Vegetation Ecology and Diversity 63 (2026) e195340 | DOI 10.3897/ved.195340 Topical Collection

PENSOFT

VEGETATION ECOLOGY AND DIVERSITY

Research Article

Petrifying (tufa forming) springs in Cyprus: first record and ecological characterization*

Athina Papatheodoulou[1,2], Daniel Spitale[3], Constantinos Kounnamas[1], Maria Sarika[4]

1 *Nature Conservation Unit, Frederick University, Nicosia, Cyprus*

2 *BIOME Hub - Biomonitoring & Ecological Research, Limassol, Cyprus*

3 *BMT BioMonitoring Team, Trento, Italy*

4 *Section of Genetics & Biotechnology, Department of Biology, National and Kapodistrian University of Athens, Athens, Greece*

Corresponding author: Daniel Spitale (spitale@biomonitoraggi.it)

Academic editor: Marta Puglisi ♦ **Received** 12 April 2026 ♦ **Accepted** 20 May 2026 ♦ **Published** 26 June 2026

Abstract

This study provides the first documentation of petrifying (tufa-forming) springs in Cyprus and describes their floristic composition and habitat classification in detail. Field surveys conducted in 2024–2025 identified six active tufa-forming sites across five catchments in the southwestern part of Cyprus. Each locality exhibited alkaline, calcium-rich waters and ongoing precipitation of calcium carbonate. Vegetation analysis revealed consistent assignment of the recorded plant assemblages to the association *Eucladio–Adiantetum* (alliance *Adiantion*, class *Adiantetea*), dominated by the diagnostic species *Eucladium verticillatum* and *Adiantum capillus-veneris*. Based on indicator species and structural attributes, this vegetation type corresponds to EUNIS habitat H3.41 (U3D) "Mediterranean wet inland cliffs" and meets the criteria for the description of the EU priority habitat type 7220* "Petrifying springs with tufa formation (*Cratoneurion*)". This represents the first evidence of this rare groundwater-dependent habitat on the island and provides baseline data for its biogeographic characterization and conservation assessment.

Keywords

Cyprus, *Eucladio-Adiantetum*, habitat type 7220*, Natura 2000, petrifying springs, tufa

Introduction

Petrifying (tufa-forming) springs are freshwater springs in which calcium-rich groundwater deposits tufa (Lyons and Kelly 2016). Tufa is a highly porous calcareous rock formation, typical of karst environments. It forms primarily at springs, seepages, and stream channels from calcium-rich waters under ambient temperatures when CO_2 degassing, driven by changes in hydrodynamic pressure, water agitation, exposure to air, photosynthetic uptake, and evaporation, induces supersaturation and precipitation of $CaCO_3$ (Pentecost 2005; Heery 2007; Capezzuoli et al. 2014). Carbonate nucleation occurs on submerged surfaces, particularly on bryophytes, green algae and cyanobacteria, whose tissues become progressively encrusted, creating the structural framework for tufa deposits (Onete et al. 2014; Garner et al. 2025).

In addition to the hydrochemical conditions required for tufa deposition, its formation is largely controlled by biological activity, through which cyanobacteria, algae, and bryophytes trap and bind calcite crystals through secreted mucopolysaccharides, thereby promoting mineral precipitation (Janssen et al. 2016), while vascular plants further shape the development of deposits (Heery 2007; Onete et al. 2014). This process leads to the gradual "petrification" of plant tissues and other organic substrates, creating a

* Topical Collection: Conservation and biodiversity of bryophytes in the ecosystems, and community variability.

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complex and highly specialized biogenic habitat (Capezzuoli et al. 2014; Garner et al. 2025). The tufa formation may be small deposits around the bases of plants within the spring, attached or unattached coated particles (stones or plant fragments) or can comprise very large mounds and cascades (Lyons and Kelly 2016; Denyer et al. 2023).

Petrifying (tufa-forming) springs support highly specialized bryophyte- and fern-dominated communities, often including rare or threatened species adapted to the distinctive conditions of these systems (Heery 2007; Denyer et al. 2023). Due to their ecological specificity and rarity, they are listed as a priority habitat under Annex I of the European Union (EU) Habitats Directive (92/43/EEC) as habitat type 7220* "Petrifying springs with tufa formation (*Cratoneurion*)" (European Commission 2013). They are also recognised as groundwater-dependent terrestrial ecosystems (GWDTEs) under the Water Framework Directive (2000/60/EC), which requires the maintenance of the hydrological and chemical status of the aquifers that feed them (Schutten et al. 2011). Furthermore, this habitat is included in the European Red List of Habitats, classified as Vulnerable (C2.1.b Calcareous Spring and spring brook) (Janssen et al. 2016), reflecting its sensitivity to alterations in the hydrological regime and water quality.

The floristic core of habitat type 7220* corresponds to the alliance *Cratoneurion commutati* (class *Montio-Cardaminetea*), comprising moss-rich vegetation of calcareous springs in the montane and subalpine regions of Europe (Mucina et al. 2016). This vegetation type is rare outside the Alpine Folding Zone, particularly in the Central European Highlands (Pentecost 2005). However, an ecological continuum between the Central European *Cratoneurion* and Mediterranean *Adiantion* vegetation has been described by several authors, both of which are dominated by bryophyte- and fern-rich communities on calcareous wet cliffs (Zechmeister and Mucina 1994; Spampinato et al. 2023).

In southern Europe, these communities are often assigned to the association *Eucladio-Adiantetum* (alliance *Adiantion*), characterized by *Adiantum capillus-veneris* and *Eucladium verticillatum*. Although the syntaxonomic relationship between temperate *Cratoneurion* and Mediterranean *Adiantion* remains debated, both are ecologically linked to lime-rich, permanently moist habitats and contribute actively to tufa formation. Mucina et al. (2016) emphasizes the marginal position of *Cratoneurion commutati* within the class *Montio-Cardaminetea* and propose its closer affinity to *Adiantetea.* Similarly, Zechmeister and Mucina (1994) report the absence of a clear phytosociological boundary between *Adiantetea* and *Montio-Cardaminetea* communities, supporting the interpretation of these vegetation units forming an ecological continuum across spring habitats.

Although Pedley (2009) provides an extensive synthesis of tufa in the Mediterranean region, Cyprus is not included among the documented regions. To our knowledge, petrifying springs and the associated EU priority habitat type 7220* have not been previously reported on the island. To address this, we conducted dedicated field surveys to investigate their potential presence and document their floristic, geomorphological, and hydrological characteristics. Specifically, this study aimed to identify, and map springs whose vegetation structure, floristic composition and active tufa-forming processes correspond to the characterisation of Annex I habitat type 7220* under Directive 92/43/EEC.

Methods

Study area

The survey focused on a set of representative spring locations that were considered particularly relevant. The study area is in southwestern Cyprus (Fig. 1). Cyprus has a typical Mediterranean climate with hot, dry summers and mild, rainy winters. The average annual rainfall for the period 1971–2022 was 471 mm (Department of Meteorology 2024), making Cyprus the most water-stressed country in the European Union (EEA 2025a). Water demand for domestic and agricultural use peaks in summer and since the 1960s, has been increasingly met through the construction of 108 dams (Sofroniou and Bishop 2014), rendering the island the most densely dammed country in Europe (WDD 2023).

Geologically, Cyprus comprises four major tectonostratigraphic zones (GSD 2002). The Pentadaktylos (Kyrenia) Zone in the north is dominated by allochthonous limestones, dolomites, and marbles, overlain by sedimentary formations. The central part of the island is occupied by the Troodos Ophiolite, one of the world's most complete and best-preserved fragments of the oceanic crust. Surrounding the Troodos massif is the Circum-Troodos sedimentary succession, composed mainly of marls, chalks, limestones, cherts, and clays. In the southwest, the Mammonia Zone consists of igneous, sedimentary, and metamorphic rocks of the Triassic–Cretaceous age, emplaced during the Maastrichtian (GSD 2002).

Sampling sites 1–5 (Fig. 1), are located within the Mammonia Zone, whereas site 6 lies within the Circum-Troodos sedimentary succession. At all sites, the underlying bedrock was composed of autochthonous sedimentary formations. Sites 1, 2, 3, 5, and 6 are in the Pakhna Formation, a carbonate-dominated unit consisting of pelagic limestones, bioclastic grainstones, calcarenites, calcirudites, and chalks derived from marine biogenic and ophiolite-related materials (Eaton and Robertson 1993; GSD 2002). Site 4 is located on the Nicosia Formation, composed of siltstones interbedded with calcarenites and marls (GSD 2002; Kinnaird et al. 2011).

Groundwater abstraction is extensive throughout the island, with water from at least 24 major springs used for irrigation and domestic water supply. Chronic over-pumping has resulted in increasing aquifer salinity, and the chemical status of many groundwater bodies remains below "good" ecological status (WDD 2023). This hydrological context highlights the importance of identifying and conserving GWDTEs, including petrifying springs. Groundwater resources depend primarily on rainfall, aquifer storage, and transmissivity. The main

aquifers develop in areas of clastic deposition, river valleys, and deltas, including the surveyed catchments. Although no detailed hydrogeological survey was conducted, available data from the Geological Survey Department- GSD (2002) indicate that the studied springs occur in limestone aquifers (sites 1 and 2), unconfined groundwater within sandy marls and calcarenites (site 3), shallow unconfined aquifers controlled by impervious or semi-pervious strata (site 4), and highly retentive chalk layers interbedded with marls (sites 5 and 6).

The six sampling sites were distributed across five catchment areas in southwestern Cyprus (Fig. 1). Three sites fall within the Natura 2000 Special Areas of Conservation (SACs): CY4000010 Chersonisos Akama and CY4000008 Koili–Mavrokolympos. The descriptive site characteristics are presented in Table 1. Hydrochemical parameters were measured in situ using a JQ-006 digital multimeter.

Field surveys & data collection

Targeted field surveys were conducted in April 2024 and November 2025. Six active tufa-forming springs were located, mapped (Fig. 1), and described with respect to geomorphology, tufa deposition processes and associated vegetation. As indicators of activity, we checked the presence of flowing or dripping water, visible crystal growth and actively growing vegetation.

Vegetation was studied using the Braun-Blanquet floristic-sociological approach (Westhoff and van der Maarel 1980; Kent and Coker 1992). At each sampling site, one 4 m^2 sampling plot (relevé) was established, following the recommended standards for spring vegetation (Chytrý and Otýpková 2003). Plots were selected based on uniformity and representativeness. All vascular plants, bryophytes, and ferns were recorded, and species cover was estimated using the extended 9-point Braun–Blanquet scale (van der Maarel 1979).

Species identification was verified in the laboratory, and voucher specimens were deposited in the private herbarium of the corresponding author. For each plot, geographic coordinates in decimal degrees, elevation, hydrological conditions, pH, electrical conductivity (eC), and tufa morphology were recorded. The observed threats and pressures were documented and coded following the EEA (2025b).

Data analysis & habitat interpretation

Bryophytes were identified using Cortini-Pedrotti (2001, 2006), while vascular plants using Christofides (2017) and Hand et al. (2011–present). Nomenclature of vascular plants and bryophytes follows the most recent European checklists (Hodgetts et al. 2020; Euro+Med PlantBase, https://europlusmed.org/).

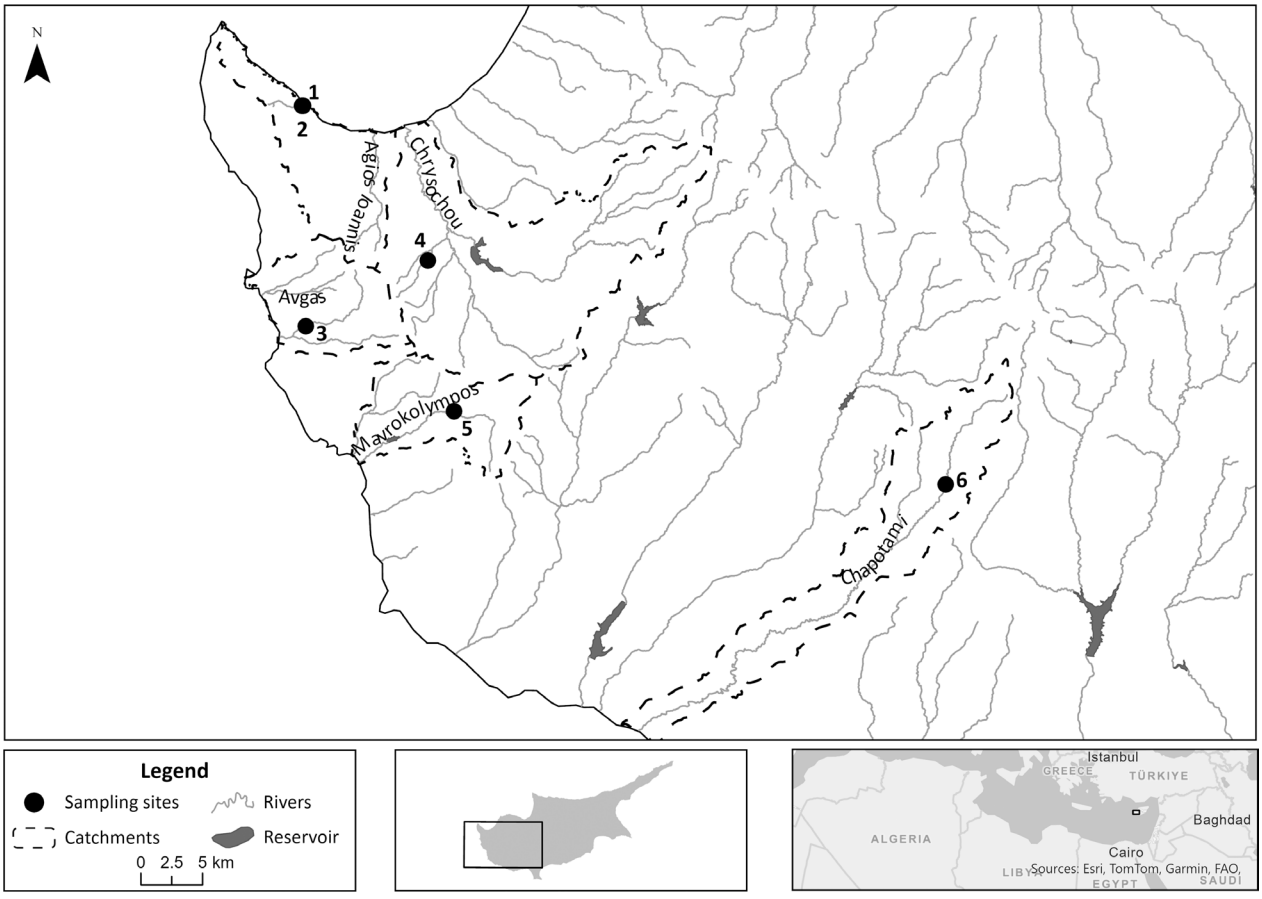


Figure 1. Petrifying springs with tufa formation in Cyprus (numbers correspond to each sampling plot).

Table 1. Descriptive information for each tufa sampling site. The numbers correspond to each sampling plot (relevé).

Plot	Site name	Area (m^2)	Hydrological conditions	Tufa formation type[1]	Longitude, Latitude	Natura 2000- SAC	pH	eC µS/ cm	Pressures/ Threats[2]
1	Baths of Aphrodite stream	20	Damp	Cascade (mound)	32.344463, 35.056426	CY4000010	8.1	1177	PC12 - P (H), PJ03- P/T (L)
2	Baths of Aphrodite spring	60	Trickling	Cascade (mound)	32.343899, 35.056393	CY4000010	8.1	1186	PC12- P (H), PJ03- P/T (L)
3	Avakas spring	60	Dripping	Cascade (mound)	32.346645, 34.924963	CY4000010	8.2	849	PC12 - P (M), PJ03- P/T (L)
4	Kremmiotis waterfall	200	Flowing	Cascade	32.435433, 34.964110	-	8.2	784	PC12- P (L), PJ03- P/T (L)
5	Mavrokolympos Martiri	120	Trickling	Cascade (mound)	32.454670, 34.874249	CY4000008	8.4	917	PC12- P (L), PJ03- P/T (L)
6	Chapotami Potamiou spring	25	Trickling	Cascade (mound)	32.812724, 34.830428	-	8.6	888	PC12- P (L), PJ03- P/T (L)

[1] Tufa formation types after Pentecost (2005) and Lyons and Kelly (2016).
[2] PC12 = Abstraction of surface and ground water for resource extraction, PJ03 = Changes in precipitation regimes due to climate change, P = pressure, T = threat H = high influence, M = moderate influence, L = low influence.

The definition of the vegetation unit described here is based on species groups identified through the application of the Braun–Blanquet tabulation technique. This method highlights species that are concentrated within particular relevé clusters (character species), as well as species that distinguish subtypes within clusters of closely related relevés (differential species). These groups of species are considered diagnostic because their association with specific relevé clusters enables the vegetation to be distinguished into discrete units (Müeller-Dombois 1984; Chytrý et al. 2002).

Following this framework—namely, the identification of species that preferably occur in a single vegetation unit (character species)—and guided by taxa recognized as diagnostic of high-rank syntaxa in the EuroVegChecklist (Mucina et al. 2016), we classified the vegetation unit occurring in the study sites into phytosociological class, order, and alliance. The taxa identified as character species of the specific vegetation unit exhibit a high concentration of occurrences within that unit. The assessment of diagnostic species followed the approach proposed by Westhoff and van der Maarel (1980). A detailed description of the application of this procedure in the present study is provided in Sarika (2012).

The nomenclature of higher rank syntaxa presented in Tables 2, 3, as well as those referred to in the text, follows Mucina et al. (2016). At the association level, previously established nomenclature was adopted in accordance with the formal syntaxonomic code (Theurillat et al. 2021).

The indicator species defining the vegetation of the study area as a distinct unit, were used to assign it to habitat types following the EUNIS classification system (Chytrý et al. 2024) and the European Union Habitats Interpretation Manual (European Commission 2013).

Results

Site characteristics and tufa occurrence

Field surveys revealed that all six investigated sites (Fig. 1) supported active tufa deposition. The petrifying (tufa-forming) springs are distributed across five catchments in southwestern Cyprus and span an elevation gradient from 50 to 650 m (Table 1). All sites were characterized by alkaline water (pH 8.1–8.6) and moderate to high electrical conductivity (784–1186 µS/cm), consistent with carbonate precipitation. Across all sites, tufa vegetation developed on shaded, calcareous dripping cliffs under a range of hydrological conditions, from damp seepage to flowing water continuously moistened by lime-rich water. Tufa formed as porous crusts and layers over rock surfaces and plant tissues, frequently encrusting moss stems and fern rhizomes. Vegetation cover ranged from 25% to 90%, and species richness varied from three to twelve taxa per plot (Table 3). Three sites supporting tufa-forming springs are located within Natura 2000 SACs (CY4000010 Chersonisos Akama and CY4000008 Koili–Mavrokolympos) (Table 1).

Vegetation composition and syntaxonomic placement

The vegetation recorded at all six sites corresponded to the association *Eucladio–Adiantetum* Br.-Bl. in Br.-Bl. et al. 1952, belonging to the alliance *Adiantion*, order *Adiantetalia*, and class *Adiantetea* (Table 2). This vegetation unit is classified as EUNIS habitat H3.41 (U3D) and

Table 2. Classification of distinguished vegetation unit into habitat typologies.

Syntaxon	EUNIS[1]	Annex I HD[2]	EU RLH[3]	CORINE[4]
Class: *ADIANTETEA* Br.-Bl. et al. 1952				
Order: *Adiantetalia* Br.-Bl. Ex Horvatić 1934				
Alliance: *Adiantion* Br.-Bl. Ex Horvatić 1934				
Association: *Eucladio-Adiantetum* Br.-Bl. in Br.-Bl. et al. 1952	H3.41 (U3D)	7220*	C2.1b	62.51

[1]: EUNIS Habitat Classification (Chytrý et al. 2024); [2]: Annex I of the Council Directive 92/43/EEC (European Commission 1992), [3]: European Red List of Habitats (Janssen et al. 2016), [4]: CORINE Biotopes (European Commission 1991).

corresponds to the EU priority habitat type 7220* "Petrifying springs with tufa formation (*Cratoneurion*)," while also matching CORINE type 62.51 and the European Red List habitat C2.1b.

The vegetation stands exhibited a simple structure dominated by a dense bryophyte layer, with *Eucladium verticillatum* consistently dominant, occasionally mixed with *Pellia endiviifolia*, *Oxyrrhynchium hians*, *Cratoneuron filicinum*, and *Hydrogonium bolleanum*. The herbaceous and fern layer included *Adiantum capillus-veneris*, *Samolus valerandi*, and scattered individuals of other hygrophilous species (Table 3).

Diagnostic & constant species

Eucladium verticillatum was the dominant moss in all sampling plots, forming thick cushions actively involved in tufa formation, with basal stems frequently encrusted with calcium carbonate ($CaCO_3$). *Adiantum capillus-veneris*, a thermophilous and calciphilous fern, occurs in moist rock crevices subjected to continuous spray or seepage. Their co-occurrence, often accompanied by *Samolus valerandi*, is a well-documented assemblage in Mediterranean tufa assemblages (Zechmeister and Mucina 1994; Hájková et al. 2011; Puglisi et al. 2018).

The presence of *Pellia endiviifolia* at three sites and *Oxyrrhynchium hians* at one site further supports the petrifying spring character of these communities, as both species are frequently associated with lime-encrusting bryophyte communities (Dakskobler et al. 2014; Guitián et al. 2020). *Cratoneuron filicinum*, a moss indicative of nutrient enrichment and characteristic of both *Adiantetea* and *Montio-Cardaminetea* classes (Mucina et al. 2016) was recorded only once.

Habitat correspondence

Based on diagnostic, species, the plant assemblages recorded at all six sites correspond to the EUNIS habitat type H3.41 (U3D) "Mediterranean wet inland cliffs" and qualify as the EU priority habitat type 7220* "Petrifying springs with tufa formation (*Cratoneurion*)" under Annex I of the Habitats Directive (92/43/EEC). Figure 2 illustrates the typical vegetation structure of the habitat (Kremmiotis waterfall).

Although the syntaxonomic core of *Cratoneurion* is described mainly for Central and Northern Europe, the Cypriot assemblages represent a Mediterranean vicariant form closely related to the *Adiantion* alliance (Spampinato et al. 2023). The dominance of carbonate-encrusted bryophytes (*Eucladium verticillatum*, *Pellia endiviifolia*), the constant presence of the fern *Adiantum capillus-veneris*, and clear evidence of active tufa deposition under specific microenvironmental conditions (spring-fed, calcareous-rich water, constant humidity, and high pH) support assignment to the EU GWDTE priority habitat type 7220* at all six sites.

Table 3. *Eucladio-Adiantetum* in Cyprus.

Elevation (m)	280	530	650	55	100	50
Catchment	**Chrysochou**	**Mavrokolympos**	**Chapotami**	**Agios Ioannis**	**Avgas**	**Agios Ioannis**
Plot size (m^2)	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2	4 m^2
Total cover (%)	90%	65%	80%	25%	30%	50%
Species N.	6	12	6	3	3	6
Sampling plot N.	4	5	6	1	3	2
Eucladium verticillatum	3	3	3	3	2a	3
Adiantum capillus-veneris	1	3	3	1	2a	1
Characteristic species of *Adiantetea*						
Samolus valerandi	+	2a	.	.	.	1
Pellia endiviifolia	2a	2a	2a	.	.	.
Characteristic species of *Salicetea herbaceae*						
Brachytheciastrum velutinum	.	+	2a	.	2a	2a
Characteristic species of *Platyhypnidio-Fontinalietea antipyreticae*						
Hydrogonium bolleanum	3	1	.	.	.	.
Cratoneuron filicinum	.	1	.	.	.	.
Characteristic species of *Psoretea decipientis*						
Pohlia melanodon	.	+	.	.	.	.
Cephaloziella calyculata	.	+	.	.	.	.
Characteristics of *Ceratodonto purpurei-Polytrichetea piliferi*						
Oxyrrhynchium hians	.	.	.	.	.	2a
Companions						
Ficus carica	.	1	1	1	.	1
Rubus sanctus	.	+	1	.	.	.
Nerium oleander	.	+	.	.	.	.
Chara sp.	+	.	.	.	.	.

Sampling plots: 1–Baths of Aphrodite stream, 2–Baths of Aphrodite spring, 3–Avakas spring, 4–Kremmiotis waterfall, 5–Mavrokolympos Martiri, 6–Chapotami Potamiou spring.

Discussion

This study provides the first confirmed record of petrifying (tufa-forming) springs in Cyprus, corresponding to European habitat type 7220*. The documented stands of the association *Eucladio-Adiantetum* exhibit all the defining features of this habitat: discharge of calcium-rich groundwater, active tufa deposition, and dominance by bryophyte–fern assemblages with *Eucladium verticillatum* and *Adiantum capillus-veneris*. These taxa are diagnostic for *Adiantion* communities and are widely recognized as key builders of the tufa crusts (Zechmeister and Mucina 1994; Lyons and Kelly 2016; Denyer et al. 2023).

The coexistence of *Eucladium verticillatum* and *Adiantum capillus-veneris*, accompanied by *Samolus valerandi* and *Pellia endiviifolia*, reflects a transitional floristic composition between Central European *Cratoneurion commutati* and Mediterranean *Adiantion*. Similar Mediterranean expressions of petrifying springs have been reported in Sicily and Calabria (Puglisi et al. 2018; Spampinato et al. 2023). Therefore, the Cypriot assemblages represent the easternmost Mediterranean vicariant of habitat type



Figure 2. Typical vegetation structure of petrifying springs with tufa formation at Kremmiotis waterfall showing (**A**) the broader setting and (**B**) a close-up of the spring and tufa-formation.

7220*, occupying analogous ecological niches under warmer and drier climatic conditions.

The dominance of *Eucladium verticillatum*, a principal tufa-generating moss, and its calcite encrustation confirm ongoing carbonate deposition. *Pellia endiviifolia* and *Oxyrrhynchium hians* are both linked to tufa-forming habitats in continental Europe (Dakskobler et al. 2014; Guitián et al. 2020), further strengthening habitat interpretation. Glime (2020) reported *Eucladium verticillatum* and *Palustriella commutata* as the most common species in petrifying springs in a pH range of 6.9–8.3. A similar group of plant communities of Irish petrifying springs of tufa cascades was described by Lyons and Kelly (2016), consisting of *Eucladium verticillatum-Pellia endiviifolia*, dominated by bryophytes, with affinities with *Adiantion* communities of damp cliffs.

Notably, *Hydrogonium bolleanum*, a rare and threatened bryophyte, largely confined to the Mediterranean region of southern Europe (Schröck et al. 2019; Puglisi et al. 2024), was detected at two localities. This species is typically associated with moist calcareous substrates such as flowing or dripping water habitats (Fiaschi et al. 2025). As a carbonate-encrusting bryophyte associated with biogenic rock formation, its occurrence further supports the active tufa-forming character and high conservation value of the investigated springs. The presence of such

specialised bryophytes also highlights the role of these spring systems as refugia for moisture-dependent and habitat-sensitive Mediterranean taxa.

At the structural level, *Eucladium verticillatum* function as keystone acrocarpous cushion-forming bryophyte that can be practically described as synonymous with tufa formation. Their adpressed leaves and the dense colonies allow an efficient capillary retention of water and progressive carbonate encrustation. The high density and small size of bryophyte leaves provide a large surface area that promotes carbonate precipitation (Bates and Smith 2011). *Pellia endiviifolia*, the most frequently reported thallose liverwort in European tufa deposits, typically colonises zones of active precipitation, where it may become incorporated into carbonate. This species prefers low nutrient levels (Glime 2020). Ferns are often recorded in tufa but are usually absent from actively depositing zones. *Adiantum capillus-veneris* is widely recorded in shaded seepages at sites across Europe, Asia, and Africa (Pentecost 2005).

Petrifying springs are among the most fragile GWDTEs in Europe. Their persistence depends on the continuity of groundwater discharge, stable hydrochemistry, and microclimatic conditions. Even small hydrological changes can disrupt carbonate deposition and the survival of bryophyte communities (Lyons and Kelly 2016; Denyer et al. 2023; de Mars et al. 2024). The high abundance of carbonate-encrusted bryophytes in the investigated springs indicates currently favourable ecological conditions, as the species found are among the positive indicator species of petrifying springs (Lyons and Kelly 2016; Denyer et al. 2023), yet these systems remain extremely vulnerable to changes in hydrological regime, water chemistry, temperature, and seasonal variability (Sironić et al. 2023).

The challenges presented by the Mediterranean climate include a high level of natural stress due to seasonal fluctuations in climate and hydrology. Although seasonality (dry summers and wet winters) is highly predictable, marked interannual variability (dry and wet years) is not (Cantonati et al. 2020). As small, usually localised GWDTEs, petrifying springs are very sensitive to changes in hydrology. In Cyprus, their vulnerability is amplified by severe water scarcity, groundwater abstraction, and localized pollution from diffuse sources (WDD 2023). Similar threats and pressures have led to an unfavourable conservation status of habitat type 7220* in the Mediterranean biogeographic region during the 2007–2012 assessment period in Italy, France, and Spain (EEA 2025c).

Because this is the first documentation of habitat type 7220* in Cyprus, the habitat is not yet listed as a qualifying interest in any SAC. Where petrifying springs are designated as qualifying interests, Article 6 of the Habitats Directive imposes strict protection (European Commission 1992). Given their groundwater dependence and potential hydrological interconnections, any development affecting aquifer systems should be evaluated with exceptional caution. Formal designation, notably within the CY4000010 Chersonisos Akama and CY4000008 Koili–Mavrokolympos SACs-would substantially strengthen their legal protection and enable systematic monitoring. Site-specific conservation objectives should prioritize the maintenance of natural groundwater regimes, regulation of water abstraction, and continuous water quality monitoring. Catchment-scale management is essential, given the small size, localised extent, and hydrological sensitivity of these systems. Furthermore, mapping potential spring sites across the island may reveal additional occurrences of this habitat type, enabling a more accurate assessment of its conservation status. The NPWS (2019) provides a list of tangibles, quantifiable conservation targets relevant to the habitat type.

Beyond biodiversity conservation, petrifying springs offer additional societal value, contributing to geodiversity, environmental education, and sustainable geotourism, as demonstrated in established geoparks (Megerle 2021; Petrović et al. 2023; Çiltepe and Uzun 2024). In Cyprus, these geo-ecological features can become focal points for sustainable tourism.

Conclusions

This study provides the first documented evidence of petrifying springs with active tufa formation in Cyprus, corresponding to the EU priority habitat type 7220*. The vegetation is assigned to the association *Eucladio–Adiantetum*, dominated by *Adiantum capillus-veneris* and *Eucladium verticillatum*, both of which are key diagnostic species of Mediterranean tufa-forming communities. Their presence, together with active $CaCO_3$ deposition, confirms the existence of a groundwater-dependent habitat on the island.

The presence of carbonate-encrusting bryophytes and the recording of species such as *Hydrogonium bolleanum* indicate sites of high ecological quality. However, the small spatial extent, hydrological dependence, and water stress conditions, render these habitats highly vulnerable to groundwater abstraction, water-quality degradation, and climate-driven hydrological change.

Further research is required to determine the full distribution of petrifying springs across Cyprus, which is likely to be broader than that currently documented. Additional tufa morphotypes (including cemented rudites, oncoids, and ooids) have already been identified, suggesting a complex and diverse carbonate system deserving continued investigation.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was required.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.

Regarding the use of AI in the preparation of this manuscript, the authors declare the following: ChatGPT (OpenAI) was used for language editing only. All scientific content, interpretations, and conclusions were developed by the authors, who take full responsibility for the final version of the manuscript.

Funding

No external funding was received for this study. All work was carried out independently by the authors.

Author contributions

PA: Conceptualization, data curation, investigation, methodology, formal analysis, visualization, writing – original draft, writing – review and editing. SD: Conceptualization, investigation, methodology, formal analysis, writing – original draft, writing – review and editing. CK: Writing – review and editing. MS: Formal analysis, writing – original draft, writing – review and editing.

Author ORCIDs

Athina Papatheodoulou https://orcid.org/0000-0001-7198-5044
Daniel Spitale https://orcid.org/0000-0002-3955-9157
Constantinos Kounnamas https://orcid.org/0000-0001-6797-2080
Maria Sarika https://orcid.org/0009-0005-5430-5939

Data availability

All of the data that support the findings of this study are available in the main text.

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