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Research Article

Bryophyte Diversity and Colonisation Patterns on the Building Stones of Küçükköy Church (Niğde, Türkiye)

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Abstract: Bryophytes are non-woody plants capable of growing on various substrates, including tree trunks, rock surfaces, and historical structures. Their colonisation of historical buildings and monuments may cause biological deterioration by altering the physical and chemical properties of building materials, potentially weakening structural integrity and diminishing aesthetic values. The distribution and colonisation of bryophytes on historical monuments depend on the lithological, mineralogical, and physical properties of the substrate, as well as microclimatic factors such as moisture, light, and temperature. This study aimed to determine the bryophyte flora of Küçükköy Church, located in Niğde, Türkiye, and to evaluate the distribution of bryophyte species across the structure. Following the identification of specimens collected from the building stones using relevant bryological literature, a total of 18 species belonging to seven genera and four families were identified. Pottiaceae was the most species-rich family, comprising 10 species, followed by Grimmiaceae with five species. Members of Pottiaceae were concentrated on the andesitic surfaces of the church façades, except for the southern façade, where they formed colonies of varying sizes. In contrast, members of Grimmiaceae formed dense cushions, particularly on the eastern and western façades and on basaltic surfaces exposed to intense solar radiation. The findings suggest that the lithological characteristics of building stones and microclimatic conditions may influence the distribution.

Keywords: Biological deterioration, Bryophyte, Building stone, Küçükköy Church, Niğde

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Introduction

Bryophytes comprise three divisions, namely Anthocerotophyta (hornworts), Marchantiophyta (liverworts), and Bryophyta (mosses), and include approximately 28,000 taxa worldwide, making them the second-largest group of terrestrial plants after vascular plants (Mossang et al., 2021). These organisms occupy an important position in the evolutionary history of land plants and have adapted to terrestrial environments while retaining their dependence on water during sexual reproduction, when male gametes (spermatozoids) require water to reach female gametes. Consequently, moisture availability is a key factor influencing their growth, reproduction, and distribution. This characteristic has earned bryophytes the designation of “amphibians” (*Amphibia*) of the plant kingdom. Distributed across a wide range of terrestrial habitats, from polar regions to arid deserts, bryophytes exhibit remarkable adaptability to diverse environmental conditions and microhabitats (Goffinet & Shaw, 2009; Delwiche & Cooper, 2015). This extensive distribution enables bryophytes to colonize not only natural ecosystems but also a variety of substrates, including rock surfaces, tree trunks, and building stones of historical structures.

The Cappadocia region of Central Anatolia is home to numerous historical churches that constitute an important part of its cultural heritage. Among these, Küçükköy Church, built in 1834, is notable for its icons and distinctive roof architecture (Ekiz, 2015). However, prolonged disuse, local atmospheric conditions, and the physical and mineralogical properties of its building stones have favoured the

development of various deterioration processes over time (Hatır et al., 2018). Among the biological components involved in these processes, bryophytes colonizing historical building stones in response to environmental conditions also warrant particular attention.

Bryophytes are non-woody plant groups capable of growing on a variety of substrates, including tree trunks, rock surfaces, historical buildings, and monuments, particularly in moist and shaded microhabitats (Buck & Goffinet, 2000). The colonisation of historical buildings and monuments by these plants may adversely affect their structural integrity by inducing changes in the physical, chemical, and mechanical properties of building materials. This process, referred to as biological deterioration (biodegradation), can lead to the gradual deterioration of building materials, alterations in surface properties, and a reduction in the aesthetic value of structures that constitute part of the cultural heritage (Allsopp et al., 2004; Dakal & Cameotra, 2012).

Monuments and historical structures are constructed using natural stones of different geological origins, such as sandstone, basalt, rhyolite, and granite, as well as artificial materials, including mortar and brick. Differences in the mineralogical composition and physical properties of these materials may influence the diversity, distribution, and development of surface-colonising organisms. Bryophytes obtain essential nutrients from environmental sources, particularly precipitation and atmospheric dust, as well as from the substrate itself (Glime, 2017). Through nutrient uptake and surface colonisation, they interact directly with building materials. In porous substrates, rhizoid development along surface irregularities, pores, and pre-existing microcracks may contribute to mechanical deterioration, while bryophyte metabolism and interactions with associated microorganisms may promote chemical deterioration under favourable conditions. These processes can alter surface properties and gradually compromise the structural integrity of building materials. Therefore, bryophytes constitute one of the biological factors that should be taken into consideration in the conservation of historical structures (Mehta & Shah, 2023).

Bryophytes colonising historical building stones occupy specific microhabitats, and their distribution is influenced by environmental conditions and substrate characteristics. However, their presence does not necessarily indicate biological deterioration. Their growth, water-holding capacity, and interactions with environmental conditions may affect the moisture regime and surface properties of building stones. Accordingly, conservation studies on Küçükköy Church should consider not only the deterioration status of the building stones but also the identification of the bryophyte flora and the assessment of species distribution and colonisation patterns.

The aim of this study is to investigate bryophyte diversity on the building stones of Küçükköy Church and evaluate their distribution across the structure. Specifically, it examines colonisation patterns on different stone surfaces and the relationships between species occurrence, microhabitat characteristics, and building-material properties. Potential associations between bryophyte occurrence and observable signs of deterioration are also assessed. However, bryophyte presence is not considered direct evidence of deterioration; instead, observed patterns are evaluated in relation to environmental conditions and substrate characteristics. By documenting bryophyte diversity and their colonisation patterns, this study seeks to improve understanding of the microhabitats that historical structures provide for bryophytes and their potential involvement in biological deterioration processes, thereby contributing scientific data to future research and the sustainable conservation of cultural heritage.

Material and Methods

Study area

Küçükköy Church, located in Küçükköy village in Niğde Province, lies approximately 11 km west of the city centre (Fig. 1).

The church, dedicated to Saint Nicholas and constructed in 1834 (Ekiz, 2015), is situated on sloping terrain along an east–west axis and has a basilica plan with three apses and three naves. The naves are separated by three rows of columns, with the side naves covered by barrel vaults and the central nave surmounted by a dome. The transitional sections of the dome feature frescoes depicting the four Evangelists, as well as floral motifs, including flowers emerging from vases, depicted against a blue background (Fig. 2a) (Kocaman, 2016; Hatır et al., 2018).

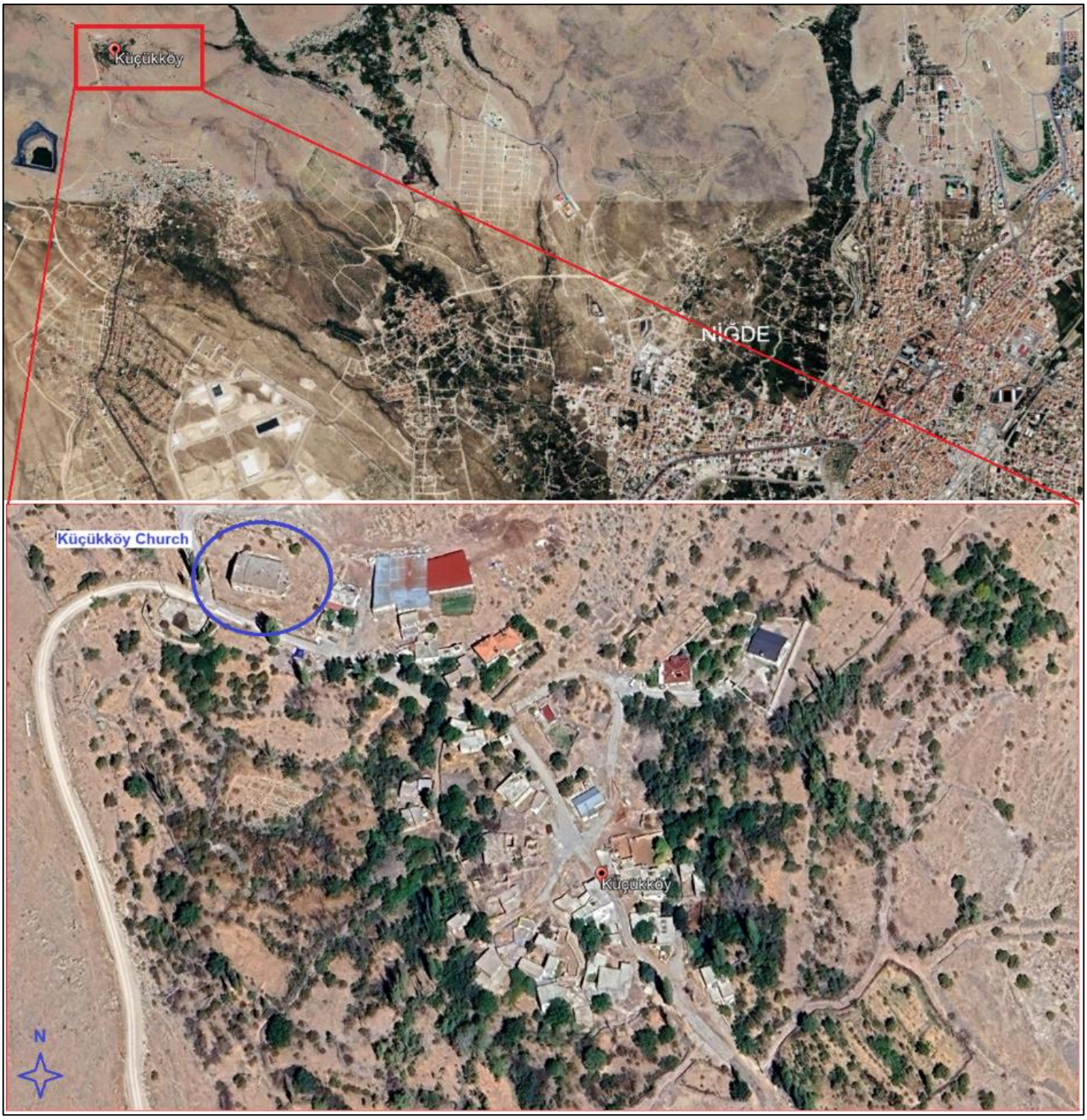

Figure 1. Location of Küçükköy Church (modified from Google Earth)

At the western entrance of the church, a three-bay narthex extends along the entire façade. This section, covered with cross vaults, contains the main entrance door in its central bay. The southern side of the narthex was enclosed with a concrete block wall at a later date (Fig. 2e). The semicircular apses on the eastern façade of the building are covered by a low conical roof system (Fig. 2b). The mouldings defining the cornice line of the apses continue along the northern and southern walls, terminating in serpent-head figures.

The northern and southern façades of the church have a relatively plain architectural appearance (Fig. 2c, d, f). Due to the northward rising topography, the windows on the northern façade are positioned at a

higher level than those on the southern façade. The building has a double-pitched roof arranged at two different levels and measures 22.90 × 12.70 m. It was constructed using a masonry technique with dressed andesite stones. Küçükköy Church was legally protected and registered as a historic monument in 1992 (Açıkgöz et al., 2009; Hatır et al., 2018). The building stones used in the construction of Küçükköy Church were obtained from volcanic geological units in the surrounding area. These units exhibit lithological variation, with andesitic characteristics predominating in the lower levels and basaltic characteristics becoming more prominent in the upper levels (Hatır et al., 2018).



Figure 2. Küçükköy Church (Photograph: T. Ezer)

Field sampling and species identification

Fieldwork was conducted on 26 April and 23 May 2026 to document the bryophyte taxa occurring on the building stones of Küçükköy Church. During the land studies, specimens of bryophytes growing on different building stone surfaces of the church were collected for subsequent identification. The collected specimens were placed in bryological specimen envelopes and transported to the laboratory. Information regarding the collection locality, ecological characteristics, and colonisation patterns was recorded on each specimen envelope.

In the laboratory, the collected bryophyte specimens were identified through morphological examinations under a light microscope, with reference to relevant bryological literature (Zander, 1993; Munoz, 1999; Smith, 2004; Guerra et al., 2006; Kürschner & Frey, 2020). The identification of the taxa was based on the diagnostic morphological characteristics of the respective species.

Results

A total of 18 species belonging to seven genera and four families were identified following the examination of 48 bryophyte specimens collected from the andesitic and basaltic building stones of Küçükköy Church (Table 1).

No representatives of Marchantiophyta (liverworts) or Anthocerotophyta (hornworts) were recorded on the building stones of Küçükköy Church.

Discussion

Pottiaceae was the most species-rich family in the bryoflora of the church, comprising 10 species, followed by Grimmiaceae with five species. Bryaceae was represented by two species, whereas Orthotrichaceae was represented by a single species.

Pottiaceae, which is widely distributed throughout the Mediterranean Basin and is rich in drought-tolerant species, is a moss family characterised by

taxa adapted to arid and semi-arid environmental conditions (Çulha & Ezer, 2025). Members of this family possess ecological adaptations that enable them to maintain their development, particularly in regions where precipitation decreases and drought becomes more pronounced during the summer months. Niğde Province is characterised by a continental climate with hot, dry summers and cold, snowy winters. Long-term meteorological data provided by the Turkish State Meteorological Service indicate a marked decrease in precipitation, particularly during July and August (MGM, 2026). These climatic conditions can be considered among the major environmental factors influencing the distribution and colonisation patterns of bryophytes growing on building stone surfaces with limited water-holding capacity.

Table 1. Floristic composition and distribution of bryophyte species on the andesitic and basaltic building stones of Küçükköy Church. An: Andesite; Ba: Basalt

Family	Genus	Species	An	Ba
Pottiaceae	*Didymodon* Hedw.	*D. rigidulus* Hedw.	+	
Pottiaceae	*Syntrichia* Brid.	*S. calcicola* J.J.Amann	+	
Pottiaceae	*Syntrichia* Brid.	*S. princeps* (De Not.) Mitt.	+	
Pottiaceae	*Syntrichia* Brid.	*S. ruralis* (Hedw.) F.Weber & D.Mohr	+	+
Pottiaceae	*Syntrichia* Brid.	*S. subpapillosissima* (Bizot & R.B.Pierrot ex W.A.Kramer) M.T.Gallego & J.Guerra	+	
Pottiaceae	*Tortula* Hedw.	*T. muralis* Hedw.	+	
Pottiaceae	*Tortula* Hedw.	*T. canescens* Mont.	+	
Pottiaceae	*Tortula* Hedw.	*T. inermis* (Brid.) Mont.	+	
Pottiaceae	*Tortula* Hedw.	*T. brevissima* Schiffn.	+	
Pottiaceae	*Tortula* Hedw.	*T. vahliana* (Schultz) Mont.	+	
Grimmiaceae	*Grimmia* Hedw.	*G. anodon* Bruch & Schimp.	+	+
Grimmiaceae	*Grimmia* Hedw.	*G. laevigata* (Brid.) Brid.		+
Grimmiaceae	*Grimmia* Hedw.	*G. ovalis* (Hedw.) Lindb.		+
Grimmiaceae	*Grimmia* Hedw.	*G. pulvinata* (Hedw.) Sm.	+	+
Grimmiaceae	*Schistidium* Bruch & Schimp.	*S. atrofuscum* (Schimp.) Limpr.		+
Bryaceae	*Bryum* Hedw.	*B. argenteum* Hedw.	+	
Bryaceae	*Bryum* Hedw.	*B. dichotomum* Hedw.	+	
Orthotrichaceae	*Orthotrichum* Hedw.	*O. cupulatum* Brid.	+	

The dominance of the Pottiaceae family in terms of species diversity within the bryoflora of Küçükköy Church may be associated with the ability of its members to tolerate arid conditions. Xerophytic acrocarpous species of the family were distributed across all façades of the church except the southern façade. These species formed colonies of varying sizes on the surfaces of the building stones, ranging from small patches to extensive and dense turfs. The development of colonies of different sizes and densities across the façades indicates that Pottiaceae members exhibit a heterogeneous distribution on the building stones (Fig. 3). In addition to climatic conditions, various microenvironmental factors, including the mineralogical composition of the substrate, façade orientation, duration of solar exposure, porosity and water-holding capacity, surface moisture, and surface roughness, may also influence the development of these colonisation patterns (Mehta & Shah, 2023). Therefore, the widespread occurrence and distribution of members of Pottiaceae on the building stones of Küçükköy Church may be associated with both their ecological tolerances and the lithological and physical properties of the building materials.

The higher abundance of Pottiaceae members on andesitic surfaces suggests a potential relationship between the physical properties of building stones and the ecological tolerances of bryophytes. In particular, the porous structure of andesite stones facilitates water retention within pores and helps maintain surface moisture to some extent, thereby

creating favourable microhabitats for bryophyte attachment and growth. The fact that Pottiaceae includes numerous species capable of tolerating drought and fluctuating moisture conditions may be considered one of the ecological characteristics that could explain their widespread occurrence on the church walls, particularly on andesitic surfaces. However, this distribution pattern cannot be explained solely by the porosity of the stone. Mineralogical composition, surface roughness, duration of solar exposure, and ambient moisture conditions are also factors that may influence bryophyte colonisation and development. Therefore, the high abundance of Pottiaceae on andesitic surfaces may be attributed to the combined effects of the physical and mineralogical properties of the substrate and the ability of these species to tolerate environmental stress.

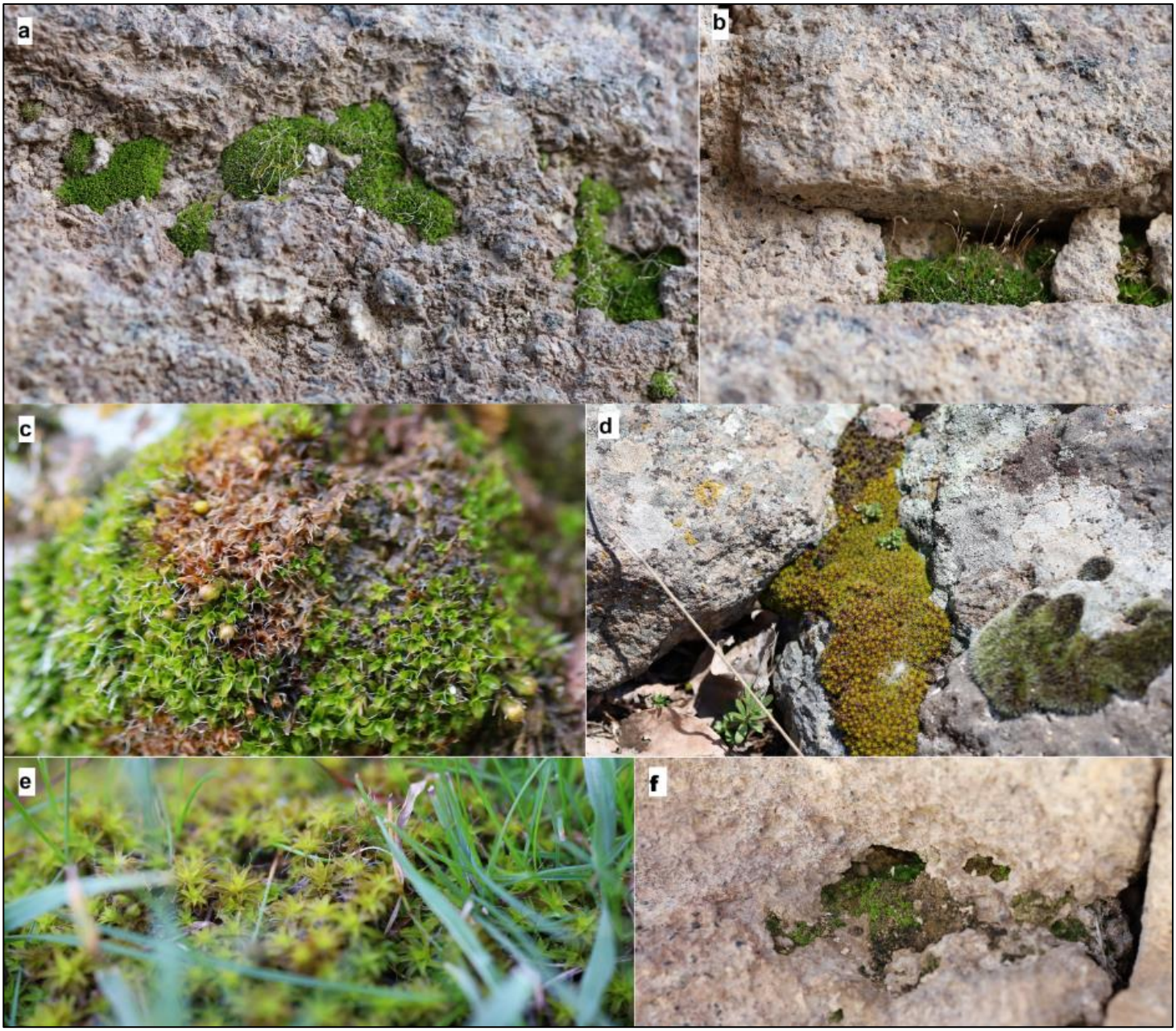

Figure 3. Colonisation by members of Pottiaceae. a, f: *Tortula vahliana*; b: *Tortula muralis*; c: *Tortula brevissima*; d: *Syntrichia calcicola*; e: *Syntrichia ruralis* (Photograph: T. Ezer)

Grimmiaceae, a family characterised by xerophytic species, is represented by five species on the building stones of Küçükköy Church and is prominent in terms of species diversity. Acrocarpous species belonging to this family are widely distributed, particularly on the eastern and western façades and on the upper

sections exposed to intense solar radiation, where they form dense and compact cushions on the stone surfaces (Fig. 4). The relatively low porosity and limited water-holding capacity of basaltic building stones restrict the persistence of moisture on their surfaces, thereby creating selective environmental conditions for bryophytes adapted to drought stress. The frequent occurrence of Grimmiaceae members in rocky and stony habitats is generally associated with their adaptations to fluctuating moisture conditions and water loss. The formation of distinct colonies by members of this family, particularly on the basaltic upper sections exposed to intense solar radiation, suggests that their xerophytic ecological characteristics and tolerance to water loss, together with the physical properties of the building stones, influence their colonisation success.



Figure 4. Colonisation by members of Grimmiaceae (Photograph: T. Ezer)

Bryaceae, a family comprising predominantly mesophytic species, is represented by two species that occur in small colonies, particularly on the andesitic building stones of the northern façade of the church. This distribution pattern highlights the relationship between the moisture requirements of these species and the physical properties of andesitic building stones. The porous structure and high water-holding capacity of andesite contribute to moisture retention on stone surfaces, thereby creating favourable microhabitats for the growth of mesophytic bryophytes. In addition to the properties of the building stones, façade-related microclimatic conditions, such as limited solar exposure and reduced evaporation on the northern façade, have also influenced the colonisation success of Bryaceae members.

The predominantly epiphytic and acrocarpous family Orthotrichaceae was represented by *Orthotrichum cupulatum* on the andesitic building stones of the northern façade of Küçükköy Church. The species colonized the lower sections of the walls on the northern façade, forming relatively dense cushions. In this distribution pattern, the physical properties of the andesitic building stones, together with the microclimatic conditions of the northern façade, appear to have played a role in supporting the colonisation success of *O. cupulatum*.

The colonisation of historical monuments by bryophytes can be viewed as part of an ecological succession process driven by interactions between substrate properties and microenvironmental conditions, involving the sequential establishment of different groups of organisms. During this process, pioneer organisms such as cyanobacteria, green algae, and lichens contribute to biofilm formation and alterations in substrate surface properties. In particular, lichen acids, such as oxalic acid released by lichens, may interact with mineral surfaces, leading to mineral dissolution and changes in the biochemical properties of the substrate. The species diversity and colonisation density of lichens, particularly crustose lichens, developing on the building stones of Küçükköy Church provide important indicators for assessing the extent of biological deterioration occurring on stone surfaces (Fig. 5).



Figure 5. Colonisation by crustose lichens (Photograph: T. Ezer)

Over time, changes in the physical and biochemical properties of substrate surfaces contribute to the formation of suitable microhabitats for bryophyte establishment and development (Mehta & Shah, 2023). In particular, bryophyte communities comprising mosses and liverworts develop on substrate surfaces and constitute an important stage in the colonisation process. Under favourable ecological conditions, this process may continue with the establishment of various vascular plants. Indeed, vascular plants belonging to the genera *Rhamnus* L., *Verbascum* L., *Muscari* Mill., and *Alkanna* Tausch were observed colonizing the upper sections of Küçükköy Church, particularly those characterised by basaltic building stones (Fig. 6).

The distribution and colonisation success of bryophytes on historical monuments are closely associated with the lithological and mineralogical composition, surface roughness, porosity, water-holding capacity, and chemical properties of the substrate, as well as microclimatic factors such as moisture, light, and temperature. Lacking true root systems, bryophytes absorb water and mineral nutrients largely through their surfaces, obtaining these resources from precipitation, atmospheric deposition, and dissolved substances on substrate surfaces. Therefore, the composition and cover of bryophyte communities observed on historical monuments can be considered indicators not only of microclimatic conditions but also of the physical and chemical properties of building materials. Nevertheless, the effects of bryophyte colonisation on monument surfaces may vary depending on the ecological characteristics of the species, colonisation density, and the nature of the substrate.



Figure 6. Colonisation by vascular plants (Photograph: T. Ezer)

Ethical Approval

No need to ethical approval for this study.

Conflicts of Interest

The authors declare no conflict of interest.

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