www.biodicon.com Biological Diversity and Conservation

ISSN 1308-8084 Online ISSN 1308-5301 Print

Research article
DOI: 10.46309/biodicon.2026.1735320
19/1 (2026) 33-45

Biodiversity assessment of Kaynak Sea Cave (Mersin, Türkiye): a baseline study for the conservation of Eastern Mediterranean marine cave ecosystems

H. Abdullah UÇAN[1], Alper EVCEN [*] [2], Bülent GÖZCELİOĞLU[3]
ORCID: 0000-0001-9049-8858; 0000-0003-1134-2551; 0000-0003-1835-2701

[1] Ministry of Environment, Urbanization and Climate Change, General Directorate of Natural Assets, No:64/2 06560 Yenimahalle/Ankara, Türkiye.
[2] The Scientific and Technological Research Council of Türkiye (TÜBİTAK) Marmara Research Center, Gebze, Kocaeli, Turkiye
[3]Hacettepe Üniversitesi Biyolojik Çeşitlilik Araştırma ve Uygulama Merkezi (HUBİOM)
06800 Beytepe Ankara

Abstract

Purpose: Sea caves are exceptional yet highly vulnerable marine habitats that support rich and specialized biodiversity. This study aims to document the biodiversity of Kaynak Sea Cave, located in the Aydıncık district of Mersin (Türkiye), and to contribute to a scientific framework for the conservation of sensitive species and key habitats in the region.
Method: Biodiversity was assessed through scuba diving surveys and photographic documentation by experienced divers.
Findings: A total of 117 species belonging to 12 major taxonomic groups (Phaeophyceae, Rhodophyta, Chlorophyta, Porifera, Cnidaria, Polychaeta, Crustacea, Mollusca, Bryozoa, Echinodermata, Tunicata, and Pisces) were identified from visual and photographic records. However, it is presumed that the actual species richness is significantly higher.
Conclusion: This baseline inventory underscores the ecological value of Kaynak Sea Cave and highlights the need for future comprehensive studies focusing on cryptic fauna, soft-bottom habitats, and the seasonal-spatial dynamics of benthic communities.

Keywords: marine cave, Eastern Mediterranean, biodiversity, benthic communities, Porifera

---------- * ----------

Kaynak Deniz Mağarası'nın (Mersin, Türkiye) biyoçeşitlilik değerlendirmesi: Doğu Akdeniz deniz mağarası ekosistemlerinin korunmasına yönelik temel bir çalışma

Özet

Amaç: Deniz mağaraları, zengin ve özelleşmiş biyoçeşitliliğe sahip, istisnai ancak hassas denizel habitatlardır. Bu çalışma, Mersin'in Aydıncık ilçesinde yer alan Kaynak Deniz Mağarası'nın biyoçeşitliliğini belgelemeyi ve bölgedeki hassas türler ile önemli habitatların korunmasına yönelik bilimsel bir çerçeveye katkı sağlamayı amaçlamaktadır.
Metod: Biyoçeşitlilik değerlendirmeleri, deneyimli dalgıçlar tarafından gerçekleştirilen scuba dalışları ve fotoğrafik dokümantasyon yoluyla yapılmıştır.
Bulgular: Fotoğraf kayıtlarından 12 ana taksonomik gruba (Phaeophyceae, Rhodophyta, Chlorophyta, Porifera, Cnidaria, Polychaeta, Crustacea, Mollusca, Bryozoa, Echinodermata, Tunicata, Pisces) ait toplam 117 tür tespit edilmiştir. Ancak, gerçek tür zenginliğinin bu sayının oldukça üzerinde olduğu düşünülmektedir.

[*] *Corresponding author*: Tel.: +902626772913; Fax.: +902626412309; E-mail: alper.evcen@tubitak.gov.tr
 Received: 04.07.2025; Published: 15.03.2026 BioDiCon. 1206-040725

Sonuç: Bu ön envanter, Kaynak Deniz Mağarası'nın ekolojik değerini ortaya koymakta ve kriptik fauna, yumuşak tabanlı habitatlar ile bentik toplulukların mevsimsel-mekânsal dinamiklerine odaklanan gelecekteki kapsamlı çalışmalara ihtiyaç duyulduğunu vurgulamaktadır.

Anahtar kelimeler: deniz mağarası, Doğu Akdeniz, biyoçeşitlilik, bentik topluluklar, Porifera

1. Introduction

Marine caves are ecologically unique and structurally complex habitats that host a wide array of sessile and mobile organisms, many of which are rare, endemic, or highly specialized. Because their semi-enclosed nature increases their environmental sensitivity, these habitats become particularly vulnerable to anthropogenic pressures such as pollution, unregulated tourism, and coastal development. Owing to their elevated biodiversity and ecological significance, marine caves are therefore widely regarded as biological hotspots [1].

Thus, they are designated as priority habitats under the EU Habitats Directive (92/43/EEC) and the Barcelona Convention's Action Plan for Dark Habitats (UNEP-MAP-RAC/SPA, 2015).

The Mediterranean Basin, particularly along its rocky coastlines, contains a high density of marine caves [2,3], collectively harboring more than 2,300 marine taxa, including numerous rare and threatened species [4]. The pronounced environmental gradients within these caves—such as decreasing light penetration, oligotrophic conditions, and reduced hydrodynamics—generate a variety of ecological niches that sustain distinct biological communities [5]. Because these gradients mimic those found in deep-sea ecosystems, marine caves function as natural laboratories that allow researchers to study processes and species that are otherwise difficult to observe in situ.

Marine caves are typically structured into three ecological zones: the entrance area, the semi-dark zone, and the fully dark interior [6]. Species richness tends to decrease from the entrance inward, with some long, dark caves lacking visible macrofauna altogether. Organisms in these habitats often form zoned assemblages depending on their tolerance to light and other abiotic factors. Among the 905 species recorded in Mediterranean caves, sponges represent the most dominant group, followed by polychaetes, red algae (Rhodophyta), bivalves, fishes, and gastropods [7].

In addition to their dominance in marine cave systems, sponges are also one of the key components of hard-substrate benthic communities across the Mediterranean. Through complex associations with microbial and macrofaunal communities, they play essential roles in structuring cave ecosystems. Their high taxonomic diversity makes them particularly valuable as an indicator taxa for studying community structure and biogeographical patterns within these habitats [10, 17].

Although the exploration of marine caves began in the mid-20th century [8], a clear geographical imbalance persists in scientific efforts. Western and Central Mediterranean caves have been studied extensively, whereas Eastern Mediterranean caves—especially in the Levantine Basin—remain underexplored [9]. This uneven research focus likely contributes to a significant underestimation of biodiversity in eastern regions. While the Aegean Sea has received some attention [4, 7, 10], data from the southern coast of Türkiye are still limited [11, 12].

Some of the earliest records from Eastern Mediterranean marine caves date back to several expeditions of the ship Calypso in the 1950s [13]. More recently, the detection of non-indigenous species (NIS) such as *Pempheris vanicolensis* in Antalya [14], *Niphates toxifera* in Samandağ [15], and *Chelidonura fulvipunctata* near Cyprus [16] highlights the susceptibility of these habitats to biological invasions.

Currently, over 738 marine caves have been recorded in the Eastern Mediterranean, accounting for approximately one-quarter of all known caves in the region [3]. Yet, only a minority have been subjected to detailed ecological investigation. Even in countries with large cave inventories, such as Greece, biological assessments have covered only a fraction of the known systems. Despite formal recognition under international conservation agreements, marine cave protection remains limited in practice. Of the 62 designated Marine Protected Areas (MPAs) in the Mediterranean, only 33 include cave habitats, and targeted management plans are still lacking in most cases [3].

The limited availability of comprehensive ecological data is particularly alarming, especially in the face of growing pressures from climate change, habitat degradation, and the spread of cryptogenic and non-indigenous species—more than 60 of which have already been reported from Mediterranean marine caves [9]. Furthermore many sciaphilic (light-avoiding) species exploit caves as dispersal corridors, and this is complicating conservation strategies.

In light of these challenges and the ecological significance of marine caves, there is a critical need to expand scientific research in underrepresented regions. This study aims to provide a baseline assessment of the macrofaunal and macrofloral biodiversity of Kaynak Sea Cave, located along the southern coast of Türkiye in the district of Aydıncık (Mersin). The results are intended to inform future ecological research and contribute to the conservation strategies for marine cave habitats in the Eastern Mediterranean.

2. Materials and methods

The study was conducted in Kaynak Sea Cave (Aydıncık, Mersin, 36.141649 N, 33.415478 E) (Fig. 1). Due to weather conditions that allowed only short and limited diving opportunities, Kaynak Sea Cave was visited and dives were performed on 8–9 October 2022, 18–20 November 2022, and 24–25 December 2022.

Biodiversity surveys were conducted through direct underwater observations and detailed photographic documentation by highly experienced scientific divers, as the cave's narrow passages, restricted visibility, strong currents, and variable depth profiles require advanced cave-diving skills and strict adherence to safety protocols. The need for such expertise is critical to avoid unsafe or careless attempts in similarly challenging environments.

All organisms observed in situ or recorded in high-resolution photographs were identified to the lowest possible taxonomic level using standard identification keys and reference literature. Although the study was non-invasive and qualitative in nature, it provides essential insight into the cave's megabenthic diversity and establishes a baseline for future monitoring and conservation efforts.

Figure 1. Satellite image of the study area with the locations of the submarine caves studied

The entrance of Kaynak Cave is located at a depth of approximately 8–15 meters below sea level and faces north. The outermost section narrows into a passage 2–4 meters wide, leading after about 7–8 meters to a narrow siphon that connects to larger interior galleries. The entrance zone exhibits a coralligenous habitat structure, with dense sponge colonies dominating the area. In addition to corals, various cnidarians are also abundant.

At a depth of 19 meters, the siphon leads into three main galleries through a narrow tunnel. At the entrance of the first gallery, a strong outward current is present, gradually weakening toward the gallery's midpoint. This first gallery descends vertically to a depth of 15 meters, and an inner tunnel extends westward beyond the siphon. No additional branches or side tunnels were observed on the right side of the siphon.

The first gallery measures approximately 32 meters in length and 15 meters in width. It begins at a depth of 24 meters and connects to the second gallery at 28 meters via a relatively narrow corridor. An additional arm within the first gallery extends 18 meters to the south, with a width of 6.5 meters.

The second gallery starts at a depth of 22 meters and extends to 33 meters. A northern branch extends 45 meters in length, originating from a passage measuring 4 meters in width and 1.3 meters in height, with noticeable upward sediment accumulation. This section lies 24 meters below sea level.

The third gallery begins at 33 meters depth and features a southern wall that extends westward for approximately 180 meters, reaching a depth of 58 meters. Beyond this point, an additional 200 meters of tunnel length was visually estimated, with indications that the gallery continues both horizontally and vertically beyond the explored area. The photographs and descriptions related to the cave are presented below in Figure 2-6.

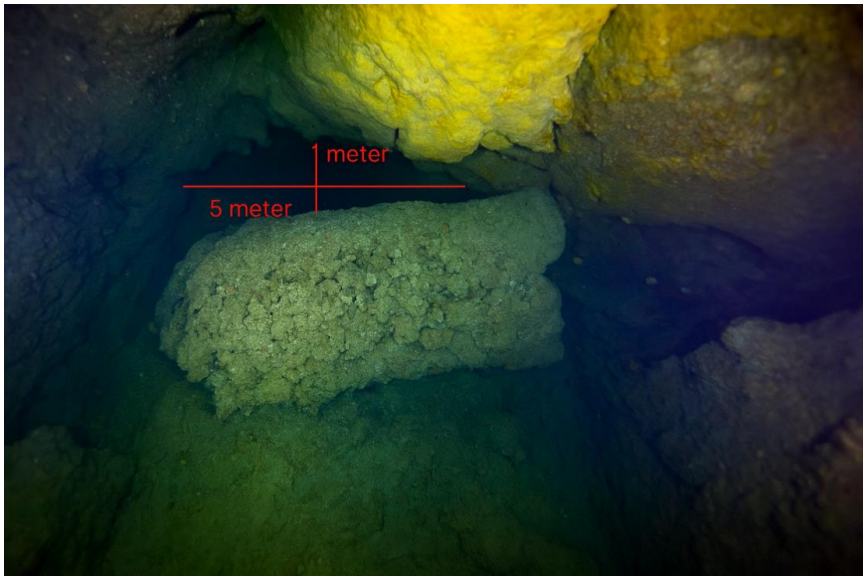

Figure 2. The narrow entrance of the cave at 19 meters depth, approximately 1 meter in height and 5 meters in width

Figure 3. A diver passing through the cave entrance

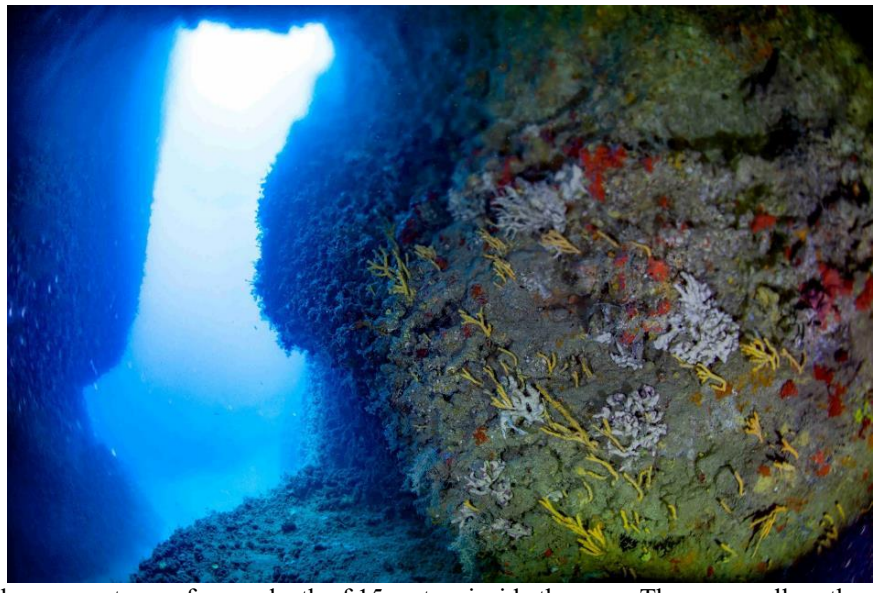

Figure 4. View of the cave entrance from a depth of 15 meters inside the cave. The cave wall on the right corresponds to the western side

Figure 5. The northward branch in the second gallery of the cave, extending 45 meters in length at a depth of 24 meters

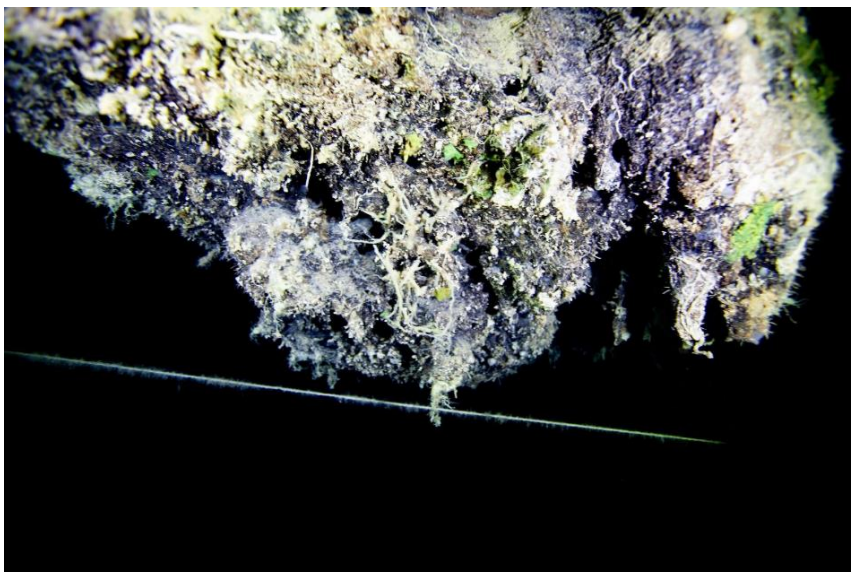

Figure 6. A section from the dark zone of the cave where no light penetrates, located at a depth of 33 meters. This marks the beginning of the third gallery

3. Results

Based on the examination of extensive photographic documentation and a limited number of collected specimens obtained from Kaynak Sea Cave, a total of 117 species were identified, representing 12 major taxonomic groups: Phaeophyceae, Rhodophyta, Chlorophyta, Porifera, Cnidaria, Polychaeta, Crustacea, Mollusca, Bryozoa, Echinodermata, Tunicata, and Pisces (Table 1). Although few in number, the collected specimens have been included in the species list below for completeness. Within the cave's benthic assemblages, sponges (Phylum: Porifera) stand out as a dominant group in terms of both species richness and spatial coverage (Figure 7). This inventory provides a preliminary yet significant insight into the biodiversity of the cave's benthic community. Nevertheless, it is important to acknowledge that the actual species richness is likely underestimated. A considerable number of observed organisms—particularly within Porifera, Cnidaria, and Bryozoa could not be reliably identified to the species level due to limitations in photographic resolution and the morphological similarities among taxa in these groups. In addition, specimen collection was highly constrained because of restricted diving time, safety considerations inside the narrow cave passages, and the need to minimize disturbance to fragile cave communities. As a result, many records were conservatively assigned to the genus or higher taxonomic levels. These constraints, together with the cryptic nature of numerous cave-dwelling species, suggest that Kaynak Sea Cave may support a much more diverse assemblage than currently documented. Therefore, comprehensive surveys involving in situ specimen collection and integrative taxonomic approaches (e.g., microscopy and molecular analyses) are recommended to more accurately characterize the full extent of biodiversity within this habitat.

Table 1. List of marine species found in Kaynak Sea Cave (Mersin, Türkiye).

	Group	Species	Observation	Photograph
1	OCHROPHYTA	*Dictyota dichotoma* (Hudson) J.V.Lamouroux, 1809		+
2	OCHROPHYTA	*Padina pavonica* (Linnaeus) Thivy, 1960		+
3	RHODOPHYTA	*Ceramium* sp.		+
4	RHODOPHYTA	*Amphiroa rigida* J.V.Lamouroux, 1816		+
5	RHODOPHYTA	*Corallina* sp.		+
6	RHODOPHYTA	*Jania rubens* (Linnaeus) J.V.Lamouroux, 1816		+
7	RHODOPHYTA	*Gelidium* sp.		+
8	RHODOPHYTA	*Mesophyllum* sp.		+
9	RHODOPHYTA	*Peyssonnelia* sp.		+
10	CHLOROPHYTA	*Codium bursa* (Olivi) C. Agardh, 1817		+
11	CHLOROPHYTA	*Cladophora prolifera* (Roth) Kützing, 1843		+
12	PORIFERA	*Acanthella acuta* Schmidt, 1862		+
13	PORIFERA	*Agelas oroides* (Schmidt, 1864)		+
14	PORIFERA	*Aplysilla sulfurea* Schulze, 1878		+
15	PORIFERA	*Axinella cannabina* (Esper, 1794)		+
16	PORIFERA	*Axinella damicornis* (Esper, 1794)		+
17	PORIFERA	*Axinella polypoides*		+

	Group	Species	Observation	Photograph
		Schmidt, 1862		
18	PORIFERA	*Axinella verrucosa* (Esper, 1794)		+
19	PORIFERA	*Chondrosia reniformis* Nardo, 1847		+
20	PORIFERA	*Cliona* sp.		+
21	PORIFERA	*Crambe crambe* (Schmidt, 1862)		+
22	PORIFERA	*Dysidea avara* (Schmidt, 1862)		+
23	PORIFERA	*Dysidea fragilis* (Montagu, 1818)		+
24	PORIFERA	*Haliclona (Soestella) mucosa* (Griessinger, 1971)		+
25	PORIFERA	*Haliclona* spp.	+	+
26	PORIFERA	*Hexadella pruvoti* Topsent, 1896		+
27	PORIFERA	*Ircinia* sp.	+	+
28	PORIFERA	*Ircinia variabilis* (Schmidt, 1862)	+	+
29	PORIFERA	*Levantiniella levantinensis* (Vacelet, Bitar, Carteron, Zibrowius & Pérez, 2007)		+
30	PORIFERA	*Mycale (Mycale) massa* (Schmidt, 1862)		+
31	PORIFERA	*Oscarella* sp.	+	+
32	PORIFERA	*Petrosia (Petrosia) ficiformis* (Poiret, 1789)		+
33	PORIFERA	*Phorbas fictitius* (Bowerbank, 1866)		+
34	PORIFERA	*Phorbas tenacior* (Topsent, 1925)	+	+
35	PORIFERA	*Placospongia decorticans* (Hanitsch, 1895)		+
36	PORIFERA	Porifera (spp.)		+
37	PORIFERA	*Sarcotragus foetidus* (Schmidt, 1862)	+	+
38	PORIFERA	*Spirastrella cunctatrix* Schmidt, 1868		+
39	PORIFERA	*Sycon* sp.		+
40	PORIFERA	*Terpios gelatinosa* (Bowerbank, 1866)		+
41	PORIFERA	*Tethya citrina* Sarà & Melone, 1965		+
42	CNIDARIA	*Aglaophenia* sp.	+	
43	CNIDARIA	*Eudendrium* sp.	+	

	Group	Species	Observation	Photograph
44	CNIDARIA	*Nausithoe punctata* Kölliker, 1853	+	
45	CNIDARIA	*Caryophyllia* (*Caryophyllia*) *smithii* Stokes & Broderip, 1828		+
46	CNIDARIA	*Cerianthus membranaceus* (Spallanzani, 1784)		+
47	CNIDARIA	*Hoplangia durotrix* Gosse, 1860		+
48	CNIDARIA	*Madracis pharensis* (Heller, 1868)		+
49	CNIDARIA	*Parazoanthus axinellae* (Schmidt, 1862)		+
50	ANNELIDA	*Hermodice carunculata* (Pallas, 1766)		+
51	ANNELIDA	*Janua heterostropha* (Montagu, 1803)		+
52	ANNELIDA	*Myxicola aesthetica* (Claparède, 1870)	+	+
53	ANNELIDA	*Protula tubularia* (Montagu, 1803)		+
54	ANNELIDA	*Spirorbis* sp.	+	
55	ANNELIDA	*Spirobranchus* sp.		+
56	ANNELIDA	*Terebellidae* (sp.)	+	
57	CRUSTACEA	*Alpheus* sp	+	
58	CRUSTACEA	*Polybius depurator* (Linnaeus, 1758)		+
59	CRUSTACEA	*Plesionika narval* (Fabricius, 1787)	+	
60	CRUSTACEA	*Pagurus anachoretus* Risso, 1827		+
61	CRUSTACEA	Mysida (sp.)		+
62	MOLLUSCA	*Lithophaga lithophaga* (Linnaeus, 1758)	+	
63	MOLLUSCA	*Brachidontes pharaonis* (P. Fischer 1870)	+	
64	MOLLUSCA	*Malvufundus regulus* (Forsskål, 1775)	+	
65	MOLLUSCA	*Chama pacifica* Broderip, 1835		+
66	MOLLUSCA	*Pinctada radiata* (Leach, 1814)		+
67	MOLLUSCA	*Spondylus sp*		+
68	MOLLUSCA	*Felimare picta* (Philippi, 1836)	+	
69	MOLLUSCA	*Muricopsis cristata* (Brocchi, 1814)	+	

	Group	Species	Observation	Photograph
70	MOLLUSCA	*Tonna galea* (Linnaeus, 1758)		+
71	MOLLUSCA	*Charonia tritonis* (Linnaeus, 1758)		+
72	MOLLUSCA	*Pleurobranchus forskalii* Rüppell & Leuckart, 1828		+
73	MOLLUSCA	*Ergalatax obscura* Houart, 1996		+
74	MOLLUSCA	*Erosaria spurca* (Linnaeus, 1758)		+
75	BRYOZOA	*Bugula* sp.	+	
76	BRYOZOA	*Bryozoa* (spp.)		+
77	ECHINODERMATA	*Echinaster (Echinaster) sepositus* (Retzius, 1783)		+
78	ECHINODERMATA	*Marthasterias glacialis* (Linnaeus, 1758)		+
79	ECHINODERMATA	*Ophidiaster ophidianus* (Lamarck, 1816)		+
80	ECHINODERMATA	*Antedon mediterranea* (Lamarck, 1816)	+	
81	ECHINODERMATA	*Holothuria sanctori* Delle Chiaje, 1823		+
82	ECHINODERMATA	*Holothuria (Panningothuria) forskali* Delle Chiaje, 1823		+
83	ECHINODERMATA	*Synaptula reciprocans* (Forsskål, 1775)		+
84	ECHINODERMATA	*Ophiothrix fragilis* (Abildgaard in O.F. Müller, 1789)	+	
85	ECHINODERMATA	*Arbacia lixula* (Linnaeus, 1758)	+	
86	ECHINODERMATA	*Paracentrotus luvidus* (Linnaeus, 1758)	+	
87	ECHINODERMATA	*Diadema setosum* Leske, 1778		+
88	ECHINODERMATA	*Spatangus purpureus* O.F. Müller, 1776		+
89	TUNICATA	*Pycnoclavella nana* (Lahille, 1890)		+
90	TUNICATA	*Lissoclinum perforatum* (Giard, 1872)		+
91	TUNICATA	*Microcosmus* sp		+
92	TUNICATA	*Herdmania momus* (Savigny, 1816)		+
93	PISCES	*Apogon imberbis* (Linnaeus, 1758)		+

	Group	Species	Observation	Photograph
94	PISCES	*Parablennius gattorugine* (Linnaeus, 1758)		+
95	PISCES	*Parablennius* sp.	+	
96	PISCES	*Sargocentron rubrum* (Forsskål, 1775)		+
97	PISCES	*Gobius cruentatus* Gmelin, 1789	+	
98	PISCES	*Gobius geniporus* Valenciennes, 1837		
99	PISCES	*Gobius sp*		
100	PISCES	*Ariosoma balearicum* (Delaroche, 1809)		+
101	PISCES	*Chromis chromis* (Linnaeus, 1758)		+
102	PISCES	*Pteragogus pelycus* Randall, 1981		+
103	PISCES	*Pempheris vanicolensis* Cuvier, 1831		+
104	PISCES	*Sciaena umbra Linnaeus, 1758*	+	
105	PISCES	*Siganus rivulatus* Forsskål & Niebuhr, 1775	+	
106	PISCES	*Siganus luridus* (Ruppell 1829)	+	
107	PISCES	*Scorpaena* sp.	+	
108	PISCES	*Pterois* sp.		+
109	PISCES	*Epinephelus costae* (Steindachner, 1878)		+
110	PISCES	*Epinephelus marginatus* (Lowe, 1834)		+
111	PISCES	*Serranus cabrilla* (Linnaeus, 1758)	+	
112	PISCES	*Serranus scriba* Linnaeus, 1758	+	
113	PISCES	*Diplodus annularis* (Linnaeus, 1758)	+	
114	PISCES	*Diplodus puntazzo* (Walbaum, 1792)	+	
115	PISCES	*Diplodus vulgaris* (Geoffroy Saint-Hilaire, 1817)		+
116	PISCES	*Tripterygion sp*	+	
117	PISCES	*Torquigener flavimaculosus* Hardy & Randall, 1983	+	

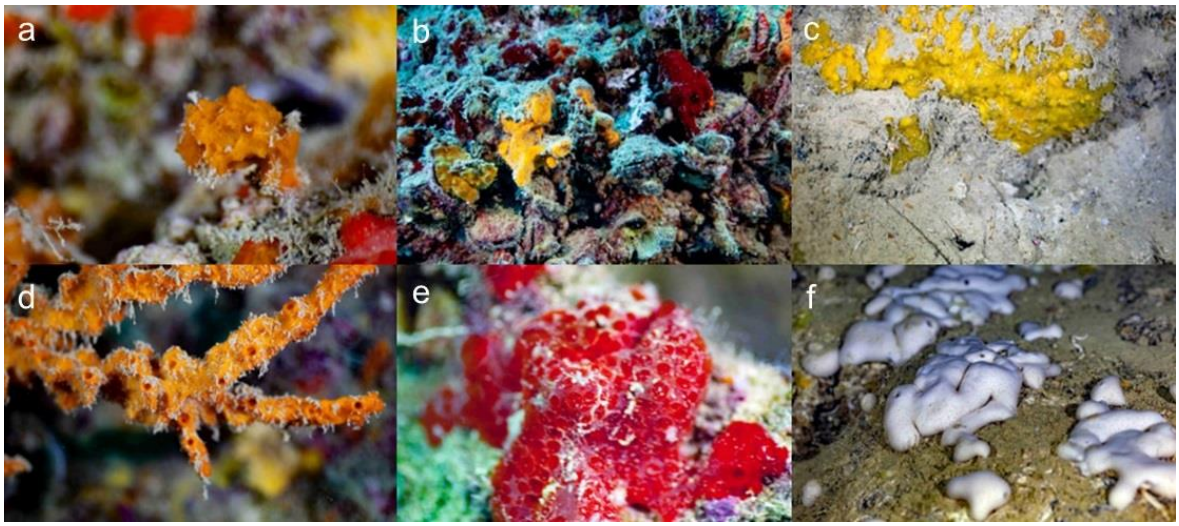

Figure 7. Some sponge species from cave wall. a. *Dictyonella incisa*, b. *Agelas oroides*, c. *Aplysilla sulfurea*, d. *Axinella cannabina*, e. *Cliona* sp., f. *Chondrosia renifromis*

4. Conclusions and discussion

This study demonstrates that Kaynak Sea Cave hosts a taxonomically and functionally diverse benthic community, in line with the well-documented characteristics of Mediterranean marine caves, which are increasingly recognized as biodiversity hotspots of high ecological and conservation importance [7]. The identification of 117 species across 12 major taxonomic groups reflects substantial biological richness and structural complexity. Nonetheless, the true diversity is likely underestimated due to methodological limitations such as qualitative sampling, exclusion of cryptic and soft-bottom habitats, and restricted temporal coverage.

Marine caves serve as natural refugia, particularly for sciaphilic, stenotopic, and often endemic species. In Kaynak Sea Cave, such taxa include characteristic cave sponges *(e.g., Agelas oroides*, *Pleraplysilla spinifera*, *Spirastrella cunctatrix*, *Hexadella racovitzai*), azooxanthellate anthozoans (e.g., *Madracis pharensis*, *Leptopsammia pruvoti*), and stenotopic polychaetes (e.g., *Protula tubularia*, *Metavermilia multicristata*), all of which are also highlighted in the species list. Their presence underlines the cave's ecological uniqueness and aligns with patterns reported from other Eastern Mediterranean caves.

Among the recorded taxa, Porifera emerged as the most species-rich phylum, aligning with previous studies that highlight the ecological dominance of sponges in cave ecosystems. Genera such as *Axinella*, *Dysidea*, and *Ircinia* fulfill key ecological roles in substrate stabilization, nutrient cycling, and microhabitat formation. The occurrence of dark-zone–associated taxa most notably *Hexadella racovitzai* indicates the presence of bathyal-like, low-light ecological conditions within the deeper sections of the cave, shaped by steep environmental gradients. Due to their sensitivity to environmental change, sponge assemblages in Kaynak Sea Cave hold significant potential as bioindicators for long-term ecological monitoring.

A particularly noteworthy finding is the presence of multiple non-indigenous and Lessepsian species including *Pempheris vanicolensis, Siganus luridus, Siganus rivulatus, Sargocentron rubrum, Pteragogus pelycus,* as well as several additional NIS belonging to other taxonomic groups which collectively have the potential to alter native cave communities through competition, habitat encroachment, and disruption of local food webs. Their establishment in this semi-enclosed and environmentally selective system indicates a weakening of traditional biogeographic barriers, likely exacerbated by ocean warming and increasing propagule pressure. This pattern underscores the vulnerability of the biota of marine caves to biological invasions and highlights their value as early-warning systems for ecological homogenization in the Mediterranean.

From a conservation perspective, Kaynak Sea Cave's ecological attributes namely its high species richness, habitat specificity, and exposure to anthropogenic threats warrant formal protection. Although marine caves are recognized as priority habitats under Annex I of the EU Habitats Directive and the Barcelona Convention's Action Plan for Dark Habitats, many remain outside designated Marine Protected Areas (MPAs), particularly in the Levantine Basin. The ecological integrity and representative character of Kaynak Sea Cave position it as a strong candidate for official conservation designation.

The site also offers a valuable opportunity for long-term ecological monitoring. Its pronounced biotic and abiotic gradients and rich biodiversity make it a suitable sentinel habitat to study the effects of environmental change, including invasion dynamics, eutrophication, and warming trends. Incorporating advanced methods such as environmental DNA (eDNA) metabarcoding, 3D photogrammetry, and acoustic habitat mapping would enable high-resolution monitoring and support adaptive ecosystem-based management.

Importantly, this study provides essential baseline knowledge on the biodiversity and ecosystem functions of Eastern Mediterranean marine caves. More broadly, it emphasizes the urgent need to incorporate such habitats into national and regional marine spatial planning not only to conserve species richness but to preserve evolutionary legacy,

This preliminary biodiversity inventory lays the groundwork for future ecological research and conservation planning. Given the cave's distinct biological assemblages and its vulnerability to anthropogenic and climatic stressors, comprehensive assessments and sustained monitoring are urgently needed. Future efforts should employ multidisciplinary, quantitative approaches combining eDNA analyses, habitat mapping, and seasonal observations—to deepen our understanding of species dynamics, community structure, and ecosystem processes.

From a marine policy standpoint, Kaynak Sea Cave exemplifies a vulnerable and ecologically important habitat that merits prioritization in marine spatial planning and protected area frameworks. Its environmental gradients, habitat-dependent taxa, and exposure to external stressors underscore the necessity for targeted conservation measures. Official recognition under the Barcelona Convention's Action Plan for Dark Habitats would represent a critical step toward the preservation of marine cave ecosystems in the Eastern Mediterranean.

In addition, national legislation in Türkiye provides a legal basis for the protection of natural caves through Principle Decision No. 95, issued by the Ministry of Environment and Urbanization (Official Gazette No. 29664, dated 25 March 2016). This decision classifies natural caves into three categories (Group A, B, and C) based on geological, geomorphological, ecological, and scientific values. Group B caves those with ecological and scientific importance and suitable for limited educational or ecotourism use are especially relevant here.

Based on this study's findings specifically the high species richness, presence of indicator sponge species (*e.g.*, *Petrosia ficiformis*, *Axinella spp.*), and observed sensitivity to invasive species Kaynak Sea Cave fulfills the ecological and regulatory criteria for designation as a Group B Natural Monument (B Grubu Tabiat Varlığı). We recommend that the cave be formally evaluated and registered as such by the General Directorate for the Protection of Natural Assets. This designation would ensure alignment with national conservation priorities, enable regulated scientific access, and promote ecosystem-based management in accordance with both Turkish law and international conservation frameworks.

Ultimately, this study underscores that marine caves like Kaynak are not merely geological formations, but dynamic ecological systems of high biological and scientific value. Their conservation is not only a legal and environmental necessity but a moral imperative to protect the Mediterranean's unique marine heritage amid accelerating global change.

References

[1] Hiscock, K. & Breckels, M. (2007). *Marine Biodiversity Hotspots in the UK: A report identifying and protecting areas for marine biodiversity*. UK: WWF. 116 p.

[2] Hofrichter, R. (2002). *Das Mittelmeer. Fauna, Flora, Ökologie. Band I: Allgemeiner Teil*. Heidelberg, Berlin: Spektrum Akademischer Verlag.

[3] Giakoumi, S., Sini, M., Gerovasileiou, V., Mazor, T., Beher, J., Possingham, H. P., Abdulla, A., Ertan, M., Dendrinos, P., Gucu, A. C., Karamanlidis, A. A., Rodic, P., Panayotidis, P., Taskin, E., Jaklin, A., Voultsiadou, E., Webster, C., Zenetos, A. & Katsanevakis, S. (2013). Ecoregion-based conservation planning in the Mediterranean: dealing with large-scale heterogeneity. *PLoS ONE*, 8(10), e76449. https://doi.org/10.1371/journal.pone.0076449

[4] Gerovasileiou, V. & Bianchi, C. N. (2021). Mediterranean marine caves: A synthesis of current knowledge. *Oceanography and Marine Biology*, 59, 1–87. https://doi.org/10.1201/9781003138846-1

[5] Cicogna, F., Bianchi, C. N., Ferrari, G. & Forti, P. (Eds.). (2003). *Le Grotte Marine: Cinquant'Anni di Ricerca in Italia*. Rome: Ministero dell'Ambiente e della Tutela del Territorio.

[6] Martí, R., Uriz, M. J., Ballesteros, E. & Turon, X. (2004). Benthic assemblages in two Mediterranean caves: species diversity and coverage as a function of abiotic parameters and geographic distance. *Journal of the Marine Biological Association of the United Kingdom*, 84(3), 557–572. https://doi.org/10.1017/S0025315404009680h

[7] Gerovasileiou, V., Chintiroglou, C., Vafidis, D., Koutsoubas, D., Sini, M., Dailianis, T. & Voultsiadou, E. (2015). Census of biodiversity in marine caves of the eastern Mediterranean Sea. *Mediterranean Marine Science*, 16(1), 245–265. https://doi.org/10.12681/mms.1060

[8] Harmelin, J. G. (1985). Les grottes sous-marines obscures: un milieu extrême et un remarquable biotope refuge. *Téthys*, 11, 214–229.

[9] Gerovasileiou, V., Voultsiadou, E., Issaris, Y. & Zenetos, A. (2016). Alien biodiversity in Mediterranean marine caves. *Marine Ecology*, 37(2), 239–256. https://doi.org/10.1111/maec.12271

[10] Gerovasileiou, V. & Voultsiadou, E. (2012). Marine caves of the Mediterranean Sea: a sponge biodiversity reservoir within a biodiversity hotspot. *PLoS ONE*, 7(7), e39873. https://doi.org/10.1371/journal.pone.0039873

[11] Vacelet, J., Bitar, G., Carteron, S., Zibrowius, H. & Pérez, T. (2007). Five new sponge species (Porifera: Demospongiae) of subtropical or tropical affinities from the coast of Lebanon (eastern Mediterranean). *Journal of the Marine Biological Association of the United Kingdom*, 87, 1539–1552. https://doi.org/10.1017/S0025315407058570

[12] Harmelin, J. G., Bitar, G. & Zibrowius, H. (2009). Smittinidae (Bryozoa, Cheilostomata) from coastal habitats of Lebanon (Mediterranean Sea), including new and non-indigenous species. *Zoosystema*, 31(1), 163–187. https://doi.org/10.5252/z2009n1a9

[13] Laborel, J. (1961). Le concrétionnement algal "coralligène" et son importance géomorphologique en Méditerranée. *Recueil des Travaux de la Station Marine d'Endoume*, 23(37), 37–60.

[14] Bilecenoğlu, M. & Taşkavak, E. (1999). Some observations on the habitat of the Red Sea immigrant sweeper, *Pempheris vanicolensis*, on the Mediterranean coast of Türkiye. *Zoology in the Middle East*, 17, 67–70.

[15] Evcen, A., Gözcelioğlu, B. & Çınar, M. E. (2020). *Niphates toxifera* (Porifera, Demospongiae), a possible Lessepsian species now colonizing the coast of Türkiye. *Journal of the Black Sea/Mediterranean Environment*, 26(3), 289–296.

[16] Tsiakkiros, L. & Zenetos, A. (2011). Further additions to the alien mollusc fauna along the Cypriot coast: new opisthobranchia species. *Acta Adriatica*, 52, 115–124.

[17] Rastorgueff, P. A., Bellan-Santini, D., Bianchi, C. N., Bussotti, S., Chevaldonné, P., Guidetti, P. & Personnic, S. (2015). An ecosystem-based approach to evaluate the ecological quality of Mediterranean undersea caves. *Ecological Indicators*, 54, 137–152. https://doi.org/10.1016/j.ecolind.2015.02.013