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VIOLA - the vegetation database of the central Apennines: structure, current status and usefulness for monitoring Annex I EU habitats (92/43/EEC)

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Abstract
In this paper we describe VIOLA (VegetatIOn of centraL Apennines), a database of high mountain vegetation relevés in the Central Apennines (Italy). We explore the general features of the data collected, specifically the variation in plot size, time range of the relevés and geographical position accuracy. VIOLA gathers a representative number of relevés from 7 Annex I habitats *sensu* Habitat Directive (92/43/EEC) (4060, 4070*, 6170, 6210, 6230*, 8120 and 8210). We characterize the dataset in terms of the total number of relevés, the total number of species, the most abundant species, the total number of endemics, the total number of phytosociological alliances and the most abundant alliance. For each habitat, life form and chorotype spectra were also calculated using the species frequency. In total, we collected 1,687 relevés including both published and unpublished phytosociological information collected above an altitude of 1,600 m a.s.l. in the Central Apennines (Gran Sasso, Majella, Monti del Matese, Monti della Meta and Velino massifs). The oldest relevés back to 1955, whereas the newest ones to 2014. A total of 45% of the relevés were recorded with the exact GPS coordinates, and 55% were referred to general description of the localities (toponyms); most of the relevés (77.8%) are between 10 and 100 m^2 wide. The Alpine and subalpine calcareous grasslands (6170) and the Calcareous and calcshist screes (8120), with over 50% and almost 20% of the relevés, respectively, are the most represented Annex I EU habitats in the database. Our results highlight that the stalked hemicryptophytes and Southern Europe Orophilous dominate in all EU habitats. Endemics are present in all habitats but higher percentages occur in Calcareous and calcshist screes, followed by Calcareous rocky slopes and Alpine and subalpine calcareous grasslands. Based on our results, we can confirm the value and usefulness of large vegetation databases for supporting theoretical and applied vegetation and ecological studies at different scales.

Key words: Eco-informatics, endemic species, Habitats Directive, high mountain, long-term vegetation monitoring, phytosociology.

Introduction

Mountain vegetation in Europe contains approximately two-thirds of the vascular plants of the continent, constituting an authentic hotspot of plant diversity that hosts highly specialized vascular plants (Myers *et al*., 2000) and many endemics (Pauli *et al*., 2012). In these environments the plant-plant interactions play an important role for biological diversity (Bonanomi *et al*., 2016). Moreover, the European high mountain ecosystems, which are included in the alpine region, support 119 habitat types and 107 plant species listed in the Habitat Directive (92/43/EEC) (Sundseth, 2009).

The Habitat Directive (92/43/EEC) calls for measures for monitoring and protecting habitats in the European Union (EU) territory. Each country is requested to adopt specific measures to preserve habitats over time and to periodically report their extension and conservation status. In this context, large vegetation databases provide an opportunity to examine and increase knowledge on plant communities and may help to assess the presence and the conservation status of Annex I habitat types across Europe (Schaminée *et al*., 2009).

In last decades, interest in vegetation cataloguing and gathering and efforts towards the compilation and elaboration of large electronic phytosociological databases have strongly increased (Haveman & Janssen, 2008). The first vegetation database in Europe was the Dutch National Vegetation Database created in 1988 (Schaminée *et al*., 1995a, 1995b, 1998), followed by the French (Brisse *et al*., 1995) and the Swiss (Wohlgemuth, 1992) databases. In the following years, the introduction of database programmes for metadata storage, such as TURBOVEG (Hennekens & Schaminée, 2001), the Global Index of Vegetation-Plot Database (GIVD; http://www.givd.info; Dengler *et al*., 2011) and the European Vegetation Archive (EVA; http://www.euroveg.org; Chytrý *et al*., 2016), has promoted the creation of several databanks gathering information at international, national and local levels (e.g., Bonis & Bouzillé, 2012; Dimopoulos *et al*., 2012; Font *et al*., 2012). A recent study has estimated the number of plots stored electronically in Europe at 1.8 million (Schaminée *et al*., 2009).

The uses of large vegetation databases combined with environmental and geographical information systems are manifold (e.g., Schaminée *et al*., 2007). Recent examples demonstrate the usefulness of these databases for exploring basic ecological and biogeographical issues (Dengler *et al*., 2011), for analysing the species response across environmental gradients (Coudun & Gegout, 2005) and for assessing long-term changes

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in plant communities (Chytrý *et al*., 2014; Schaminée *et al*., 2002, 2011; Frate *et al*., 2016). Moreover, the use of vegetation databases remains the only method to document historical vegetation development where long-term permanent plot data are not available (Stöckli *et al*., 2011).

In 2009 in Italy, the number of phytosociological relevés was approximately 150,000, and of these, only 20,000 were electronically stored (Schaminée *et al*., 2009). During the last years, Italian researchers have devoted large efforts towards creating and upgrading the Italian National Vegetation Database – VegItaly (Gigante *et al*., 2012; Landucci *et al*., 2012; Venanzoni *et al*., 2012; Lucarini *et al*., 2015). Several local or regional databases exist in Italy, describing a very heterogeneous set of habitats (e.g., coastal dunes vegetation, dry grasslands, volcanic lakes, deciduous forests, etc.). However, a specific database of high-mountain vegetation of the Central Apennines (Italy) is lacking. The Central Apennines are characterized by the presence of several peaks of over 2,000 m (Monte Corno on the Gran Sasso Massif is the highest peak, 2,912 m a.s.l.), and 515 plant species and subspecies have been identified over the treeline (Conti, 2004), of which 100 are exclusive endemics of the Central Apennines (Conti *et al*., 2012).

High mountain ecosystems in the Central Apennines are now facing important climatic and land use changes that modify their composition, ecology and structure (Petriccione, 2005; Theurillat *et al*., 2007; Catorci *et al*., 2012; Evangelista *et al*., 2016; Stanisci *et al*., 2016a) with negative effects on their conservation status (Frate *et al*., 2016). Based on this information, we created a specific database called VIOLA (VegetatIOn of centraL Apennines), which gathers high mountain vegetation relevés of the Central Apennines (Italy) (Stanisci *et al*., 2016b). VIOLA is included in the Global Index of Vegetation-Plot Databases (Dengler *et al*., 2011) with ID EU-IT-019.

In this paper, we described the VIOLA database focusing on its structure, chorology and species composition in order to provide an overview of the high mountain EU habitats in the Central Apennines and to show the useful applications of this type of databases. We discuss the potential uses of this database for monitoring the conservation status of Annex I EU habitats (hereinafter referred to simply as EU habitats) and for assessing the ecological effects of global change (climate warming and land use change) on such a vulnerable hot spot of biodiversity.

Materials and Methods

Database structure

VIOLA is the first standardized and accessible database describing Mediterranean high-elevation vegetation in Italy. VIOLA was built using the software TURBOVEG (Hennekens & Schaminée, 2001). It contains 1,687 relevés collected in the last six decades (see Appendix 1) all localized in the central Apennines (Gran Sasso, Majella, Monti del Matese, Monti della Meta and Velino massifs). The phytosociological relevés are distributed above the tree line (between 1,600 and 2,900 m a.s.l.) and correspond to dwarf shrublands, oro-mediterranean grasslands and scree and cliff vegetation. Most of the location partially include three National Parks ("Gran Sasso e Monti della Laga", "Majella" and "Abruzzo, Lazio e Molise"), one Regional Park (Sirente-Velino) and a Special Area of Conservation (La Gallinola - Monte Miletto - Monti del Matese, code IT7222287) (Fig. 1). Many of these areas are part of the LTER site “Apennines: high elevation ecosystems” (Long Term Ecological Research network - ID: IT01-000-T) (Stanisci, 2012). For VIOLA implementation, we performed a detailed search for published and unpublished phytosociological information, gathering accessible sources and contacting researchers involved in past and current vegetation studies in the Apennines. For each relevé, we registered the list of vascular plants along with the respective cover/abundance values (Braun-Blanquet scale - Braun-Blanquet, 1964). Although bryophytes and lichens should be presumably abundant in high mountain habitats (Väre *et al*., 2003), their sampling protocols and identification procedures are different from those used for sampling the vascular flora and thus they were neglected in the phytosociological relevés of Central Apennines. For each relevé, all of the metadata available from the reference sources (e.g., sampling year, plot size, altitude, aspect, slope, vegetation cover, location and phytosociological association) were also recorded. Most of the relevés were georeferenced with different levels of accuracy based on the available information, e.g., toponyms, altitude, slope, aspect and GPS coordinates. Based on the phytosociological classification of the vegetation types provided in the reference source, the “Prodrome of the Italian Vegetation" (Biondi *et al*., 2014), the guidelines of the Italian Interpretation Manual of the 92/43/EEC Directive Habitats (Biondi *et al*., 2009) and the Interpretation Manual of European Union Habitats (European Commission, 2013), each relevé was assigned to one EU habitat type.

Taxonomical and nomenclatural information

The taxonomic scheme and the nomenclature reported in the original sources have been harmonized and updated according to recent taxonomic and nomenclatural studies (Conti *et al*., 2005, 2007a). To solve synonymy problems, we consulted Fiori (1923-1929), Tutin *et al*. (1964-1980, 1993), and Pignatti (1982). The floristic nomenclature has been updated according to recent publications (Foggi *et al*., 2005; Greuter *et*

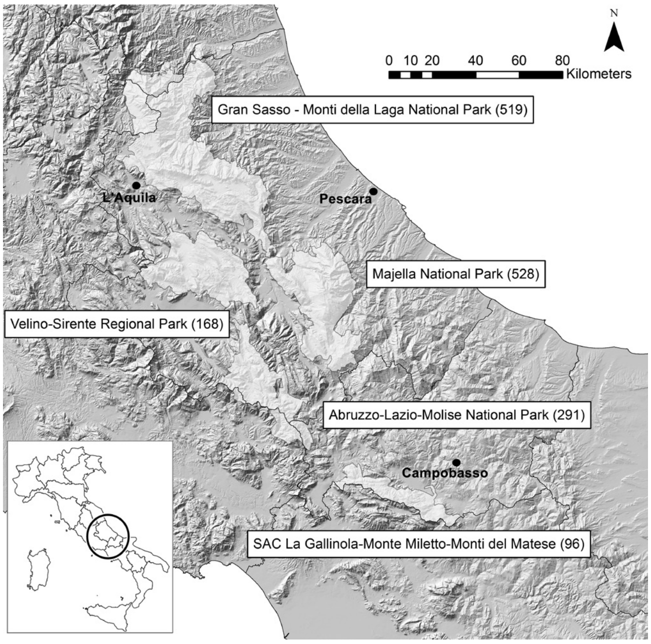

Fig. 1 - Localization of the protected areas in Central Apennines. The total number of relevés stored in VIOLA database per protected area is reported in brackets.

al., 2006; Valdés & Scholz, 2006; Brullo *et al*., 2009; Selvi & Cecchi, 2009; Conti & Uzunov, 2011; Bartolucci *et al*., 2012; Foggi *et al*., 2012; Arrigoni, 2014; Dillenberger & Kadereit, 2014; Arrigoni, 2015). The floristic list includes 670 names of specific and infraspecific taxa. For each taxon (hereinafter mentioned as species), the cover/abundance value recorded in the relevés is reported. In addition, the Ellenberg indicator values proposed for the Italian Flora (Pignatti *et al*., 2005), the life form (Raunkiaer, 1934) and the chorotype (Pignatti, 1982) are described. For the attribution of life forms, we considered the following categories: dwarf-shrubs (a woody plant assemblage that consists of fruticose chamaephytes, reptant chamaephytes and nano-phanerophytes), cushion chamaephytes (ChC), succulent chamaephytes (ChS), geophytes (Geo), caespitose hemicryptophytes (Hcae), hemicryptophytes with rosette (Hros), stalked hemicryptophytes (Hsca), therophytes (Th), biennial hemicryptophytes (Hbie) and phanerophytes (P). For chorotypes, we identified the following groups: Endemic, Steno-Mediterranean, Euri-Mediterranean, Mediterranean Montane, Eurasian, Atlantic, South-European-Orophilous, Boreal species and Wide distribution groups.

Analysis of the information included in VIOLA

For a comparison with other databases contained in GIVD (Dengler *et al*., 2011), we briefly explored the variation in plot size, the level of geographic accuracy, and the date of collection. We also characterized each EU habitat in terms of the total number of relevés, the number of species, the most abundant species, the number of endemics, the number of phytosociological alliances and the most abundant alliance. For each habitat, life form and chorotype spectra were also calculated using the species frequency.

Results and discussion

The relevés gathered in VIOLA mainly correspond to herbaceous plant communities (91.6%) and secondarily to shrubland communities (8.4%). The oldest relevés are dated back to 1955, whereas the newest ones are dated 2014, and most of them (70.3%) were collected in the period 1990/2016 (Fig. 2a). The low number of relevés collected in the last 6 years, probably depends on the remarkable phytosociological knowledge produced in the past for the study area. Indeed during the last years few relevés have been made mainly for land management purposes (e.g. technical reports for mountain national parks). Geographic accuracy varies from the exact geographical coordinates measured by the Global Positioning System (GPS, approximately 45% of the relevés) to the general description of localities (toponyms, currently 55%). The size of the relevés ranges from 0.5 to 300 m^2 (the mean plot size is 38.54 m^2), and most of them (78.6%) are between 10 and 100 m^2 wide (Fig. 2b). The mean size of the relevés present in VIOLA varies across habitats. The sampling size of the existing relevés is, on average, bigger than the minimum homogeneous sampling area suggested by the ISPRA (Istituto Superiore della Protezione e la Ricerca Ambientale - Angelini *et al*., 2016) in the guidelines for monitoring Natura-2000 habitats (Tab. 1). The extension of the oldest relevés was very large, but in the last 30 years, the relevés have become smaller (see Fig. 2c). Such a reduction in sampling area is most likely related to changes in the conceptual frame of phytosociology that in the last decades gave particular attention to the ecology, dynamic and landscape features of plant communities (Biondi, 2011).

The mean vegetation cover per relevés is 66.34% (S.D. 30.39). The vegetation cover is higher in the relevés of the oro-mediterranean grasslands and dwarf shrublands than in the scree and cliff vegetation, where harsh environmental conditions determine lower cover value.

High mountain EU habitats

A total of 98% of the relevés stored in VIOLA belong to seven EU habitats: Alpine and Boreal heaths (4060), Bushes with *Pinus mugo* (4070*), Alpine and subalpine calcareous grasslands (6170), Semi-natural dry grasslands (6210), Species-rich Nardus grasslands (6230*), Calcareous and calcshist screes (8120) and Calcareous rocky slopes (code 8210). These EU habitats are the most widespread ones in the higher

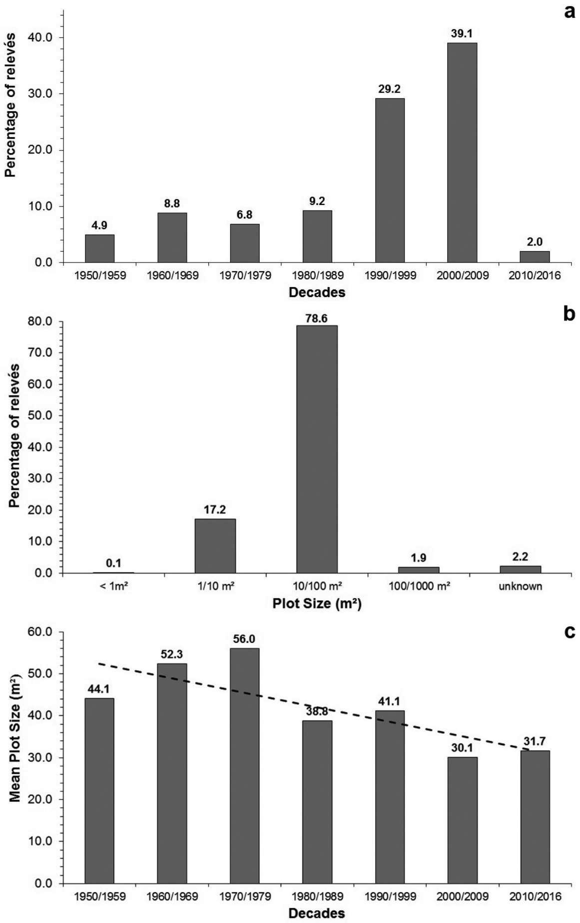

Fig. 2 - a) Percentage of relevés recorded by decade, b) Percentage of relevés recorded per sample size class, c) Mean plot size per decades.

sectors of the Central Apennines (Biondi *et al.*, 2009). For each EU habitat, we reported the main features, as follows.

Alpine and Boreal heaths (habitat 4060)

This habitat, characterized by dwarf or prostrate shrub formations in the alpine and sub-alpine zone of the mountains of Eurasia, is represented in the Central Apennines by the alliance *Daphno oleoidis-Juniperion alpinae* Stanisci 1997. This alliance is distributed in moderately steep slopes of the calcareous massifs of the Gran Sasso, Majella, Velino and Monti della Meta. In the VIOLA database, this habitat represents 5.4% of the relevés (87 rel.) with a mean plot size of 43.60 m^2 (S.D. 29.18). The most abundant species are *Juniperus communis*, *Brachypodium genuense* and *Globularia meridionalis* (see Tab. 1). The total number of species is 196, and the mean richness is 18.33 (S.D. 7.43). *Juniperus communis* dominated shrublands have, in general, higher values of species richness compared to those of *Pinus mugo* bushes (4070*) because they are open shrublands inside a landscape matrix dominated by *Brachypodium genuense* grasslands or *Sesleria juncifolia* grasslands, and in the interior part of juniper formations, many species from the neighbouring grasslands can be found (Petriccione, 1993; Stanisci, 1997).

Bushes with* Pinus mugo *(habitat 4070*)

This habitat is characterized by the dominance of *Pinus mugo* subsp. *mugo*, which forms a monoplane formation with a low undergrowth and few herbaceous species. In the Central Apennines, it is represented by the alliance *Epipactido atropurpureae-Pinion mugo* Stanisci 1997. Bushes with *Pinus mugo* subsp. *mugo* are a priority habitat that grows above the upper limit of beech forest and is very rare in the Central Apennines (only on the Majella and Monti della Meta massif), which is its southern distribution limit in Italy. In VIOLA, bushes with *Pinus mugo* subsp. *mugo* account for 3.9% of the relevés (63) with a mean plot size of 39.29 m^2 (S.D. 38.83). The number of taxa is 148, and the mean richness is 16.67 (S.D. 6.24) (see Tab. 1). The species richness in *Pinus mugo* bushes depends on vegetation cover with poor stands (average richness = 10 species) in closed formations and rich stands (average richness = 23 species) in open ones. Furthermore, *Pinus mugo* bushes include some focal species that are typical of this habitat in the Central Apennines, such as *Moneses uniflora* and *Epipactis atropurpurea* (Stanisci, 1997).

Alpine and subalpine calcareous grasslands (habitat 6170)

Alpine and subalpine calcareous grasslands are the most common habitat in the Central Apennines, growing above the tree line on carbonatic soil. In the study area, this habitat has a high heterogeneity and is characterized by the highest number of phytosociological alliances (*Arabidion caeruleae* Br.-Bl. in Br.-Bl. & Jenny 1926, *Cerastio tomentosi-Globularion meridionalis* Ciaschetti *et al.*, 2015, *Oxytropido-Kobresion myosuroidis* Rivas-Martinez *et al.*, 2002, *Ranunculo pollinensis-Nardion strictae* Bonin 1972, *Salicion herbaceae* Br.-Bl in Br.-Bl. & Jenny 1926 and *Seslerion apenninae* Bruno & Furnari 1966). However, in the Viola dataset, the dominant alliance is *Ranunculo pollinensis-Nardion strictae*, a typical formation of mesophilous grasslands of the high mountains on the Central Apennines. The highest percentage of the relevés contained in VIOLA belong to this habitat, accounting for 52.9% (847). The mean plot size is 32.42 m^2 (S.D. 29.67), and the total number of taxa is the highest among all of the habitats listed in the database, with 499 species. The mean richness is equal to 21.22 (S.D. 7.17). The most abundant species are *Poa alpina* subsp. *alpina*, *Carex kitaibeliana* subsp. *kitaibeliana*, *Sabulina verna* subsp. *verna*, *Armeria gracilis* subsp. *majel-*

lensis (see Tab. 1). The high species richness is due to the heterogeneous (morphological and microclimatic) conditions that characterize this habitat (Biondi *et al*., 1999; Blasi *et al*., 2003). Indeed, the presence of different environments, such as steep slopes, gentle slopes, plateau, dolines and ridges, with their typical species pool, contributes to the high overall species richness (Stanisci *et al*., 2010).

Semi-natural dry grasslands (habitat 6210)

This habitat is characterized by endemic plant communities and in the database is represented by one alliance, *Phleo ambigui-Bromion erecti* Biondi *et al*., 2012, characterized by xerophilous and meso-xerophilous grasslands that grow on calcareous substrates around and below the treeline zone. The percentage of relevés belonging to this habitat is 7.9% (127), the mean plot size is 43.60 (S.D. 29.18), the number of taxa is 354, and the mean richness is 26.07 (S.D. 6.85). The most abundant species are *Pilosella officinarum*, *Brachypodium genuense*, *Bromopsis erecta*, and *Festuca circunmediterranea* (see Tab. 1). This habitat has the highest species richness of all the habitats included in VIOLA and often hosts *Juniperus communis* shrubs.

Species-rich* Nardus *grasslands (habitat 6230*)

This habitat is rare in the Central Apennines and belongs to the alliance *Ranunculo pollinensis-Nardion strictae* Bonin 1972 characterized by mesophilous grasslands, where partial or complete soil decarbonation occurs. The percentage of plots belonging to this habitat is 2.2% (36), the mean plot size is 32.64 m^2 (S.D. 28.07), the number of taxa is 183, and the mean richness is 19.75 (S.D. 4.82). In these communities, the most abundant species is *Nardus stricta*, followed by other hemicryptophytes (e.g., *Potentilla rigoana*, *Brachypodium genuense*, and *Cerastium arvense* subsp. *suffruticosum*) (see Tab. 1). *Nardus*-dominated communities grow in gentle slopes and on the plateau of the subalpine belt and have a relatively high species richness compared to that of the other habitats in VIOLA. These plant communities are quite rare in VIOLA database and are represented by relevés sampled on the Gran Sasso (Furrer & Furnari, 1960; Bruno *et al*., 1965; Biondi *et al*., 1999); further relevés are available for other mountains of Central and Southern Apennines, which have not yet been included in the database.

Calcareous and calcshist screes (habitat 8120)

Habitat 8120 is characterized by calcareous and calcshist screes ranging from the montane to alpine belts. In VIOLA, three alliances occur in this habitat (*Linario-Festucion dimorphae* Avena & Bruno 1975, *Violo magellensis-Cerastion thomasii* Biondi *et al*. 2014 and *Petasition paradoxi* Zollitsch Ex Lippert 1966), but the *Linario-Festucion dimorphae*, which corresponds to glareicole communities developed on carbonatic screes, dominates. In addition to the alpine and sub-alpine calcareous grasslands, this habitat has the highest number of plots included in VIOLA, with a percentage of 20.3% (325); the mean plot size is 56.48 m^2 (S.D. 52.66), the number of taxa is 310, and the mean richness is 13.41 (S.D. 6.96).The dominant species are *Leucopoa dimorpha*, *Galium magellense*, *Poa alpina* subsp. *alpina* and *Doronicum columnae* (see Tab. 1).

Calcareous cliffs (habitat 8210)

This habitat corresponds to the vegetation of limestone cliffs in the Mediterranean alpine region. It is present in the VIOLA database with two alliance *Cystopteridion fragilis* Richard 1972 and *Saxifragion australis* Biondi & Ballelli ex Brullo 1984; the most represented in the database is the second alliance, which includes chasmophytic and sciaphilous communities growing on calcareous substrata. The percentage of plot stored in VIOLA is 5.2% (83 relevés), with a mean plot size of 11.36 m^2 (S.D. 14.10), which is the lowest among the considered habitats. The number of species is 162, and the mean species richness is 10.74 (S.D. 4.71), the lowest of the database set. The plant species that dominate this habitat are *Potentilla apennina* subsp. *apennina*, *Silene acaulis* subsp. *bryoides*, *Edraianthus graminifolius* subsp. *graminifolius* and *Saxifraga callosa* (see Tab. 1).

Growth forms and chorotypes

Our results highlight that stalked hemicryptophytes dominate in all the EU habitats stored in the database (e.g., *Campanula scheuchzeri*, *Myosotis graui*, *Ranunculus pollinensis*, *Viola eugeniae* subsp. *eugeniae*) and are widespread in natural and semi-natural grasslands (habitat 6170, 6210 and 6230), where snow cover persists for 5-6 months, and in temperate land and shrubs (habitat 4060 and 4070*) and decrease according to the elevation (Fig. 3). This growth form is very common in VIOLA together with caespitose hemicryptophytes and hemicryptophytes with rosette (e.g., *Armeria gracilis* subsp. *majellensis*, *Carex kitaibeliana* subsp. *kitaibeliana*, *Helictochloa praetutiana*, and *Poa alpina* subsp. *alpina*). Stalked hemicryptophytes are widespread in the subalpine/alpine belts of the Central Apennines and tend to expand probably due to climate warming (Evangelista *et al*., 2016; Frate *et al*., 2016).

Dwarf shrubs (i.e., fruticose chamaephytes and reptant chamaephytes e.g. *Cerastium tomentosum* and *Edraianthus graminifolius* subsp. *graminifolius*) (Fig. 3) are also quite common growth forms, especially in Alpine and boreal heaths (4060), in Calcareous and calcshist screes (8120) and in Calcareous rocky slopes (8210). Moreover, a high frequency of dwarf shrubs is present in Bushes with *Pinus mugo* subsp. *mugo* (habitat 4070*). Furthermore, cushion chamaephytes, succulent

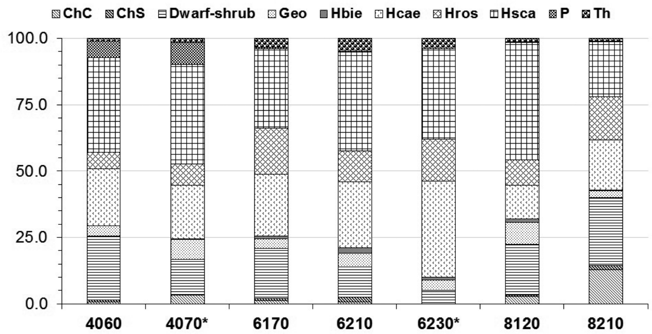

Fig. 3 - EU habitat growth form frequency spectra. ChC: cushion chamaephytes; ChS: succulent chamaephytes; Dwarf-shrub: assemblage of fruticose chamaephytes, reptant chamaephytes and nano-phanerophytes; Geo: Geophytes; Hbie: biennial hemicryptophytes; Hcae: caespitose hemicryptophytes; Hros: hemicryptophytes with rosette; Hsca: stalked hemicryptophytes; P: phanerophytes; Th: therophytes.

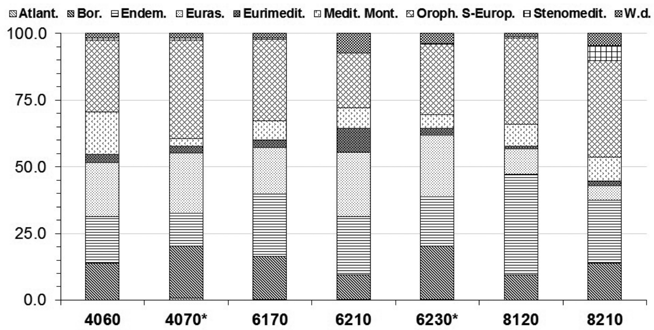

Fig. 4 - EU habitat chorotype frequency spectra. Atlant.: Atlantic, Bor.: Boreal, Endem.: Endemic, Euras.: Eurasian, Eurimedit.: Euri-Mediterranean, Medit. Mont.: Mediterranean Montane, Oroph. S-Europ.: South European Orophilous, Stenomedit.: Steno-Mediterranean, W.d.: Wide distribution.

chamaephytes, geophytes, and therophytes are distributed with similar proportions in the different habitats.

The chorotypes tend to be equally allocated between the seven EU habitats (Fig. 4), but the dominating chorotype is the Southern-Europe Orophilous. These species (mostly stalked hemicryptophytes) are generally distributed in the montane and alpine belts of Southern Europe (including the Central Apennines). Particular focus should be given to Endemic species as their high percentages are closely related to the highly fragmentary character of the alpine bioclimatic belt that, in the Central Apennines, consists of "orographic islands", which have promoted isolation and speciation processes (Di Pietro *et al*., 2008).

The percentage of endemics, calculated by comparing the sum of endemic species to the total sum of taxa recorded for each EU habitats is highest in Calcareous and calcshist screes (8210 - 14.2%), followed by Calcareous rocky slopes (8120 - 23.5%) and Alpine and subalpine calcareous grasslands (6170 - 23.2%). In general, the percent of endemic species in Central Apennines (13%) is comparable to that of other mountain systems in Europe, such as the Pyrenees (13%), the Carpathians (12%) and the Eastern Alps (13%) (Conti *et al*., 2007b). As already known, the percentage of endemism increases with altitude (Catonica & Manzi, 2002), and the mean endemic species richness significantly increases in scree and cliff environments (Stanisci *et al*., 2010; Pirone & Frattaroli, 2011). The high-mountain sector in the Central Apennines includes important endemic species, such as *Adonis distorta*, *Androsace mathildae*, *Myosotis graui*, *Papaver alpinum* subsp. *ernesti-mayeri*, *Viola magellensis* and many more (Conti *et al*., 2007b). Moreover, some of these, such as *Adonis distorta* and *Androsace mathildae*, are listed in the Annex II of the Habitats Directive (92/43/EEC) due to their rare status.

Conservation implications

Most of the high-mountain plant communities in the Central Apennines are of European conservation concern. Indeed, 98% of VIOLA's relevés refer to Annex I EU habitats. The Alpine and subalpine calcareous grassland (6170) and the Calcareous and calcshist screes (8120), with over 50% and almost 20% of the relevés, respectively, are the most represented habitats in the database.

The Alpine and subalpine grasslands (6170) are very abundant and widespread in the sampled high elevation ecosystems. Their distribution is mainly related with the presence of summit plateaux, gentle slopes and steep slopes, which promote the growth of many grassland specialists (*Poa alpina* subsp. *alpina*, *Carex kitaibeliana* subsp. *kitaibeliana*, and *Armeria gracilis* subsp. *majellensis*). The habitat 6170 is distributed in a complex environmental mosaic occurring along an extensive elevation gradient (1,800-2,800 m a.s.l.) and includes both alpine and subalpine grasslands, each with a specific response to anthropogenic global change. The effects of global warming seems to be weaker on subalpine grasslands than on alpine communities. In particular, *Sesleria juncifolia* grassland forms a dense community with high competition levels for light and soil resources, which limit the colonization of new species (Frate *et al*., 2016). In addition, the presence of a rich pool of stress-tolerant species particularly adapted to cope with the current effect of global warming gives to subalpine grasslands a large temporal inertia and allows them to tolerate an increase in temperature of up 1-2°C (Theurillat & Guisan, 2001). However, frequent exceptional drought events may accelerate community changes by opening gaps for new species (Vittoz *et al*., 2009). On the other hand, alpine grasslands in the study area are quite sensitive to global warming, and susceptible to the thermophilization (Gottfried *et al*., 2012; Pauli *et al*., 2012; Stanisci *et al*., 2016a). Recent

Tab. 1 - Main features of the EU habitats included in VIOLA. For each EU habitats in VIOLA database we reported: N: number of relevés; %: percentage of total number of relevés; Area m^2 (S.D.): mean plot size; S.D.: Standard deviation; ISPRA: minimum plot size suggested by Angelini *et al*., 2016 for monitoring EU habitats, S: total number of species; Smean (S.D.): Mean richness per plot; S.D.: Standard deviation; Most abundant: most abundant species; Endemics: total number of endemics; % Endemics: percentage of endemics on total flora; N. Alliances: number of alliances; Alliance: Most frequent phytosociological alliance. 4060: Alpine and Boreal heaths; 4070*: Bushes with *Pinus mugo*; 6170: Alpine and subalpine calcareous grasslands; 6210: Semi-natural dry grasslands, 6230*: *Nardus* grasslands; 8120: Calcareous and calcshist screes; 8210: Calcareous rocky slopes (* = priority habitat). The table is based on the 1602 relevés currently harmonized for taxa nomenclature.

HABITAT	RELEVÈS				SPECIES					PHYTOSOCIOLOGICAL ALLIANCE	
	N	%	Area m^2 (S.D.)	ISPRA	S	S mean (S.D.)	Most abundant	Endemics	% Endemics	N. Alliances	Alliance
4060	87	5.4	43.60 (29.18)	25-50	196	18.33 (7.43)	*Juniperus communis, Brachypodium genuense, Globularia meridionalis, Daphne oleoides*	23	11.7	1	*Daphno oleoidis-Juniperion alpinae* Stanisci 1997
4070*	63	3.9	46.14 (31.40)	50-100	148	16.67 (6.24)	*Pinus mugo* subsp. *mugo, Phyteuma orbiculare, Campanula scheuchzeri* subsp. *scheuchzeri, Leucopoa dimorpha*	15	10.1	1	*Epipactido atropurpureae-Pinion mugo* Stanisci 1997
6170	847	52.9	32.42 (29.87)	10-20	499	21.22 (7.17)	*Poa alpina* subsp. *alpina, Carex kitaibeliana* subsp. *kitaibeliana, Sabulina verna* subsp. *verna, Armeria gracilis* subsp.*majellensis*	74	14.8	6	*Ranunculo pollinensis-Nardion strictae* Bonin 1972; *Seslerion apenninae* Bruno & Furnari 1966
6210	127	7.9	43.60 (29.18)	16	354	26.07 (6.85)	*Pilosella officinarum, Brachypodium genuense, Bromopsis erecta, Festuca circunmediterranea*	48	13.6	1	*Phleo ambigui-Bromion erecti* Biondi *et al.* 2012
6230*	36	2.2	32.64 (28.07)	16	183	19.75 (4.82)	*Nardus stricta, Potentilla rigoana, Brachypodium genuense, Cerastium arvense* subsp. *suffruticosum*	20	10.9	1	*Ranunculo pollinensis-Nardion strictae* Bonin 1972
8120	325	20.3	56.48 (52.66)	16-20	310	13.41 (6.96)	*Leucopoa dimorpha, Galium magellense, Poa alpina* subsp. *alpina, Doronicum columnaea*	44	14.2	3	*Linario-Festucion dimorphae* Avena & Bruno 1975; *Violo magellensis-Cerastion thomasii* Biondi *et al.* 2014
8210	84	5.2	11.36 (14.10)	9-16	162	10.74 (4.71)	*Potentilla apennina* subsp. *apennina, Silene acaulis* subsp. *bryoides, Edraianthus graminifolius* subsp. *graminifolius, Saxifraga callosa*	35	21.6	2	*Saxifragion australis* Biondi & Ballelli ex Brullo 1984
Habitat not assigned	33	2.1	27.24 (28.52)		72	12.27 (3.81)	*Poa alpina* subsp. *alpina*, *Polygonum aviculare*, *Urtica dioica* subsp. *dioica*, *Trifolium repens* subsp. *repens*	12	18.1	5	Nitrophilous vegetation

short-term temporal analysis on alpine grasslands in central Apennines found a significant decline of some cryophilic species, typical of ridges, including *Viola magellensis* and *Silene acaulis* subsp. *bryoides*, whereas thermophilous species (subalpine and treeline), such as *Minuartia verna* subsp. *verna*, *Ranunculus pollinensis*, *Armeria gracilis* subsp. *majellensis* and *Carex kitaibeliana* subsp. *kitaibeliana*, had increased in frequency (Evangelista *et al*., 2016). In this context VIOLA, containing long term georeferenced relevés that conforms to the national and international protocols for monitoring these habitats, offers an exceptional tool for nature management purposes and for planning new re-visitation studies that could converge on a wider long-term monitoring network. Semi-natural dry grasslands (6210) are characterized by a high number of species and are particularly rich in endemics but at the same time are highly threatened by land use change. In particular, the abandonment of traditional grazing activities in the Central Apennines, promotes scrubland encroachment, which substitutes seminatural grasslands with significant consequences for biodiversity (Allegrezza *et al*., 2016). In such context, VIOLA provides a sound basis for analysing and determining the effect of these threats. Alpine and boreal heaths (4060) and Bushes with Pinus mugo (4070*) are poor in species but host some exclusive taxa that make them habitats of particular interest for species conservation. In recent decades, shrubland habitats in high mountain areas experienced a natural expansion due to the cessation, in many areas, of grazing and silvicultural practices (Palombo *et al*., 2013; Campagnaro *et al*., 2017). This process lead to an increase in the cover of shrubs and woody species and the exclusion of grasslands species with a serious reduction in the total number of species. VIOLA, with relevés collected over six decades, offers detailed information about the upward shifting of shrubland communities and their effect on alpine and subalpine grassland biodiversity. Such information might be used for improving management strategies aimed at reducing the negative effects of land use change on natural ecosystems.

In the Central Apennines, the vegetation of calcareous screes (8120) with a rich contingent of endemic species is also quite frequent. This habitat, growing under harsh environmental conditions, has been only slightly affected by direct human pressure and could be considered a good arena for performing specific studies on the ecological effects of global warming on native undisturbed ecosystems using multi-temporal relevés. The less widespread cliffs and screes (8120 and 8210), whose data in the database mainly derive from Gran Sasso and Majella massifs, are very important for conservation purposes. In particular, the percentage of endemic species of the total species pool is higher in scree and cliff habitats because they contain a high proportion of cryophilous elements, most of them locally endemic or with a disjoined distribution in the Mediterranean orobiome (Conti *et al*., 2007b; Stanisci *et al*., 2010). VIOLA can be a valuable tool for analysing and monitoring the habitat preference of endemic and rare plant species in the upper belts of the Apennines, which are expected to be the most sensitive to the effect of climate change compared to other Mediterranean high mountains (Pauli *et al*., 2012).

Conclusions

VIOLA is the first standardized and accessible database describing Mediterranean high-elevation vegetation in Italy. The information contained in VIOLA offers an excellent overview of the diversity of Mediterranean high-mountain habitats in the Central Apennines and, therefore, can be a valuable tool for nature conservation issues and for ecological monitoring. This type of information is fundamental, for example, in the context of the application of Habitats Directive. Indeed, the European Union requires the member states to report periodically on the conservation status and changes within EU habitat types. Thus, the detailed information included in VIOLA, with its 1687 relevés and more than 670 taxa collected over the last six decades, offers a basis for starting several monitoring and research programs aimed at improving our knowledge about the potential impacts of global change (i.e., land-use change and climate change) and for identifying efficient conservation strategies for high mountain ecosystems. In addition, it can serve to identify hot spots of biodiversity and/or to identify less explored sites, thus guiding management strategies and monitoring site distribution. On the other hand, the use of a large vegetation database gravely affected by the spatial distribution of data (Haveman & Janssen, 2008) and the reliability of the results could be increased when implementing taxonomic harmonization and improving the stratified resampling procedure.

In summary, we are confident that the use of large vegetation databases, such as the here-presented VIOLA, represents a good tool for many future studies at the local, regional and European scale for flora, vegetation and habitats of the Directive 92/43/EEC.

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Appendix I: Distribution of phytosociological relevés contained in the VIOLA according to their EU habitats assingmetn. The complete list of relevés references is also provided

References	4060	4070	6170	6210	6230	8120	8210	no habitat	TOT.
Furrer & Furnari 1960			49	6	3	19		6	83
Bruno *et al.* 1965			22	1	2	2			27
Migliaccio 1966		18							18
Feoli & Feoli-Chiapella 1976							11		11
Feoli-Chiapella & Feoli 1977			28			31			59
Bonin 1978			29			7			36
Feoli-Chiapella 1983						33			33
Petriccione 1988		7							7
Blasi *et al.* 1990				2					2
Conti & Manzi 1992						14			14
Petriccione 1993	23		72	18	3	18	5		139
Petriccione 1993 (unpublished relevés)			4						4
Tammaro 1995	2		8	4		10	4	4	32
Stanisci 1997	50	38							88
Ballelli 1999						6			6
Biondi *et al.* 1999	12		59	20	18	30	11	23	173
Biondi *et al.* 2000			32			13			45
Catonica 2001			11	4					15
Pirone & De Nuntiis 2002							14		14
Blasi *et al.* 2003			79			17	17		113
Di Pietro *et al.* 2004				9		37			46
Blasi *et al.* 2005			78		2	14			94
Di Pietro *et al.* 2005			25	9	8				42
Pelino *et al.* 2005			154			43	10		207
Giancola *et al.* 2007			144	54		19	12		229
Di Pietro *et al.* 2008			7			8			15
Lancioni *et al.* 2011			3						3
Ciaschetti *et al.* 2015			14						14
Evangelista *et al.* 2016			29			4			33
SUBTOTAL	87	63	847	127	36	325	84	33	1602

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