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Rediscovering Harmankaya: A Critical Habitat for Bryophyte Biodiversity in Zonguldak, Türkiye

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Abstract

This study investigates the bryophyte biodiversity of Harmankaya Waterfalls Nature Park in Zonguldak, Türkiye, an area with critical biological significance for hornworts and other bryophyte species. Fieldwork conducted in 2023-2024 documented bryophyte diversity across three environmental zones based on substrate-water interaction levels. A total of 164 bryophyte taxa were identified, including 3 hornwort, 39 liverwort, and 122 moss taxa, with 32 new records for the Zonguldak bryoflora. Bryodiversity was assessed using the Shannon diversity index, revealing that Zone II, characterized by a mix of aquatic, semi-aquatic, and terrestrial taxa, exhibited the highest diversity. This study highlights the need for enhanced conservation strategies for Harmankaya due to increasing anthropogenic pressures from recreational activities, underscoring the importance of reevaluating its protected status.

Keywords: Bryodiversity, Conservation areas, Harmankaya Waterfalls, Türkiye, Zonguldak

Harmankaya'yı Yeniden Keşfetmek: Zonguldak, Türkiye'de Briyofit Biyoçeşitliliği İçin Kritik Bir Habitat

Öz

Bu çalışma briyofitler, özellikle boynuzotları için kritik bir öneme sahip olan Zonguldak Harmankaya Şelaleleri Tabiat Parkı'nın briyofit biyoçeşitliliğini incelemektedir. 2023-2024 yılları arasında yürütülen arazi çalışmalarında su ile ilişkileri açısından üç çevresel zonda değerlendirilen substratlardaki briyofit örnekleri toplanmıştır. Alandan 3 boynuzotu, 39 ciğerotu ve 122 karayosunu olmak üzere toplam 164 briyofit taksonu tanımlanmış olup, Zonguldak briyoflorası için 32 yeni taksonun kaydı verilmiştir. Shannon çeşitlilik indeksi kullanılarak alanın briyoçeşitliliği değerlendirilmiş ve sucul, yarı sucul ve karasal taksonların bir karışımı ile karakterize edilen Bölge II'nin en yüksek çeşitliliğe sahip olduğu ortaya çıkarılmıştır. Çalışma, rekreasyonel faaliyetlerden kaynaklanan artan antropojenik baskılar nedeniyle Harmankaya Şelaleleri için koruma stratejilerinin geliştirilmesine duyulan ihtiyacı vurgulayarak, alanın koruma statüsünün yeniden değerlendirilmesinin önemini vurgulamaktadır.

Anahtar kelimeler: Briyolojik çeşitlilik, Harmankaya Şelaleleri, Korunan alanlar, Türkiye, Zonguldak

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1. Introduction

Conservation biology is a scientific field that focuses on species, communities, and ecosystems impacted by various factors, especially anthropogenic activities. Its primary objective is to develop guidelines and strategies for preserving biological diversity (Soulé, 1985). It is widely recognized that identifying and maintaining protected areas is crucial for safeguarding wildlife and global biodiversity, as these areas serve as refuges for endangered species (Chape et al., 2005; Gaston et al., 2008; Ament and Cumming, 2016; Sarıoğu et al. 2017). As of July 2024, around 16.11% of the Earth's surface is currently within protected area boundaries (URL 1). However, the concept of the "Global Safety Net", which has gained significant traction in recent years, suggests expanding the existing protected areas to encompass an additional approximately 35.3% of the Earth's surface to limit global warming to 1.5-2°C and mitigate further biodiversity loss (Dinerstein et al., 2019, 2020; Finkelstein et al., 2023).

Türkiye is considered a "Biodiversity Hotspot" due to its hosting of over 11,000 vascular plant species, emphasizing the ongoing conservation efforts in the country (Unan et al., 2021; Borelli et al., 2022). Türkiye's terrestrial surface area designated as protected currently stands at 7.77% (URL 2.), which falls significantly short of the Aichi Targets' goal of 17% (URL 3). In the country, four types of protected areas exist, ranked in decreasing order of importance: national parks, nature reserves, nature parks, and natural monuments (URL 4). Until 2010, Türkiye had 40 nature parks (Sarıoğlu et al. 2017). However, in 2011, the status of nature parks was extended to 138 recreation areas, bringing a total of 178. By 2021, this number had grown to 259. This rapid expansion of nature parks has led to a shift in focus towards recreational use rather than prioritizing biodiversity and ecosystem protection (Atmiş and Artar, 2013; Atmiş, 2018; Atmiş et al., 2020). However, there is still substantial potential for biodiversity conservation in all kinds of protected areas. The Harmankaya Waterfalls, within the borders of Zonguldak province, the subject of this study, exemplifies this situation. Originally designated as a natural monument in 2019, its status was later downgraded to that of a nature park (URL 5). This study aims to uncover the bryophyte biodiversity of this waterfall system, which remains a crucial area for biological diversity, especially in terms of bryophytes, despite being classified as having the lowest conservation status.

2. Materials and Methods

2.1. Study area

Harmankaya Stream is situated within the borders of Zonguldak province in northwestern Türkiye, lying between latitudes 41.3833°N and 41.4167°N, and longitudes 31.8167°E and 31.8500°E. This stream, which is a second-order tributary of the Üzülmez Stream, extends for 5,200 meters and flows through a karst landscape composed of carboniferous rocks (Küçükali et al., 2006). Harmankaya Waterfalls Nature Park, situated along the Harmankaya Stream, features seven waterfalls and spreads across a forested mountain basin of approximately 158 hectares (The Ministry of Agriculture and Forestry, n.d). This basin, characterized by significant precipitation, is classified under the Cfa (subtropical climate) zone according to the Köppen classification (URL 6). The park is populated by beech (*Fagus orientalis* Lipsky), hornbeam (*Carpinus betulus* L.), chestnut (*Castanea sativa* Mill.), and fir (*Abies nordmanniana* subsp. *equi-trojani* (Asch. & Sint. ex Boiss.) Coode & Cullen)) forests throughout its expanse.

2.2. Field excursions, specimen collection, and identification

Field excursions were conducted in the study area between 2023 and 2024, with coordinate information about the sample collection locations provided in Table 1. The substrates from which the samples were collected were categorized into three zones based on structure of the area (Figure 1). Zone, I comprises substrates situated on both sides of the hiking trail that are not in direct contact with water. Zone II includes substrates periodically exposed to water, particularly influenced by the rising Harmankaya stream during heavy rains and snowmelt. Zone III encompasses substrates situated within the stream bed, in continuous contact with water throughout most of the year. Bryophyte samples were collected from these zones in quantities that would not disturb the population dynamics of the colonies, and they were identified at the Bryophyte Research Laboratory of Zonguldak Bülent Ecevit University. Identification was conducted using the flora of countries with climates similar to Türkiye (e.g Smith, 1996, 2004; Paton, 1999; Frey et al., 2006), along with relevant revisions and monographs (e.g Lara et al., 2009; Orgaz et al., 2012, 2013). The identified samples were then processed into herbarium specimens and archived at the Zonguldak Bülent Ecevit University Bryophyte Herbarium (ZNG).

Table 1. Sampling localities.

No	Coordinates	Altitude (m)	No	Coordinates	Altitude (m)
1	41.424167°N 31.818333°E	90	**5**	41.417833°N 31.829556°E	143
2	41.422722°N 31.818722°E	95	**6**	41.415972°N 31.829972°E	335
3	41.421139°N 31.820444°E	137	**7**	41.415139°N 31.832444°E	336
4	41.418667°N 31.829472°E	222	**8**	41.406361°N 31.840139°E	340

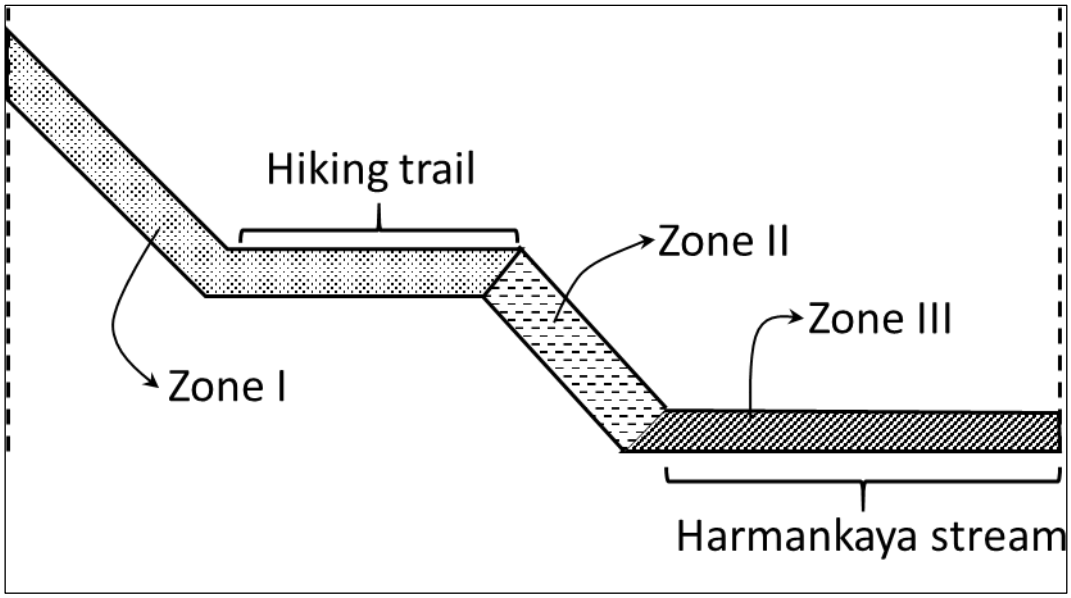

Figure 1. Substrate categories.

3. Results

3.1. Floristic list

Field excursions and subsequent identification revealed a diverse array of bryophytes in the study area: 3 hornwort taxa from 2 families, 39 liverwort taxa from 22 families, and 122 moss taxa from 31 families, totaling 164 distinct taxa. The floristic list, taxonomically validated by Hodgetts et al. (2020), is shown in Table 2, in which author names have been excluded to conserve space. Notably, the list includes 8 liverwort, 1 hornwort, and 23 moss taxa recorded for the first time for the Zonguldak bryoflora (Ören et al., 2016; Kürschner and Erdağ, 2021); these new records are marked with an asterisk (*).

Table 2. Floristic list. Sub.: Substrate type, M: Moss, R: Rock, S: Soil, T: Tree, W: Woody material.

MARCHANTIOPHYTA				
Family	**Taxon**	**Locality Nr.**	**Zone**	**Sub.**
Aneuraceae	*Riccardia chamedryfolia*	5	III	W
	**Riccardia multifida*	2	I	S
	Riccardia palmata	3, 5	II, III	W
Aytoniaceae	*Reboulia hemisphaerica*	1, 2, 5	II, III	R, S
Calypogeiaceae	*Calypogeia fissa*	1, 2, 8	I, II	R, S
Cephaloziaceae	*Cephalozia bicuspidata*	5, 6, 7	I, II	S
	**Fuscocephaloziopsis lunulifolia*	3, 4	II	R, W
Cephaloziellaceae	*Cephaloziella dentata*	1	II	S
	Cephaloziella divaricata	5, 7	II	R, S
	**Cephaloziella rubella*	2	I	R
	Cephaloziella turneri	1, 5, 6, 7	I, II	R, S
Conocephalaceae	*Conocephalum conicum*	1, 2, 3, 4, 5, 7	I, II, III	R, S

Family	Taxon	Locality Nr.	Zone	Sub.
Corsiniaceae	*Corsinia coriandrina*	7, 8	I, II	R, S
Fossombroniaceae	*Fossombronia angulosa*	4, 6, 8	I, II, III	R, S
Frullaniaceae	*Frullania dilatata*	2, 3, 4, 5, 6	I, II, III	S, T, W
	Frullania tamarisci	2	I	T
Jubulaceae	*Jubula hutchinsiae* subsp. *caucasica*	3, 5, 6	I, II, III	R, W
Jungermanniaceae	**Mesoptychia bantriensis*	3	III	R
Lejeuneaceae	*Cololejeunea rossettiana*	3	II	R
	Lejeunea cavifolia	1, 2, 3, 7	I, II	M, R, S, T, W
Lophocoleaceae	*Chiloscyphus polyanthos*	1,2, 4, 5	II, III	R
	Lophocolea heterophylla	1, 2, 3, 4, 5	I, II, III	R, S, T, W
Lophoziaceae	**Lophozia ventricosa*	2	I	R
Lunulariaceae	*Lunularia cruciata*	2, 5	II, III	R
Metzgeriaceae	*Metzgeria conjugata*	2, 3, 4, 6, 7	I, II	M, R, S, T
	Metzgeria furcata	1, 2, 4, 5	I, II	S, T, W
Pelliaceae	*Apopellia endiviifolia*	2, 3, 5, 7, 8	II, III	S, R
Plagiochilaceae	*Pedinophyllum interruptum*	4	II, III	R
	Plagiochila porelloides	1, 3, 4, 7	II	R
Porellaceae	*Porella arboris-vitae*	7	I	T
	**Porella obtusata*	5	II	W
	Porella platyphylla	4	II	W
Radulaceae	*Radula complanata*	1, 2, 5 ,6	I, II	R, T, W
Ricciaceae	**Riccia glauca*	1	I	S
Scapaniaceae	*Diplophyllum albicans*	1, 2, 3, 5, 6	I, II	S, R
	Scapania irrigua	3, 5	II, III	R
	Scapania nemorea	2	I	R
	**Scapania scandica*	3, 5	II, III	R
Southbyaceae	*Southbya tophacea*	4	II	R

ANTHOCERATOPHYTA

Family	Taxon	Locality Nr.	Zone	Sub.
Anthocerotaceae	**Anthoceros caucasicus*	2	I	S
	Anthoceros punctatus	2	I	S
Notothyladaceae	*Phaoceros laevis*	2	I, II	R, S

BRYOPHYTA

Family	Taxon	Locality Nr.	Zone	Sub.
Amblystegiaceae	*Amblystegium serpens*	2, 3	I, II, III	R, S
	Cratoneuron filicinum	7	III	R
	Palustriella commutata	4	III	R
	Serpoleskea confervoides	2, 5, 6	I, II	R
Anomodontaceae	*Anomodon viticulosus*	3	II	R
Aongstroemiaceae	**Dichodontium pellucidum*	2, 3, 5	I, II, III	R, S
Bartramiaceae	**Bartramia halleriana*	8	III	R
	Bartramia pomiformis	1	II	S
	Philonotis capillaris	1, 2, 6, 8	I, II, III	S, R
	**Philonotis marchica*	7	III	S
	**Philonotis rigida*	2, 6	I	S
	**Plagiopus oederianus*	4	II	R
Brachytheciaceae	**Brachytheciastrum olympicum*	7	III	R
	Brachythecium rivulare	2	II	R
	Brachythecium rutabulum	2, 3, 5, 8	I, II	R, S, T, W

Family	Taxon	Locality Nr.	Zone	Sub.
Brachytheciaceae	*Brachythecium velutinum*	1, 2, 3, 4, 8	I, II	R, T, W
	Cirriphyllum crassinervium	2, 4	II, III	R
	Eurhynchium striatum	2, 5	I	S
	Homalothecium lutescens	5	III	W
	Homalothecium sericeum	3, 5, 8	I, II	R, T, W
	Kindbergia praelonga	1, 2, 3	I, II	R, S, T, W
	Microeurynchium pumilum	2, 3, 4	I, II, III	R, S
	Oxyrrhynchium hians	1, 2, 4	I, II, III	R, S
	Palamocladium euchloron	3, 4, 5, 6	I, II	R, S
	Plasteurhynchium meridionale	7	I	R
	Plasteurhynchium striatulum	4	II	R
	Pseudoscleropodium purum	7	I	S
	**Rhynchostegiella curviseta*	5	I	R
	Rhynchostegiella teneriffae	4	II, III	R
	Rhynchostegium confertum	1, 2, 5, 7	I, III	R, W
	Rhynchostegium riparioides	2, 3, 5	I, II	R
	Sciuro-hypnum populeum	8	I	R
	Scorpiurium circinatum	2, 7	I, II	S
Bryaceae	*Bryum dichotomum*	7	I	S
	**Bryum klinggraeffii*	1	II	S
	Imbribryum alpinum	4	II	R
	Ptychostomum capillare	8	II	R
	Ptychostomum donianum	1	I	S
	Ptychostomum moravicum	4, 5	II	W
	Ptychostomum pseudotriquetrum	4, 7, 8	II, III	R, S
Dicranaceae	*Dicranum scoparium*	2	I, II	W
Dicranellaceae	*Dicranella heteromalla*	1, 2, 5, 6, 7	I, II, III	R, S
	**Dicranella staphylina*	7	I	S
Diphysciaceae	*Diphyscium foliosum*	6	I	S
Ditrichaceae	**Ditrichum heteromallum*	2	I, III	R, S
	**Ditrichum pallidum*	2	I	S
	Pleuridium acuminatum	1, 7	I	R, S
Encalyptaceae	*Encalypta streptocarpa*	4	II	R
Fissidentaceae	**Fissidens crassipes* subsp. *warnstorfii*	2, 3	I, III	R, S
	Fissidens dubius	3, 4, 5, 6, 7	I, II, III	R, S, W
	**Fissidens rivularis*	2	III	R
	Fissidens taxifolius	2, 3, 4, 5, 7	I, II, III	R, S, W
	Fissidens viridulus	1, 2, 5	I, II, III	R, S
Fontinalaceae	**Fontinalis antipyretica*	3	I	R
Funariaceae	*Funaria hygrometrica*	1, 2	I	S
Grimmiaceae	*Schistidium apocarpum*	5, 8	I, III	R
	Schistidium crassipilum	8	II	R
	**Schistidium rivulare*	2, 3, 4, 5 ,7, 8	I, II, III	R
Hookeriaceae	*Hookeria lucens*	3, 5	I, III	S
Hypnaceae	*Hypnum andoi*	8	I	R
	Hypnum cupressiforme var. *cupressiforme*	1, 2, 3, 4, 5, 8	I, II, III	R, S, T, W
	Hypnum cupressiforme var. *filiforme*	4, 5	II	W

Family	Taxon	Locality Nr.	Zone	Sub.
Lembophyllaceae	*Heterocladium heteropterum*	2	II, III	R
	Isothecium alopecuroides	2, 5, 6, 7	I, II	R, S, W
	Isothecium myosuroides	1, 2, 3, 6	I, II	T, W
Leucobryaceae	*Leucobryum juniperoideum*	1, 2, 3, 5, 6	I, II	R, S, W
Leucodontaceae	*Leucodon sciuroides*	5	II	W
Mniaceae	*Epipterygium tozeri*	2, 5	I, II, III	R, S
	Mnium hornum	2, 3, 6	I, II, III	R, S
	Mnium spinosum	3	III	S
	Mnium stellare	2, 4	II	R
	Plagiomnium affine	2, 6, 7	I, II, III	R, S
	Plagiomnium elatum	2	I, II	R, W
	Plagiomnium rostratum	4, 5	II, III	R
	Plagiomnium undulatum	2, 3, 5, 7	II, III	R
	**Pohlia cruda*	1	II	S
	Pohlia wahlenbergii	2, 4	II, III	R
	Rhizomnium punctatum	2, 5, 6	I, II, III	R, S, T, W
Myuriaceae	*Ctenidium molluscum*	2, 3, 4, 5, 6, 7, 8	I, II, III	R, W
Neckeraceae	*Alleniella besseri*	4	II	R
	Alleniella complanata	2, 4, 5, 7	I, II	T, W
	Exsertotheca crispa	3, 4, 5, 6	I, II	R, S, T, W
Neckeraceae	*Leptodon smithii*	8	2	R
	Pseudanomodon attenuatus	5	II	W
	Thamnobryum alopecurum	1, 2, 3, 4, 5, 7	II, III	R, S
Orthotrichaceae	*Lewinskya striata*	4	II	W
	Pulvigera lyellii	5	II	W
	Ulota crispa	4, 5	II	W
Plagiotheciaceae	*Herzogiella seligeri*	5, 6	I, II	R, S
	Plagiothecium cavifolium	2	I	S
	Plagiothecium curvifolium	5, 7	II, III	S, W
	Plagiothecium nemorale	2, 3, 4, 5, 6	I, II, III	R, S, T, W
	Plagiothecium succulentum	2, 4, 6, 7	II, III	R, S
	Pseudotaxiphyllum elegans	1, 2, 3	I, II	R, S, W
Polytrichaceae	*Atrichum angustatum*	7	II	R, S
	Atrichum undulatum	1, 2, 5	I	R, S
	Pogonatum aloides	1, 2, 7	I, II	R, S
	Polytrichum formosum	1, 2, 6, 7, 8	I, II	R, S
Pottiaceae	*Barbula unguiculata*	1, 8	I	R, S
	Chionoloma tenuirostre	6	I	R
	Cinclidotus riparius	3	I, II	R
	Dialytrichia mucronata	2	III	R
	**Ephemerum crassinervium* subsp. *sessile*	7	I, II	S
	Eucladium verticillatum	4	II	R
	**Gymnostomum aeruginosum*	6	I	S
	Gymnostomum calcareum	4, 8	II	R
	**Gyroweisia tenuis*	5, 8	I, III	R
	Tortella squarrosa	8	III	R
	Tortella tortuosa	4, 8	II, III	R

Family	Taxon	Locality Nr.	Zone	Sub.
Pottiaceae	**Tortula inermis*	8	I	R
	Tortula muralis	8	I	R
	Tortula truncata	1	I	S
	Trichostomum brachydontium	1, 2, 5, 6, 8	I, II	R, S
	Trichostomum crispulum	3, 4, 8	II, III	R
	**Weissia condensa*	4	II	R
	Weissia controversa	1, 6, 8	I	R, S
Pterigynandraceae	*Pterigynandrum filiforme*	4, 5	II	R, W
Pylaisiaceae	*Calliergonella cuspidata*	1, 7, 8	II, III	S
	Pylaisia polyantha	5	II	W
Seligeriaceae	**Blindiadelphus recurvatus*	8	I, II, III	R
	**Seligeria acutifolia*	5	III	R
Tetraphidaceae	*Tetraphis pellucida*	3	II	W

Based on the floristic list, Zone I contains several aquatic and semi-aquatic taxa, including *Cinclidotus riparius* (Host ex Brid.) Arn., *Conocephalum conicum* (L.) Dumort., *Fissidens crassipes* subsp. *warnstorfii* (M.Fleisch.) Brugg.-Nann., *Fissidens rivularis* (Spruce) Schimp., *Fontinalis antipyretica* Hedw., *Schistidium rivulare* (Brid.) Podp., *Rhynchostegium riparioides* (Hedw.) Cardot, and *Thamnobryum alopecurum* (Hedw.) Gangulee, likely due to the proximity of Harmankaya Stream. Additionally, Zone I includes species associated with moist environments but not strictly aquatic, such as *Dicranum scoparium* Hedw. and *Scapania nemorea* (L.) Grolle. Zone II supports a mix of hydrophilic species and others not closely associated with water, including *Alleniella besseri* (Lobarz.) S.Olsson, Enroth & D.Quandt, *Imbribryum alpinum* (Huds. ex With.) N.Pedersen, and *Lewinskya striata* (Hedw.) F.Lara, Garilleti & Goffinet. One of the most notable taxon for this zone is *Jubula hutchinsiae* subsp. *caucasica* Konstant. & Vilnet, which is abundant on shaded, horizontal, and moist rocks bordering Harmankaya stream. Zone III also hosts some aquatic taxa, though it predominantly includes terrestrial species, such as *Gyroweisia tenuis* (Hedw.) Schimp., *Homalothecium lutescens* (Hedw.) H.Rob., *Blindiadelphus recurvatus* (Hedw.) Fedosov & Ignatov, *Seligeria acutifolia* Lindb., and *Schistidium apocarpum* (Hedw.) Bruch & Schimp. One notable species identified in this zone is *Diphyscium foliosum* (Hedw.) D. Mohr, which was observed on damp path edges near the exit of the Nature Park, situated away from the main Harmankaya Waterfall system. Another notable taxon recorded in this zone, *Hookeria lucens* (Hedw.) Sm., primarily inhabits shaded, damp soil, consistent with findings from other studies conducted in Zonguldak. Given the area's consistently moist climatic conditions, no true xerophytic species are present (Dierßen, 2001).

3.2. Noteworthy records

3.2.1 Hornworts

As of 2024, four hornwort species (*Anthoceros caucasicus* Steph., *A. punctatus* L., *Phaeoceros laevis* (L.) Prosk., and *Phymatoceros bulbiculosus* (Brot.) Stotler, W.T.Doyle & Crand.-Stotl.) have been documented within the bryoflora of Türkiye (Kürschner and Erdağ, 2021). Studies on Turkish bryophytes typically record one, occasionally two, hornwort species in surveyed areas. However, Harmankaya Waterfalls Nature Park is the first site in Türkiye where three hornwort species (*A. caucasicus*, *A. punctatus*, and *P. laevis*) have been observed co-existing. This nature park provides favorable environmental conditions, particularly the overly wet or waterlogged habitats in which hornworts tend to thrive. The presence of three species within a relatively small area underscores the importance of this area for hornwort conservation in Türkiye. Furthermore, *A. caucasicus*, recorded here, is known from only four other sites in Yalova, Kocaeli, and Rize provinces (Kürschner and Erdağ, 2021). This new record from Zonguldak province partially fills the distribution gap between its known eastern and western ranges. Future bryofloristic surveys in humid regions along this distributional line could further clarify the species' range and enhance resolution of its distribution.

3.2.2. Mosses

Among the 122 moss taxa recorded in the field, several species are particularly noteworthy.

Historically, *Brachytheciastrum olympicum* (Jur.) Vanderp. et al. was documented in Türkiye only between 1913 and 1970, with occurrences in the provinces of Bolu, Bursa, İzmir, Denizli, and on Ilgaz and Nemrut Mountains (Kürschner and Erdağ, 2021). This study presents the first contemporary distribution record of *B. olympicum*, expanding its known range. Similarly, *Dicranella staphylina* H. Whitehouse was first documented in Türkiye in

2021 from Bursa and Sakarya provinces, followed by a record from Rize later that year and a subsequent record from Çankırı in 2022 (Ursavaş et al. 2021, Erata et al. 2021; Uyar et al. 2022). This study provides the fourth recorded occurrence of *D. staphylina*, a relatively recent addition to the bryophyte flora of Türkiye.

This study also contributes valuable insights into the distributional range of certain taxa. *Bryum klinggraeffii* Schimp. was previously documented in the provinces of Ardahan, Trabzon, Ankara, Gümüşhane, Iğdır, and Adana (Kürschner and Erdağ, 2021). This research provides the first record of this species in Western and Northwestern Anatolia, advancing understanding of its distribution limits in Türkiye. The initial locality-based record for *Ephemerum crassinervium* subsp. *sessile* (Bruch) Holyoak was from Yalova, although unpublished herbarium records (Naturhistoriska Riksmuseet Herbarium, Herbarium S, URL 7) also note occurrences in Isparta and Muğla provinces. This study provides a second confirmed locality for this taxon with detailed geographic data, extending its known eastern distribution boundary.

In this study, the aquatic taxa *Fissidens crassipes* subsp. *warnstorfii*, *F. rivularis*, *Fontinalis antipyretica* Hedw., and *Schistidium rivulare* (Brid.) Podp. were also recorded for the first time in Zonguldak. While these taxa have been documented across various regions in Türkiye, their absence in Zonguldak—a province recognized for its extensive river systems—highlights the need for comprehensive bryofloristic surveys within these habitats. Additionally, *Seligeria acutifolia* Lindb. and *Blindiadelphus recurvatus* (Hedw.) Fedosov & Ignatov, newly recorded from Zonguldak, are notable for their minute size, which has contributed to their being overlooked in surveys. Their occurrence in shady rock crevices within the study area emphasizes the importance of thoroughly examining such microhabitats in bryophyte studies.

3.3 Biodiversity assessment

The Shannon diversity index (also known as the Shannon–Wiener index, H') (Shannon, 1948) was used to assess biodiversity across zones, collection localities, and substrates in the study area. This index was calculated using the *dplyr* (Wickham et al., 2023) and *vegan* (Oksanen et al., 2022) packages in R version 4.4.1 (R Core Team, 2024). A summary of the H' values is shown in Figure 2.

The analysis of biodiversity indices across the zones revealed that Zone II had the highest index value. This can be attributed to the presence of a wide range of species, including aquatic, semi-aquatic, moisture-loving, and terrestrial ones. In contrast, Zone I primarily supports aquatic and semi-aquatic species, while Zone III is dominated by terrestrial species, resulting in lower Shannon index (H') values for these zones compared to Zone II.

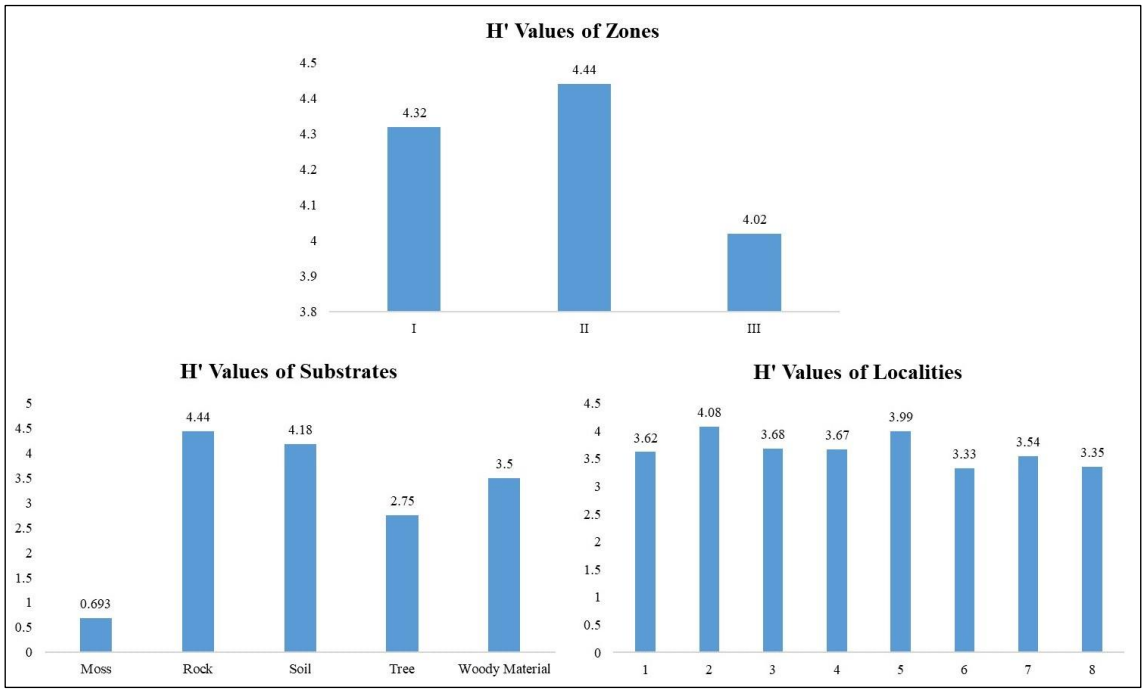

Figure 2. H' values.

Among the substrates, rock supports the richest biodiversity, likely due to its foundational presence in the structure of the area, and its role as a habitat for nearly all species in the region. Since many rock-associated species also interact with soil, the H' value for soil closely approximates that of rock. The high biodiversity index for woody materials is also notable. This is driven by the exclusive presence of taxa such as *Dicranum scoparium* Hedw., *Homalothecium lutescens* (Hedw.) H.Rob., *Hypnum cupressiforme* var. *filiforme* Brid., *Leucodon sciuroides (*Hedw.) Schwägr., *Lewinskya striata* (Hedw.) F.Lara, Garilleti & Goffinet, *Pseudanomodon attenuates* (Hedw.) Ignatov & Fedosov, *Ptychostomum moravicum* (Podp.) Ros & Mazimpaka, and *Pulvigera lyellii* (Hook. & Taylor) Plášek, Sawicki & Ochyra on logs, which increases the biodiversity value of this substrate.

Regarding locality-specific findings, the H' value at the 2nd station is slightly higher than at other stations. This station is situated where the Üzülmez Stream intersects the entrance of the nature park, away from the waterfall system. The combination of terrestrial, aquatic, and semi-aquatic species in this location, along with a low water flow rate that enables semi-aquatic species to establish themselves on substrates, likely contributes to its enhanced biodiversity. Nevertheless, the Shannon indices for the stations are generally similar, which may reflect the homogeneous and consistently humid climate of the area.

4. Discussion

Zonguldak has been the focus of numerous bryofloristic studies (Uyar and Çetin, 2006; Alataş et al., 2011, 2015, 2019; Alataş and Batan, 2014; Ören et al., 2015). However, the discovery of 32 new bryophyte taxa in Harmankaya Waterfalls Nature Park underscores the significance of the park for bryophyte diversity, particularly as the only site in which three hornwort species coexist. These findings suggest that the conservation status the area warrants re-evaluation. Unfortunately, recreational use of natural parks in Türkiye often does not safeguard the biodiversity they host. In Harmankaya, where active trekking routes span all zones, increased domestic tourism has heightened anthropogenic pressure on local bryophyte flora. This pressure likely affects all plant, animal, and fungal species, thereby posing an escalating threat to biodiversity. Detailed biological assessments of protected areas across Türkiye are crucial for fully understanding the distribution and conservation needs of numerous species whose status remains unclear.

Declaration

Author contributions

Idea/Concept: ADU, DB, NT, MÖ; Conceptualization and design: ADU, DB, NT, MÖ; Auditing consulting: ADU, DB, NT, MÖ; References: ADU, MÖ; Materials: ADU, MÖ, DB; Data collection and/or processing: ADU, MÖ, DB, NT; Analysis and/or interpretation: ADU, MÖ, DB; Literature search: ADU, MÖ, NT; Writing phase: ADU, MÖ; Critical review: ADU, MÖ, DB, NT.

Conflict of interest

The authors have no competing interests to declare regarding the content of this article.

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Ethical approval

This research did not involve human or animal subjects and therefore does not require ethical approval.

References

Alataş M. Batan N. 2014. Epiphytic bryophytes and vegetation of the *Platanus orientalis* trees in Zonguldak. Ekoloji. 23:91, 52-63.

Alataş M. Ezer T. Batan N. 2019. Epiphytic bryophyte vegetation of Beldibi and Babadağ forests (Zonguldak, Turkey). Eurasian Journal of Forest Science. 7:4, 205-219.

Alataş M. Kara R. Ezer, T. Uyar G. Batan N. 2015. The epiphytic bryophyte flora and vegetation of Zonguldak Province, Turkey. Pakistan Journal of Botany. 47:4, 1439-1449.

Alataş M. Ören M. Uyar G. 2011. The bryophyte flora in campus center of Zonguldak Karaelmas University. Journal of Bartin Faculty of Forestry. 13:20, 38-51.

Ament J. Cumming G. S. 2016. Scale dependency in effectiveness, isolation, and social-ecological spillover of protected areas. Conservation Biology. 30:4, 846-855.

Atmiş E. 2018. A critical review of the (potentially) negative impacts of current protected area policies on the nature conservation of forests in Turkey. Land Use Policy. 70, 675-684.

Atmiş E. Günşen H.B. Yıldız D. 2020. Tabiat parklarının korunan alan statülerinin

değerlendirilmesi: Batı Karadeniz örneği. Turkish Journal of Forestry. 21:2, 148-158.

Atmiş E. Artar M. 2013. Türkiye'de Korumadan Kullanmaya Yönelen Doğa Koruma Politikalarının Değerlendirilmesi. 2023'e Doğru 2. Doğa ve Ormancılık Sempozyumu Bildiriler Kitabı. Artar M. Editör. Orman Mühendisleri Odası. Ankara.

Borelli T. Güzelsoy N.A. Hunter D. Tan A. Karabak S. Uçurum H.Ö. Yetim H. Gebhardt W. Taşcı R. 2022. Assessment of the nutritional value of selected wild food plants in Türkiye and their promotion for improved nutrition. Sustainability. 14:17, 11015.

Chape S. Harrison J. Spalding M. Lysenko I. 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philosophical Transactions of the Royal Society B: Biological Sciences. 360: 1454, 443-455.

Dierßen K. 2001. Distribution, Ecological Amplitude and Phytosociological Characterisation of European Bryophytes. J. Cramer Publishing Company. Stuttgart.

Dinerstein E. Joshi A. Vynne C. Lee A.T.L. Pharand-Deschênes F. França M.G.C. Fernando S.A. Birch T. Burkart K. Holland R.A. et al. 2020. A "global safety net" to reverse biodiversity loss and stabilize earth's climate. Science Advances. 6:36.

Dinerstein E. Vynne C. Sala E. Joshi A. Fernando S.A. Lovejoy T.E. Mayorga J. Olson D. Asner G.P. Baillie J.E.M. et al. 2019. A global deal for nature: Guiding principles, milestones, and targets. Science Advances. 5:4.

Erata H. Batan N. Abay G. Özdemir T. 2021. Anzer Vadisi ve Çevresinin Briyofit Florası (İkizdere, Rize). Anatolian Bryology. 7:2, 131-145.

Finkelstein S.A. Doherty C. Loder A.L. 2023. Safety net Ontario: Ontario's outsized role in the "global safety net" for climate and biodiversity. Facets. 8, 1-17.

Frey W. Frahm J. P. Fischer E. Lobin W. 2006. The liverworts, mosses and ferns of Europe. Harley Books. Devon.

Gaston K. Jackson S. Cantú-Salazar L. Cruz-Piñón G. 2008. The ecological performance of protected areas. Annual Review of Ecology, Evolution and Systematics. 39:1, 93-113.

Hodgetts N.G. Söderström L. Blockeel T.L. Caspari S. Ignatov M.S. Konstantinova N.A. Lockhart N. Papp B. Schröck C. Sim-Sim M. et al. 2020. An annotated checklist of bryophytes of Europe, Macaronesia and Cyprus. Journal of Bryology. 42:1, 1-116.

Küçükali S. Çokgör S. Kartal B. 2006. Temporal variation of dissolved oxygen in a mountain stream plunge pool: An example from northern Turkey. In Proceedings of the World Environmental and Water Resources Congress 2006. American Society of Civil Engineers.

Kürschner H. Erdağ A. 2021. Bryophyte locality data from the Near and Middle East 1775-2019. Hiperyayın. İstanbul.

Lara F. Garilleti R. Medina R. Mazimpaka V. 2009. A new key to the *Orthotrichum* Hedw. in Europe and the Mediterranean Region. Cryptogamie Bryologie. 30:1, 129-142.

Oksanen J. Blanchet F.G. Friendly M. Kindt R. Legendre P. McGlinn D. Minchin P.R. O'Hara R.B. Simpson G.L. Solymos P. at al. 2022. vegan: Community Ecology Package. R package version 2.6-4. https://CRAN.R-project.org/package=vegan.

Orgaz J.D. Cano M.J. Guerra J. 2013. Taxonomic revision of *Brachytheciastrum* (Brachytheciaceae, Bryophyta) from the Mediterranean region. Systematic Botany. 38:2, 283-294.

Orgaz J.D. Cano M.J. Guerra J. 2012. A taxonomic study of genus *Brachythecium* Schimp. (Brachytheciaceae, Bryophyta) in the Mediterranean region. Nova Hedwigia. 95:3, 295-318.

Ören M. Bozkaya S. Özçelik A.D. Hazer Y. Uyar G. 2015. Zonguldak ili briyofit florasına katkılar. Anatolian Bryology. 1:1, 34-41.

Ören M. Uyar G. Bozkaya S. Özçelik A.D. Hazer Y. 2016. II. Bölüm: Briyofitler. Zonguldak Ekosistemi. Büyükgüzel K. Kaplan A. Alan Ş. Editors. Zonguldak Bülent Ecevit Üniversitesi Yayınları. Zongudak. pp. 17-46.

Paton J. 1999. The liverworts flora of the British Isles. Harley Books. Devon.

R Core Team 2024. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Version 4.4.1, "Race for Your Life". Available at: https://www.R-project.org/.

Sarıoğlu S. Işın Z. Ursavaş S. Keçeli T. 2017. Türkiye'deki Milli Parkların Briyofit Zenginliği Açısından İrdelenmesi. Anatolian Bryology, 3:2, 103-115.

Shannon C.E. 1948. A mathematical theory of communication. Bell System Technical Journal. 27:3, 379-423.

Smith A.J.E. 1996. The liverworts of Britain and Ireland. Cambridge University Press. London.

Smith A.J.E. 2004. The moss flora of Britain and Ireland. Cambridge University Press. London.

Soulé M.E. 1985. What is Conservation Biology? A new synthetic discipline addresses the dynamics and problems of perturbed species, communities, and ecosystems. BioScience. 35:11, 727–734.

Unan, A.D. Potemkin, A. Ursavaş, S. Çalışkan, S. Ören M. 2021. New records of two *Scapania* species (Scapaniaceae, Marchantiophyta) from north of Turkey. Plant Biosystems, 155:4, 679-684.

URL 1. Protected Planet. Website: https://www.protectedplanet.net/en [Retrieved: 5 July 2024].

URL 2. Tabiat Koruma Durum Raporu. Website: https://www.tarimorman.gov.tr/DKMP/Belgeler/Tabiat%20Koruma%20Durum%20Raporu/TKDR_TR_2023.pdf [Retrieved: 5 July 2024].

URL 3. Convention on Biological Diversity. Target 11 - Technical rationale extended (provided in document COP/10/INF/12/Rev.1). Website: https://www.cbd.int/sp/targets/rationale/target-11 [Retrieved: 5 July 2024].

URL 4. Milli Parklar Kanunu No. 2873. Website: https://www.mevzuat.gov.tr/MevzuatMetin/1.5.2873.pdf [Retrieved: 5 July 2024].

URL 5. Zonguldak Harmankaya Şelaleleri Tabiat Anıtı. Website: https://bolge10.tarimorman.gov.tr/Menu/84/Zonguldak-Harmankaya-Selaleleri-Tabiat-Aniti [Retrieved: 5 July 2024].

URL 6. Climate: Kardeşler. Website: https://tr.climate-data.org/asya/tuerkiye/zonguldak/kardesler-681877/ [Retrieved 5 July 2024].

URL 7. Herbarium S catalogue. Website: https://herbarium.nrm.se/.

Ursavaş S. Keçeli T. Uyar G. Ören M. 2021. *Dicranella staphylina* (Dicranaceae), a new moss record from Turkey and Southwest Asia. Plant Biosystems. 155:3, 48-486.

Uyar G. Çetin B. 2006. Contribution to the Moss Flora of Turkey: Western Black Sea Region (Bolu, Kastamonu, Karabük, Bartin and Zonguldak). International Journal of Botany. 2: 229-241.

Uyar G. Ören M. Alataş M. 2022. Işık Dağı (Ankara-Çankırı) Briyofit Florası. Anatolian Bryology. 8:1, 11-29.

Wickham H François R Henry L Müller K 2023. dplyr: A Grammar of Data Manipulation. R package version 1.1.3. https://CRAN.R-project.org/package=dplyr.