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RESEARCH PAPER

Relevant but neglected habitat types by the Directive 92/43 EEC in southern Italy

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Abstract
The 92/43/EEC Habitats Directive is the main European Union legal tool concerning nature conservation. The habitat types listed in Annex I to the Directive are phytosociology-based. It is widely acknowledged that phytosociological analysis is a crucial approach for habitats characterization and for monitoring their conservation status. Based on bibliographic investigations and new field survey campaigns, a list of habitat types neglected by the Habitats Directive is here presented and described for southern Italy. In this paper, 8 new habitat types and 13 subtypes are proposed. For each of these proposed new habitat types, a wide range of information, including ecology, chorology, species composition, syntaxonomy, threats, and conservation status, is here provided. To supply more detailed phytogeographical and coenological information about the proposed new habitat types, distribution maps based on 10 × 10 km reference grids and phytosociological tables including unpublished relevés were carried out.

Keywords Habitats Directive · Annex I · Biodiversity conservation · Endemic species · Rare plants · Plant conservation

Abbreviation
HD 92/43/EEC "Habitat Directive"

1 Introduction

The Habitats Directive (Dir. 92/43/EEC, hereafter HD) is the main European Union (EU) legal tool concerning nature conservation (European Commission 1992, 2013). It defines plant and animal species, and natural and semi-natural habitat types of Community importance, listed in the Directive's Annexes, relevant to biodiversity conservation.

Correctly identifying of habitat types is a fundamental prerequisite for setting up adequate management policies and adopting biodiversity conservation measures. Habitat types of European Community importance listed in Annex I of the HD are primarily identified on a phytosociological basis, and mainly characterized by their floristic and geographic features (Evans 2006; Biondi et al. 2009, 2012). The use of phytosociology for the analysis and interpretation of habitat types is a widely established methodology (Loidi et al. 2007; Angelini et al. 2016; Tomaselli et al. 2016; Attorre et al. 2018; Stinca et al. 2020; Cano Carmona et al. 2022). In fact, the HD explicitly refers to the phytosociological syntaxa for the identification of the habitat types of community interest included in Annex I and described in the European interpretation manual (latest version EUR/28, European Commission 2013). The phytosociological classification, thanks to a synthetic approach that considers floristic, biogeographic, ecological, and syndynamic (successional-serial) features of plant communities, is probably the most complete framework available, to classify such a complex system as the list of European habitat types (Loidi et al. 2010). A standardized

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phytosociological reference for all the Annex I Habitats of the HD recognized in the Italian territory is provided by Biondi et al. (2012).

One of the basic principles on which the HD is based is that the maintenance of habitats in a good conservation status is the best way to conserve animal and plant species (Lengyel et al. 2008; Bunce et al. 2008; Henle et al. 2013; Evangelista et al. 2016; Hoffmann et al. 2018). The EU has recently launched a new Biodiversity Strategy intended to create Protected Areas for 30% of its land and sea territory by 2030 and ensure no deterioration in conservation trends and status of protected species and habitats (European Commission 2020), with the consequent estimation of important economic investments in this direction (Mammola et al. 2020). Consequently, it becomes important to invest in Protected Areas and their enhancement. Since in the EU, the main network of protected areas is represented by the Natura 2000 network (often considered one of the most important and largest conservation networks worldwide; Lockwood 2006), it becomes a crucial issue to operate in the sense of its strengthening and also in the integration and amending the HD Annexes (e.g., greater flexibility of the lists of species and habitat types in the Annexes; Hochkirch et al. 2013; Maes et al. 2013).

The HD defines natural habitat types of community interest as those that (i) are in danger of disappearance in their natural range; (ii) have a small natural range following their regression or by reason of their intrinsically restricted area; (iii) present outstanding examples of typical characteristics of one or more of the nine following biogeographic regions: Alpine, Atlantic, Black Sea, Boreal, Continental, Macaronesian, Mediterranean, Pannonian, and Steppic (Article, current consolidated version: 01/07/2013—https://eur-lex.europa.eu). In the same article is reported that "such habitat types are listed or may be listed in Annex I", highlighting that the list of habitat types is not comprehensive. Moreover, several authors have pointed up that there are some habitats which do not appear in Annex I but which probably fall within the definition of 'habitats of community interest' (e.g., Evans 2006). Therefore, in this paper, it is proposed to integrate the Annex I with those habitat types falling within the study area and which are of Community interest, as defined in Article 1c. Many contributions have focused on the effectiveness of the HD in protecting biodiversity, especially in terms of species, highlighting the presence of gaps, that is on how the Natura 2000 ecological network is effective in covering target species and minimizing the number of gap species (i.e., species not represented in a single site of the Natura 2000 network) (Cardoso 2012; Gruber et al. 2012; Trochet and Schmeller 2013). Numerous authors have also focused on the several gaps in the protection of plant communities by the HD (Petermann and Ssymank 2007; Rosati et al. 2008; Hochkirch et al. 2013; Tomaselli et al. 2012; Angiolini et al. 2017; Spampinato et al. 2018). Many of these gaps concern wetlands and humid environments, but others concern forest environments, open grasslands, shrubland, and garrigues (Quinto-Canas et al. 2018; Spampinato et al. 2018; Cano-Ortiz et al. 2021). Moreover, some habitat type diagnoses in the HD interpretation manual may lead to problems of identification or inaccuracies in the description of local southern European habitat types being the original description focused on central-northern European communities (Feola et al. 2011; Biondi et al. 2009, 2012).

The list of habitat types included in Annex I to the HD has been progressively implemented by the accession of new Member States, with the latest in 2013 (Croatia). However, despite the significant production of vegetation studies in the last 30 years throughout Europe, and notwithstanding the awareness of the occurrence of significant gaps in the list of protected vegetation types, neither amendments nor additions have been adopted so far. During the drawing up of the "Italian Interpretation Manual of the Dir. 92/43/EEC", the need to consider possible new habitat types of community interest to be proposed as relevant for updating the current nature conservation framework in the Mediterranean bioregion clearly emerged (Biondi et al. 2012). To fill this knowledge gap, in the framework of the third report on the monitoring of species and habitats of the EEC directive 42/93, Biondi et al. (2014c) highlighted the need to consider new habitat types to be included in Annex I to the Directive and provided descriptive data sheets. More recently, new habitat types or new subtypes have recently been proposed for central Italy (Casavecchia et al. 2021), Sardinia (Fois et al. 2021), and Sicily (Guarino et al. 2021). In this paper, new habitat types suitable to be included in HD are proposed and described for southern Italy based on the expert knowledge of the authors and supported by both relevant phytosociological literature and new field investigations. The new habitat types proposed are characterized by plant communities hosting several species of conservation concern (e.g., rare, endemic, and endangered species or species included in international protection standards).

2 Study area

Southern Italy is a part of the Italian peninsula, which extends from 42°04′16″ to 37°54′59″ N in latitude, from 13°45′45″ to 18°31′13″ E in longitude, and which can be broadly defined by the following administrative regions: Molise, Apulia, Campania, Basilicata, and Calabria (Fig. 1).

It covers a total area of 62966 km^2, with 2256 km of coastline lapped by the Tyrrhenian, Ionian, and Adriatic seas. The altitude range of the study area spans from the sea level to 2267 m a.s.l. of Serra Dolcedorme, which is the

Fig. 1 Southern Italy: study area with borders of administrative regions

highest peak of the Pollino massif, and it is located in the North of the Calabria region.

Southern Italy is particularly heterogeneous from both lithological and geomorphological point of view. The backbone of the southern Apennines, from the Matese Mountains to the Pollino massif, is mainly characterized by limestone–dolomitic rocks, generally intensely fractured and karstified. In the Daunian sub-Apennines, there is a prevalence of marls and pelithic–arenaceous flysch substrates. The Calabrian Arc exhibits a varied geological feature with granite and gneiss (Sila massif), predominant granite rocks (Serre), and prevalent gneiss (Aspromonte). Sedimentary deposits emerge along the Ionian edge, while the Campania Tyrrhenian area is characterized by volcanic activity (e.g., Vesuvio, Campi Flegrei) and by large depressions and alluvial plains (Campania plain and Sele plain). The area between the southern Apennines and Apulia is occupied by the "Bradanica" foreland, developing NW–SE and consisting of sedimentary rocks, as well as in Ionian Basilicata. At last, the most of Apulia consists of an extensive carbonatic platform including Gargano promontory, Murge plateau and Salento (Budetta et al. 1993).

The southern Apennines almost entirely falls within the Mediterranean macrobioclimate, with some important enclaves of Temperate macrobioclimate (e.g., the high-altitude areas of the main Apennine massifs) and few scattered areas of the Gargano promontory and Murgian plateau (Rivas-Martínez et al. 2004; Blasi and Michetti 2005). Bioclimates range from Mediterranean Pluviseasonal Oceanic to Temperate Oceanic (mainly in the submediterranean variant). Thermotypes are from lower thermomediterranean (southern Calabria and Apulia, as well as coastal areas of Campania and Basilicata) to upper supramediterranean (in Mediterranean macrobioclimate), whereas in Temperate, macrobioclimate thermotypes range from upper thermotemperate (inner hilly areas of Apennines and some areas of Gargano) to lower upper orotemperate (e.g., Pollino). Ombrotypes range from lower dry to lower hyperhumid (Rivas-Martínez et al. 2011; Pesaresi et al. 2014). The bioclimatic and geomorphologic features of southern Italy lead to remarkable floristic (Stinca et al. 2019, 2021) and phytocoenotic diversity, as emphasized by the presence of several alliances and sub-alliances endemic to this territory (Spampinato 2009a).

3 Materials and methods

The identification of habitat types neglected by HD in southern Italy was based on field investigation supported by vegetation surveys (see Online Resource 1) carried out with the Braun-Blanquet phytosociological approach (Braun-Blanquet 1964), and on careful analysis of phytosociological and geobotanical literature (see Online Resource 2). Detailed information on date and localities, coordinates, environmental data, and authors of the original relevés are reported in Online Resource 3. For each habitat, the table containing the relevés used for classification is given (Online Resource 1); the number of relevés, their area (average, maximum, and minimum) and the average number of species are also specified. Habitat description, syntaxonomic classification, and diagnostic species designation were based on field and bibliographic data.

Plant nomenclature follows the checklist of Italian vascular flora (Bartolucci et al. 2018) and the updates available on the information system "FlorItaly-Portal to the Flora of Italy" (2022), Pignatti et al. (2017–2019), and Aleffi et al. (2020) for Bryophytes. Syntaxonomic nomenclature, at the levels of alliance, order, and class, refers to the Italian Vegetation Prodrome (Biondi et al. 2014b). Reference was made also to the Checklist of European vegetation (Mucina et al. 2016) for those habitat types whose syntaxonomic classification is still controversial at European level and for the identification or coenological interpretation of the habitat types considered. Bioclimatic classification is in accordance with Pesaresi et al. (2014).

For each neglected habitat type identified, the following data were provided: name, macrocategory, correspondence with other habitat classification systems (EUNIS, CORINE

Biotopes), description, closest habitat types already included in the Annex I to the HD, biogeographic, ecological and conservation importance, subtypes and variants (if any), diagnostic species, phytosociological reference, successional stages and spatial contacts, distribution, and possible threats. Species of conservation concern (e.g., Red List, rare, endemic, at the limits of distribution area) were also highlighted. Threats and Pressures were identified and coded as reported under Article 17 of the Habitats Directive (Eionet 2022; first reference in brackets), and also according to the IUCN-CMP Classification of Threats (IUCN-CMP 2012; the second reference). We assessed the protection status of neglected habitats by analyzing the distribution of each site in the Natura 2000 Network and in the Italian protected areas (National and Regional Parks, State and Regional Reserves).

The graphical processing of the distribution maps was carried out using the open-source software ©QGIS 3.26.3 Buenos Aires.

4 Results

Mediterranean helophytic sub-halophilous meadows

Macrocategory: 14 Mediterranean and thermo-Atlantic saltmarshes and salt meadows.

Correspondence with other habitat classification systems

EUNIS: A2.5d—Mediterranean and Black Sea coastal salt marsh; A2.53C—Saline beds of *Phragmites australis*; A2.53D—Geolittoral wetlands and meadows: saline and brackish reed, rush and sedge stands; A5.541—Vegetation of brackish waters dominated by *Phragmites australis*; C3.2—Water-fringing reedbeds and tall helophytes other than canes.

CORINE Biotopes: 53.11—Common reed beds; 53.17—Halophile clubrush beds.

Description. Mediterranean helophytic sub-halophilous plant communities belonging to the *Scirpion maritimi* alliance (*Bolboschoenetalia maritimi* (=*Scirpetalia compacti*), *Phragmito-Magnocaricetea*) and partly to the *Phragmition communis* (*Phragmitetalia*, *Phragmito-Magnocaricetea*), growing in coastal areas, usually in correspondence of areas behind the dunes and river mouths, on soils flooded by brackish waters for medium–long periods.

Closest habitat types of the Annex I

1410: Mediterranean salt meadows (*Juncetalia maritimi*).

7210: Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae.*

Importance. These plant communities often provide essential habitat for wildlife; moreover, they act as very important resting, feeding, and nesting sites for many bird species (Martínez-Vilalta et al. 2002; Orłowski and Górka 2013). The dominant species of these vegetation types are widespread and have no special conservation value, with some exceptions (see below).

Subtypes and variants. Three subtypes of this habitat type can be distinguished:

(a) communities dominated by tall rushes and sedges (*Bolboschoenus maritimus*);
(b) communities dominated by small rushes and sedges (*Cyperus distachyos*);
(c) subalophilous reedbeds (*Phragmites australis* subsp. *australis*) of the mouth of Mediterranean rivers and of the back-dune lagoons.

Diagnostic species. Dominant and frequent species: *Bolboschoenus maritimus*, *Phragmites australis* subsp. *australis*, *Schoenoplectus litoralis*, *Typha angustifolia*. Species of conservation interest: *Cyperus distachyos*, *Ipomoea sagittata*.

Phytosociological reference. (Tab. 1, 16 relevés, area: mean 55 m^2, minimum 20 m^2, maximum 100 m^2, mean number of species: 6; Online Resource 1) *Cyperetum distachyi* Bolòs & Molinier 1984, *Phragmitetum communis* (Koch 1926) Schmale 1939, *Scirpetum maritimi* (Christiansen 1934) R. Tx. 1937, *Scirpetum maritimo-litoralis* (Br.-Bl. in Br.-Bl., Roussine & Nègre 1952) O. de Bolòs 1962.

Dynamics and contacts. The plant communities included in this habitat type are stable edapho-hygrophilous formations, conditioned by various ecological factors, including salinity and water availability. They are in spatial contact with vegetation types belonging to *Juncetea maritimi* (habitat 1410), *Salicornietea fruticosae* (habitat 1420), as well as *Saginetea maritimae* and *Therosalicornietea* (habitat 1310), in some cases forming complex mosaics (Maiorca et al. 2002, 2007; Giusso del Galdo et al. 2008; Tomaselli et al. 2011, 2020; Sciandrello and Tomaselli 2014).

Distribution. Coastal areas of all the regions falling in the study area (Corbetta 1970; Gehu and Biondi 1988; Taffetani and Biondi 1989; Corbetta et al. 1992; Maiorca et al. 2002, 2007; Tomaselli et al. 2008, 2011; Spampinato et al. 2019b; Tomaselli and Sciandrello 2017; Veronico et al. 2017) (Fig. 2; Fig. 3; Tab. 2; Online Resource 2). The distribution of this habitat type extends to other territories within the Mediterranean basin and in the Temperate bioregions of Europe (Landucci et al. 2020; Sarika et al. 2016; Stešević et al. 2019).

Pressures and threats. Abstraction of surface and ground water, as well as modification of the water regime (C14—7.2) are the main threats. Land drainage and reclamation for agriculture (A31—2.1) and also water-borne pollutants from agricultural, silvicultural, and aquaculture systems (A26, B23—9.3) may also heavily affect this habitat type. Mediterranean coastal salt marsh is assessed as

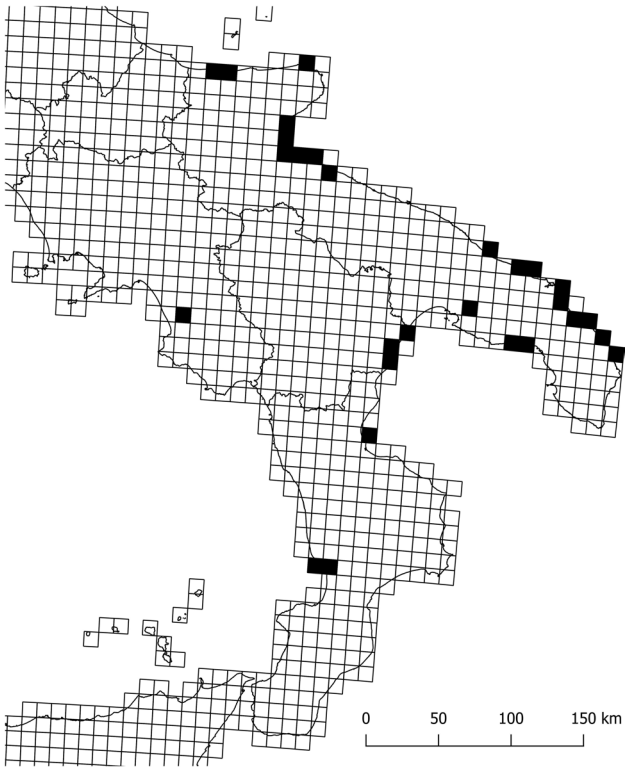

Fig. 2 Distribution of Mediterranean helophytic sub-halophilous meadows

Fig. 3 *Bolboschoenus maritimus* communities (Puglia)

Near Threatened (NT) in the European Red List of Habitats (Janssen et al. 2016).

Streams and springs of the southern Apennines and Sicily

Macrocategory: 32 Running water.

Correspondence with other habitat classification systems

EUNIS Classification: C2.11—Soft water springs; C2.16—Crenal streams (spring brooks).

CORINE Biotopes: 24.11—Springs and rivulets.

Description. Springs, brooks, little streams, or small watercourses of the southern Apennines and Sicily mountains with acid or neutral water, oligotrophic to slightly eutrophic, non-calcareous, permanently flowing but not swirling, with high stability in temperature, near the annual average of the groundwater.

Closest habitat types of the Annex I

3260: Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation.

7160: Fennoscandian mineral-rich springs and springfens.

Importance. The relevance of this habitat type had already been reported during the monitoring activities on habitat types of community interest in Italy for the "3rd National Report on the Habitats Directive" (Biondi et al. 2014c) and in the "Italian interpretation Manual of the habitats Directive" (Spampinato 2009b).

The markedly humid environmental conditions, characterized by more or less slowly flowing and well-oxygenated waters, allow the presence of hygrophilous herbaceous communities that host various species of biogeographic importance.

This habitat type hosts several endangered endemic hygrophilous vascular plants, such as *Soldanella calabrella*, *Cryptotaenia thomasii*, and *Petagnaea gussonei*, the latter being the only known species of *Petagnea*, a genus of the *Apiaceae*, phylogenetically isolated and restricted to the Nebrodi Mountains in north-eastern Sicily (De Castro et al. 2013; Bellino et al. 2015; Stinca et al. 2019; Stinca and Ricciardi 2019; Orsenigo et al. 2020).

In a study on the bryophytic flora of the Aspromonte streams, Puglisi et al. (2021) highlighted a set of species of phytogeographical interest that play an important role in this habitat type as *Racomitrium aciculare*, *Dichodontium pellucidum*, *Chiloscyphus pallescens* var. *pallescens*, *Philonotis capillaris*, rare in the south Italy, *Diobelonella palustris*, *Calypogeia sphagnicola*, these last two species very rare in the Mediterranean.

The brooks are the breeding site for some amphibians of the Apennine Range, including the endemic *Salamandra salamandra giglioli* and *Salamandrina terdigitata*, both included among the endangered species of fauna (Bulgarini et al. 1998).

Europe's peninsulas protruding into the Mediterranean, such as southern Italy, with their high diversity in habitats, have been refuge areas for many species during the Quaternary (Médail and Diadema 2009). Streams and springs are climatically stable habitats and provide a refuge for species

of high conservation priority. They are crucial for the long-term persistence of species and genetic diversity, especially in light of the threat posed by climate change. Zhang et al. (2001) highlight that *Soldanella* species growing in this habitat experienced different cycles of range expansion and contraction during late Quaternary climatic changes. This process probably affected many of the endemic species that inhabit southern Apennines' streams and springs.

Subtypes and variants. Two subtypes of this habitat type can be distinguished:

(a) oligotrophic waters subtype (*Montio-Cardaminetea*);
(b) mesotrophic waters subtype (*Galio-Urticetea*).

Diagnostic species. Dominant and frequent species. Vascular plants: *Athyrium filix-femina*, *Cardamine flexuosa*, *Carex remota*, *Chrysosplenium dubium*, *Lysimachia nemorum*, *Rhynchocorys elephas*, *Sagina saginoides*. Bryophytes: *Philonotis fontana*, *Ptychostomum pseudotriquetrum*, *Pellia epiphylla*, *Phaeoceros laevis*. Species of conservation interest: Vascular plants: *Alchemilla austroitalica*, *Adenostyles alpina* subsp. *macrocephala*, *Cardamine silana*, *Cryptotaenia thomasii*, *Digitalis purpurea*, *Petagnaea gussonei*, *Senecio ovatus* subsp. *stabianus*, *Soldanella calabrella*, *Soldanella sacra*. Bryophytes: *Sciuro-hypnum plumosum*, *Scapania undulata*, *Racomitrium aciculare*, and *Dichodontium pellucidum*.

Phytosociological reference. Streams and springs of southern Italy host different plant communities depending on the variation of the main ecological factors, such as light and nutrient availability (Codogno et al. 1984; Maiorca and Spampinato 1999; Brullo et al. 2001). The plant communities growing in the upper part of streams (Tab. 3; 9 relevés, area: mean 16 m^2, minimum 10 m^2, maximum 20 m^2; mean number of species: 11; Online Resource 1), between 1400 and 1800 m a.s.l., such as *Adenostylo-Soldanelletum calabrellae* (plant community with *Soldanella calabrella* growing on small humid rocky walls along mountain streams of Aspromonte and Sila) and *Rhynchocoryto-Alchemilletum austroitalicae* (localized phytocoenosis near small waterfalls or water jumps), are referred to the *Caricion remotae* alliance.

The communities growing in mountain streams with mesotrophic waters located between 900 and 1900 m a.s.l., such as the *Chrysosplenio-Cryptotaenietum thomasii*, *Digitali purpureae-Urticetum dioicae*, and *Petasito-Chaerophylletum calabrici*, are referred to the *Impatienti noli-tangere-Stachyion sylvaticae*.

The same alliance also includes *Petagnaetum gussonei*, a nemoral plant community rich in mosses which occurs on the humid shady sides of the northern Sicily Mountain streams only (Brullo and Grillo 1978; Gianguzzi and La Mantia 2004).

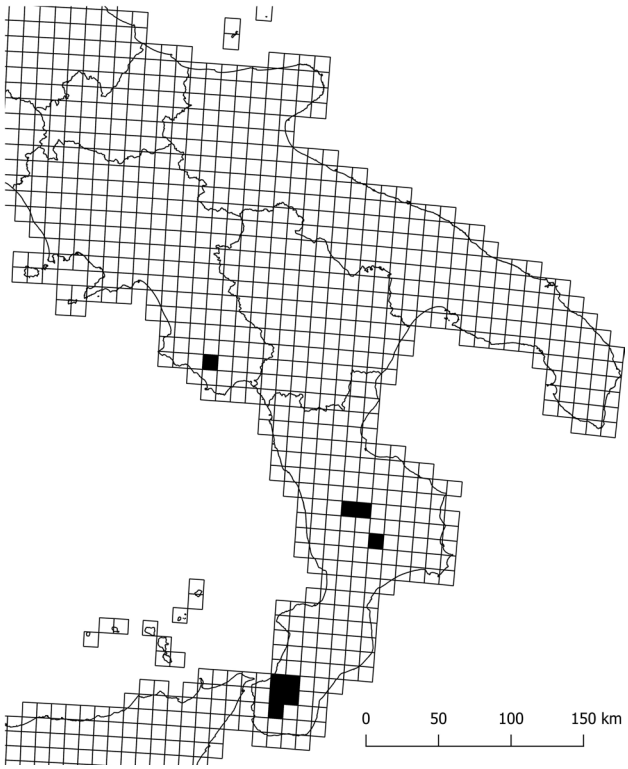

Fig. 4 Streams and springs of the southern Apennines and Sicily

Dynamics and contacts. The plant communities of this habitat type are permanent vegetation types linked to peculiar micro-ecological conditions. In the Calabro-Lucanian Apennines, they are in spatial contact with deciduous mesophilic broad-leaved forests of the mountain belt of the *Querco roboris-Fagetea sylvaticae* (Brullo et al. 2001). In Sicily, where this habitat type occurs from 1400 to 300 m a.s.l., in particular heterotopic environmental conditions, it is in spatial contact with *Fraxino orni-Quercion ilicis* woods (Gianguzzi and La Mantia 2004).

Distribution. Mountain belt of Campania, Basilicata, Calabria. (Fig. 4; Fig. 5; Tab. 4; Online Resource 2). This habitat type is also found in northern Sicily. Due to its biogeographic characteristics, this habitat type can be considered endemic to southern Italy and Sicily.

Pressures and threats. Springs and streams are restricted to small plots and exhibit a scattered distribution in southern Italy, so they are strongly influenced by the anthropogenic disturbance both in the area covered by the habitat type and in the surrounding areas.

Many springs have been destroyed or extremely damaged by water extraction or by the abstraction of streams to supply aqueducts (C14—7.2). Grazing (A10—2.3.1) and deforestation of surrounding habitats (B05, B09—5.3). Habitats which fall at high-altitude within the maximum protection zones of protected areas tend to preserve their natural

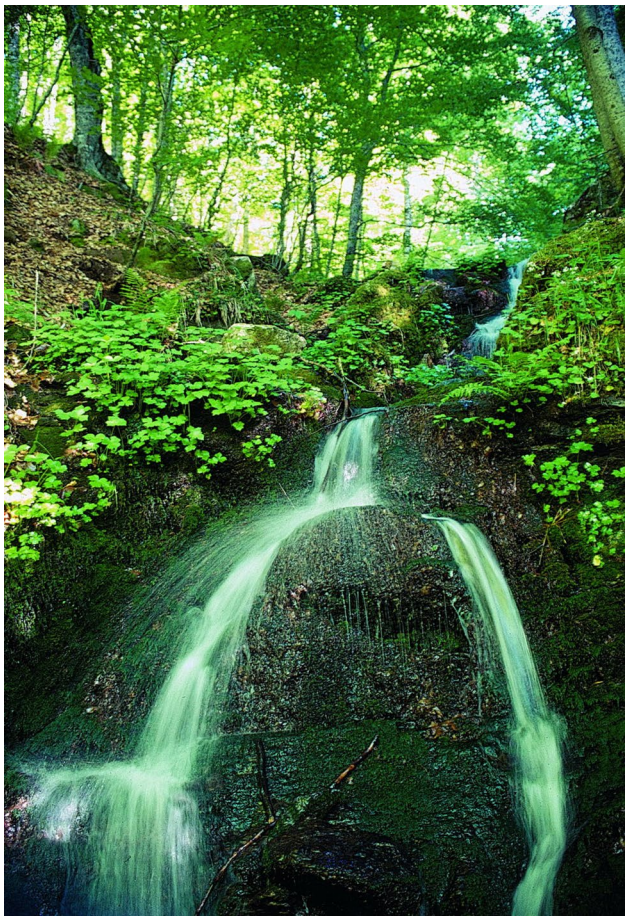

Fig. 5 Stream in southern Apennines (Calabria)

features, whereas those occurring at lower altitudes are often subject to a significant decrease in their quality.

Helophytic communities of flowing and well-oxygenated waters

Macrocategory: 32 Running water.

Correspondence with other habitat classification systems

EUNIS: C3.421—Short Mediterranean amphibious communities.

CORINE Biotopes: 53.14—Medium-tall waterside communities.

Description. Helophytic or hemicryptophytic communities, of slowly flowing and well-oxygenated fresh waters typical of streams of the Temperate and Mediterranean bioclimatic regions (Landucci et al. 2020), classified in the *Glycerio fluitantis-Sparganion neglecti* and *Apion nodiflori*, alliance of *Phragmito australis-Magnocaricetea elatae.*

Closest habitat type of the Annex I

3260: Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion vegetation.*

This habitat type frames submerged or floating rooted macrophytic communities (Batrachids) of limpid and unshaded running water of *Potametea* class that develops in the central part of watercourses where the current is faster (Biondi et al. 2009). The proposed habitat, on the other hand, refers to amphibious communities characterized by hemicryptophytes and helophytes, and not by hydrophytes, growing at the margins of perennial watercourses or streams, with fresh and shallow waters where there may be brief periods of desiccation.

Importance. The importance of this habitat type is linked to the degree of vulnerability which affects riverine systems. Although this habitat type does not host particularly rare or endemic vascular plant species, nevertheless, it plays an important ecological role by forming a transition belt between aquatic and terrestrial environments. It is also a refuge, reproduction, or shelter area for various fauna species, such as batrachians, aquatic invertebrates, and fishes.

Subtypes and variants. Two subtypes can be distinguished:

(a) communities dominated by *Sparganium erectum*, *Glyceria* sp. pl. (*Glycerio fluitantis-Sparganion neglecti*);
(b) communities dominated by *Helosciadium nodiflorum*, *Nasturtium officinale* (*Apion nodiflori*).

Diagnostic species. Dominant and frequent species: *Berula erecta*, *Glyceria fluitans*, *Glyceria notata*, *Helosciadium nodiflorum* subsp. *nodiflorum*, *Nasturtium officinale*, *Scrophularia umbrosa*, *Sparganium erectum*, *Veronica anagallis-aquatica*, and *Veronica beccabunga*. Species of conservation interest: *Ranunculus* sect. *Batrachium*.

Phytosociological reference. *Helosciadietum nodiflori*, *Polygono salicifolii-Nasturtietum officinalis* (Tab. 5, 3 relevés, area: mean 3.3 m^2, minimum 2 m^2, maximum 5 m^2, mean number of species: 6; Online Resource 1), *Apio nodiflori-Glycerietum plicatae*, *Sparganietum erecti*, *Glycerietum notatae*. In Mucina et al. (2016), the alliance *Apion nodiflori* is considered a syntaxonomical synonym of *Glycerio fluitantis-Sparganion neglecti* as both referred to "Herbland vegetation of small freshwater streams and in shallow water bodies of temperate Europe". This more inclusive interpretation of the EuroVegChecklist would shift the identification of the habitat subtypes from the alliance level to the association level.

Dynamics and contacts. The plant communities of this habitat type are permanent vegetation types linked to particular ecological and micro-environmental conditions in spatial contact with the riverine forests of the *Salici purpureae–Populetea nigrae* or with perennial helophytic communities of large size such as reeds, sedges, of *Phragmito australis-Magnocaricetea elatae*. Inside of the water body, the spatial contacts occur with the floating vegetation of the *Ranunculion fluitantis* and *Ranunculion aquatilis*.

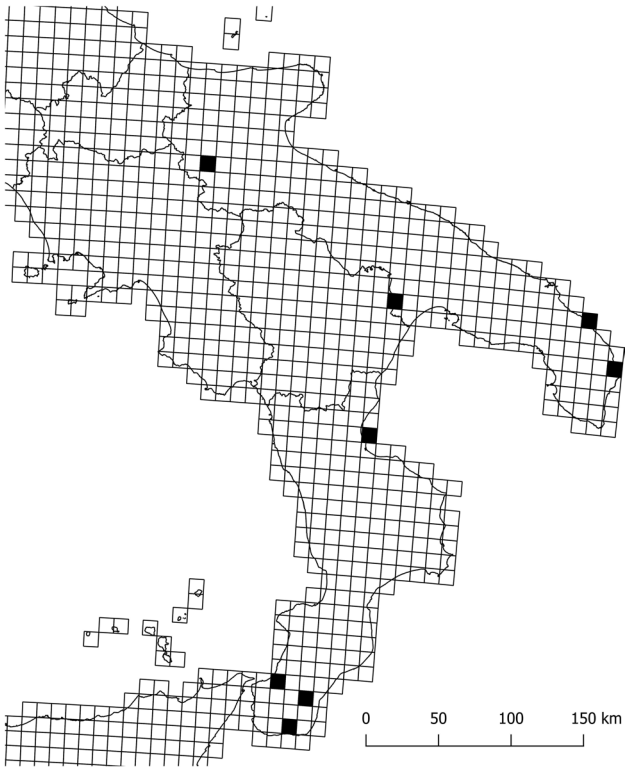

Fig. 6 Helophytic communities of flowing and well-oxygenated waters

Fig. 7 *Helosciadium nodiflorum* subsp. *nodiflorum* communities (*Helosciadietum nodiflori*, Calabria)

Distribution. Coastal, hilly, and submontane belts of all the Italian southern regions (Fig. 6; Fig. 7; Tab. 6; Online Resource 2), Sicily (Brullo and Spampinato 1990), and of other Mediterranean territories (Navarro et al. 2001) (Fig. 7).

Pressures and threats. Modification of the water regime (C14—7.2) and also water-borne pollutants from different origin as domestic and urban activity (F12—9.1), industrial and commercial activities (F15—9.2); agricultural and forestry activity (A25, B23—9.3) may affect this habitat type.

Mediterranean and sub-Mediterranean dwarf garrigues with rare and/or endemic species

Macrocategory: 54 Phrygana.

Correspondence with other habitat classification systems

EUNIS: F6.1—Western garrigues; F6.2—Eastern garrigues.

CORINE Biotopes: 32.212—Thermo-Mediterranean heath garrigues; 32.46—Lavender garrigues; 32.47—Thyme, sage, germander and other labiate garrigues; 32.4B—Erica garrigues; 32.4D—*Helianthemum* and *Fumana* garrigues.

Description. Thermo-Mediterranean, meso-Mediterranean and sub-Mediterranean, primary and secondary garrigues, growing on poorly developed carbonatic soils with outcrops, physiognomically dominated by chamaephytes, often with cushion-like-thorny habitus.

Closest habitat types of the Annex I

5410: West Mediterranean cliff top phryganas (*Astragalo-Plantaginetum subulatae*).

5420: *Sarcopoterium spinosum* phryganas.

5430: Endemic phryganas of the *Euphorbio-Verbascion.*

Importance. This habitat type differs from other types of dwarf garrigues, because it is characterized by rare, and often endemic species or by species of particular phytogeographic and/or conservation value. The garrigues belonging to this habitat type may be of primary or secondary origin, mainly developed on inland limestone rocky outcrops. Numerous physiognomically very different plant communities belong to this habitat type and most of them show a high species richness. According to Janssen et al. (2016), the proposed habitat type represents an outstanding example of typical characteristics of Mediterranean region as it is exclusively occurring on eroded soils of this region subjected to Mediterranean macrobioclimate.

Subtypes and variants. None.

Diagnostic species. Dominant and frequent species: *Erica forskalii* (= *E. manipuliflora*), *Euphorbia spinosa*, *Fumana ericifolia*, *F. laevis*, *F. procumbens*, *F. thymifolia*, *Helianthemum oleandicum* subsp. *incanum*, *Micromeria juliana*, *M. graeca* subsp. *graeca*, *Petrosedum ochroleucum* subsp. *mediterraneum*, *Phagnalon rupestre* subsp. *illyricum*, *Phlomis fruticosa*, *Rhamnus saxatilis*, *Satureja montana*, *S. cuneifolia*, *Teucrium capitatum*, *Thymbra capitata*. Bryophytes: *Cheilothela chloropus*, *Tortella squarrosa*, *Scorpiurium circinatum*. Species of conservation interest: *Allium apulum*, *Aristida adscensionis*, *Asyneuma limonifolium* subsp. *limonifolium*, *Centaurea brulla*, *C. subtilis*, *Dianthus tarentinus*, *Erica forskalii*, *Fumana scoparia*, *Genista michelii*, *Helianthemum farinulentum*, *H. jonium*, *H. lippii*,

Lavandula austroapennina, *L. multifida*, *Leontodon apulus*, *Linum tommasinii*, *Micromeria graeca* subsp. *garganica*, *Onobrychis calabrica*, *Ptilostemon gnaphaloides*, *Salvia ceratophylloides*, *S. officinalis*, *S. fruticosa* subsp. *thomasii*, *Scabiosa pseudisetensis*, and *Tuberaria lignosa*.

Phytosociological reference. The vegetation shows a great floristic diversity, and many dwarf garrigues rich in endemic species or species of particular phytogeographical interest are known for southern Italy (Tab. 7, 28 relevés, area: mean 60 m^2, minimum 20 m^2, maximum 100 m^2, mean number of species: 19; Online Resource 1): *Saturejo cuneifoliae-Ericetum manipuliflorae* Brullo et al. 1986, *Chamaecytiso spinescentis-Genistetum michelii* De Faveri & Nimis ex Biondi 2000, *Centaureo subtilis-Thymetum capitati* Terzi & D'Amico 2006, *Asyneumo limonifolii-Saturejetum montanae* Biondi & Guerra 2008, *Cisto eriocephali-Phlomidetum fruticosae* Brullo, Scelsi & Spampinato 2001, *Phagnalo saxatilii-Saturejetum cuneifoliae* Biondi & Guerra 2008, *Helianthemo jonii-Thymetum capitati* Biondi & Guerra 2008, *Rhamno saxatilis-Saturejetum montanae* Tomaselli et al. 2021, *Ruto chalepensis-Salvietum trilobae*, Biondi & Guerra 2008, *Sedo ochroleuci-Saturejetum cuneifoliae* Di Pietro & Misano 2010, *Thymo-Lavanduletum multifidae* Brullo, Minissale & Spampinato 1987, *Ptilostemo-Helianthetum farinulentum* Brullo, Scelsi & Spampinato 2001, *Thymelaeo hirsutae-Rosmarinetum officinalis* Brullo, Minissale & Spampinato 1997. The garrigues, due to their climatic and edaphic features, favor the settlement of thermo-xerophytic bryophyte communities as *Pleurochaeto squarrosae-Cheilotheletum chloropidi* Privitera & Puglisi 1996 (Puglisi et al. 2019). At higher syntaxonomic level, the Prodrome of the Italian vegetation classifies these Mediterranean garrigue communities in two classes, i.e., *Cisto-Micromerietea* for the central and eastern Mediterranean and *Rosmarinetea officinalis* for the western Mediterranean. Conversely, Mucina et al. (2016) consider one class only, *Ononido-Rosmarinetea* (*Cisto-Micromerietea* = syntax. syn.) as representative of all the Mediterranean scrub on base-rich substrates, distinguishing a western order (*Rosmarinetalia officinalis*) from an eastern one (*Cisto-Micromerietalia julianae*). The most of the aforementioned associations belong to two alliances of *Cisto-Micrtomeretalia*, such as *Cisto-Ericion manipuliflorae* (lower hilly belt) and *Cytiso spinescentis-Satureion montanae* (upper hilly belt–lower montane belt). However, as regards the *Salvia officinalis* communities and the coenological circumscription of the whole alliance *Cytiso spinescentis-Satureion montanae*, there is not a general agreement, especially as regards their classification at higher syntaxonomical rank. For more in-depth analysis on this topic, we refer to the following papers: Biondi et al. 1995, 2014a, 2014c; Brullo et al. 1996; Allegrezza et al. 1997; Pirone and Tammaro 1997; Di Pietro et al. 2002; Di Pietro 2011; Cutini et al. 2007; Mucina et al. 2016; Terzi et al. 2021; Tomaselli et al. 2021.

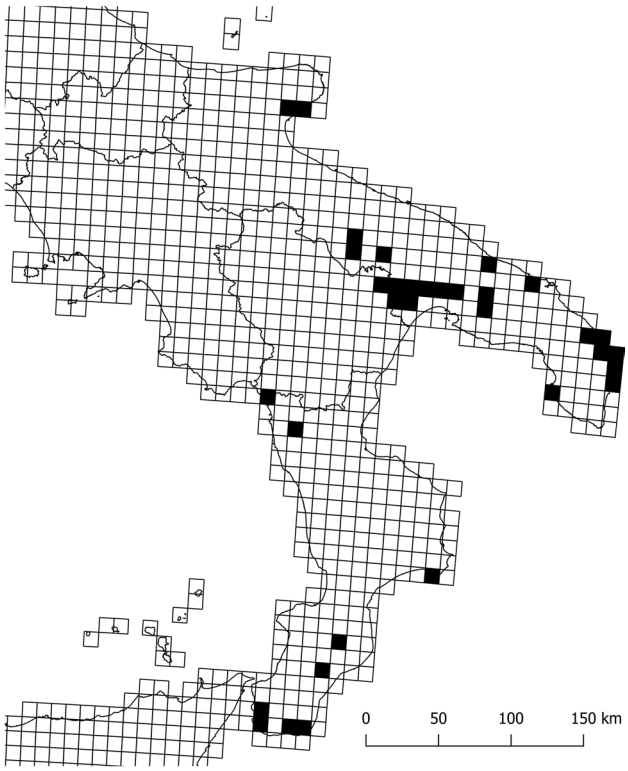

Fig. 8 Mediterranean and sub-Mediterranean dwarf garrigues with rare and/or endemic species

Dynamics and contacts. The dwarf garrigues in issue may act as permanent vegetation (highly rocky outcrops) or secondary vegetation (deeper soils), and are in spatial contact with the ephemeral herbaceous vegetation of *Tuberarietea guttati*, the dry grasslands of *Festuco-Brometea* or pseudosteppes of *Lygeo-Stipetea*, nano-phanerophytic garrigues (e.g., *Cistus* sp. pl. dominated garrigues) of *Cisto-Micromerietalia julianae*, shrub communities of *Rhamno-Prunetea* and *Quercetea ilicis* (*Pistacio lentisci-Rhamnetalia alaterni*), forest vegetation of *Quercetalia ilicis* and of *Quercetalia pubescenti-petraeae*. It can also be in contact with chasmophytic vegetation of *Asplenietea trichomanis* and with bryophyte communities of *Psoretea decipientis* Mattick ex Follmann 1974 (De Faveri and Nimis 1982; Brullo et al. 1997; Terzi and D'Amico 2006; Biondi and Guerra 2008; Di Pietro and Misano 2010; Puglisi et al. 2019; Tomaselli et al. 2021).

Distribution. Coastal, hilly, and submontane belts of all the Italian southern regions (Fig. 8; Figs. 9, 10; Tab. 8; Online Resource 2) as well as in Sicily, Sardinia and Italian peninsula (Gehu and Biondi 1988; Taffetani and Biondi 1989; Corbetta et al. 1992; Brullo et al. 1987a, 1987b, 2001; Cutini et al. 2007; Tomaselli et al. 2008, 2011; Forte et al.

Fig. 9 *Thymbra capitata* garrigues in Puglia (*Helianthemo jonii–Thymetum capitati*)

Fig. 10 *Centaurea subtilis*, endemic to Puglia and Basilicata (*Centaureo subtilis–Thymetum capitati*)

2011; Tomaselli and Sciandrello 2017; Veronico et al. 2017; Panuccio et al. 2018; Spampinato et al. 2019a, b). Its distribution extends also to other Mediterranean territories (Brullo et al. 1997).

Pressures and threats. The main factors threatening the conservation of this habitat type are overgrazing (A10—2.3), fire (H04—7.1), agricultural conversion (A01—2.1), afforestation (B01—2.2), urbanization, and touristic expansion (F01—1.1) in some areas. Garrigues are included in the European Red List of Habitats resulting Least Concern (LC) assessment (Janssen et al. 2016).

Centuries-old olive groves

Macrocategory: 63 Sclerophillous grazed forests (dehesas).

Correspondence with other habitat classification systems

Eunis: G2.91—*Olea europaea* groves.

CORINE Biotopes: 83.111—Traditional olive groves.

Description. Olive groves characterized by centuries-old trees of *Olea europaea*. They may derive from transformations of the Mediterranean scrub by grafting wild olive trees, or from plantations made in past centuries of wild olive trees grafted with different agronomic varieties of *Olea europaea*.

Closest habitat type of the Annex I

9320: *Olea* and *Ceratonia* forests.

Importance. The centuries-old olive groves are cultivated using traditional, low environmental impact techniques and create a semi-natural habitat that has remained unchanged for centuries. They are cultivated ecosystems typical of Mediterranean territories, characterized by a good level of naturalness, rich in biodiversity where cultivated and spontaneous species coexist, and some of these latter are of considerable conservation interest (Crocè 1999; Gangale and Uzunov 2003; Calabrese et al. 2012, 2015; Perrino et al. 2011, 2014; Perrino and Calabrese 2014; Cohen et al. 2015). Biondi et al. (2007), and later, Casavecchia et al. (2021) have proposed the inclusion in Annex I to HD of the new habitat type, named "Centuries-old olive groves with evergreen *Quercus* spp. and arborescent matorral", because these environments fit two criteria for the identification of habitat types of Community interest: they are in danger of disappearing in their natural range and represent exceptional examples of typical characteristics of the Mediterranean biogeographic region. However, even if this habitat type is referred by the Authors to the Macrotype 63 "Sclerophillous grazed forests (dehesas)", it is then phytosociologically framed within the *Oleo sylvestris-Ceratonion siliquae* and described by a list of diagnostic species including exclusively shrub and tree species mostly of *Quercetea ilicis*. In doing so, this habitat type includes only the olive groves that are no longer cultivated for a long time and where, in the absence of cultural practices, evergreen sclerophyllous species take over as a consequence of the succession dynamics that tend toward the formations of potential natural vegetation of the Mediterranean scrub (Blasi et al. 2000; Di Pietro and Filibeck 2001; Di Pietro and Blasi 2002). In our proposal, we refer also to centuries-old olive groves sometimes terraced and bordered by dry stone walls, that are currently cultivated, even if using the traditional techniques and that constitute an integral and significant part of the Mediterranean culture and environment. It partially matches the new habitat type, proposed by Fois et al. (2021) for the Sardinia region, "Mediterranean wooded pasturelands", subtype 2 "wooded pasturelands dominated by wild olive and carob trees". Traditionally cultivated and abandoned centuries-old olive groves are two aspects of the same vanishing landscape (Vos and Meekes 1999), both of which risk disappearing either through intensification of agricultural practices or total abandonment of cultivation. The list of species of conservation interest

reported below in the text is in accordance with Gangale and Uzunov (2003) and Perrino et al. (2014). Centuries-old olive groves are an important habitat providing nourishment and refuge to numerous animal species, many of which are priority species and listed in annexes II and IV of the HD (Biondi et al. 2007, 2014a, b, c; Marzano and Scarafino 2012).

Subtypes and variants. Two subtypes can be here proposed:

(a) centuries-old olive groves subject to traditional agricultural practices;
(b) centuries-old olive groves evolving toward *Oleo sylvestris-Ceratonion siliquae* shrublands.

Diagnostic species. Dominant and frequent species: Plant, woody species: *Olea europaea* var. *europaea*, *Olea europaea* var. *sylvestris*, *Ceratonia siliqua*, *Prunus domestica*, *P. dulcis*, *Ficus carica*, *Pyrus communis*, *Quercus ilex*, *Q. pubescens*, *Q. trojana*, *Punica granatum*, *Pistacia lentiscus*, *Phillyrea angustifolia*, *Sorbus domestica*, *Myrtus communis*, *Rhamnus alaternus*; herbaceous species: *Anisantha diandra*, *Arabidopsis thaliana*, *Avena barbata*, *Calendula arvensis*, *Capsella bursa-pastoris*, *C. rubella*, *Cardamine hirsuta*, *Crepis neglecta*, *C. sancta*, *Diplotaxis erucoides*, *D. tenuifolia*, *Euphorbia helioscopia*, *Fumaria officinalis*, *Geranium molle*, *Hypochaeris achyrophorus*, *Lamium amplexicaule*, *Medicago orbicularis*, *M. truncatula*, *Muscari neglectum*, *Myosotis arvensis*, *Ornithogalum gussonei*, *O. divergens*, *Papaver rhoeas*, *Rumex bucephalophorus*, *Sagina apetala*, *Saxifraga tridactylites*, *Sherardia arvensis*, *Sinapis alba*, *Tordylium apulum*, *Vicia villosa*. Reptiles: *Cyrtopodion kotschyi*; Birds: *Certhia brachydactyla*, *Turdus viscivorus*, *Sylvia melanocephala*, *Turdus philomelos*. Species of conservation interest: *Artemisia campestris* subsp. *variabilis*, *Barlia robertiana*, *Biscutella maritima*, *Crepis apula*, *Erucastrum virgatum*, *Muscari parviflorum*, *Ophrys bertolonii*, *O. incubacea*, *Orchis italica*, *O. purpurea*, *Pseudopodospermum hispanicum* subsp. *neapolitanum*, and *Triticum uniaristatum*.

Dynamics and contacts. The abandonment of olive cultivation favors the natural evolution toward Mediterranean maquis formations of the *Oleo sylvestris-Ceratonion siliquae*; over time, the vegetation may evolve toward forest vegetation of *Quercetea ilicis*.

Phytosociological reference. The centuries-old olive groves cultivated in the traditional way of subtype (a) (Tab. 9, 5 relevés, area: mean, minimum and maximum 100 m^2, mean number of species: 30; Online Resource 1) are characterized by a large number of herbaceous nitrophilous and sub-nitrophilous species of the *Stellarietea mediae*. However, many species of the *Tuberarietea guttatae* are also present; this class includes the ephemeral, xerophilous and thermophilous, non-nitrophilous annual plant communities with a short winter-spring growth cycle.

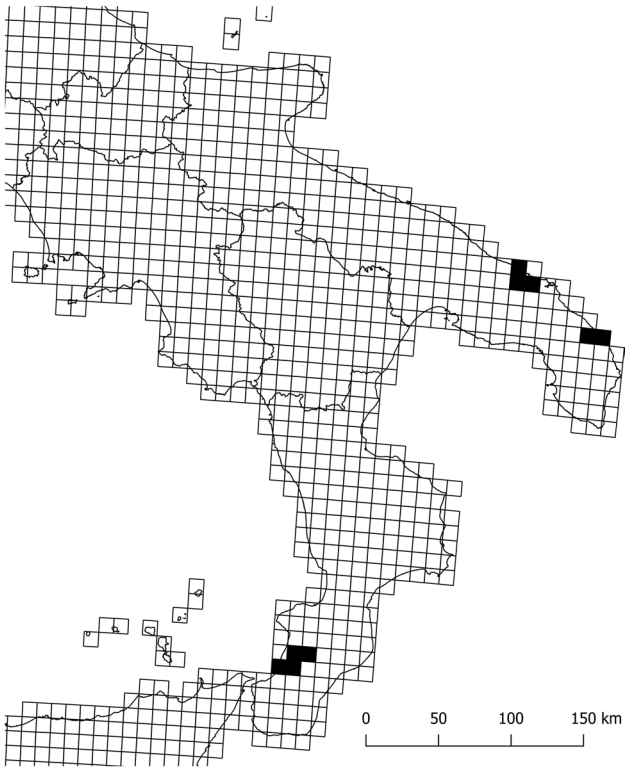

Fig. 11 Centuries-old olive groves

Distribution. Apulia, Calabria (Fig. 11; Fig. 12; Tab. 10; Online Resource 2) and other regions of southern and central Italy, Sicily, and Sardinia (Casavecchia et al. 2021; Fois et al. 2021; Guarino et al. 2021). Inventories of centuries-old olive groves are available for Italy and other European territories (Ismaili 2018).

Pressures and threats. Centuries-old olive groves are at risk of disappearing as a result of the changing of the socio-economic conditions of the rural populations. In many regions, such as Calabria and Apulia, ancient olive trees are uprooted to decorate gardens (G09—5.2). In other cases, they were eliminated because due to their low productivity and poor economic yield and replaced with more modern plantings made with varieties suitable for mechanical harvesting (A01—2.1.). Olive groves near residential areas are cleared for urban development (F01—1.1). *Xylella fastidiosa* infestations are a serious threat to the centuries-old olive groves of southern Apulia (I05—8.5), generating severe economic repercussions affecting not only farmers and olive oil producers, but directly or indirectly the local society (Saponari et al. 2019; Scortichini 2020; Ali et al. 2021). It should be emphasized that the proposal of a new habitat type, based on traditional cultivation of centuries-old olive groves that can also include areas of active cultivation, is a delicate topic,

Fig. 12 Centuries-old olive groves in Puglia

because it would impose management rules on the owners who should be the guardians of this habitat type and of a traditional vanishing landscape.

Mofettes and mud volcanoes

Macrocategory: 83—Other rocky habitats.

Correspondence with other habitat classification

EUNIS: H6.1—Active volcanic features.

CORINE Biotopes: 66.6—Fumaroles, solfataras, and mofettes.

Description. Phenomena of secondary volcanism characterized by cold emissions of carbon dioxide, various other gases, water, or mud.

Closest habitat type of the Annex I

8320: Fields of lava and natural excavations.

The proposed habitat type differs from fumaroles because set on sedimentary sequences and characterized by low temperatures. It includes phenomena commonly referred to as "mofettes" or "mud volcanoes".

Importance. Mofettes and mud volcanoes are extreme habitats located in volcanic or tectonically active areas that strongly influence the presence of living beings. Mofettes are important sites for studying the action of CO_2 on living organisms. Dry CO_2 gas exhalations at ambient temperatures change the living conditions in the soil so much, that the community consists of few highly specialized microbial species. The food web in the soil become less efficient in the degradation of organic material, which then accumulates in large amounts in the ground (Schime 2016). Carbon dioxide influences the presence of living beings according to an ecological gradient. The vascular flora growing on the areas less exposed to gases is generally paucispecific and strictly related to the potential of the surrounding vegetation. A few vascular plants adapt to the conditions of anoxia and acidity and settle closer to the source of CO_2. In the Tuscany mofettes, *Agrostis stolonifera* is among the best-adapted vascular plants (Selvi 1998).

In Campania, Haworth et al. (2010) studied the population of *Agrostis canina* growing close to natural springs of Mefite d'Ansanto (AV) emitting CO_2, SO_2, and H_2S (Paoletti et al. 2005); the authors showed that individuals living in these so harsh conditions possess resistance to toxic gases and are adapted to grow at elevated CO_2 levels, even if this resistance is not associated with a reduction in stomatal index. In the German mofettes, Pfanz et al. (2019) point out that the number of species and the vegetation cover decrease with increasing CO_2 concentration and only a few marsh species such as *Carex acutiformis* and *Phragmites australis* grow closer to the emission areas.

Mud volcanoes are landforms formed by the expulsion of water, gas, and mud which originate from a sedimentary sequence, often from great depth (Martinelli and Judd 2004). In mud volcanoes, the precipitation of salts contained in the rising waters leads to considerable salinity of the substrate, allowing the sporadic presence of only a few halophytes, such as species of the genera *Salsola* and *Suaeda*, that structure pioneer plant assemblages growing on fresh mud-volcanic flows (Korzhenevsky and Klyukin 1991; Guarino et al. 2021).

The need to revise the Interpretation Manual and include Mud volcanoes among the habitats of community interest was also highlighted by the EEC "Group of Experts on Protected Areas and Ecological Networks" (CoE 2018) who also included this habitat type among those endangered requiring specific conservation measures (CoE 2019).

Subtypes and variants. Two subtypes can be here proposed:

(a) mofettes: natural sources mainly of carbon dioxide, wet cold (small gurgling ponds) or only cold, with presence of paucispecific communities formed by organisms adapted to these extreme environments with very low pH values. Among these species, acid-tolerant unicellular algae such as *Viridiella fridericiana* and *Ochromonas vulcanica* are reported (Albertano et al. 1991, 1994);
(b) mud volcanoes: mud natural sources, characterized by the emission of clay mixed with water and gas, with

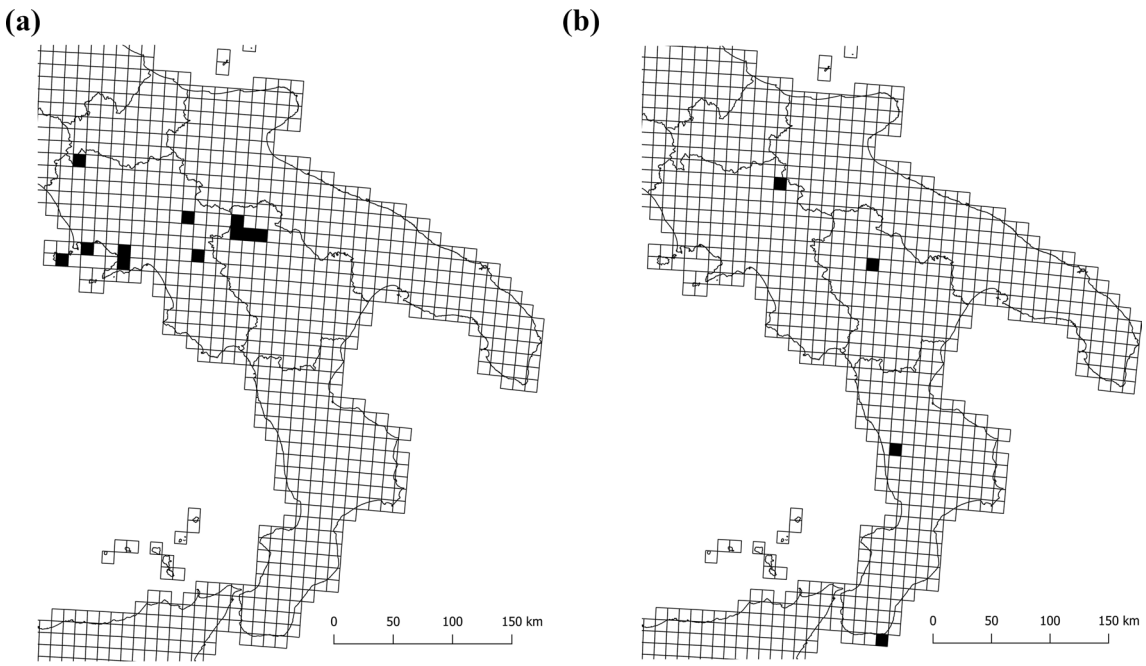

Fig. 13 **a** Mofettes and **b** mud volcanoes

morphology variable in relation to the characteristics of the mud, the viscosity, the interstitial pressure, as well as the topography of the area.

Diagnostic species. Dominant and frequent species. Mofettes, Algae: *Viridiella fridericiana* and *Ochromonas vulcanica*. Vascular plants: *Agrostis canina, A. stolonifera*. Mud volcanoes, Vascular plants: *Salsola* sp. pl., *Suaeda* sp. pl.

Phytosociological reference. In close proximity of the mud volcanoes, a halophilous vegetation grows on the salty clays, which can be classified in the classes *Thero-Suaedetea splendentis* Rivas-Martínez 1972 and *Festuco-Puccinellietea* Soó ex Vicherek 1973 (Korzhenevsky and Klyukin 1991).

Distribution: Campania, Basilicata, Calabria (Fig. 13a, b; Fig. 14; Tab. 11a, b; Online Resource 2), and other regions of Italy (Martinelli and Judd 2004; Minissale et al. 2019; Guarino et al. 2021); but it is also known for many other places of the world preferentially located along faults and tectono-sedimentary accretionary wedges, or are characteristic of thick deep sedimentary basins of continental margins (Mazzini and Etiope 2017).

Pressures and threats. Mofettes and mud volcanoes are affected by various anthropogenic activities that transform the environment for productive purposes. Mofettes are sometimes destroyed and transformed into industrial sites for the storage of carbon dioxide (C03, F03—1.2). These sites are sometimes used as waste dumps (F09—9.4).

Mediterranean dripping cliffs (***Adiantetalia***)

Macrocategory: 83—Other rocky habitats.

Correspondence with other classification systems

EUNIS: H3.41—Mediterranean wet inland cliffs.

CORINE Biotopes: 62.51—Mediterranean wet inland cliffs.

Description. Cliffs with water percolation of *Adiantetalia* in Mediterranean regions, colonized by hygrophilous vegetation characterized by carpets of mosses on which grow various species of pteridophytes and spermatophytes.

Closest habitat type of the Annex I

7220: Petrifying springs with tufa formation (*Cratoneurion*).

The plant communities of the *Adiantetalia* are often referred to Habitat 7220 which, however, is characterized by different ecological conditions and floristic composition. This habitat type, in fact, concerns hard water springs with active formation of travertine or tufa due to *Cratoneurion* lime-encrusted moss mats, while vascular plants are rare or absent.

Importance. Dripping cliffs and walls in the Mediterranean environment are characterized by a water-soaked moss layer on which some vascular plants grow, especially pteridophytes of considerable phytogeographical interest, often threatened by extinction, such as *Woodwardia radicans*, included in Annex II of HD, and in the IUCN Red List with the status of "Endangered" for the Mediterranean basin (De Bélair 2010), "Vulnerable" for Europe (Christenhusz et al.

Fig. 14 Mofettes in Campania

2017) and Italy (Spampinato and Puglisi 2009), and Critically Endangered (CE) for Sicily (Crisafulli et al. 2021).

Subtypes and variants. Two subtypes can be here proposed:

(a) communities dominated by *Adiantum capillus-veneris* and rich in bryophytes that grow on siliceous or calcareous dripping cliffs that can contribute to the genesis of travertine;
(b) fern-rich communities of shady dripping siliceous cliffs with *Woodwardia radicans* and other large ferns in narrow ravines.

Diagnostic species. Dominant and frequent species. Pteridophytes: *Adiantum capillus-veneris*, *Osmunda regalis*, *Phyllitis scolopendrium* subsp. *scolopendrium*, *Pteris vittata*, *P. cretica*, *Struthiopteris spicant*. Angiosperms: *Samolus valerandi*, *Trachelium caeruleum* subsp. *caeruleum*, *T. caeruleum* subsp. *lanceolatum*. Bryophytes: *Conocephalum conicum*, *Didymodon tophaceus*, *Dumortiera hirsuta*, *Eucladium verticillatum*, *Palustriella commutata*, and *Pellia endiviifolia* (Cortini Pedrotti 1992). Species of conservation interest. Pteridophytes: *Woodwardia radicans.* Angiosperms: *Pinguicula hirtiflora*, *P. poldinii*, and *P. vallis-regiae*.

Phytosociological reference. Plant communities of cliffs with water percolation in Mediterranean regions are included in the *Adiantetea* class (Deil 1998). Many *Adiantum capillus-veneris* communities rich in bryophytes are known for southern Italy (Tab. 12, 22 relevés, area: mean 22 m^2, minimum 2 m^2, maximum 40 m^2, mean number of species: 17; Online Resource 1), as *Eucladio verticillati-Adiantetum capilli-veneris*, *Adianto capilli-veneris-Osmundetum regalis*, *Adianto capilli-veneris-Pteridetum vittatae* (Tab 12b; Online Resource 1). Communities rich in large ferns of shady dripping siliceous cliffs are referred to *Polysticho setiferi-Phyllitidion scolopendrii* alliance (Biondi et al. 2014b) which includes *Conocephalo conici-Woodwardietum radicantis* and *Thamnobryo alopecuri-Phyllitidetum scolopendrium* (Tab. 12a, Online Resource 1) (Brullo et al. 1993, 2001). Mucina et al. (2016) classified the alliance *Polysticho setiferi-Phyllitidion scolopendrii* in the class *Polypodietea*, which is considered ecologically separated by *Adiantetea* being mainly composed of fern- and moss-rich communities.

Dynamics and contacts. *Adiantetelia* order gathers permanent communities tied to dripping rocks. This habitat type is sometimes located at the mouth of the caves referable to habitat 8310: "Caves not yet exploited for tourism". In gorges, they take catenal contact with the forest communities of the habitat 9180*: "*Tilio-Acerion* forests of slopes, screes and ravines", mixed mesophilic broad-leaved forests growing on steep rocky slopes or gorges, with the evergreen forests dominated by holm oaks of the habitat 9340: "*Quercus ilex* and *Quercus rotundifolia* forests", or with secondary evergreen scrub (Piñar Fuentes et al. 2017).

Distribution. Coastal, hilly, and submontane belts of all the Italian southern regions (Fig. 15; Fig. 16; Tab. 13; Online Resource 2), Sicily (Brullo et al. 1989), and of many other Mediterranean territories (Deil 1998; Foucault 2015).

Pressures and threats. Water uptaking, or the modification of the water regime (C14—7.2), are the main threats to this habitat type. Moreover, the logging activities (B05, B09—5.3) in the adjacent areas, by altering the microclimatic conditions, are a factor of considerable disturbance.

Acidophilous oak woods with *Quercus petraea* subsp. *austrotyrrhenica* of the southern Apennines and Sicily

Macrocategory: 92 Mediterranean deciduous forests.

Correspondence with other classification systems

EUNIS: G1.7513—Southern Italic *Quercus petraea* woods.

CORINE Biotopes: 41.7513—Southern Italic *Quercus petraea* woods.

Description. Southern sessile oak-dominated woodlands typical of acidic, draining soils with mor humus on metamorphic and igneous rocks, sandstones, and sandy and

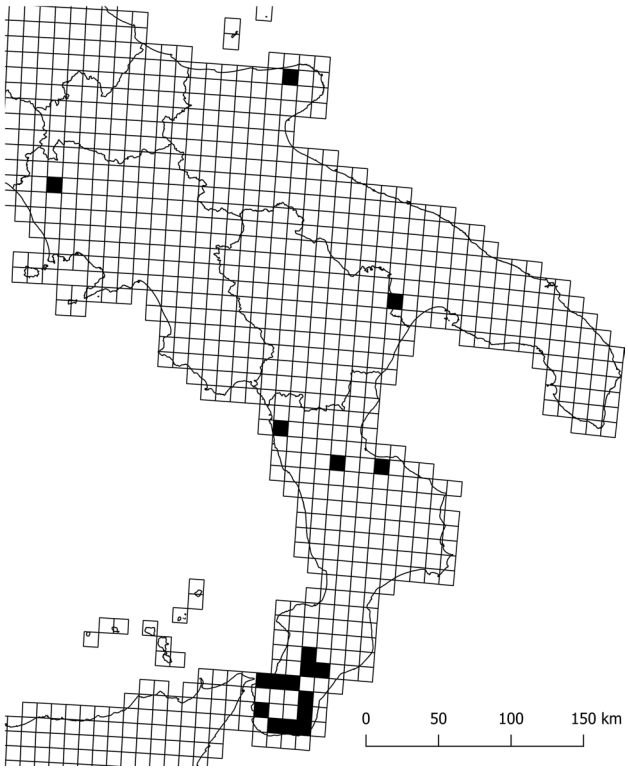

Fig. 15 Mediterranean dripping cliffs (*Adiantetalia*)

Fig. 16 Dripping cliffs with *Woodwardia radicans* in Calabria

gravelly soils through the temperate of supra-Mediterranean belts.

Closest habitat type of the Annex I

91M0: Pannonian-Balkanic turkey oak-sessile oak forests.

This habitat type concerns sub-continental thermo-xerophilous *Quercus cerris*, *Q. petraea*, or *Q. frainetto* forests of the Pannonic and northern Balkanic hilly regions and in lower mountains distributed generally between 250 and 600 (800) m a.s.l. and developed on varied substrates (European Commission 2013). In the Italian manual of habitat interpretation, Biondi et al. (2012) expanded the significance of habitat 91M0 in order to include the sub-acidophilic formations of the *Q. petraea* mountain range of the central-southern Apennines and Sicily.

Importance. The oak forests of southern Italy are an example of relict vegetation of high phytogeographic interest (Petit et al. 2002). Brullo et al. (1999) referred to the southern populations of *Q. petraea* as a subspecies endemic to southern Italy and Sicily (*Q. petraea* subsp. *austrotyrrhenica*). Although the taxonomic classification of southern Italy white oaks is currently being updated on the basis of recent in-depth studies on their micro- and macromorphological traits (Fortini et al. 2015a; Musarella et al. 2018; Di Pietro et al. 2020) as well as on their genetic features (Antonecchia et al. 2015; Fortini et al. 2015b; Di Pietro et al. 2021), there is no doubt that the sessile oak communities of southern Italy represent refuge areas for the white oak species genetic lineages from which the post-glacial migration started (Dumolin-Lapegue et al. 1997). Many stands of *Q. petraea* subsp. *austrotyrrhenica* woods are composed of centuries-old oak trees, as is the case of the 930 years old oak named "Demetra" in the Aspromonte National Park (Piovesan et al. 2020). Several nemoral plants endemic to the southern Apennines and Sicily grow in the undergrowth of these oak groves, such as *Epipactis meridionalis*, *Aquilegia dumeticola*, and *A. sicula*, and this allows to distinguish the sessile-oak woods of southern Italy from all the other types of sessile-oak woods of southern Europe.

Subtypes and variants. None.

Diagnostic species. Dominant and frequent species: *Quercus petraea* subsp. *austrotyrrhenica*, *Carpinus betulus*, *Aristolochia lutea*, *Drymochloa drymeja* subsp. *exaltata*, *Euphorbia meuselii*, *Festuca heterophylla*, *Hypochaeris laevigata*, *Ilex aquifolium*, *Silene italica* subsp. *sicula*, *Luzula sylvatica* subsp. *sicula*, *Rabelera holostea*, *Taxus baccata*. Species of conservation interest: *Aquilegia sicula*, *A. dumeticola*, *Arabis collina* subsp. *rosea*, *Epipactis meridionalis, Helleborus viridis* subsp. *bocconei*, *Lathyrus jordanii*, and *Teucrium siculum* subsp. *siculum*.

Phytosociological reference. The communities of *Q. petraea* subsp. *austrotyrrhenica* of Southern Italy (Tab. 14, 19 relevés, area: mean, minimum and maximum 100 m^2, mean number of species: 26; Online Resource 1) are described as *Aristolochio luteo-Quercetum austrotyrrhenicae*, while those from Sicily as *Ilici aquifolii-Quercetum*

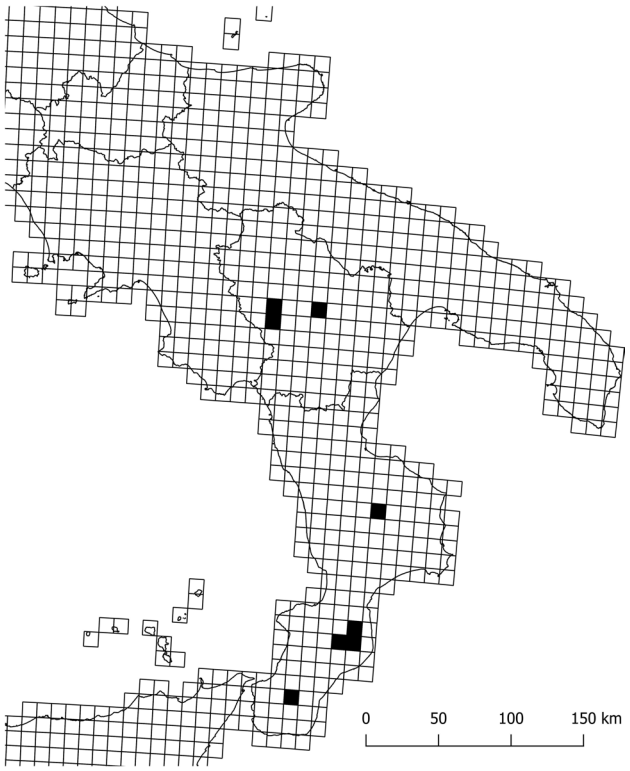

Fig. 17 Acidophilous oak woods with *Quercus petraea* subsp. *austrotyrrhenica* of the southern Apennines and Sicily

austrothyrrenicae. Both these associations were originally included in the *Geranium versicoloris-Fagion sylvaticae* (Brullo et al. 1996, 2001).

Dynamics and contacts. *Quercus petraea* subsp. *austrotyrrhenica* woods grow on particular edaphic conditions, as watersheds and in the steep areas with poorly developed soils, were they replace the climax *Fagus sylvatica* or *Q. cerris* forests of the mountain belt. Regressive successional stages are the bushes of *Prunetalia spinosae* on neutral-to-sub-acidic substrates and those of *Cytisetea scoparia-striati* on typically acidic substrates (Brullo et al. 2001).

Distribution. Mountain belt of Basilicata and Calabria (Brullo et al. 2001; Fascetti and Lapenna 2006) (Fig. 17; Fig. 18; Tab 15; Online Resource 2). This habitat type occurs also in northern Sicily (Bagnato et al. 2012).

Pressures and threats. The main factors threatening the conservation of this habitat type are overgrazing (A10—2.3.1), which affects the renewal of tree species, deforestation (B05, B09—5.3) and fire which systematically affects the forests of southern Italy (H04—7.1). Janssen et al. (2016) assess acidophilous *Quercus petraea/robur* woodlands of Europe as Vulnerable (VU) despite their large distribution range, because the majority of these forests show a strong reduction in quality.

Fig. 18 *Quercus petraea* subsp. *austrotyrrhenica* woods in Basilicata

5 Discussion and conclusions

Habitats are the fundamental indicators of biodiversity and the main reference points for the European nature conservation policy (Musarella et al. 2020; Bonari et al. 2021). As it is widely known, good habitat conservation status improves biodiversity, to which ecosystem functions are linked, both directly (e.g., productivity) and indirectly (e.g., stability). Moreover, biodiversity enhances resilience that is the capacity of an ecosystem to recover from external pressures. Effects of conservation status of habitat types on biodiversity have been extensively analyzed and reported in scientific literature, as well as their potential to maintain or improve the provisioning of ecosystem services (Loreau et al. 2001; Bullock et al. 2011; Isbell et al. 2015). The European Environmental Agency (EEA) approach on ecosystem mapping (and related services) and assessment builds on the Mapping and Assessment of Ecosystems and their Services (MAES; Maes et al. 2015) initiative. In this framework, the classification of ecosystem types and assessment of ecosystem services is based on a habitat perspective, where the underlying assumption is that at a national or regional scale, habitat types represent meaningful units forming the basis of the ecosystems for which the status and trends of the various services are reported (Potschin and Haines-Young 2013). The size and conservation status of natural habitats have direct implications on the provision of ecosystem services; assessments at European scale show that habitats with a favorable conservation status provide more biodiversity and have a higher potential to supply, in particular, "Regulation" and "Cultural" ecosystem services than habitats in an unfavorable conservation status (Maes et al. 2012). The Common International Classification of Ecosystem Services (CICES) classification is the framework adopted by

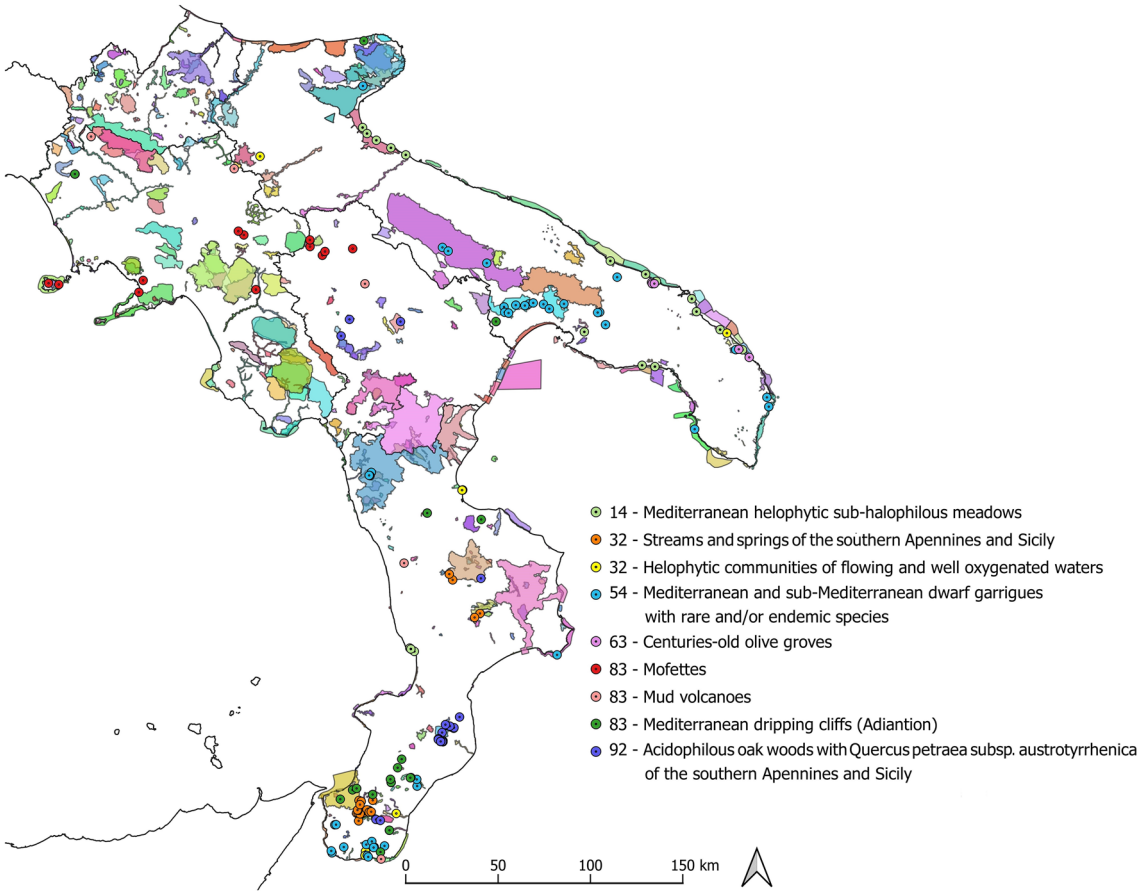

Fig. 19 Distribution of localities hosting neglected habitat types and Natura 2000 network. Natura 2000 sites have different colors to better distinguish them

the common implementation of the ecosystem assessment approach in the EU (Haines-Young and Potschin-Young 2018); it identifies three main categories of ecosystem services (i.e., Provisioning; Regulation and Maintenance; Cultural); each of them includes numerous divisions and classes. Focusing on the habitat types here proposed, aquatic ecosystems (rivers, lakes, groundwaters, and wetlands) support the delivery of crucial services, such as fish production, water provisioning, and recreation. Moreover, they have an essential role in water retention and water quality regulation (i.e., water purification); in particular, in the case of streams and springs, they contribute also to maintaining water flow for water supply and hydrological cycle (Grizzetti et al. 2016). Coastal wetlands such as saline and brackish helophytic meadows dominated by reeds, rushes, and sedges are widely recognized as essential for representing habitats that act as nurseries, spawning areas, or migratory routes; these habitats and the connectivity among them are crucial for the successful life cycle of species. Another service provided by these coastal environments is natural defense of the coastal zone against inundation and erosion from waves, storms, or sea-level rise (Liquete et al. 2013). All these ecosystem services fall within the Regulation & Maintenance category. Forests provide maintenance of soil conditions (soil stabilization and erosion control) and of climate and air quality at local-to-regional scale (i.e., micro- and regional climate regulation; Krieger 2001). Maintaining old olive groves is sure of relevance for preserving traditional management practices and landscapes (cultural heritage; Cultural section in CICES) and, more in general, all elements of wilderness provide enjoyment and opportunities for experiential–physical interactions with the natural environment.

To go forward in the direction of possible rounds of revision or integration of the HD, the correct definition of habitat types is a fundamental prerequisite and, as discussed above, this must be based on a precise phytosociological diagnosis and syntaxonomical classification (Bagella et al. 2007; Biondi et al. 2012; Cano-Ortiz et al. 2021). The numerous studies carried out so far on the vegetation of southern Italy have shown that the addition of some habitat types to Annex I of the HD would be highly desirable to guarantee adequate and explicit protection of the high degree of biodiversity occurring there (especially considering that the most of this biodiversity is due to

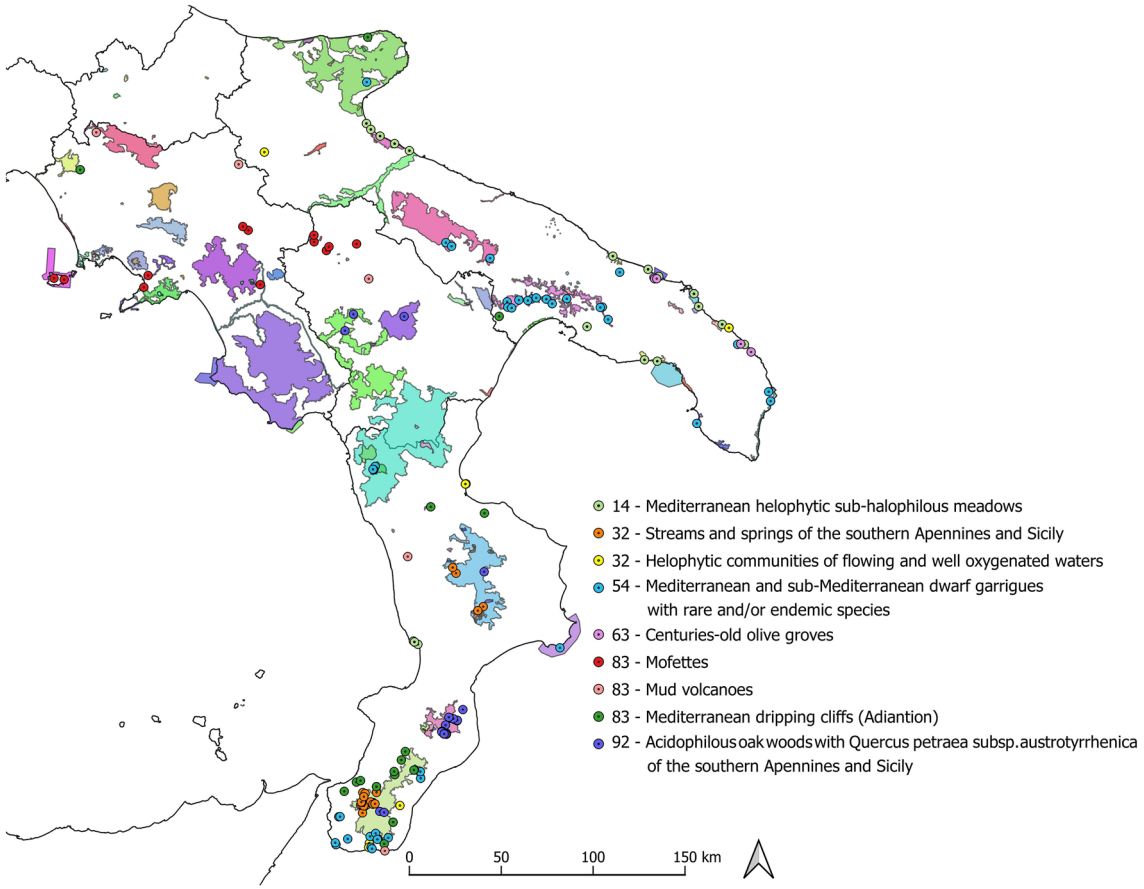

Fig. 20 Distribution of localities hosting neglected habitat types and Italian protected areas. Protected areas have different colors to better distinguish them

endemic or rare species). Furthermore, the results of this study, with the characterization and distribution of rare and threatened habitat types, could represent a contribution to the implementation of the Red List of Ecosystems that is being drawn up for Italy (Capotorti et al. 2020). The assessment of the protection status of the proposed habitat types (Figs. 19, 20; Online resources 4) shows that most of the sites fall within protected areas (Natura 2000 network and Italian protected areas), with the exception of "Mofettes and mud volcanoes", whose sites fall outside protected areas. As a general consideration, the inclusion of the proposed new habitat types in the HD would require the involvement of local institutions, management bodies, and stakeholders (e.g., to meet the need to redefine the management plans of the Natura 2000 sites, the possible identification of new sites, a greater effort in monitoring activities, the need to build the social consensus and to find the suitable financial resources necessary for the implementation of new conservation strategies, etc.); however, with the exception of the old olive groves, the new habitat types proposed here have characteristics or fall within areas generally of little interest to landowners.

Despite the awareness of the difficulties of including new habitat types in the HD, we believe that it is important to keep alive the attention of the international scientific and political community regarding the existing issues in the protection of natural and semi-natural habitat types in southern Italy.

Based on an initiative of the Italian Society of Vegetation Science and the Vegetation group of the Italian Botanical Society, other contributions have been recently provided for the definition of new habitat types suitable for possible amendments of the HD Annex I, focusing on central Italy, Sicily and Sardinia (Guarino et al. 2021; Fois et al. 2021; Casavecchia et al. 2021). Some of them (e.g., "Mediterranean dripping cliffs (*Adiantetalia*)", "Mediterranean helophytic sub-halophilous meadows", "Mofettes and mud volcanoes", "Centuries-old olive groves") correspond, and partially overlap with some habitat types here proposed. Moreover, the habitat types proposed in this contribution have been well characterized and the affinity with habitats already included in the HD has been highlighted; therefore, this study could represent a useful starting point for the implementation of an extension of the

habitat subtypes present in the habitats already included in the HD. It would be desirable if all these contributions could be merged in an integrated, comprehensive, and unified proposal at national and, hopefully, at supranational level and provide a basis for updating the Annex I, as part of ad hoc initiatives for the thirtieth anniversary of HD.

Syntaxonomic scheme (based on the prodrome of the Italian vegetation)

Montio fontanae-Cardaminetea amarae Br.-Bl.& Tüxen ex Klika & Hadac 1944

Montio fontanae-Cardaminetalia amarae Pawlowski in Pawlowski, Sokolowski & Wallisch 1928

Caricion remotae Kästner 1941

Adenostylo-Soldanelletum calabrellae Signorello 1986 corr. Brullo, Scelsi & Spampinato 2001

Rhynchocoryto-Alchemilletum austroitalicae Brullo, Scelsi & Spampinato 2001

Carici-Osmundetum regalis Brullo, Scelsi & Spampinato 2001

Galio aparines-Urticetea dioicae Passarge ex Kopecký 1969

Impatienti noli-tangere-Stachyetalia sylvaticae Boullet, Géhu & Rameau in Bardat et al. 2004

Impatienti noli-tangere-Stachyion sylvaticae Görs ex Mucina in Mucina, Grabherr & Ellmauer 1993

Chrysosplenio-Cryptotaenietum thomasii Brullo & Furnari in Barbagallo et al. 1982

Digitali purpureae-Urticetum dioicae Brullo, Scelsi & Spampinato 2001

Petasito-Chaerophylletum calabrici Brullo, Scelsi & Spampinato 2001

Petagnaetum gussonei Brullo & Grillo 1978

Adiantetea capilli-veneris Br.-Bl. in Br.-Bl., Roussine Negre 1952

Adiantetalia capilli-veneris Br.-Bl. ex Horvatić 1939

Adiantion Br.-Bl. ex Horvatić 1939

Eucladio verticillati-Adiantetum capilli-veneris Braun-Blanq. ex Horvatić 1934

Adianto capilli-veneris-Osmundetum regalis Brullo, Lo Giudice & Privitera 1989

Adianto capilli-veneris-Pteridetum vittatae Brullo, Lo Giudice & Privitera 1989

Pinguicula hirtiflora communities

Polysticho setiferi-Phyllitidion scolopendrii Ubaldi ex Ubaldi Biondi in Biondi et al. 2014

Conocephalo conici-Woodwardietum radicantis Brullo, Lo Giudice & Privitera 1989

Thamnobryo alopecuri-Phyllitidetum scolopendrium Brullo, Privitera & Puglisi 1993

Phragmito australis-Magnocaricetea elatae Klika in Klika & Novák 1941

Scirpetalia compacti Heijný in Holub, et al. 1967 corr. Rivas-Martínez et al. 1980 (=*Bolboschoenetalia maritimi* Hejny in Holub et al. 1967)

Scirpion compacti Dahl & Hadac 1941 corr. Rivas-Martínez, Costa, Castroviejo & E. Valdés 1980 (=*Scirpion maritimi* Dahl et Hadac 1941)

Scirpetum maritimi (Christiansen 1934) R. Tx. 1937

Scirpetum maritimo-litoralis (Br.-Bl. in Br.-Bl., Roussine & Nègre 1952) O. de Bolòs 1962

Cyperetum distachyi Bolòs & Molinier 1984

Phragmitetalia australis Koch 1926

Phragmition communis Koch 1926

Phragmitetum communis (Koch 1926) Schmale 1939

Nasturtio officinalis-Glycerietalia fluitantis Pignatti 1953

Glycerio fluitantis-Sparganion neglecti Br.-Bl. & Sissingh in Boer 1942

Sparganietum erecti Roll 1938

Glycerietum notatae Kulczyński 1928

Apion nodiflori Segal in Westhoff & Den Held 1969

Helosciadietum nodiflori Br.-Bl. 1952

Polygono salicifolii-Nasturtietum officinalis Gehu & Biondi 1988

Apio nodiflori-Glycerietum plicatae Brullo & Spampinato 1988

Cisto cretici-Micromerietea julianae Oberdorfer ex Horvatić 1958

Cisto cretici-Ericetalia manipuliflorae Horvatic 1958

Cisto cretici-Ericion manipuliflorae Horvatic 1958

Saturejo cuneifoliae-Ericetum manipuliflorae Brullo et al. 1986

Chamaecytiso spinescentis-Genistetum michelii De Faveri & Nimis ex Biondi 2000

Centaureo subtilis-Thymetum capitati Terzi & D'Amico 2006

Asyneumo limonifolii-Saturejetum montanae Biondi & Guerra 2008

Phagnalo saxatili-Saturejetum cuneifoliae Biondi & Guerra 2008

Ruto chalepensis-Salvietum trilobae, Biondi & Guerra 2008

Helianthemo jonii-Thymetum capitati Biondi & Guerra 2008

Sedo ochroleuci-Saturejetum cuneifoliae Di Pietro & Misano 2010

Thymo-Lavanduletum multifidae Brullo, Minissale & Spampinato 1987

Cisto eriocephali-Phlomidetum fruticosae Brullo, Scelsi & Spampinato 2001

Ptilostemo-Helianthetum farinulentum Brullo, Scelsi & Spampinato 2001

Thymelaeo hirsutae-Rosmarinetum officinalis Brullo, Minissale & Spampinato 1987
Plocama calabrica and *Dianthus longicaulis* communities
Thymbra capitata and *Fumana scoparia* communities
Satureja cuneifolia and *Euphorbia spinosa* communities
Satureja cuneifolia and *Thymbra capitata* communities
Dianthus longicaulis communities
Tuberaria lignosa communities
Cytiso spinescentis-Saturejion montanae Pirone & Tammaro 1997
Rhamno saxatilis-Saturejetum montanae Tomaselli, Silletti & Forte 2021
Elaeoselino asclepii-Salvietum officinalis Lucchese, Persia & Pignatti 1995
Erico multiflorae-Salvietum officinalis Maiorca & Spampinato 1999

Querco roboris-Fagetea sylvaticae Br.-Bl. & Vlieger in Vlieger 1937
Fagetalia sylvaticae Pawłowski in Pawłowski, Sokołowski & Wallisch 1928
Geranio versicoloris-Fagion sylvaticae Gentile 1970
Aristolochio luteae-Quercetum austrotyrrhenicae Brullo, Scelsi & Spampinato 2001
Ilici aquifolii-Quercetum austrothyrrenicae Brullo et Marcenò in Brullo 1984 corr. Brullo, Giusso del Galdo, Minissale, Spampinato 2002

Psoretea decipientis Mattick ex Follmann 1974
Barbuletalia unguiculatae von Hübschmann 1960
Homalothecio aurei-Pleurochaetion squarrosae (Ros & Guerra 1987) Marstaller 1993

Pleurochaeto squarrosae-Cheilotheletum chloropodis Privitera & Puglisi 1996.

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Data availability The authors confrm that the data supporting the fndings of this study are available in the article and in Supplementarymaterials.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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