>Elyno-Seslerietea</i>				<i>Bupleurum ranunculoides</i>	5	3	-
<i>Trifolium thalii</i>	13	41	48	<i>Leucanthemum adustum</i>	-	3	5
<i>Galium anisophyllum</i>	2	40 (35)	19	<i>Polygala alpestris</i>	-	14 (32)	-
<i>Pimpinella saxifraga</i> subsp.	8	29	24	<i>Taraxacum aemilianum</i>	-	13 (30)	-
<i>alpina</i>				<i>Senecio doronicum</i>	-	-	9
<i>Aster alpinus</i>	8	6	24	<i>Gentiana nivalis</i>	3	-	-
<i>Lotus corniculatus</i> subsp.	2	24 (32)	5	<i>Scabiosa lucida</i>	-	3	-
<i>alpinus</i>				<i>Carici-Kobresietea</i>			
<i>Hieracium villosum</i>	3	3	9	<i>Potentilla crantzii</i>	3	8	5
<i>Pulsatilla alpina</i> subsp.	13	5	-	<i>Arenaria gothica</i> subsp.	3	10	-
<i>millefoliata</i>				<i>moehringioides</i>			
<i>Clinopodium alpinum</i>	-	24	57 (48)	<i>Amphoteric species</i>			
<i>Bellidiastrum michelii</i>	17	10	-	<i>Carex sempervirens</i>	41	41	19
<i>Crepis aurea</i> subsp.	20 (33)	3	-	<i>Brachypodium genuense</i>	-	25	57 (47)
<i>glabrescens</i>				<i>Campanula scheuchzeri</i>	-	17	24
<i>Gentiana verna</i>	2	21 (36)	-	<i>Sesleria pichiana</i>	-	-	100 (100)
<i>Carduus carlinifolius</i>	-	13	9	<i>Erigeron alpinus</i>	2	5	-
<i>Phyteuma orbiculare</i>	-	3	9				

Syntaxonomy: Floristic composition is dominated by the *Juncetea trifidi* species (Table 1). Moreover, the community includes a number of species diagnostic for the alliance and for the order markedly higher with respect to the following two communities (Table 2). The attribution to the association *Sileno bryoidis-Trifolietum alpini* (sub *Sileno exscapae-Trifolietum alpini* Tomaselli & Rossi 1994 Art. 43 ICPN) was here confirmed after we added further relevés sampled later (see Supplement S1 for details). We modified also the list of the diagnostic species of the association including all those significantly faithful at a phi threshold > 50%, following the general suggestion of ILLYÉS et al. (2007). All the character species must be regarded as regional transgressive from higher syntaxa of the class. We retained only *Pilosella lactucella* as differential species.

The association was subdivided into three subassociations (Fig. 2a: SB-TATy, SB-TAad, SB-TAAs; Supplement E3). The core was represented by the relevés 1–31 with higher representation of diagnostic species and, hence, corresponding to the typical subassociation. Relevés 32–47, differentiated by *Antennaria dioica*, *Juniperus communis* subsp. *nana* and *Vaccinium uliginosum* subsp. *microphyllum* were assigned to the subassociation *Sileno bryoidis-Trifolietum alpini antennarietosum dioicae* showing some floristic features grading to the shrub heaths of the *Empetro-Vaccinietum gaultherioidis juncetosum trifidi* Ferrari et Piccoli 1997. Relevés 48–64 were assigned to the *Sileno bryoidis-Trifolietum alpini sedetosum alpestris*, differentiated by *Sedum alpestre* and *Omalotheca supina*, two chionophilous species transgressive from the contiguous *Oligotricho-Gnaphalietum supini* Petraglia et Tomaselli 2007, *Cardamine resedifolia* transgressive from scree slopes, *Trifolium thalii* transgressive from the *Caricion ferrugineae* communities, and *Luzula spicata* subsp. *conglomerata* as own class differential species.

Habitat: The typical subassociation of the *Sileno bryoidis-Trifolietum alpini* is strictly confined to the highest plateaus of the Tuscan-Emilian Apennines, from 1810 to 2110 m, where vegetation is exposed to strong winds and severe frosts and soils overlie a shallow deposit of colluvial detritus (ROSSI et al. 2014). The subassociation *antennarietosum dioicae* is exposed at not so severe habitat conditions, because occurring at summit plateaus at lower

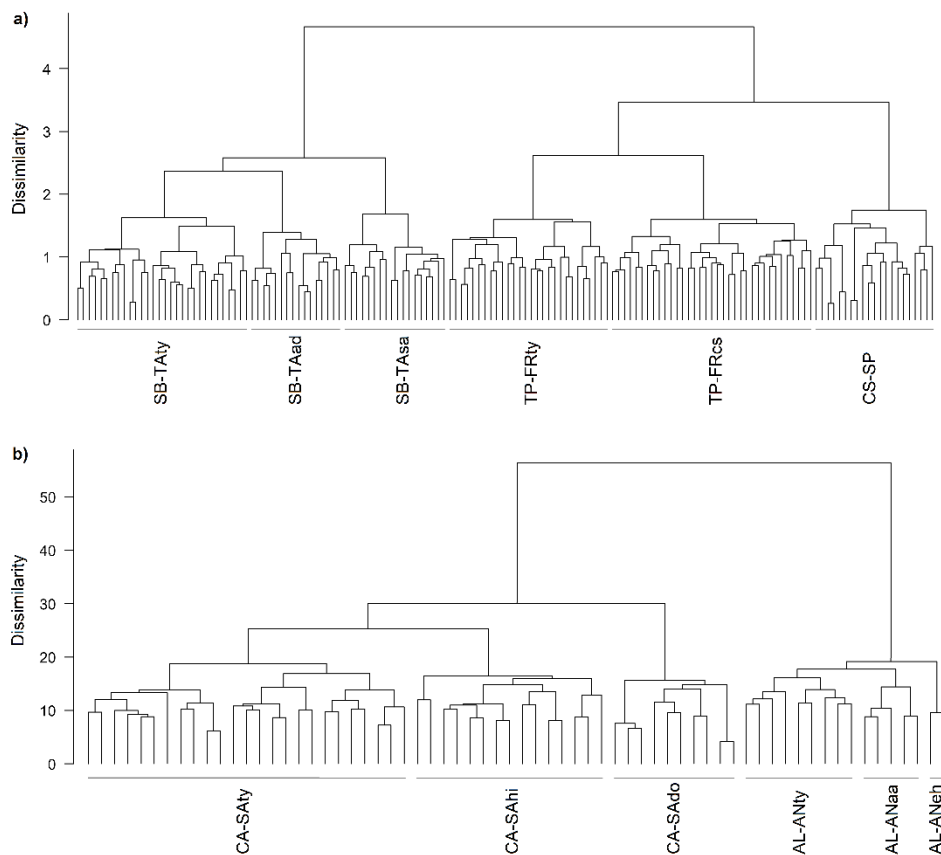


Fig. 2. Classification dendrograms of primary grasslands of the northern Apennines; **a)** *Juncetea trifidi* class: SB-TAty: *Sileno bryoidis-Trifolietum alpini typicum*; SB-TAad: *Sileno bryoidis-Trifolietum alpini antennarietosum dioicae*; SB-TAAsa: *Sileno bryoidis-Trifolietum alpini sedetosum alpestris*; TP-FRty: *Thymo polytrichi-Festucetum riccerii typicum*; TP-FRcs: *Thymo polytrichi-Festucetum riccerii cerastietosum suffruticosi*; CS-SP: *Cerastio suffruticosi-Seslerietum pichianae*. **b)** *Elyno-Seslerietea* class: CA-SAty: *Caro appuani-Seslerietum apenninae typicum*; CA-SAhi: *Caro appuani-Seslerietum apenninae Helianthemum italicum*-variant; CA-SAdo: *Caro appuani-Seslerietum apenninae dryadetosum octopetalae*; AL-ANty: *Aquilegio lucensis-Anemonastretum narcissiflorae typicum*; AL-ANaa: *Aquilegio lucensis-Anemonastretum narcissiflorae Aconogum alpinum*-variant; AL-ANeh: *Aquilegio lucensis-Anemonastretum narcissiflorae Empetrum hermaphroditum*-variant.

Abb. 2. Klassifikations-Dendrogramme der primären Rasengesellschaften des nördlichen Apennins; **a)** Aufnahmen der Klasse *Juncetea trifidi*; **b)** Aufnahmen der Klasse *Elyno-Seslerietea*. Abkürzungen der Namen der Pflanzengesellschaften siehe oben.

elevations (from 1650 to 1980 m). The habitat of the subassociation *sedetosum alpestris* corresponds to gently inclined, mostly N faced slopes with a longer snow cover occurring at elevations ranging from 1710 to 1990 m.

Distribution: Restricted to the highest summits of the central part of the Tuscan-Emilian Apennines.

***Thymo polytrichi-Festucetum riccerii* ass. nova hoc loco (Table 2, Supplement E4)**

(Type relevé of the association: rel. n. 4 in Supplement E4 and S2, *holotypus*; type relevé of the subassociation *cerastietosum suffruticosi*, rel. n. 39 in Supplement E4 and S2, *holotypus*)

Dominant species: *Festuca riccerii*

Constant species: *Alchemilla transiens*, *Festuca riccerii*, *Thymus praecox* subsp. *polytrichus*

Diagnostic species of the association: *Dianthus deltoides* (D), *Festuca riccerii* (TR), *Galium anisophyllum* (D), *Hypericum richeri* (D), *Lotus corniculatus* subsp. *alpinus* (D), *Polygala alpestris* (D), *Thymus praecox* subsp. *polytrichus* (D); differential species of the subassociation *cerastietosum suffruticosi*: *Carlina acaulis* subsp. *caulescens*, *Cerastium arvense* subsp. *suffruticosum*, *Gentiana verna*, *Poa alpina*, *Trifolium pratense*, *T. thalii*

Structure: Mostly close and species-poor to fairly rich stands ranging from 4 to 30 m². The endemic tussock grass *Festuca riccerii* is generally dominant or co-dominant, giving the community its distinctive physiognomy. Hemicryptophytes are prevailing in the floristic assemblage where they are represented by a mixture of graminoids (grasses, sedges and rushes) and forbs. Among chamaephytes, only *Thymus praecox* subsp. *polytrichus* is quite common. Ericoid sub-shrubs occur uncommonly and only occasionally with a certain abundance.

Syntaxonomy: Floristic composition is also largely dominated here by the *Juncetea trifidi* species. Nevertheless, with respect to the *Sileno bryoidis-Trifolietum alpini*, there is a significant increase of the mean cover-abundance values of the species representative of the *Elyno-Seslerietea*, *Festuco-Brometea*, *Sedo-Scleranthetea* and of “amphoteric” companions, joined with a significant decrease of the species belonging to *Loiseleurio procumbentis-Vaccinietaea*, *Vaccinio-Piceetea* and of the acidophilous companions (Table 1). Because the community retained its floristic distinctiveness, we propose to regard it as a new association under the name of *Thymo polytrichi-Festucetum riccerii*. *Festuca riccerii* is the only character species as transgressive from the alliance because it has its optimum here (Table 2); it is accompanied by several differential species (see the list above).

Two subassociations were distinguished (Fig. 2a: TP-FRty, TP-FRcs; Supplement E4). Relevés 1–28, having a higher representation of the diagnostic species inside the class *Juncetea trifidi*, corresponded to the typical subassociation. Relevés from 29 to 63 were differentiated by a mixture of: i) xero-thermophilous *Festuco-Brometea* species (*Cerastium arvense* subsp. *suffruticosum* and *Carlina acaulis* subsp. *caulescens*), ii) calcium-demanding *Elyno-Seslerietea* species (*Gentiana verna* and *Trifolium thalii*) and iii) mesotrophic nutrient-demanding *Molinio-Arrhenatheretea* species (*Poa alpina* and *Trifolium pratense*). All these species were significantly faithful to this relevé subset at a phi threshold > 30%. The name chosen for the subassociation was *Thymo polytrichi-Festucetum riccerii cerastietosum suffruticosi*.

Habitat: The *Thymo polytrichi-Festucetum riccerii* occurs along and close to the ridges of the Tuscan-Emilian Apennines, where it was encountered from lower to highest summits with elevation ranging from 1620 to 2060 m. The association as a whole is mostly characteristic of relatively sharp summits and of gently to moderately steep south-facing slopes. The stands of the typical subassociation occur mostly on calcium-poor sandstones belonging to the Macigno Formation. The *Thymo polytrichi-Festucetum riccerii cerastietosum suffruticosi* occurs preferentially on calcium-rich sandstones belonging to the Monte Modino and Monte Cervarola Formations.

Distribution: The association as a whole occurs throughout the Tuscan-Emilian Apennines. The subassociation *cerastietosum suffruticosi* is centered in the south-eastern sector of the chain.

***Cerastio suffruticosi-Seslerietum pichianae* ass. nova hoc loco (Table 2, Supplement E5)**

(Type relevé of the association: rel. n. 6 in Supplement E5 and S2, *holotypus*)

Dominant species: *Sesleria pichiana*

Constant species: *Cerastium arvense* subsp. *suffruticosum*, *Sesleria pichiana*, *Thymus praecox* subsp. *polytrichus*

Diagnostic species of the association: *Brachypodium genuense* (D), *Cerastium arvense* subsp. *suffruticosum* (D), *Cirsium bertolonii* (D), *Clinopodium alpinum* (D), *Dianthus sylvestris* (D), *Sesleria pichiana* (D)

Structure: Generally close and species-poor to fairly rich stands ranging from 4 to 20 m². The community is characterized by the dominance of the endemic grass *Sesleria pichiana*. Among hemicryptophytes, graminoids prevailed on forbs; *Thymus praecox* subsp. *polytrichus* is the only chamaephyte occurring in the swards. Ericoid sub-shrubs occur very uncommonly, though somewhat with a certain abundance.

Syntaxonomy: Despite their considerable decrease when compared to the *Sileno bryoidis-Trifolietum alpini* and the *Thymo polytrichi-Festucetum riccerii*, the species of the class *Juncetea trifidi* are still prevailing on those belonging to the classes *Elyno-Seslerietea* and *Festuco-Brometea*, but not on the species designed as “amphoteric” (see Table 1). The latter are preponderant owing to the abundance and constancy of *Sesleria pichiana* a species occurring in the north-western Italy on a variety of bedrock (ultramaphic, sandstone and, more rarely, limestone and marlstone substrates) (see FOGGI et al. 2007). We did not know of any equivalent community, so we described it as a distinct new association within the suballiance *Festucenion riccerii*. Despite its prominent role, *Sesleria pichiana* could not be regarded as character species of the association because of its wide socio-ecological amplitude, but only as the main differential species owing to the extremely high fidelity value to this community (Table 2). Other differential species are *Brachypodium genuense*, *Cerastium arvense* subsp. *suffruticosum*, *Clinopodium alpinum*, *Dianthus sylvestris* and *Cirsium bertolonii*.

Habitat: The *Cerastio suffruticosi-Seslerietum pichianae* exhibits an ecological preference for the sandstone substrates with fairly high carbonate content (Monte Cervarola Sandstones). It occurs at elevations ranging from 1740 to 1860 m; nearly all stands had aspects on the southern slopes.

Distribution: Restricted to the south-eastern part of the Tuscan-Emilian Apennines.

Class *Elyno-Seslerietea*

The 66 relevés assigned to this class were subdivided into two main clusters, each marked with four capital letters. Also here minor clusters were distinguished by adding couples of lowercase letters (Fig. 2b: AL-ANTy, AL-ANaa, AL-ANeh, CA-SATy, CA-SAhi, CA-SAdo). The relevés were classified to the order *Seslerietalia caeruleae* Br.-Bl. in Br.-Bl. et Jenny 1926 including alpine and subalpine calcicolous grasslands of the nemoral mountain ranges of Central Europe (MUCINA et al. 2016). In the study area, the order *Seslerietalia caeruleae* was represented by two alliances including plant communities alternatively occurring along the summit ridges of the Tuscan-Emilian Apennines or the Apuan Alps.

***Caricion ferrugineae* G. Br.-Bl. et Br.-Bl. in G.Br.-Bl. 1931 (Table 3)**

Diagnostic species: *Alchemilla alpina* (RD), *Anemonastrum narcissiflorum* (C), *Carex macrostachys* (C), *Festuca rubra* subsp. *commutata* (RD), *F. violacea* subsp. *puccinellii* (C), *Hedysarum hedyroides* (C), *Linum alpinum* (C), *Pulsatilla alpina* subsp. *millefoliata* (C), *Trifolium thalii* (C), *Crepis aurea* subsp. *glabrescens* (RC), *Ranunculus pollinensis* (RC), *Scabiosa lucida* (C)

The alliance includes supramontane to alpine meso-hygrophilous grasslands occurring on calcium-rich substrates in the Alps and the Carpathians (MUCINA et al. 2016), with a southern outlying occurrence in the Tuscan-Emilian Apennines (TOMASELLI 1994). The set of the character species of the alliance is here somewhat impoverished with respect to that of the more northern communities of the Alps (see GRABHERR et al. 1993, BUFFA & SBURLINO 2001). Impoverishment is partially counterbalanced by the occurrence of *Crepis aurea* subsp. *glabrescens* and *Ranunculus pollinensis*, individuated as regional character species of the *Caricion ferrugineae* by TOMASELLI et al. (2000) and by the occurrence of *Alchemilla alpina* and *Festuca rubra* subsp. *commutata* regarded here as regional differential species with respect to the other alliance occurring in the study area (see Supplement E6). The occurrence of the *Caricion ferrugineae* in the northern Apennines was already known because the association *Trifolio thalii-Festucetum puccinellii* Tomaselli et al. 2000 was assigned to this alliance.

***Aquilegio lucensis-Anemonastrum narcissiflorae* ass. nova hoc loco (Table 3, Supplement E6)**

(Type relevé of the association: rel. 7 in Supplement E6 and S2, *holotypus*)

Dominant species: *Anemonastrum narcissiflorum*

Constant species: *Anemonastrum narcissiflorum*, *Aquilegia lucensis*, *Pulsatilla alpina* subsp. *millefoliata*, *Scabiosa lucida*

Diagnostic species: *Alchemilla xanthochlora* (D), *Anemonastrum narcissiflorum* (TR), *Aquilegia lucensis* (C), *Linum alpinum* (TR), *Pulsatilla alpina* subsp. *millefoliata* (TR), *Scabiosa lucida* (TR)

Structure: Close and species-rich swards ranging from 5 to 10 m². Vegetation cover is dense and physiognomy somewhat variable. Tall forbs prevail above grasses and sedges; dwarf shrubs are prominent in few stands.

Syntaxonomy: Floristic composition is largely dominated by the *Elyno-Seslerietea* species; among the diagnostic species of other classes only those assigned to the *Juncetea trifidi* exceeded 10% (Table 1). We identified our community with the association described by TOMASELLI (1994) under the name *Aquilegio-Anemonetum narcissiflorae*, based on the comparison of our relevés with those included in the original unpublished table of this association. Because this name is not validly published according to Art. 3g ICPN, we proposed here the new name *Aquilegio lucensis-Anemonastrum narcissiflorae* according to Art. 45 ICPN (see Supplement S1 for details).

The diagnostic species of the association are the Tuscan-Emilian Apennine endemic *Aquilegia lucensis* as character species, and *Anemonastrum narcissiflorum*, *Linum alpinum*, *Pulsatilla alpina* subsp. *millefoliata* and *Scabiosa lucida* as transgressive character species from the alliance. *Alchemilla xanthochlora* is regarded as differential species with respect to the *Trifolio thalii-Festucetum puccinellii* (Table 3).

The *Aquilegio lucensis-Anemonastrum narcissiflorae* was subdivided into three different variants (Fig. 2b: AL-ANty, AL-ANaa, AL-ANeh; Supplement E6). The relevés 1–9 were assigned to the typical variant, because the diagnostic species were better represented

Table 3. Synoptic table of associations of the *Caricion ferrugineae*. Abbreviations of associations: AL-AN: *Aquilegio lucensis-Anemonastretum narcissiflorae*; TT-FP: *Trifolio thalii-Festucetum puccinellii* TOMASELLI et al. 2000. Values in the columns are percentage frequencies, phi coefficient value $\times 100$ is given in brackets for species with Fisher's exact test value < 0.01 . RC: regional character species; RD: regional differential species.

Tabelle 3. Synoptische Tabelle der Assoziationen des *Caricion ferrugineae*. Die Werte in den Spalten sind prozentuale Häufigkeiten, der Phi Koeffizientwert $\times 100$ ist in Klammern für Arten mit Exact-Fisher's exaktem Testwert $< 0,01$ angegeben. Abkürzungen der Namen der Assoziationen siehe oben. RC: regional Kennart; RD: regional Trennart.

Vegetation type	AL-AN	TT-FP	Vegetation type	AL-AN	TT-FP
No. of relevés	16	58	No. of relevés	16	58
Juncetea trifidi			<i>Anemonastrum narcissiflorum</i>		
<i>Alchemilla transiens</i>	50	28		100 (100)	-
<i>Alchemilla alpina</i>	19	52	<i>Aquilegia lucensis</i>	87 (88)	-
<i>Oreojuncus trifidus</i>	50	10	<i>Gentiana verna</i>	-	57 (63)
<i>Pedicularis tuberosa</i>	36	22	<i>Carex macrostachys</i>	44 (53)	-
<i>Luzula lutea</i>	31	19	<i>Taraxacum aemilianum</i>	-	34
<i>Agrostis rupestris</i>	6	28	<i>Carduus carlinifolius</i>	-	28
<i>Armeria marginata</i>	19	12	<i>Euphrasia salisburgensis</i>	-	10
<i>Scorzoneroideis helvetica</i>	19	10	<i>Plantago atrata</i>	-	10
<i>Anthoxanthum nipponicum</i>	12	12	<i>Alchemilla nitida</i>	-	9
<i>Helictochloa versicolor</i>	6	12	<i>Clinopodium alpinum</i>	-	5
<i>Phyteuma hemisphaericum</i>	6	12	<i>Gentiana clusii</i>	-	5
<i>Minuartia verna</i> (RD)	6	5	<i>Geranium argenteum</i>	-	5
<i>Alchemilla glaucescens</i>	-	74 (77)	<i>Biscutella laevigata</i>	-	3
<i>Plantago alpina</i>	-	57 (63)	<i>Pedicularis comosa</i>	-	3
<i>Euphrasia minima</i>	-	34	<i>Sesleria apennina</i>	-	3
<i>Geum montanum</i>	-	33	Carici-Kobresietea		
<i>Festuca riccerii</i>	-	26	<i>Gentiana nivalis</i>	-	12
<i>Gentianella campestris</i>	-	26	Amphoterie species		
<i>Euphrasia alpina</i>	-	24	<i>Campanula scheuchzeri</i>	56	34
<i>Viola ferrarinii</i>	-	16	<i>Carex sempervirens</i>	31	22
<i>Botrychium lunaria</i>	-	12	<i>Brachypodium genuense</i>	31	17
<i>Luzula spicata</i> subsp. <i>conglomerata</i>	-	5	<i>Bistorta vivipara</i>	6	9
<i>Silene acaulis</i> subsp. <i>bryoides</i>	-	3	<i>Erigeron alpinus</i>	-	17
Nardetea strictae			<i>Soldanella alpina</i>	-	10
<i>Festuca rubra</i> subsp. <i>commutata</i>	37	74	<i>Cerastium apuanum</i>	-	7
<i>Ranunculus apenninus</i>	-	38	Salicetea herbaceae		
<i>Nardus stricta</i>	-	21	<i>Luzula alpinopilosa</i>	19	17
Acidophilous species			<i>Sedum alpestre</i>	-	9
<i>Avenella flexuosa</i>	12	16	Molinio-Arrhenatheretea		
Ellyno-Sesterietea			<i>Poa alpina</i>	12	98 (86)
<i>Festuca violacea</i> subsp. <i>puccinellii</i>	44	96 (58)	<i>Trifolium pratense</i>	12	33
<i>Trifolium thalii</i>	6	95 (89)	<i>Lotus corniculatus</i> subsp. <i>corniculatus</i>	6	26
<i>Bellidiastrum michelii</i>	56	38	<i>Sagina glabra</i>	-	64 (68)
<i>Crepis aurea</i> subsp. <i>glabrescens</i>	6	86 (80)	<i>Alchemilla xanthochlora</i>	44 (53)	-
<i>Scabiosa lucida</i>	87 (68)	2	<i>Bistorta officinalis</i>	37 (48)	-
<i>Galium anisophyllum</i>	31	52	<i>Phleum rhaeticum</i>	-	19
<i>Pulsatilla alpina</i> subsp. <i>millefoliata</i>	69 (68)	3	<i>Rhinanthus minor</i>	19	-
<i>Phyteuma orbiculare</i>	50	16	<i>Achillea stricta</i>	-	7
<i>Ranunculus pollinensis</i> (RC)	44	19	<i>Leontodon hispidus</i>	-	7
<i>Linum alpinum</i>	50 (48)	7	<i>Trifolium repens</i>	-	5
<i>Lotus corniculatus</i> subsp. <i>alpinus</i>	25	14	<i>Deschampsia caespitosa</i>	-	3
<i>Pimpinella saxifraga</i> subsp. <i>alpina</i>	19	9	<i>Taraxacum officinale</i>	-	3
<i>Myosotis alpestris</i>	12	5			

Vegetation type	AL-AN	TT-FP	Vegetation type	AL-AN	TT-FP
No. of relevés	16	58	No. of relevés	16	58
Festuco-Brometea			Mulgedio-Aconitetea		
<i>Asperula cynanchica</i> var. <i>oreophila</i>	6	3	<i>Viola biflora</i>	56 (53)	7
<i>Cerastium arvense</i> subsp. <i>suffruticosum</i>	-	40	<i>Saxifraga rotundifolia</i>	19	5
<i>Sesleria pichiana</i>	12	-	<i>Aconogonum alpinum</i>	31 (43)	-
<i>Carlina acaulis</i> subsp. <i>caulescens</i>	-	9	<i>Cirsium morisianum</i>	-	3
<i>Gentianopsis ciliata</i>	-	3	Loiseleurio-Vaccinietea		
Sedo-Scleranthetea			<i>Hypericum richeri</i>	25	17
<i>Thymus praecox</i> subsp. <i>polytrichus</i>	-	55 (62)	<i>Vaccinium uliginosum</i> subsp. <i>microphyllum</i>	25	-
Thlaspietea rotundifolii			<i>Juniperus communis</i> subsp. <i>nana</i>	12	-
<i>Leucanthemum coronopifolium</i> subsp. <i>ceratophylloides</i>	31	7	<i>Empetrum hermaphroditum</i>	12	-
<i>Arenaria bertolonii</i>	6	16	Vaccinio-Piceetea		
<i>Cirsium bertolonii</i>	-	47 (55)	<i>Vaccinium myrtillus</i>	31	10
<i>Robertia taraxacoides</i>	-	7	<i>Luzula sylvatica</i> subsp. <i>sieberi</i>	19	10
<i>Carum heldreichii</i>	-	5	<i>Astrantia minor</i>	12	-
<i>Valeriana montana</i>	-	5	<i>Huperzia selago</i>	12	-
<i>Aquilegia bertolonii</i>	-	3	<i>Rosa pendulina</i>	12	-
<i>Sedum atratum</i>	-	3	Carpino-Fagetea sylvaticae		
<i>Hornungia alpina</i>	-	3	<i>Daphne mezereum</i>	19	-
Asplenietea trichomanis			<i>Lilium martagon</i>	12	-
<i>Saxifraga paniculata</i>	37	22	Scheuchzerio-Caricetea nigrae		
<i>Saxifraga exarata</i> subsp. <i>pseudoexarata</i>	12	3	<i>Parnassia palustris</i>	31	12
<i>Seseli libanotis</i> (RC)	12	-	<i>Pinguicula christinae</i>	12	-
<i>Veronica aphylla</i> subsp. <i>longistyla</i>	-	5	Montio-Cardaminetea		
			<i>Pinguicula apuana</i>	-	3

and no differential species occurred here. Relevés from 10 to 14, differentiated by some more nutrient-demanding species (*Aconogonum alpinum*, *Bistorta officinalis* and *Viola biflora*), were assigned to the *Aconogonum alpinum*-variant. Two stands (relevés 15 and 16) are differentiated by *Empetrum hermaphroditum* and *Astrantia minor*; moreover and by the prominence of other calcifuge dwarf-shrubs and forbs (*Vaccinium uliginosum* subsp. *microphyllum*, *V. myrtillus*, *Alchemilla transiens*) (*Empetrum hermaphroditum*-variant).

Habitat: Fragmentary stands occurring between about 1530 and 1980 m, all on aspects of the northern slopes. They are confined to scarcely accessible marly ledges where substrate was calcium-rich differently from the overhanging sandstone cliffs. The stands of the *Aconogonum alpinum*-variant occur preferentially on more moist soils and those of the *Empetrum hermaphroditum*-variant at the contact between marls and sandstones.

Distribution: Restricted to the Tuscan-Emilian Apennines.

***Caricion sempervirentis-Seslerion apenninae* all. nova hoc loco**

Diagnostic species: *Anthyllis vulneraria* subsp. *vulnerarioides* (D), *Asperula cynanchica* var. *oreophila* (D), *Brachypodium genuense* (D) and the character species of the *Caro appuani-Seslerietum apenninae* (see below)

The primary grasslands occurring on calcium-rich substrates along the summit ridges of the Apuan Alps were assigned to the alpine alliance *Seslerion caeruleae* Br.-Bl. in Br.-Bl. et Jenny 1926 (correct name *Seslerion caeruleae*) by BARBERO & BONO (1973). Nevertheless,

the *Seslerion caeruleae* is presently regarded as an alliance restricted to the north-western and north-eastern Alps (see GRABHERR et al. 1993). It is replaced on the south-eastern Alps by the *Caricion austroalpinae* Sutter 1962, but the diagnostic species of both alliances were completely missing in our stands (see CHIAPPELLA FEOLI & POLDINI 1993). A further hypothesis to assign this vegetation to the alliance *Seslerion apenninae* Furnari in Bruno et Furnari 1966 and to the order *Seslerietalia tenuifoliae* Horvat 1930 was discarded because the diagnostic species of these syntaxa occurred too scarcely and sporadically in our stands (see Supplement S3 and TOMASELLI 1994). The only feasible solution was to place the summit grasslands of the Apuan Alps within a new endemic alliance named *Caricion sempervirentis-Seslerion apenninae*, identified by the character species of its only association (see below and in Supplement S3). The occurrence of a substantial number of diagnostic species of the order *Seslerietalia caeruleae* enabled us to place the new alliance to this order. The list of differential species with respect to the other alliances of the order was reported above.

***Caro appuani-Seslerietum apenninae* ass. nova hoc loco (Supplement S3)**

(Type relevé of the association: rel. n. 6 in Supplement S2 and S3, *holotypus*; type relevé of the subassociation *dryadetosum octopetalae*: rel. 41 in Supplement S2 and S3, *holotypus*)

Dominant species: *Sesleria apennina* dominant or codominant in about four-fifths of the relevés, *Dryas octopetala* dominant in the residual ones.

Constant species: *Carex sempervirens*, *Carum appuanum*, *Sesleria apennina*

Diagnostic species of the association: *Astrantia pauciflora* (C), *Carum appuanum* (C), *Sesleria apennina* (C); differential species of the subassociation *dryadetosum octopetalae*: *Dryas octopetala*, *Gymnadenia odoratissima*, *Phyteuma orbiculare*, *Polygala carueliana*, *Pulsatilla alpina* subsp. *millefoliata*, *Salix crataegifolia*, *Saxifraga aizoides*, *S. caesia*

Structure: Stands are variable in size (10–80 m²), vegetation cover (from open to closed) and species richness (poor to rather rich). The Apuan endemic grass *Sesleria apennina* and the sedge *Carex sempervirens* give the community its distinctive physiognomy in most stands. Floristic assemblage includes also other grasses and sedges, many herbs, few chasmophytes (mostly *Dryas octopetala*) and the prostrate juniper *Juniperus communis* subsp. *nana*.

Syntaxonomy: The species of the class *Elyno-Seslerietea* have average cover values largely higher with respect to those of the other classes. Among these, only the *Festuco-Brometea* class and the group of amphoteric species exceed 10% (Table 1). Because the community retained its floristic distinctiveness, also after a comparison with the association *Seslerio-Caricetum sempervirentis* Br.-Bl. in Br.-Bl. et Jenny 1926 reported by BARBERO & BONO (1973) from the Apuan Alps, we regard it as a new association under the name *Caro appuani-Seslerietum apenninae*. We individuated as character species of the association three Apuan endemisms (see the list above).

The association is rather variable in its floristic composition (Fig. 2b: CA-SAty, CA-SAhi, CA-SAdo; Supplement S3). The typical association includes relevés from 1 to 40 having the higher representation of the diagnostic species. Among them, relevés from 26 to 40 are differentiated by two chamaephytes belonging to the class *Festuco-Brometea* (*Astragalus sempervirens* and *Helianthemum oelandicum* subsp. *italicum*) and by *Gypsophyla repens* and *Festuca alfrediana* subsp. *ferrariniana*. These relevés were assigned to a *Helianthemum italicum*-variant. Relevés from 41 to 50 are differentiated by the predominance of *Dryas octopetala*, by the occurrence of two endemic chasmophytes, *Polygala*

carueliana and *Salix crataegifolia*, and by other species (see the complete list above). We classified these relevés within the subassociation *Caro appuani-Seslerietum apenninae dryadetosum octopetalae*.

Habitat: The *Caro appuani-Seslerietum apenninae* occurs only on the calcium-rich substrates forming most part of the higher summits of the Apuan Alps, mostly at elevations above 1600 m and ranging from 1500 to 1880 m with stands prevalently facing northern slopes. The *Helianthemum italicum*-variant occurred on more gentle slopes or summit plateaus with a partial cover of eluvial sheets. The subassociation *dryadetosum octopetalae* is a strictly northern vegetation type, generally on steep slopes stabilized by the dominant chamaephyte.

Distribution: Restricted to the highest summits of the Apuan Alps.

Class *Carici rupestris-Kobresietea bellardii*

The occurrence of a graminoid tundra community was here firstly documented for the northern Apennines based on five phytosociological relevés (see Table 4). They were assigned to the alliance *Oxytropido-Elynion myosuroidis* Br.-Bl. 1950 and the order *Oxytropido-Elynetalia* Albrecht 1969 occurring in the alpine and subnival belts of the Alps, Pyrenees and Carpathians (MUCINA et al. 2016).

***Geranio argentei-Caricetum rupestris* ass. nova hoc loco (Table 4)**

(Type relevé of the association: rel. 3 in Table 4, holotypus)

Dominant species: *Carex rupestris*

Constant species: *Alchemilla flabellata*, *A. transiens*, *Aster alpinus*, *Carex rupestris*, *Geranium argenteum*, *Saxifraga paniculata*, *Thymus praecox* subsp. *polytrichus*

Diagnostic species: *Carex rupestris* (TR), *Aster alpinus* (D), *Geranium argenteum* (D)

Structure: Very small-sized (1 m²), closed and species-poor swards with a mixture of forbs, graminoids and a minority of dwarf-shrubs. The most distinctive component of the community is the arctic-alpine sedge *Carex rupestris*.

Syntaxonomy: The floristic composition of the community is characterized by a mixture of calcifugous and calciphilous species. The calcifugous species belonging to the class *Juncetea trifidi* are slightly prevailing; nevertheless, by summing the values of the calciphilous species of the classes *Carici rupestris-Kobresietea bellardii* and *Elyno-Seslerietea* they largely prevail (see Table 1). Consequently, we placed our community in the class *Carici rupestris-Kobresietea bellardii*, also considering the prominent role of *Carex rupestris* within all swards. Because we did not know of any equivalent community within the alliance *Oxytropido-Elynion myosuroidis*, we propose to assign our stands to a new association named *Geranio argentei-Caricetum rupestris* characterized by *Carex rupestris* as transgressive species and differentiated by *Aster alpinus* and *Geranium argenteum*.

Habitat: Fragmentary small stands on gently inclined tops of rocky spurs lying around 2000 m of elevation and exposed to severe winds and free of long-lying snow. The substrate is given by sandstones belonging to Monte Modino Formation.

Distribution: The association is very local, entirely confined to Mt. Cimone, the highest summit of the Tuscan-Emilian Apennines.

Table 4. Phytosociological table of the *Geranio argentei-Caricetum rupestris*. D: differential species.

Tabelle 4. Pflanzensoziologische Tabelle des *Geranio argentei-Caricetum rupestris*. D: Trennart.

Relevé no.	1	2	3	4	5	
Site	CI	CI	CI	CI	CI	Mean (\pm SD)
Elevation (m asl)	1990	2005	1975	1975	1995	1988 (\pm 13)
Aspect ($^{\circ}$)	340	5	330	25	300	
Slope angle ($^{\circ}$)	5	5	10	30	10	
Relevé area (mq)	1	1	1	1	1	1
Vegetation cover (%)	80	75	95	100	100	90.0 (\pm 11.7)
No. of species	15	11	12	6	6	10 (\pm 3.94)
						Frequency
<i>Geranio argentei-Caricetum rupestris</i>						
<i>Oxytropido-Elyinion myosuroidis</i>						
<i>Carex rupestris</i>	4	3	4	4	4	100
<i>Geranium argenteum</i> (D)	+	2	1	+	1	100
<i>Aster alpinus</i> (D)	1	.	+	1	+	80
Companions						
<i>Juncetea trifidi</i>						
<i>Alchemilla transiens</i>	+	.	1	2	1	80
<i>Alchemilla flabellata</i>	+	.	1	+	+	80
<i>Festuca riccerii</i>	2	1	1	.	.	60
<i>Luzula lutea</i>	+	+	+	.	.	60
<i>Agrostis rupestris</i>	+	+	.	.	.	40
<i>Phyteuma hemisphaericum</i>	r	.	.	.	.	20
<i>Elyno-Seslerietea</i>						
<i>Trifolium thalii</i>	.	+	.	.	.	20
Other companions						
<i>Thymus praecox</i> subsp. <i>polytrichus</i>	+	1	+	.	+	80
<i>Saxifraga paniculata</i>	+	r	+	+	.	80
<i>Asperula cynanchica</i> var. <i>oreophila</i>	+	.	+	.	.	40
<i>Poa alpina</i>	+	+	.	.	.	40
<i>Sempervivum arachnoideum</i>	r	.	+	.	.	40
<i>Cotoneaster juranus</i>	.	.	1	.	.	20
<i>Carum heldreichii</i>	.	+	.	.	.	20
<i>Festuca alfrediana</i> subsp. <i>ferrariniana</i>	+	.	.	.	.	20
<i>Meum athamanticum</i>	.	r	.	.	.	20

The above syntaxonomic results can be summarized in the following scheme:

Juncetea trifidi Hadač in Klika et Hadač 1944

Caricetalia curvulae Br.-Bl. in Br.-Bl. et Jenny 1926

Caricion curvulae Br.-Bl. 1925

Festucenion riccerii Tomaselli et al. *hoc loco*

Sileno bryoidis-Trifolietum alpini Tomaselli et Rossi nom. mut. propos.

Thymo polytrichi-Festucetum riccerii Tomaselli et al. *hoc loco*

Cerastio suffruticosi-Seslerietum pichianae Tomaselli et al. *hoc loco*

Elyno-Seslerietea Br.-Bl. 1948
 Seslerietalia caeruleae Br.-Bl. in Br.-Bl. et Jenny 1926
 Caricion ferrugineae G. Br.-Bl. et Br.-Bl. in G.Br.-Bl. 1931
 Aquilegio lucensis-Anemonastretum narcissiflorae Tomaselli 1994 ex Tomaselli et
 al. *hoc loco*
 Trifolio thalii-Festucetum puccinellii Tomaselli et al. 2000
 Carici sempervirentis-Seslerion apenninae Tomaselli et al. *hoc loco*
 Caro appuani-Seslerietum apenninae Tomaselli et al. *hoc loco*
Carici rupestris-Kobresietea bellardii Ohba 1974
Oxytropido-Elynetalia Albrecht 1969
 Oxytropido-Elynon myosuroidis Br.-Bl. 1950
 Geranio argentei-Caricetum rupestris Tomaselli et al. *hoc loco*

4.2 Fidelity patterns

The analysis of fidelity patterns was applied to the five associations occurring in the study area with a sufficient representative number of stands, to which we added the *Trifolio thalii-Festucetum puccinellii* because belonging to the alliance *Caricion ferrugineae* and well represented in the alpine life zone of the Tuscan-Emilian Apennines. Calculation of RIN indicated that among the associations of the suballiance *Festucenion riccerii* the *Sileno bryoidis-Trifolietum alpini* showed the highest floristic distinctiveness as it was characterized by the highest proportion of faithful species and many species with high values of fidelity (Fig. 3a), whereas the *Cerastio suffruticosi-Seslerietum pichianae* showed intermediate values of the proportion of faithful species combined with the highest average value of the phi coefficient for the faithful species. Among the associations belonging to the class *Elyno-Seslerietea* (Fig. 3b), it was impossible to establish the association with the highest floristic distinctiveness. Indeed, the *Caro appuani-Seslerietum apenninae* and the *Trifolio thalii-Festucetum puccinellii* were characterized by the highest proportion of faithful species, but they were overruled in the right side of the diagram by the *Aquilegio lucensis-Anemonastretum narcissiflorae* having the highest phi values of faithful species. This occurred because this association had several very faithful species, representing, however, a lower percentage in the floristic assemblage, when compared to the other two associations of the class.

4.3 Environmental gradients

Floristic variation within the different types of summit grasslands of the northern Apennines could be explained by differences in habitat conditions detected through supplementary explanatory variables represented by EIVs. Among the EIVs considered, R-EIV and T-EIV were significantly related to the first two ordination axes, explaining a cumulative variation in floristic assemblages of about 25% (Table 5).

As expected, considering that plant associations occurred along a gradient from calcium-poor to calcium-rich substrates, the strongest differences among them were in relation to R-EIV. The first ordination axis was, in fact, primarily positively correlated with soil reaction and, secondarily, with temperature (Fig. 4). The relevés corresponding to the associations belonging to the classes *Juncetea trifidi* and *Elyno-Seslerietea* were clearly separated along this axis, indicating a gradient of increasing pH (Fig. 4). Main separation was between the *Sileno bryoidis-Trifolietum alpini* and the *Thymo polytrichi-Festucetum riccerii*, whose

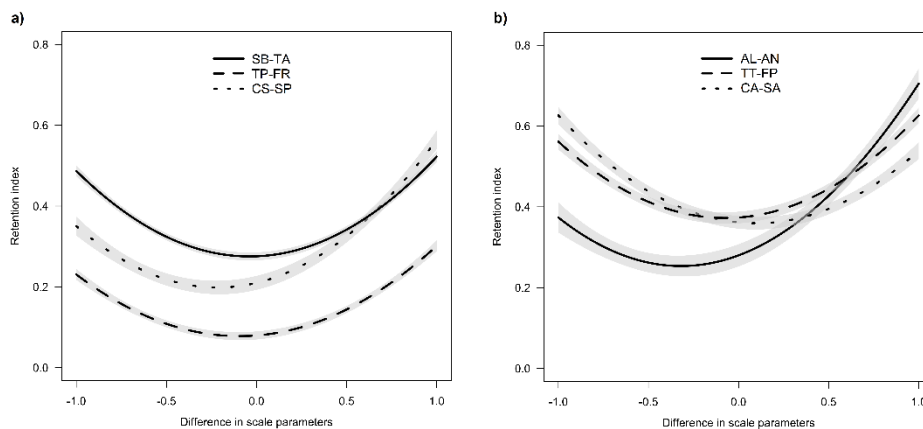


Fig. 3. Retention Index (RIN) values for the associations belonging to **a)** the class *Juncetea trifidi* and **b)** the class *Elyno-Seslerietea*. RIN was calculated by multiplying the proportion of faithful species (quantity factor) by the average phi coefficient of faithful species (quality factor). By varying the scale parameters (exponent, ranging from 0 to 1) applied to the two factors, the retention profile depends only on the quantity of faithful species on the left (corresponding to a difference in scale parameters of -1) and only on the quality of faithful species on the right (corresponding to a difference in scale parameters +1), whereas at null difference in scale parameters the two components have the same weight in influencing the RIN. For each of these two vegetation classes, the retention profiles were computed by means of multiple regression models fitted with a quadratic polynomial term for the difference in scale parameters, the association (3-level factor) and their interactions as explanatory variables. SB-TA: *Sileno bryoidis-Trifolietum alpini*, TP-FR: *Thymo polytrichi-Festucetum riccerii*, CS-SP: *Cerastio suffruticosi-Seslerietum pichianae*, AL-AN: *Aquilegio lucensis-Anemonastretum narcissiflorae*, TT-FP: *Trifolio thalii-Festucetum puccinellii*, CA-SA: *Caro appuani-Seslerietum apenninae*, GA-CR: *Geranio argentei-Caricetum rupestris*.

Abb. 3. Retentionindexwerte (RIN) für die Assoziationen, die zu **a)** der Klasse *Juncetea trifidi* und **b)** der Klasse *Elyno-Seslerietea* gehören. Die RIN wurden durch Multiplikation des Anteils treuer Arten (Mengenfaktor) mit dem durchschnittlichen Phi-Koeffizienten treuer Arten (Qualitätsfaktor) berechnet. Durch Variation der Skalenparameter (Exponent im Bereich von 0 bis 1), die auf die beiden Faktoren angewendet werden, hängt das Retentionsprofil nur von der Menge der treuen Arten auf der linken Seite ab (entsprechend einer Differenz der Skalenparameter von -1) und nur von der Qualität der treuen Arten auf der rechten Seite (entsprechend einer Differenz der Skalenparameter von +1), wohingegen bei einer Nulldifferenz der Skalenparameter die beiden Komponenten das gleiche Gewicht bei der Beeinflussung der RIN haben. Für jede dieser beiden Vegetationsklassen wurden die Retentionsprofile mit Hilfe mehrerer Regressionsmodelle berechnet, deren quadratischer Polynomialterm die Differenz der Skalenparameter, die Assoziation (3-Stufen-Faktor) und ihre Werte sowie Wechselwirkungen erklärender Variablen berücksichtigt. Namen der Assoziationen siehe oben.

relevés were all located on the left-hand side of the ordination diagram corresponding to negative values of the axis, and the *Caro appuani-Seslerietum apenninae* having all relevés at the opposite side corresponding to the highest positive values. Other two associations (*Geranio argentei-Caricetum rupestris* and *Cerastio suffruticosi-Seslerietum pichianae*) were located at a central position along the first axis. It could be explained considering that they colonized sandstone substrates (Monte Modino and Monte Cervarola Formations) increasingly more calcium-rich than Macigno Formation where occurred most of the stands of the *Sileno bryoidis-Trifolietum alpini* and the *Thymo polytrichi-Festucetum riccerii*.

Table 5. Correlation between Ellenberg indicator values (L: light, T: temperature, K: continentality, U: moisture, R: soil reaction, N: nutrients) and the first two PCA axes; R² and significance level (*p*-value) of indicator values derived from the modified procedure of ZELENY & SCHAFFERS (2012) are shown.

Tabelle 5. Korrelation zwischen den Ellenberg-Indikatorwerten (L: Licht, T: Temperatur, K: Kontinentalität, U: Feuchtigkeit, R: Bodenreaktion, N: Nährstoffe) und den ersten beiden PCA-Achsen; Es werden R² und das Signifikanzniveau (P-Wert) der aus dem modifizierten Verfahren von ZELENY & SCHAFFERS (2012) abgeleiteten Indikatorwerte angezeigt.

	PCA 1	PCA 2	R ²	<i>p</i> -value
L	0.102	-0.995	0.011	0.958
T	0.858	-0.514	0.568	0.016
K	-0.986	0.166	0.021	0.925
U	-0.814	0.581	0.075	0.762
R	0.993	-0.115	0.920	0.001
N	-0.323	-0.946	0.027	0.917

The *Aquilegio lucensis-Anemonastretum narcissiflorae*, which occurred on calcium-rich marls, was located at the right side of the diagram, close to the vegetation of the *Caro appuani-Seslerietum apenninae*, which was confined to carbonate substrates.

In addition, the vegetation of the summit grasslands clearly changed following a T-EIV gradient likely related to the elevation of stands, explaining part of the floristic variation occurring along the second ordination axis. The *Sileno bryoidis-Trifolietum alpini* occurred mostly between 1800 and 2000 m (Fig. 5) and its distribution along the gradient is significantly different from those of the *Thymo polytrichi-Festucetum riccerii*, ranging from about 1700 to 1900 m, the *Cerastio suffruticosi-Seslerietum pichiana*, restricted between about 1750 and 1800 m and the *Caro appuani-Seslerietum apenninae* occurring between about 1600 and 1800 m. The elevational distribution of the *Sileno bryoidis-Trifolietum alpini* did not significantly differ from that of the *Geranio argentei-Caricetum rupestris*, whose five stands were all concentrated around 2000 m. The *Aquilegio lucensis-Anemonastretum narcissiflorae* was mostly encountered between 1750 and 1900 m and its elevational range differed significantly from that of the *Caro appuani-Seslerietum apenninae*.

5. Discussion

We distinguished six independent associations quite distinct in their general floristic composition all having their own diagnostic species. Because the concept of diagnostic species is crucial for defining associations, we tried to validate them using statistical fidelity measures as proposed by CHYTRÝ et al. (2002) and recently followed by LANDUCCI et al. (2013). The number of reported associations was higher with respect to that documented by TOMASELLI (1994) and TOMASELLI & ROSSI (1994). This can be explained considering that our sampling strategy aimed at including all the primary grasslands occurring on different bedrock and at the whole variety of exposures within the alpine life zone of the northern Apennines and that we based our study on a data set considerably larger than that used by the above quoted authors.

After a comparison with recent literature concerning primary grasslands occurring in the Alps (GERDOL et al. 2008, PIGNATTI & PIGNATTI 2014) and the central Apennines (LANCIONI et al. 2011, DI PIETRO et al. 2017), none of the six associations recorded in the study area

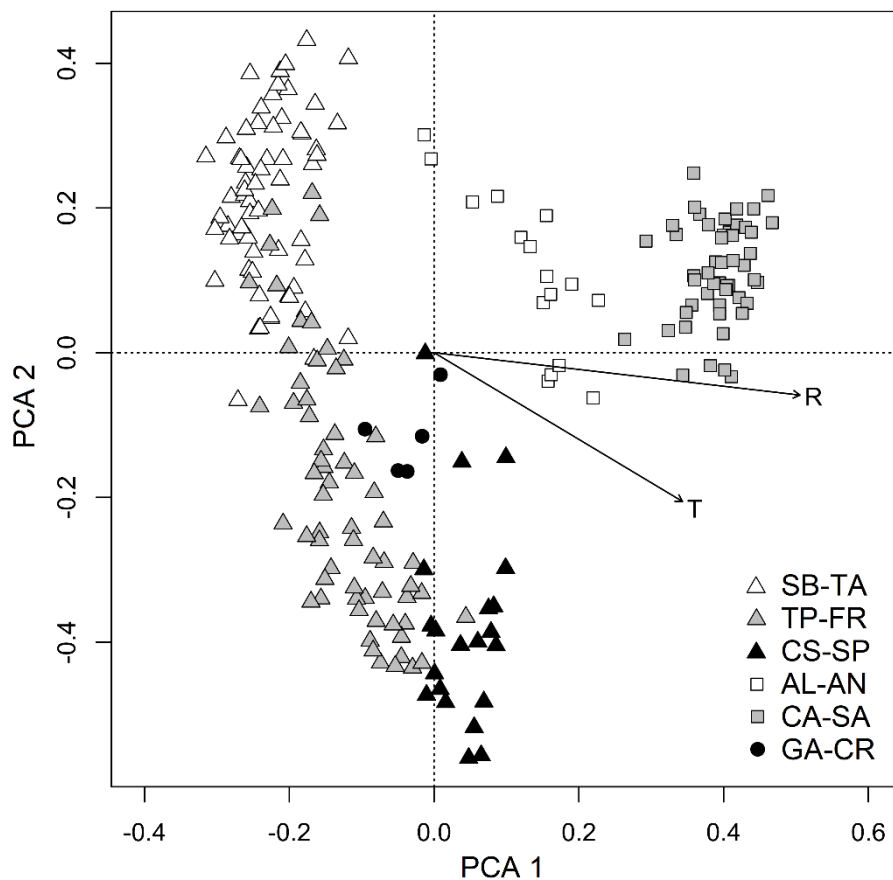


Fig. 4. Principal Component Analysis (PCA) of the 219 phytosociological relevés. Vectors of significant Ellenberg indicator values (R: soil reaction; T: temperature) are shown. SB-TA: *Sileno bryoidis-Trifolietum alpini*; TP-FR: *Thymo polytrichi-Festucetum riccerii*; CS-SP: *Cerastio suffruticosi-Seslerietum pichianae*; AL-AN: *Aquilegio lucensis-Anemonastretum narcissiflorae*; CA-SA: *Caro appuani-Seslerietum apenninae*; GA-CR: *Geranio argentei-Caricetum rupestris*.

Abb. 4. Hauptkomponentenanalyse (PCA) der 219 Vegetationsaufnahmen. Vektoren von signifikanten Zeigerwerten nach Ellenberg sind dargestellt (R: Reaktionszahl; T: Temperaturzahl). Abkürzungen der Namen der Assoziationen siehe oben.

were reported for other mountain systems. As a result, all of them can be regarded as endemic in the northern Apennines. Four associations were here described for the first time and typified according to the ICPN rules. For two already known associations it was necessary to emend the characteristic species combination and to correct or typify the names (Supplement S1).

The occurrence of endemic associations could be expected in the Apuan Alps, because it is well known that they represent a hotspot of speciation and endemism for vascular plants (BECHI & GARBARI 1994). The reason why also the summits of the Tuscan-Emilian Apennines hosted endemic plant associations is quite different. The rate of endemic species was here very lower than in the summit areas of the Apuan Alps (see FOGGI 1990, TOMASELLI & AGOSTINI 1994). Nevertheless, these associations retained a floristic distinctiveness with

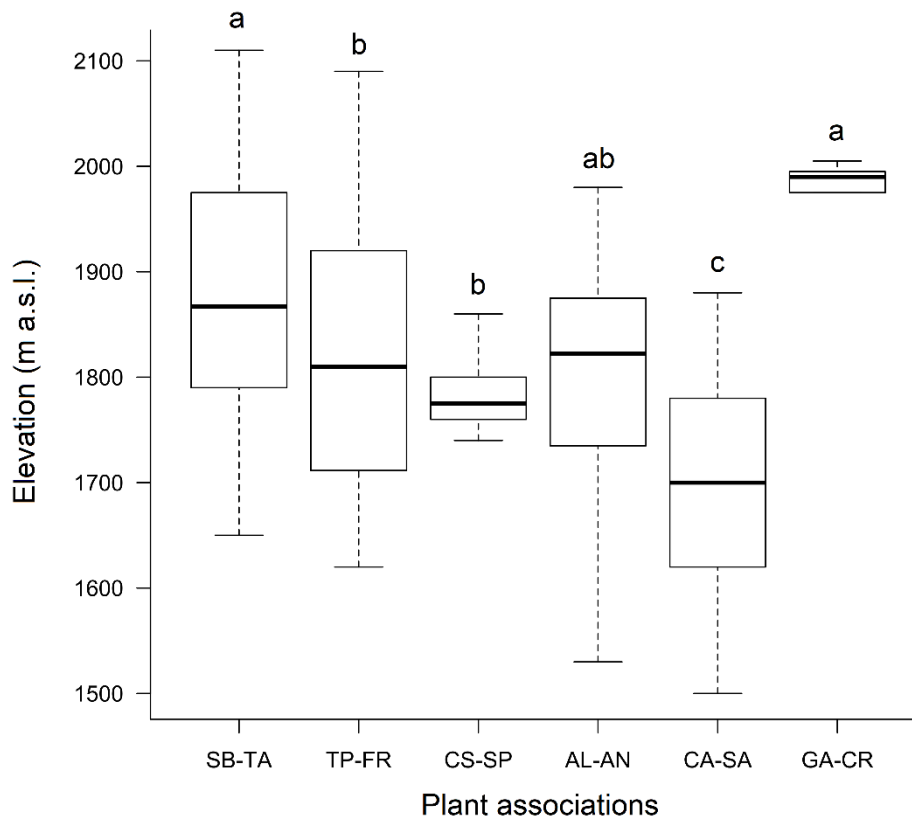


Fig. 5. Elevation of stands belonging to different plant associations. SB-TA: *Sileno bryoidis-Trifolietum alpini*, TP-FR: *Thymo polytrichi-Festucetum riccerii*, CS-SP: *Cerastio suffruticosi-Seslerietum pichinanae*, AL-AN: *Aquilegio lucensis-Anemonastretum narcissiflorae*, CA-SA: *Caro appuani-Seslerietum apenninae*, GA-CR: *Geranio argentei-Caricetum rupestris*. Different letters indicate significant differences between associations pairs (Conover multiple comparisons test, $p < 0.05$) after testing for overall difference among associations (Kruskal-Wallis test, $p < 0.001$).

Abb. 5. Höhenlage der Vegetationsaufnahmen verschiedener Assoziationen. Verschiedene Buchstaben weisen auf signifikante Unterschiede zwischen Assoziationspaaren hin (Conover-Mehrfachvergleichstest, $p < 0,05$); nachdem der Gesamtunterschied zwischen Assoziationen getestet wurde (Kruskal-Wallis-Test, $p < 0,001$). Namen der Assoziationen siehe oben.

respect to the corresponding ones occurring in the alpine life zone of the contiguous Alps. This because their assemblages are characterized by a peculiar floristic mixture including some Apennine endemic species co-occurring with a markedly reduced number of central-European orophytes (see TOMASELLI et al. 2000, PETRAGLIA & TOMASELLI 2007, GENNAI et al. 2014).

The allocation of the six associations to higher syntaxa was to some extent problematic, as frequently when dealing with syntaxa occurring in phytogeographical and ecological transition areas, as underlined as early as forty years ago by WERGER & VAN GILS (1976). Our proposal was to allocate our associations within three alliances, belonging to three classes. One of the alliances, namely *Carici sempervirentis-Seslerion apenninae*, and one

suballiance, the *Festucenion riccerii*, are endemic and documented here for the first time. Differently from TOMASELLI & ROSSI (1994), we assigned the relevés concerning the acidophytic grasslands to this new suballiance, while maintaining them to the alliance *Caricion curvulae* as proposed by these authors. As stated above, the alliance was ascribed to the order *Caricetalia curvulae*, whose distribution extended so southwards to the northern Apennines, as already suggested by GENNAI et al. (2014).

The subxerophilous basiphytic grasslands showed a wider floristic variation range along the Italian mountains with respect to their acidophytic analogues. Four different alliances were, in fact, reported along the eco-geographic gradient from the northern Alps to the southern Apennines: *Seslerion caeruleae* Br.-Bl. in Br.-Bl. et Jenny 1926 (northern Alps), *Caricion austroalpinae* Sutter 1962 (southern Alps), *Carici sempervirentis-Seslerion apenninae* (Apuan Alps) and *Seslerion apenninae* Furnari in Bruno et Furnari 1966 (central and southern Apennines). The wider floristic variation range within the basiphytic grasslands with respect to their acidophytic analogues could be explained by their higher rate of endemism as consequence of a higher geographic isolation among the different calcareous mountain systems, strengthened by glaciations (BEDINI et al. 2007, CASAZZA et al. 2016). This overall trend was also confirmed in the study area, where retention profiles showed RIN values tending to rise more in the basiphytic communities than in the acidophytic ones. Both the communities of the *Festucenion riccerii* and that of the *Carici sempervirentis-Seslerion apenninae* occur as relatively open swards characteristic of windswept plateaus and ridges.

The alliances *Caricion ferrugineae* and *Oxytropido-Elyinion myosuroidis*, including respectively meso-hygrophilous grasslands and graminoid tundra communities, are represented in the study area only by small stands occurring in very peculiar habitat conditions and exclusively on the Tuscan-Emilian Apennines. Moreover, they occur as closed swards with an average vegetation cover ranging from 90 to 95%, which was far higher with respect to the ones of the other primary grasslands under study.

The community of the *Caricion ferrugineae* occurs at the southern distribution edge of this vegetation in Italy (TOMASELLI 1994), whereas the community of graminoid tundra fills a gap between the communities of the *Oxytropido-Elyinion myosuroidis* occurring in the Alps and those restricted to the highest calcareous summits of the Central Apennines, assigned to the independent suballiance *Leontopodio nivalis-Elyinion myosuroidis* Blasi, Di Pietro, Fortini & Catonica 2003 by LANCIONI et al. (2011). From a more general perspective, our data confirmed the occurrence of a relevant phytogeographical and ecological threshold between the northern and the central-southern Apennines also concerning the summit primary grasslands as already suggested by PIGNATTI (1994).

Erweiterte deutsche Zusammenfassung

Einleitung – Rasengesellschaften stellen einen wichtigen Bestandteil der Vegetation in der alpinen Höhenstufe dar (KÖRNER 2003), wo sie in einem natürlichen Zustand verbleiben oder bei gemäßigten Standortbedingungen als naturnahe Weidefläche von Wildtieren oder Nutzvieh fungieren können (primäre Alpenrasen). Unsere Arbeit konzentriert sich speziell auf solche primären Alpenrasen, die auf den Gipfeln des nördlichen Apennins vorkommen. Durch eine umfassende Studie wird eine Lücke pflanzensoziologischer und ökologischer Erkenntnisse innerhalb der Vegetation der alpinen Stufe des nördlichen Apennins geschlossen, wodurch die bisher verfügbaren Erkenntnisse erweitert werden.

Untersuchungsgebiet – Die Studie wurde in den nördlichen Apenninen (N-Italien) durchgeführt (Abb. 1). Die Untersuchungsgebiete befinden sich in der alpinen Höhenstufe zweier Bezirke dieses Bergsystems (Toskanisch-Emilianische Apenninen und Apuanische Alpen). Die Geologie ist äußerst

vielfältig und reicht von Sandstein der Macigno-Formation, Sandstein im Wechsel mit Schluffsteinen (Mt. Modino Formation), Sandstein mit schuppigen Mergeln (Mt. Cervarola-Formation) bis zu Karbonatgesteinen (Kalkstein, Dolomit, Marmor) (DALLAN NARDI & NARDI 1974, DINELLI et al. 1999). Das Klima ist gemäßigt und mehr oder weniger ozeanisch, mit einem durchschnittlichen jährlichen Niederschlag von mehr als 2000 mm in den Apuanischen Alpen und etwa 1500 mm in den Toskanisch-Emilianischen Apenninen (GIANNECCHINI 2006).

Methoden – Die Studie basiert auf 219 Vegetationsaufnahmen, die nach einem schrittweisen Verfahren analysiert wurden. Im ersten Schritt wurden die Aufnahmen, basierend auf der vorherrschenden Kombination ihrer diagnostischen Arten gemäß der aktuellen Literatur, den pflanzensoziologischen Klassen zugeordnet (s. DENGLER et al. 2006, MICHL et al. 2010). Im zweiten Schritt wurde eine Clusteranalyse auf die zuvor in Klassen unterteilten Aufnahmen angewendet. Die Clusteranalyse wurde mit der Methode der kleinsten Varianz nach Ward in der Akkordabstandsmatrix durchgeführt. Die erhaltenen Cluster wurden als unterschiedliche Vegetationstypen interpretiert und in ihrer floristischen Zusammensetzung unter Berücksichtigung des Vorkommens der diagnostischen Arten analysiert. Für jeden Vegetationstyp haben wir die Kennarten und die Trennarten von der Verbands- bis zur Variantenebene nach dem Prinzip der Artengüte definiert, basierend auf dem Phi-Koeffizient (CHYTRÝ et al. 2002). Die Phi-Werte wurden mit der Software JUICE 7 (TICHÝ 2002) berechnet. Als Ergebnis des Klassifizierungsverfahrens konnten wir die Vegetationstypen als Pflanzengesellschaften im Sinne von BRAUN-BLANQUET (1964) interpretieren. Diese Assoziationen wurden sowohl in synoptischen als auch in pflanzensoziologischen Tabellen dokumentiert. Eine Principal Component Analysis (PCA) wurde verwendet, um indirekt die floristischen Variationen innerhalb der verschiedenen Assoziationen mit den Lebensraumbedingungen mit Hilfe der von PIGNATTI et al. (2005) an die italienische Flora angepassten Ellenberg-Indikatorwerte (EIVs) zu verknüpfen. Schließlich wurde eine Metrik mit dem Namen "Retention Index" (RIN) entwickelt, um die Quantität und Qualität der Artengenauigkeit innerhalb der Verbände abzuschätzen.

Ergebnisse – Dem in der Klasse *Juncetea trifidi* neu beschriebenen Unterverband *Festucenion riccerii* wurden 148 Aufnahmen in drei Assoziationen zugeordnet (Abb. 2a, Tab. 2, Anhänge E3–5).

Das *Sileno bryoidis-Trifolietum alpini* umfasst drei Subassoziationen: *typicum*, *antennarietosum dioicae* und *sedetosum alpestris*. Diese Gesellschaft kommt im zentralen Teil des toskanisch-emilianischen Apennins vor, wo sie auf die höchsten Plateaus und auf leicht geneigte, meist nach Norden gerichtete Abhänge begrenzt ist.

Das *Thymo polytrichi-Festucetum riccerii* wird hier neu beschrieben. Es ist durch die Dominanz des Grases *Festuca riccerii* gekennzeichnet und umfasst zwei Subassoziationen: *typicum* und *cerastietosum suffruticosi*. Die Assoziation findet sich im gesamten Toskanisch-Emilianischen Apennin, wo sie vor allem für relativ scharfe Gipfel und sanfte bis mäßig steile Hänge in den südlichen Seiten charakteristisch ist.

Auch das *Cerastio suffruticosi-Seslerietum pichianae* wird hier neu beschrieben. Seine Physiognomie ist durch die Dominanz des Grases *Sesleria pichiana* bestimmt. Die Gesellschaft ist auf den südöstlichen Teil des Toskanisch-Emilianischen Apennins beschränkt, wo sie mit verschiedenen Aspekten in den südlichen Seiten auftritt.

66 Aufnahmen wurden der Klasse *Elyno-Seslerietea* zugeordnet. Sie gehören zu zwei Verbänden (*Caricion ferrugineae* und *Caricion sempervirentis-Seslerion apenninae*), die beide nur eine Assoziation enthalten (Abb. 2b, Tab. 3, Beilage S3, Anhang E6). Das *Aquilegio lucensis-Anemonastretum narcissiflorae* (*Caricion ferrugineae*) zeichnet sich durch *Aquilegia lucensis* und einige transgressive Arten aus. Es ist auf die Toskanisch-Emilianischen Apenninen beschränkt, wo es mit fragmentarischen Beständen auf schwer zugänglichen, nach Norden gerichteten Mergeln vorkommt.

Der Verband *Caricion sempervirentis-Seslerion apenninae* und die Assoziation *Caro appuani-Seslerietum apenninae* werden hier neu beschrieben. Letztere umfasst die Subassoziationen *typicum* und *dryadetosum octopetalae*. Das *Caro appuani-Seslerietum apenninae* ist auf die höchsten Gipfel der Apuanischen Alpen beschränkt, wo es auf Karbonat-Substraten in überwiegend nördlich gelegenen Seiten auftritt.

Der neuen Assoziation *Geranio argentei-Caricetum rupestris* wurden fünf Aufnahmen zugeordnet, welche die einzige im Untersuchungsgebiet vorkommende Gesellschaft mit Tundra-Graminoiden darstellen. Die Assoziation wurde in die Klasse *Carici rupestris-Kobresietea bellardii* gestellt. Sie ist nur sehr lokal verbreitet, ganz auf den Berg Cimone, den höchsten Gipfel des Toskanisch-Emilianischen Apennins beschränkt. Ihre kleinen Bestände befinden sich auf leicht geneigten Gipfeln der Felsspitzen, die auf rund 2000 m Höhe liegen, starken Winden ausgesetzt und weit vom Schnee entfernt sind.

Die Berechnung des Retentionsindex zeigte, dass kalkreiche Wiesen eine höhere floristische Differenzierung gegenüber den kalkarmen haben (Abb. 3).

Floristische Unterschiede innerhalb der verschiedenen Vegetationstypen werden durch unterschiedliche Lebensraumbedingungen erklärt. Da die Pflanzenassoziationen entlang eines Gefälles von Kalzium-armen bis Kalzium-reichen Substraten vorkommen, bestehen die stärksten Unterschiede zwischen ihnen in Bezug auf den R-EIV (Abb. 4). Darüber hinaus ändert sich die Vegetation nach einem T-EIV, der wahrscheinlich mit der Standerhöhung zusammenhängt (Abb. 5).

Diskussion – Wir haben sechs grundlegende Vegetationseinheiten (Assoziationen) beschrieben, die sich in ihrer floristischen Zusammensetzung unterscheiden. Sie wurden vier Verbänden und Unterverbänden zugeordnet, die drei pflanzensoziologischen Klassen angehören. Zwei dieser Verbände und Unterverbände wurden hier erstmals für die italienische Vegetation dokumentiert. Alle sechs Assoziationen sind endemisch, weil sie nur aus dem Untersuchungsgebiet beschrieben worden sind. Die feinen Unterschiede entlang des Gefälles von kalkarmen zu kalkreichen Substraten, die im Untersuchungsgebiet auftreten, bilden die Hauptursache für die Erklärung der Vegetationsvielfalt unter den Primärrasen in der alpinen Stufe des nördlichen Apennins.

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Author contribution statement

Marcello Tomaselli planned the sampling design and led the field sampling and the writing; Michele Carbognani performed the statistical analyses, contributed to the writing and to the revision of the manuscript; Bruno Foggi carried out the relevés in the field, revised taxonomic nomenclature and took relevant syntaxonomic decisions; Alessandro Petraglia and Graziano Rossi carried out the relevés on the field and contributed to the revision of the manuscript; Leonardo Lombardi carried out the relevés on the field; Matilde Gennai carried out the relevés on the field, identified many vascular plant species, integrated and revised the manuscript.

Supplements

Supplement S1. Correction and Typification of syntaxon names proposed to the Committee for Nomina Conservanda, Ambigua, Inversa and Mutata.

Anhang S1. Korrektur und Typisierung von Syntaxon-Namen, die dem Komitee für Nomina Conservanda, Ambigua, Inversa and Mutata vorgeschlagen wurden.

Supplement S2. Type relevés of all newly described associations and subassociations.

Anhang S2. Typenaufnahmen aller neu beschriebenen Assoziationen und Subassoziationen.

Supplement S3. Phytosociological table of the *Caro appuani-Seslerietum apenninae*.

Beilage S3. Pflanzensoziologische Tabelle des *Caro appuani-Seslerietum apenninae*.

Additional supporting information may be found in the online version of this article.

Zusätzliche unterstützende Information ist in der Online-Version dieses Artikels zu finden.

Supplement E1. Relevé locations.

Anhang E1. Lokalitäten der Vegetationsaufnahmen.

Supplement E2. Silhouette width bar plot used to identify the optimal number of clusters for the vegetation belonging to the class *Juncetea trifidi* (left) and *Elyno-Seslerietea* (right).

Anhang E2. Silhouettenbreiten-Balkendiagramm, mit dem die optimale Anzahl von Clustern für die Vegetation der Klasse *Juncetea trifidi* (links) und *Elyno-Seslerietea* (rechts) ermittelt wurde.

Supplement E3. Phytosociological table of the *Sileno bryoidis-Trifolietum alpini*.

Anhang E3. Pflanzensoziologische Tabelle des *Sileno bryoidis-Trifolietum alpini*.

Supplement E4. Phytosociological table of the *Thymo polytrichi-Festucetum riccerii*.

Anhang E4. Pflanzensoziologische Tabelle des *Thymo polytrichi-Festucetum riccerii*.

Supplement E5. Phytosociological table of the *Cerastio suffruticosi-Seslerietum pichianae*.

Anhang E5. Pflanzensoziologische Tabelle des *Cerastio suffruticosi-Seslerietum pichianae*.

Supplement E6. Phytosociological table of the *Aquilegio lucensis-Anemonastretum narcissiflorae*.

Anhang E6. Pflanzensoziologische Tabelle des *Aquilegio lucensis-Anemonastretum narcissiflorae*.

References

- AESCHIMANN, D., LAUBER, K., MOSER, D.M. & THEURILLAT, J.-P. (2004): Flora alpina. Vols. 1–3. – Zanichelli, Bologna: 2670 pp.
- ARRIGONI, P.V. (2015): Contribution to the study of the genus *Armeria* (Plumbaginaceae) in the Italian peninsula. – *Flora Medit.* 25 (Special issue): 7–32.
- BARBERO, M. & BONO, G. (1973): La végétation orophile des Alpes Apuanes (The mountain vegetation of the Apuan Alps) [in French]. – *Vegetatio* 27: 1–48.
- BARTOLUCCI, F., PERUZZI, L., GALASSO, G. ... CONTI, F. (2018): An updated checklist of the vascular flora native to Italy. – *Plant Biosyst.* 152: 179–303.
- BECHI, N. & GARBARI, F. (1994): Intraspecific variation and taxonomic aspects of some plants from the Apuan Alps (Tuscany, Italy). – *Fl. Medit.* 4: 213–225.
- BEDINI, G., ANSALDI, M. & GARBARI, F. (2007): Mapping and demography of endangered plants in the Apuan Alps, NW Tuscany, Italy. – *Bocconea* 21: 27–44.
- BRAUN-BLANQUET, J. (1964): Pflanzensoziologie: Grundzüge der Vegetationskunde. 3rd ed. – Springer, Wien: 865 pp.
- BRUNI, P., CIPRIANI, N. & PANDELI, E. (1994): New sedimentological and petrographical data on the Oligo-Miocene turbiditic formations of the Tuscan Domain. – *Mem. Soc. Geol. It.* 48: 251–260.
- BUFFA, G. & SBURLINO, G. (2001): *Carex ferruginea* grasslands in the south-eastern Alps. – *Plant Biosyst.* 135: 195–206.
- CASAZZA, G., BARBERIS, G., GUERRINA, M., ZAPPA, E., MARIOTTI, M. & MINUTO, L. (2016): The plant endemism in the Maritime and Ligurian Alps. – *Biogeographia* 31: 73–88.
- CHIAPELLA FEOLI, L. & POLDINI, L. (1993): Prati e pascoli del Friuli (NE Italia) su substrati basici (Grasslands and pastures of Friuli (NE Italy) on basic substrates) [in Italian]. – *Stud. Geobot.* 13: 3–140.
- CHYTRÝ, M., TICHÝ, L., HOLT, J. & BOTTA-DUKÁT, Z. (2002): Determination of diagnostic species with statistical fidelity measures. – *J. Veg. Sci.* 13: 79–90.
- CHYTRÝ, M. & OTÝPKOVÁ, Z. (2003): Plot sizes used for phytosociological sampling of European vegetation. – *J. Veg. Sci.* 14: 563–570.

- DALLAN NARDI, L. & NARDI, R. (1974): Schema stratigrafico e strutturale dell'Appennino settentrionale (Stratigraphic and structural scheme of the northern Apennines) [in Italian]. – Mem. Acc. Lunig. Sc. 42: 1–212.
- DENGLER, J., BERG, C. & JANSEN, F. (2005): New ideas for modern phytosociological monographs. – Ann. Bot. (Roma) 5: 193–210.
- DENGLER, J., CHYTRÝ, M. & EWALD, J. (2008): Phytosociology. – In: JØRGENSEN, S.E. & FATH, B.D. (Eds.): Encyclopedia of Ecology 4: 2767–2779. Elsevier, Oxford.
- DENGLER, J., EISENBERG, M. & SCHRÖDER, J. (2006): Die grundwasserfernen Saumgesellschaften Nordostniedersachsens im europäischen Kontext. Teil I: Säume magerer Standorte (*Trifolio-Geranietea sanguinei*). – Tuexenia 26: 51–93.
- DENGLER, J., JANIŠOVÁ, M., TÖRÖK, P. & WELLSTEIN, C. (2014): Biodiversity of Palaearctic grasslands: a synthesis. – Agric. Ecosys. Environ. 182: 1–14.
- DIEKMANN, M. (2003): Species indicator values as an important tool in applied plant ecology – a review. – Basic Appl. Ecol. 4: 493–506.
- DINELLI, E., LUCCHINI, F., MORDENTI, A. & PAGANELLI, L. (1999): Geochemistry of Oligocene-Miocene sandstones of the northern Apennines (Italy) and evolution of chemical features in relation to provenance changes. – Sediment. Geol. 127: 193–207.
- DI PIETRO, R., TERZI, M. & FORTINI, P. (2017): A revision of the high-altitude acidophilous and chionophilous grasslands of the Apennines (Peninsular Italy), a long-lasting intricate syntaxonomic issue. – Phytocoenologia 47: 261–304.
- FERRARI, C. & PICCOLI, F. (1997): The ericaceous dwarf shrublands above the Northern Apennine timberline (Italy). – Phytocoenologia 27: 53–76.
- FOGGI, B. (1990): Analisi fitogeografica del distretto appenninico tosco-emiliano (Phytogeographic analysis of the Tuscan-Emilian Apennine district) [in Italian]. – Webbia 44: 169–196.
- FOGGI, B., ROSSI, G. & PIGNOTTI, L. (2007): *Sesleria pichiana* (*Poaceae*): a new species from North-West Italian peninsula. – Webbia 62: 1–10.
- GENNAI, M., FOGGI, B., VICIANI, D., CARBOGNANI, M. & TOMASELLI, M. (2014): The *Nardus*-rich communities in the northern Apennines (N-Italy): a phytosociological, ecological and phytogeographical study. – Phytocoenologia 44: 55–80.
- GERDOL, R., STANISCI, A., TOMASELLI, M. & FAZZINI, M. (2008): La vegetazione delle montagne italiane (The vegetation of the Italian mountains) [in Italian]. – Club Alpino Italiano, Comitato Scientifico Centrale, Roma: 387 pp.
- GIANNECCHINI, R. (2006): Relationship between rainfall and shallow landslides in the southern Apuan Alps (Italy). – Nat. Hazard Earth Sys. 6: 357–364.
- GRABHERR, G., GREIMLER, J. & MUCINA, L. (1993): *Seslerietea albicantis*. – In: GRABHERR, G. & MUCINA, L. (Eds.): Die Pflanzengesellschaften Österreichs. Teil II: 402–446. Fischer, Jena.
- GRABHERR, G. & MUCINA, L. (1993): Die Pflanzengesellschaften Österreichs. Teile 1–3. – Fischer, Jena: 1263 pp.
- HOLUB, J. (1973): New names in *Phanerogamae* 2. – Folia Geobot. Phytotax. 8: 155–179.
- ILLYÉS, E., CHYTRÝ, M., BOTTA-DUKÁT, Z., JANDT, U., ŠKODOVÁ, I., JANIŠOVÁ, M., WILLNER, W. & HÁJEK, O. (2007): Semi-dry grasslands along a climatic gradient across Central Europe: vegetation classification with validation. – J. Veg. Sci. 18: 835–846.
- KÖRNER, C. (2003): Alpine plant life: functional plant ecology of high mountain systems. 2nd ed. – Springer, Heidelberg: 344 pp.
- LANCIONI, A., FACCHI, J. & TAFFETANI, F. (2011): Syntaxonomical analysis of the *Kobresio myosuroidis*-*Seslerietea caeruleae* and *Carici Rupestris*-*Kobresietea Bellardii* classes in the central southern Apennines. – Fitosociologia 48: 3–21.
- LANDUCCI, F., GIGANTE, D., VENANZONI, R. & CHYTRÝ, M. (2013): Wetland vegetation of the class *Phragmito-Magnocaricetea* in central Italy. – Phytocoenologia 43: 67–100.
- LEGENDRE, P. & GALLAGHER, E.D. (2001): Ecologically meaningful transformations for ordination of species data. – Oecologia 129: 271–280.
- MICHL, T., DENGLER, J. & HUCK, S. (2010): Montane-subalpine tall herb vegetation (*Mulgedio-Aconitetea*) in central Europe: large-scale synthesis and comparison with northern Europe. – Phytocoenologia 40: 117–154.

- MOSYAKIN, S.L. (2016): Nomenclatural notes on North American taxa of *Anemonastrum* and *Pulsatilla* (*Ranunculaceae*), with comments on the circumscription of *Anemone* and related genera. – *Phytoneuron* 79: 1–12.
- MUCINA, L., BÜLTMANN, H., DIERBEN, K. ... CHYTRÝ, M. (2016): Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. – *Appl. Veg. Sci.* 19 (Suppl. 1): 3–264.
- NARDI, E. (2015): Il genere *Aquilegia* (*Ranunculaceae*) in Italia (The genus *Aquilegia* (*Ranunculaceae*) in Italy) [in Italian]. – Edizioni Polistampa, Firenze: 688 pp.
- PETRAGLIA, A. & TOMASELLI, M. (2007): Phytosociological study of the snowbed vegetation in the Northern Apennines (Northern Italy). – *Phytocoenologia* 37: 67–98.
- PIGNATTI, E. & PIGNATTI, S. (2014): Plant life of the Dolomites. Vegetation structure and ecology. – *Museum Nature of South Tyrol* 8, Springer, Heidelberg: 769 pp.
- PIGNATTI, S. (1994): The climax vegetation above timberline in the northern and central Apennines. – *Fitosociologia* 25: 5–17.
- PIGNATTI, S. & MENGARDA, F. (1962): Un nuovo procedimento per l'elaborazione delle tabelle fitosociologiche (A new procedure for processing phytosociological tables) [in Italian]. – *Acc. Naz. dei Lincei, Rend. Cl. Sc. fis.mat. nat. s.8.* 32: 215–222.
- PIGNATTI, S., MENEGONI, P. & PIETROSANTI, S. (2005): Valori di bioindicazione delle piante vascolari della Flora d'Italia (Bioindicator Values of vascular plants of the Italian Flora) [in Italian]. – *Braun-Blanquetia* 39: 1–97.
- R CORE TEAM (2018): R: A language and environment for statistical computing. – R Foundation for Statistical Computing, Vienna. – URL: <http://www.R-project.org>.
- RAPETTI, F. & VITTORINI, S. (1989): Aspetti del clima nei versanti tirrenico ed adriatico lungo l'allineamento Livorno-Monte Cimone-Modena (Climatic features in the Tyrrhenian and Adriatic slopes along the alignment Livorno-Mt. Cimone-Modena) [in Italian]. – *Atti Soc. Tosc. Sci. Nat. Mem. Serie A*, 96: 159–192.
- ROSSI G., FERRARINI, A., DOWGIALLO, G., CARTON, A., GENTILI, R. & TOMASELLI, M. (2014): Detecting complex relations among vegetation, soil and geomorphology. An in-depth method applied to a case study in the Apennines (Italy). – *Ecol. Complex.* 17: 87–98.
- ROUSSEEUW, P.J. (1987): Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. – *J. Comput. Appl. Math.* 20: 53–65.
- THEURILLAT, J.-P. (1996): Les pelouses à *Carex curvula* subsp. *curvula* (*Caricion curvulae*) dans les Alpes. – In: VITTOZ, P., THEURILLAT, J.-P. & GALLANDAT, J.-D. (Eds.): Volume jubilaire J.-L. Richard: 267–294. *Dissertationes Botanicae* 258, Cramer, Stuttgart.
- THEURILLAT, J.P., AESCHIMANN, D., KÜPFER, P. & SPICHIGER, R. (1995): The higher vegetation units of the Alps. – *Colloq. Phytosoc.* 23: 189–239.
- TICHÝ, L. (2002): JUICE, software for vegetation classification. – *J. Veg. Sci.* 13: 451–453.
- TICHÝ, L. & CHYTRÝ, M. (2006): Statistical determinations of diagnostic species for site groups of unequal size. – *J. Veg. Sci.* 17: 809–818.
- TOMASELLI, M. (1994): The vegetation of summit rock faces, talus slopes and grasslands in the northern Apennines (N Italy). – *Fitosociologia* 26: 35–50.
- TOMASELLI, M. & AGOSTINI, N. (1994): A comparative phytogeographic analysis of the summit flora of the Tuscan-Emilian Apennines and of the Apuan Alps. – *Fitosociologia* 26: 99–109.
- TOMASELLI, M., FOGGI, B., CARBOGNANI, M., GENNAI, M. & PETRAGLIA, A. (2019): The rock-face vegetation in the northern Apennines and neighbouring mountain areas, from the coast line to the highest summits. – *Phytocoenologia* 49: 7–70.
- TOMASELLI, M. & ROSSI, G. (1994): Phytosociology and ecology of *Caricion curvulae* vegetation in the northern Apennines (N Italy). – *Fitosociologia* 26: 51–62.
- TOMASELLI, M., ROSSI, G. & DOWGIALLO, G. (2000): Phytosociology and ecology of the *Festuca puccinellii*-grasslands in the northern Apennines (N-Italy). – *Bot. Helv.* 110: 125–149.
- UBALDI, D., ZANOTTI, A.L. & PUPPI, G. (1993): Les paysages forestiers de l'Emilie-Romagne et leur signification bioclimatique (The forest landscapes of Emilia-Romagna and their bioclimatic significance) [in French]. – *Colloq. Phytosoc.* 21: 269–286.
- VAN DER MAAREL, E. (1979): Transformation of cover-abundance values in phytosociology and its effect on community similarity. – *Vegetatio* 39: 97–114.

- WEBER, H.E., MORAVEC, J. & THEURILLAT, J.-P. (2000): International code of phytosociological nomenclature. 3rd ed. – J. Veg. Sci. 11: 739–768.
- WERGER, M.J.A. & VAN GILS H. (1976): Phytosociological classification in chorological borderline areas. – J. Biogeogr. 3: 49–54.
- ZELENÝ, D. & SCHAFFERS, A.P. (2012): Too good to be true: Pitfalls of using mean Ellenberg indicator values in vegetation analyses. – J. Veg. Sci. 23: 419–431.

Supplement S1. Correction and Typification of syntaxon names proposed to the Committee for Nomina Conservanda, Ambigua, Inversa and Mutata.

Anhang S1. Korrektur und Typisierung von Syntaxon-Namen, die dem Komitee für Nomina Conservanda, Ambigua, Inversa and Mutata vorgeschlagen wurden.

1) *Sileno bryoidis-Trifolietum alpini* Tomaselli et Rossi 1994 nom.corr. *hoc loco*

Original form: *Sileno exscapae-Trifolietum alpini* Tomaselli et Rossi 1994, holotypus relevé number 2 of Table 1 in TOMASELLI & ROSSI 1994.

We propose the correction of the name as in the heading according to Art. 43 ICPN, because the revision of the herbarium specimens originally attributed to *Silene acaulis* subsp. *exscapa* (All.) Killias showed that they represent *Silene acaulis* subsp. *bryoides* (Jord.) Nyman.

2) *Aquilegio lucensis-Anemonastretum narcissiflorae* Tomaselli, Carbognani, Foggi, Petraglia, Rossi, Lombardi et Gennai *hoc loco*

Original form: *Aquilegio-Anemonetum narcissiflorae* Tomaselli 1994, holotypus relevé number 7 of unpublished original table in TOMASELLI 1994.

The name *Aquilegio-Anemonetum narcissiflorae* is not validly published according to paragraph g of Art. 3g ICPN, because it was published after 1.1.1979 and it is not clear from what species of the genus *Aquilegia* the name is formed (see TOMASELLI 1994: 43).

To provide the association of a valid name, we propose the following procedure: i) to use the nomenclatural combination *Aquilegia lucensis* after that it was identified as the only species of the genus *Aquilegia* occurring in the Tuscan-Emilian Apennines by NARDI (2015); ii) to replace the nomenclatural combination *Anemone narcissiflora* L., that is no longer adopted in the taxonomic and floristic literature after the segregation of the genus *Anemonastrum* proposed by HOLUB (1973) and recently confirmed also by MOSYAKIN (2016) and BARTOLUCCI et al. (2018), with *Anemonastrum narcissiflorum* (L.) Holub. This correction of the name is based on Art. 45 ICPN. The new name is reported in the headings.

3) *Festucion riccerii* Tomaselli, Carbognani, Foggi, Petraglia, Rossi, Lombardi et Gennai *hoc loco*

Lectotypus: *Sileno exscapae-Trifolietum alpini* Tomaselli 1994: p. 54.

4) *Caricion sempervirentis-Seslerion apenninae* Tomaselli, Carbognani, Foggi, Petraglia, Rossi, Lombardi et Gennai *hoc loco*

Holotypus: *Caro appuani-Seslerietum apenninae* Tomaselli, Carbognani, Foggi, Petraglia, Rossi, Lombardi et Gennai *hoc loco*

Supplement S2. Type relevés of all newly described associations and subassociations.

Anhang S2. Typenaufnahmen aller neu beschriebenen Assoziationen und Subassoziationen.

***Sileno bryoidis-Trifolietum alpini antennarietosum dioicae* subass. nova hoc loco**

Holotypus: Supplement E3 relevé number 40, site Mt. Giovo, elevation 1790 m, aspect ESE, slope angle 10°, relevé area 10 m², vegetation cover 65%, species number 20.

Alchemilla transiens 2, *Antennaria dioica* 2, *Vaccinium uliginosum* subsp. *microphyllum* 2, *Carex sempervirens* 1, *Festuca riccerii* 1, *Oreojuncus trifidus* 1, *Agrostis rupestris* +, *Alchemilla flabellata* +, *Asperula cynanchica* var. *oreophila* +, *Bellidiastrum michelii* +, *Euphrasia minima* +, *Gentianella campestris* +, *Juniperus communis* subsp. *nana* +, *Minuartia verna* +, *Phyteuma hemisphaericum* +, *Pilosella lactucella* +, *P. officinarum* +, *Plantago maritima* subsp. *serpentina* +, *Thymus praecox* subsp. *polytrichus* +, *Vaccinium myrtillus* +.

***Sileno bryoidis-Trifolietum alpini sedetosum alpestris* subass. nova hoc loco**

Holotypus: Supplement E3 relevé number 62, site Mt. Alpe Tre Potenze, elevation 1780 m, aspect N, slope angle 30°, relevé area 50 m², vegetation cover 50%, species number 16.

Alchemilla transiens 2, *Festuca riccerii* 2, *Luzula spicata* subsp. *conglomerata* 2, *Agrostis rupestris* 1, *Avenella flexuosa* 1, *Poa alpina* 1, *Festuca rubra* subsp. *commutata* +, *Luzula sylvatica* subsp. *sieberi* +, *Omalotheca supina* +, *Oreojuncus trifidus* +, *Phyteuma hemisphaericum* +, *Sagina glabra* +, *Scorzoneroides helvetica* +, *Sedum alpestre* +, *Trifolium thalii* +, *Cardamine resedifolia* r.

***Thymo polytrichi-Festucetum riccerii* ass. nova hoc loco subass. typicum**

Holotypus: Supplement E4 relevé number 4, site Mt. Libro Aperto, elevation 1880 m, aspect SW, slope angle 45°, relevé area 20 m², vegetation cover 90, species number 28.

Festuca riccerii 3, *Alchemilla transiens* 1, *Carex sempervirens* 1, *Geum montanum* 1, *Lotus corniculatus* subsp. *alpinus* 1, *Nardus stricta* 1, *Phyteuma hemisphaericum* 1, *Thymus praecox* subsp. *polytrichus* 1, *Alchemilla flabellata* +, *Anthoxanthum nipponicum* +, *Asperula cynanchica* var. *oreophila* +, *Avenella flexuosa* +, *Brachypodium genuense* +, *Carlina acaulis* subsp. *caulescens* +, *Clinopodium alpinum* +, *Galium anisophyllum* +, *Hypericum richeri* +, *Luzula multiflora* +, *Oreojuncus trifidus* +, *Pilosella officinarum* +, *Pimpinella saxifraga* subsp. *alpina* +, *Plantago maritima* subsp. *serpentina* +, *Polygala alpestris* +, *Trifolium pratense* +, *Viola ferrarinii* +, *Anthyllis vulneraria* subsp. *vulnerarioides* r, *Cerastium arvense* subsp. *suffruticosum* r, *Luzula spicata* subsp. *conglomerata* r.

***Thymo polytrichi-Festucetum riccerii cerastietosum suffruticosi* subass. nova hoc loco**

Holotypus: Supplement E4 relevé number 39, site Mt. Cusna, elevation 2000 m, aspect SSW, slope angle 35°, relevé area 10 m², vegetation cover 100%, species number 29.

Festuca riccerii 3, *Anthoxanthum nipponicum* 1, *Campanula scheuchzeri* 1, *Carlina acaulis* subsp. *caulescens*, *Cerastium arvense* subsp. *suffruticosum* 1, *Lotus corniculatus* subsp. *alpinus* 1, *Luzula multiflora* 1, *Thymus praecox* subsp. *polytrichus* 1, *Trifolium pratense* 1, *Alchemilla flabellata* +, *A. transiens* +, *Anthyllis vulneraria* subsp. *vulnerarioides* +, *Asperula cynanchica* var. *oreophila* +, *Brachypodium genuense* +, *Carex sempervirens* +, *Cirsium morisianum* +, *Clinopodium alpinum* +, *Euphrasia alpina* +, *Galium obliquum* +, *Gentiana verna* +, *Geum montanum* +, *Hypericum richeri* +, *Minuartia verna* +, *Phyteuma hemisphaericum* +, *Poa alpina* +, *Scabiosa lucida* +, *Seseli libanotis* +, *Trifolium thalii* +, *Viola ferrarinii* +.

***Cerastio suffruticosi-Seslerietum pichianae* ass. nova hoc loco**

Holotypus: Supplement E5 relevé number 6, site CS: Mt. Corno alle Scale, elevation 1760 m, aspect ESE, slope angle 35°, relevé area 20 m², vegetation cover 75%, species number 22.

Sesleria pichiana 3, *Alchemilla transiens* 2, *Asperula cynanchica* var. *oreophila* 1, *Brachypodium genuense* 1, *Cirsium bertolonii* 1, *Festuca riccerii* 1, *Galium obliquum* 1, *Minuartia verna* 1, *Thymus praecox* subsp. *polytrichus* 1, *Trifolium thalii* 1, *Alchemilla flabellata* +, *Aster alpinus* +, *Campanula scheuchzeri* +, *Carum heldreichii* +, *Cerastium arvense* subsp. *suffruticosum* +, *Clinopodium alpinum* +, *Dianthus sylvestris* +, *Draba aizoides* +, *Murbeckiella zanonii* +, *Sempervivum tectorum* +, *Seseli libanotis* +, *Viola ferrarinii* +.

***Aquilegia lucensis-Anemonastretum narcissiflorae* ass. nova hoc loco**

Holotypus: Supplement E6 relevé number 7, site CS: Mt. Corno alle Scale, elevation 1700 m, aspect ENE, slope angle 10°, relevé area 5 m², vegetation cover 95%, species number 26.

Anemonastrum narcissiflorum 2, *Festuca violacea* subsp. *puccinellii* 2, *Aquilegia lucensis* 1, *Linum alpinum* 1, *Pedicularis tuberosa* 1, *Rosa pendulina* 1, *Scabiosa lucida* 1, *Alchemilla alpina* +, *A. xanthochlora* +, *Asperula cynanchica* var. *oreophila* +, *Brachypodium genuense* +, *Carex macrostachys* +, *Daphne mezereum* +, *Dianthus hyssopifolius* +, *Galium anisophyllum* +, *Hieracium villosum* +, *Juniperus communis* subsp. *nana* +, *Minuartia verna* +, *Myosotis alpestris* +, *Phyteuma hemisphaericum* +, *P. orbiculare* +, *Polygonatum verticillatum* +, *Pulsatilla alpina* subsp. *millefoliata* +, *Saxifraga paniculata* +, *Carex sempervirens* r, *Lilium martagon* r.

***Caro appuani-Seslerietum apenninae* ass. nova hoc loco subass. typicum**

Holotypus: Supplement S3 relevé number 6, site Mt. Pania della Croce, elevation 1830 m, aspect NE, slope angle 35°, relevé area 80 m², vegetation cover 70%, species number 31.

Sesleria apennina 3, *Carex sempervirens* 2, *Brachypodium genuense* 1, *Festuca violacea* subsp. *puccinellii* 1, *Globularia cordifolia* 1, *Asperula cynanchica* var. *oreophila* +, *Astrantia pauciflora* +, *Bellidiastrum michelii* +, *Carex mucronata* +, *Biscutella laevigata* +, *Carum appuanum* +, *Cerastium apuanum* +, *Clinopodium alpinum* +, *Erica carnea* +, *Galium anisophyllum* +, *G. lucidum* +, *G. palaeotalicum* +, *Gentiana clusii* +, *Iberis sempervirens* +, *Juniperus communis* subsp. *nana* +, *Pedicularis tuberosa* +, *Phyteuma orbiculare* +, *Ranunculus pollinensis* +, *Sedum atratum* +, *Thesium sommierii* +, *Thymus praecox* subsp. *polytrichus* +, *Valeriana saxatilis* +, *Aquilegia bertolonii* r, *Primula auricula* r, *Saxifraga paniculata* r, *Silene pichiana* r.

***Caro appuani-Seslerietum apenninae dryadetosum octopetalae* subass. nova hoc loco**

Holotypus: Supplement S3 relevé number 41, site Mt. Contrario, elevation 1700 m, aspect NNE, slope angle 50°, relevé area 30 m², vegetation cover 70%, species number 28.

Dryas octopetala 3, *Carex sempervirens* 2, *Sesleria apennina* 1, *Anthyllis vulneraria* subsp. *vulnerarioides* +, *Arenaria bertolonii* +, *Asperula cynanchica* var. *oreophila* +, *Astrantia pauciflora* +, *Bellidiastrum michelii* +, *Campanula scheuchzeri* +, *Carum appuanum* +, *Erica carnea* +, *Euphrasia salisburgensis* +, *Galium palaeotalicum* +, *Gentiana clusii* +, *Gymnadenia odoratissima* +, *Gypsophila repens* +, *Lotus corniculatus* +, *Meum athamanticum* +, *Pedicularis tuberosa* +, *Phyteuma orbiculare* +, *Pulsatilla alpina* subsp. *millefoliata* +, *Salix crataegifolia* +, *Saxifraga aizoides* +, *S. caesia* +, *S. callosa* +, *S. oppositifolia* +, *S. paniculata* +, *Valeriana saxatilis* +.

***Geranio argentei-Caricetum rupestris* ass. nova hoc loco**

Holotypus: Table 4, relevé number 3, site Mt. Cimone, elevation 1975 m, aspect NNW, slope angle 10°, relevé area 1 m², vegetation cover 95%, species number 12.

Carex rupestris 4, *Alchemilla transiens* 1, *A. flabellata* 1, *Cotoneaster juranus* 1, *Festuca riccerii* 1, *Geranium argenteum* 1, *Asperula cynanchica* var. *oreophila* +, *Aster alpinus* +, *Luzula lutea* +, *Saxifraga paniculata* +, *Sempervivum arachnoideum* +, *Thymus praecox* subsp. *polytrichus* +.

Tomaselli et al.: Primary grasslands of the northern Apennine summits

Supplement E1. Relevé locations: locality acronym, locality indication name, province name (abbreviated in parentheses).

Anhang E1. Lokalitäten der Vegetationsaufnahmen: Lokalisationsakronym, Lokalitätsname, Name der Provinz (abgekürzt in Klammern).

Tuscan-Emilian Apennines

AM: Mt. Alpe di Mommio (RE); AN: Annibale pass (MO); AR: Croce Arcana pass (MO); BE: Mt. Belfiore (RE); BO: Mt. Bocco (PR); BS: Mt. Bocca di Scala (LU); BZ: Mt. Balzone (MO); CA: Mt. Casarola (RE); CC: Mt. Cornaccio (MO, PT); CG: ridge between Mt. Cornaccio and Mt. Gennaio (PT); CI: Mt. Cimone (MO); CL: Mt. Cupolino (MO); CP: Foce di Campolino pass (PT); CS: Mt. Corno alle Scale (BO); CU: Mt. Cusna (RE); DV: Mt. Denti della Vecchia (PT); FG: summit close Foce a Giovo pass (LU, MO); FM: Mt. Femmina Morta (MO, PT); GE: Mt. Gennaio (PT); GI: Mt. Giovo (MO); GO: Mt. Gomito (PT); GR: ridge between Mt. Giovo and Mt. Rondinaio (MO); LA: Mt. Libro Aperto (PT); LG: Mt. I Lagoni (MO); NB: Mt. La Nuda (BO); NM: Mt. La Nuda (MO); NU: Mt. La Nuda (RE); PA: Mt. Paitino (PR); PC: summit close to Pian Cavallaro (MO); PE: Alpe San Pellegrino (LU); PR: Mt. Prado (RE); PT: La Porticciola pass (MO); RD: Mt. Rondinaio; RO (MO): Mt. Romecchio (MO); SC: Mt. Scalocchio (RE); SI: Mt. Sillara (PR); SP: Mt. Spigolino (MO); SU: Mt. Alpe di Succiso (RE); TA: Mt. Tauffi (MO); TO: Mt. Tondo (LU); TP: Mt. Alpe Tre Potenze (PT); VE: Mt. Vecchio (RE); VN: Mt. Ventasso (RE).

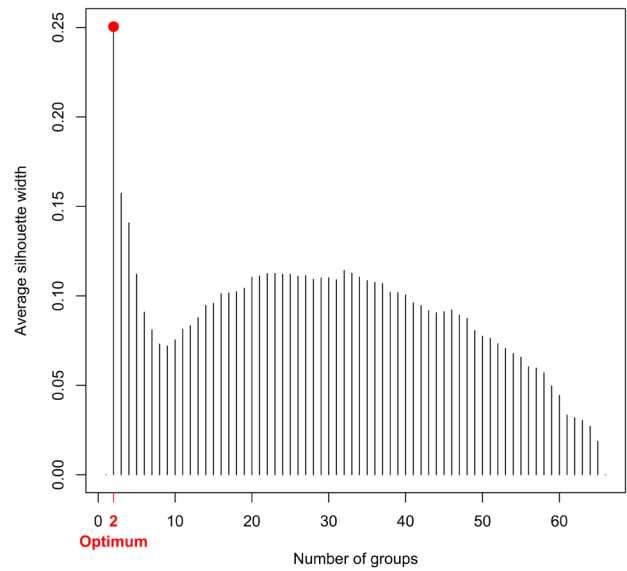
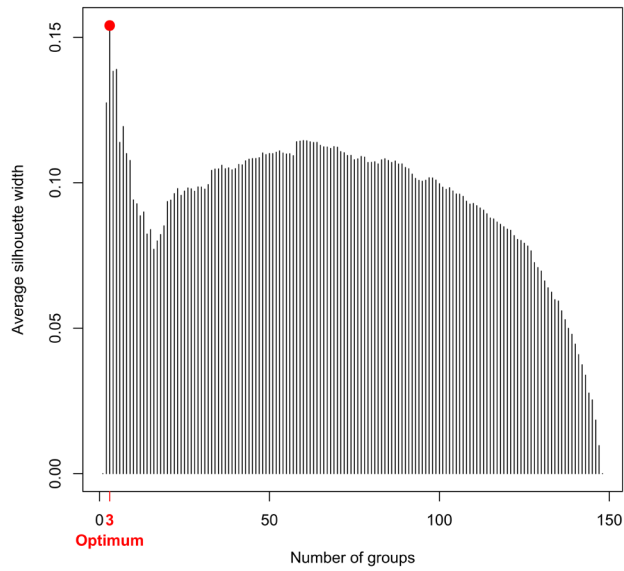
Apuan Alps

CH: Mt. Corchia (LU); CO: Mt. Contrario (LU); CR: Mt. Pania della Croce (LU); CV: Mt. Cavallo (LU); FI: Mt. Fiocca (LU); GA: Mt. Garnerone (MS); GD: Mt. Grondilice (LU); PS: Mt. Pizzo delle Saette (LU); SA: Mt. Sagro (MS); SE: Mt. Pania Secca (LU); SL: Mt. Sella (LU); SM: Mt. Penna di Sumbra (LU); TB: Mt. Tambura (MS); UC: Mt. Pizzo d'Uccello (MS).

Tomaselli et al.: Primary grasslands of the northern Apennine summits

Supplement E2. Silhouette width bar plot used to identify the optimal number of clusters for the vegetation belonging to the class *Juncetea trifidi* (left) and *Elyno-Seslerietea* (right).

Anhang E2. Silhouettenbreiten Balkendiagramm mit dem die optimale Anzahl von Clustern für die Vegetation der Klasse *Juncetea trifidi* (links) und *Elyno-Seslerietea* (rechts) ermittelt wird.



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Supplement E6. Phytosociological table of the *Aquilegio lucensis-Anemonastretum narcissiflorae*. D: differential species; RC: regional character species; RD: regional differential species; TR: transgressive character species.

Anhang E6. Pflanzensoziologische Tabelle der *Aquilegio lucensis-Anemonastretum narcissiflorae*. D: Trennart; RC: regional Kennart; RD: regional Trennart; TR: transgressive Kennart.

Relevé no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean (± SD)		
Site	RD	CI	CS	NB	RO	GR	CS	LA	CI	NU	SC	SC	RD	RD	PR	PR	1806 (± 112)		
Elevation (m asl)	1760	1960	1740	1530	1730	1850	1700	1820	1980	1700	1825	1810	1840	1860	1890	1900			
Aspect (°)	N	N	NNE	N	NE	ENE	ENE	NNW	N	NW	NE	N	NNE	WNW	NW	WNW			
Slope angle (°)	40	10	30	50	40	15	10	25	10	50	40	30	20	15	30	45			
Relevé area (mq)	10	10	5	10	5	5	5	5	5	5	5	5	5	5	5	5	5.9 (± 2.0)		
Vegetation cover (%)	100	90	100	100	90	100	95	80	80	90	100	100	100	100	100	90	94.7 (± 7.2)		
No. of species	22	9	27	17	18	20	26	14	15	14	18	20	24	20	25	22	19.4 (± 4.9)		
No. of rare species	1	-	3	5	2	1	5	1	1	-	1	-	2	-	2	4			
Aquilegio lucensis-Anemonastretum narcissiflorae																	Frequency	phi (a)	phi (va)
Anemonastrum narcissiflorum (TR)	3	3	3	2	+	1	2	3	3	2	3	3	2	3	1	1	100	< 0.001	< 0.05
Aquilegia lucensis	2	2	2	+	2	2	1	1	1	.	1	1	1	+	+	.	87	100	88
Scabiosa lucida (TR)	+	.	1	1	2	+	1	2	+	1	+	.	1	+	+	+	87	86	86
Pulsatilla alpina subsp. millefoliata (TR)	1	1	+	.	1	.	+	.	+	.	.	+	1	+	+	+	69	68	68
Linum alpinum (TR)	.	.	+	+	+	1	1	1	.	.	+	+	.	.	.	.	50	48	48
Carex macrostachys	.	.	.	3	.	.	+	1	.	2	1	1	2	.	.	.	44	53	53
Alchemilla xanthochlora (D)	1	+	1	.	.	.	+	+	.	.	.	1	.	.	+	.	44	53	53
Aconogonum alpinum-variant																			
Aconogonum alpinum	.	.	.	.	.	.	.	.	.	2	2	2	1	1	.	.	31		100
Viola biflora	1	.	+	.	.	.	.	.	.	1	1	+	+	1	1	1	56		42
Bistorta officinalis	.	.	+	.	.	+	.	.	.	.	+	+	1	1	.	.	37		68
Empetrum hermaphroditum-variant																			
Empetrum hermaphroditum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	12		100
Astrantia minor	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	12		100
Caricion ferrugineae																			
Festuca violacea subsp. puccinellii	.	.	.	1	.	+	2	.	2	.	+	+	.	.	.	+	44		
Festuca rubra subsp. commutata (RD)	1	.	.	.	.	1	.	.	.	+	.	.	+	1	1	.	37		
Alchemilla alpina (RD)	.	.	+	1	.	.	+	.	.	.	.	.	.	.	.	.	19		
Hedysarum hedysaroides	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	6		
Trifolium thalii	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	6		
Crepis aurea subsp. glabrescens (RC)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	6		
Seslerietalia caeruleae																			
Elyno-Seslerietea																			
Bellidiastrum michelii	+	.	+	.	.	+	.	+	+	+	.	+	.	.	+	+	56		
Phyteuma orbiculare	1	.	+	+	+	1	+	.	.	.	.	.	+	+	.	.	50		
Ranunculus pollinensis (RC)	.	.	.	.	.	+	.	.	.	.	+	+	r	+	+	.	37		
Galium anisophyllum	.	+	.	.	.	.	+	.	.	.	.	.	+	1	+	.	31		
Lotus corniculatus subsp. alpinus	.	2	1	.	.	.	.	.	.	.	.	.	1	1	.	.	25		
Myosotis alpestris	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	12		
Hieracium villosum	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	6		
Saussurea discolor	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	6		
Companions																			
Juncetea trifidi																			
Alchemilla transiens	+	.	.	.	+	1	.	+	.	.	.	.	+	+	3	2	50		
Pedicularis tuberosa	+	1	.	.	1	+	1	+	.	+	.	+	.	.	.	.	50		
Oreojuncus trifidus	+	.	+	.	1	.	.	.	+	+	+	.	.	.	+	1	50		
Luzula lutea	.	.	.	.	+	.	.	.	.	+	+	.	.	.	+	+	31		
Alchemilla alpina	.	.	+	1	.	.	+	.	.	.	.	.	.	.	.	.	19		
Armeria marginata	.	.	.	.	.	.	.	+	1	.	.	.	.	.	.	+	19		
Scorzoneroides helvetica	+	.	.	.	.	.	.	.	.	+	r	.	.	.	.	.	19		
Anthoxanthum nipponicum	1	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	12		
Loiseleurio-Vaccinieta																			
Vaccinium uliginosum subsp. microphyllum	1	.	.	.	1	.	.	.	.	.	.	.	.	.	2	1	25		
Hypericum richeri	.	.	.	.	.	.	.	.	.	.	.	+	+	1	+	.	25		
Juniperus communis subsp. nana	.	.	.	.	.	.	+	1	.	.	.	.	.	.	.	.	12		
Vaccinio-Picetea																			
Vaccinium myrtillus	+	1	+	.	.	.	.	.	.	.	.	.	.	.	1	+	31		
Luzula sylvatica subsp. sieberi	+	.	+	.	.	.	.	.	.	.	.	.	+	.	.	.	19		
Rosa pendulina	.	.	.	.	.	.	1	.	.	.	.	1	.	.	.	.	12		
Huperzia selago	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	12		
Other companions																			
Campanula scheuchzeri	.	.	+	.	+	+	.	.	+	+	.	.	+	1	r	+	56		
Saxifraga paniculata	.	.	+	.	+	+	.	+	.	.	.	.	.	+	.	+	37		
Brachypodium genuense	.	.	.	1	.	+	+	.	.	.	.	.	1	1	.	.	31		
Parnassia palustris	+	.	.	+	1	.	.	.	.	.	.	+	1	.	.	.	31		
Leucanthemum coronopifolium subsp. ceratophylloides	.	.	+	.	+	.	.	.	.	+	+	r	.	.	.	.	31		
Carex sempervirens	.	.	r	.	.	.	r	.	+	.	.	.	.	.	+	r	31		
Luzula alpinopilosa	.	+	.	.	.	.	.	.	1	.	.	.	.	.	+	.	19		
Daphne mezereum	.	.	.	.	.	.	+	.	.	.	+	.	.	+	.	.	19		
Rhinanthus minor	.	.	+	.	.	.	.	.	.	.	.	.	+	+	.	.	19		
Pimpinella saxifraga subsp. alpina	+	.	.	.	.	.	.	.	.	.	.	r	.	+	.	.	19		
Saxifraga rotundifolia	.	.	.	.	.	.	.	+	+	.	.	r	.	.	.	.	19		
Seseli libanotis	.	.	2	.	.	+	.	.	.	.	.	.	.	.	.	.	12		
Sesleria pichiana	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	12		
Avenella flexuosa	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	12		
Poa alpina	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	12		
Trifolium pratense	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	12		
Pinguicula christinae	.	.	+	.	.	.	.	.	.	r	.	.	.	.	.	.	12		
Saxifraga exarata subsp. pseudoexarata	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	r	12		
Lilium martagon	.	.	.	.	.	r	.	.	.	.	r	.	.	.	.	.	12		

Rare species:

Rel. 1: *Gentiana purpurea* (+), *Veratrum lobelianum* (+); Rel. 3: *Arabis alpina* subsp. *caucasica* (+), *Lathyrus pratensis* (+), *Saxifraga aizoides* (+); Rel. 4: *Adenostyles australis* (1), *Calamagrostis corsica* (1), *Lotus corniculatus* subsp. *corniculatus* (1), *Doronicum columnae* (+) *Helictochloa versicolor* (+); Rel. 5: *Arenaria bertolonii* (1), *Potentilla crantzii* (+); Rel. 6: *Coeloglossum viride* (r); Rel. 7: *Asperula cynanchica* var. *oreophila* (+), *Dianthus hyssopifolius* (+), *Minuartia verna* (+), *Phyteuma hemisphaericum* (+), *Polygonatum verticillatum* (+); Rel. 8: *Sorbus aucuparia* (+); Rel. 9: *Bistorta vivipara* (+); Rel. 11: *Saxifraga oppositifolia* (r); Rel. 13: *Allium lusitanicum* (+), *Primula veris* subsp. *columnae* (+); Rel. 15: *Solidago virgaurea* subsp. *minuta* (+), *Vaccinium vitis-idaea* (+); Rel. 16: *Agrostis rupestris* (+), *Cardamine resedifolia* (+), *Hieracium amplexicaule* (+), *Primula apennina* (+).