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The aquatic diversity of ostracoda, phytoplankton and zooplankton from freshwater cave habitats in Turkey

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Abstract: During this study, a total of 13 ostracod, 2 zooplankton and 43 phytoplankton taxa were recorded from 22 aqueous caves visited between 2010 and 2013 in Turkey. Whereas three ostracods (*Candona* cf. *candida*, *Eucypris* sp., *Potamocypris* sp.) were new records for caves in Turkey, two others (*Ilyocypris* cf. *gibba* and *Pseudocandona eremita*) were reported for the second time from Turkey. With the inclusion of these taxa, the number of freshwater ostracods reported from caves globally has increased to 68 taxa, although this is probably an underestimate of the total diversity. The records of two zooplankton species (*Diacyclops bisetosus*, *Tropocyclops prasinus*) found in Cumayanı Cave (Zonguldak) is not surprising because of their cosmopolitan distribution and habitat preference characteristics. Among the phytoplankton, Bacillariophyta had the highest richness with 22 taxa followed by Cyanobacteria, Chlorophyta and Euglenophyta with 13, 6 and 2 taxa respectively. The results suggest that each cave has its own unigue biological diversity and species richness that should be recognized and studied in detail.

Keywords: ostracod, phytoplankton, zooplankton, diversity, caves, Turkey

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Although the importance of biodiversity is acknowledged among the scientific community, studies of species diversity within Turkey have largely been conducted for key taxonomic groups in specific habitats. In terms of caves, there have been few studies centred on cave organisms (Lindberg, 1952a, b, 1955, 1958; Selvi and Altuner, 2007; Kunt *et al*., 2010) and even less for aquatic invertebrate organisms from caves. For example, Kunt *et al*. (2010) listed about 203 cave-dwelling invertebrates from Turkey along with 194 Anatolian endemics comprising Mollusca, Oligochaeta, Hirudinea, Arachnida, Diplopoda, Chilopoda, Insecta, and Crustacea. Among the most widely studied groups of aquatic crustacean organisms from caves are the Amphipoda and Cyclopoida. There is little historical data regarding freshwater cave organisms including ostracods (Yavuzatmaca *et al*., 2012), algae (Ulcay *et al*., 2012), amhipod (Özbek *et al*., 2013) and zooplankton from Turkey. Even today, limited taxonomic and ecological information are available for algal communities from Turkish caves (Şen, 1988; Selvi and Altuner, 2007; Ulcay, 2012; Ulcay *et al*., 2012). However, algae have been recorded in cave waters and aerophytic habitats (Mulec *et al*., 2008). Most of the cave studies of algae globally have been focused on subaerial habitats such as rock surfaces within caves, walls in cave entrance zones and lampenflora assemblages (Poulíčková and Hašler, 2007; Czerwik-Marcinkowska and Mrozińska, 2011); with studies of planktonic assemblages within caves being less common (Sánchez *et al*., 2002; Moscatello and Belmonte, 2007). With c. 40,000 caves (Ozansoy and Mengi, 2006) Turkey supports considerable cave habitat diversity: although only around 1300 caves are officially designated by the General Directorate of Mineral Research and Exploration (MTA) of Turkey. The aims of the present study are (1) to provide data for the species recorded within the freshwater habitats of 22 caves in Turkey (Fig.1), and (2) to highlight the importance of aquatic cave biodiversity for three taxonomic groups – Ostracoda, Phytoplankton and Zooplankton.

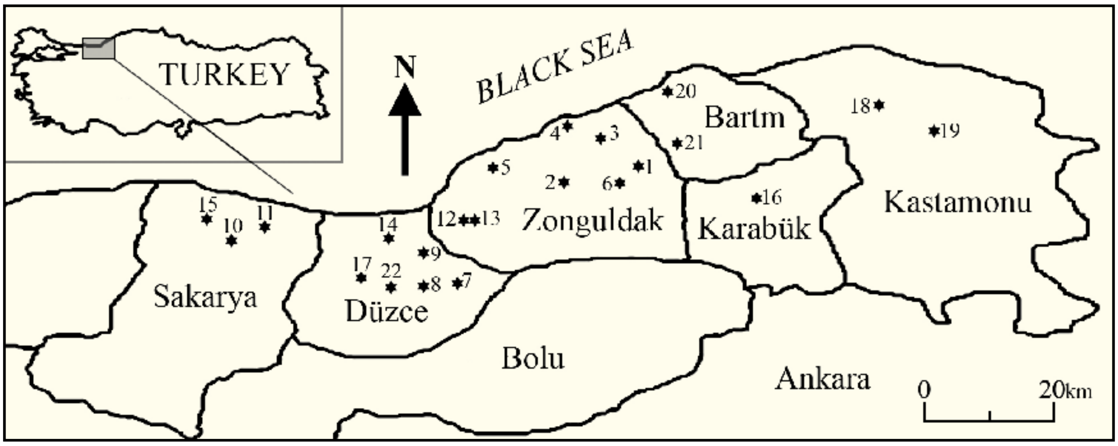

***Figure 1:** Inset shows location of the study area within Turkey, and main map shows location of the 22 caves sampled and reported. 1: Çayırköyü Cave; 2: Gökgöl Cave; 3: Cumayanı Cave; 4: İnağzı Cave; 5: Ilıksu Cave; 6: Sofular Cave; 7: Aksu Cave; 8: Gökçeağaç Cave; 9: Sarıkaya Cave; 10: Söğütlü Cave; 11: Kızılcık Cave; 12: Cehennem ağzı 1 (Kocayusuf) Cave; 13: Cehennem ağzı 2 (Ayazma) Cave; 14: Fakıllı Cave; 15: Kurumeşe Cave; 16: Mencilis Cave; 17: Kurtsuyu dereyanı; 18: Sarpunalınca Cave; 19: Kılıçlı Cave; 20: Gürcüoluk Cave; 21: Sipahiler Cave; 22: Saklıkent Cave. (After Yavuzatmaca et al. 2012).*

	City	Cave	pH	Sal	EC	S.EC	DO%	DO	Tw	Atm.	Ta	SHE	Moist	Wd	Elev	Coordinate	Date
1	Zonguldak	Çayırköyü*	7.57	0.19	392		95.1	10.56	12.72			194.08			147	N41°27'110" E31°59'240"	24.09.2010
2	Zonguldak	Çayırköyü[e]	7.71	0.19	401		120	11.8	12.27		18.9	207.97	67.4		147	N41°27'110" E31°59'240"	24.09.2010
3	Zonguldak	Gökgöl 1*	7.64	0.24	502		105.6	11.11	12.98		17.3	205.51	87.6		147	N41°26'448" E31°49'926"	25.09.2010
4	Zonguldak	Gökgöl 2*	7.65	0.2	419		103	11.11	12.97			207.22			147	N41°26'448" E31°49'926"	25.09.2010
5	Zonguldak	Cumayanı*	7.51	0.5	1003		19.1	2.09	12.72		20	190.98	78.8		147	N41°29'492" E31°53'806"	25.09.2010
6	Zonguldak	Cumayanı[e]	7.58	0.41	825		91.4	9.85	12.2		21.2	204.82	74.2		147	N.41°29'492" E31°53'806"	25.09.2010
7	Zonguldak	İnağzı*[1]									22.1	223.25	68.9		36	N41°28'750" E31°49'335"	25.09.2010
8	Zonguldak	Sofular *[1]									24.3	223.25	56.9		462	N41°25'649" E31°57'130"	25.09.2010
9	Düzce	Aksu*	8.28	0.11	234		115	11.9	12.46		17.2	199.75	86		467	N40°56'452" E31°23'586"	26.09.2010
10	Düzce	Gökçeağaç*	7.72	0.21	427		52.6	5.7	12.11		20.3	204.18	68.9		462	N40°55'827" E31°25'551"	26.09.2010
11	Düzce	Sarıkaya*	8.09	0.26	535		92.7	9.46	14.74		20.9	203.07	64.7		441	N40°56'071" E31°23'921"	26.09.2010
12	Düzce	Sarıkaya[e]	8.35	0.21	440		85.1	8.55	15.55			204.34			441	N40°57'301" E31°26'210"	26.09.2010
13	Adapazarı	Söğütlü[e]	8.17	0.33	676		106.5	10.8	13.03		18.9	199.98	74.7		138	N40°53'450" E30°28'421"	23.10.2010
14	Adapazarı	Söğütlü*	8.3	0.33	675		107.4	11.13	13.06		18.4	199.26	85.9		138	N40°53'450" E30°28'421"	23.10.2010
15	Adapazarı	Kızılcık R.[e]	7.6	0.21	431		87.2	9.12	12.9		18.2	201.87	88.2		34	N41°03'141" E30°41'580"	23.10.2010
16	Adapazarı	Kızılcık*	7.65	0.22	459		111.5	11.22	13.17		19.2	201.19	84.4		34	N41°03'141" E30°41'580"	23.10.2010
17	Zonguldak	Çayırköyü*	7.52	0.19	305.2	402.2	107.2	11.13	12.6	750.1	26.3		45.2	2.1	147	N41°27'110" E31°59'240"	08.07.2011
18	Zonguldak	Cumayanı [R.]*	7.62	0.26	397.7	538.5	52.5	5.71	11.2	762.7	22.4		54		147	N41°29'492" E31°53'806"	09.07.2011
19	Zonguldak	Gökgöl*	7.65	0.18	291.7	367.1	26.3	10.65	14.6	758	21.5		65		147	N41°26'448" E31°49'926"	09.07.2011
20	Zonguldak	Ilıksu*	7.52	0.16	255.5	334.7	110.8	11.46	12.7	762.9	22.2		60		15	N41°24'362" E31°41'168"	09.07.2011
21	Zonguldak	Cehennem Ağzı 1*	7.53	0.29	475.1	604.3	78	7.4	14.1	762	29.2		48.8		11	N41°17'280" E31°24'321"	09.07.2011
22	Zonguldak	Cehennem Ağzı 2*	8.07	0.41	645	830	79.2	8.24	13.3	761.2	22.7		69.2		11	N41°17'280" E31°24'321"	09.07.2011
23	Düzce	Fakıllı*	7.7	0.18	313.7	385.7	84.7	8.52	15.6	756.5	25.2		45.9		108	N41°03'061" E31°10'380"	09.07.2011
24	Adapazarı	Kızılcık*	7.17	0.13	202.3	264.7	53.7	5.52	12.7	756	23		73.7		34	N41°03'141" E30°41'580"	10.07.2011
25	Adapazarı	Kurumeşe*	7.46	0.22	353.7	460.1	53.6	5.56	13.2	754.2	27.5		56.9		11	N40°59'080" E30°33'211"	10.07.2011
26	Adapazarı	Söğütlü*	7.47	0.27	423.7	544.9	80.1	7.16	13.7	757.6	27.4		56		138	N40°53'450" E30°28'421"	10.07.2011
27	Düzce	Gökçeağaç*	7.55	0.15	251	321.9	25.4	2.43	13.4	695.1					462	N40°55'759" E31°25'423"	17.09.2011
28	Düzce	Sarıkaya[e]	8.36	0.23	377.9	467.7	81	7.97	15	710.8	20.3		85.9		441	N40°56'248" E31°24'031"	17.09.2011
29	Düzce	Sarıkaya*	8.18	0.24	375.1	491.4	89.5	9.46	12.6	712.3	22.2		53.9		441	N40°56'248" E31°24'031"	17.09.2011
30	Düzce	Aksu*	7.87	0.22	341.4	465.1	94.2	10.12	11.6	735.2	19.3		75.3		280	N40°43'152" E31°30'963"	17.09.2011
31	Karabük	Mencilis*	7.6	0.26	411.2	540.2	47.1	4.86	12.5	689.4	25.7	189.83	24.8	2	592	N41°15'536" E32°40'335"	27.07.2012
32	Düzce	Kurtsuyu*	7.65	0.23	330	461.4	80.3	9.47	11.7	725.6	16.3				387	N40°57'968" E31°13'419"	21.09.2012
33	Düzce	Saklıkent *	8.33	0.21	301.9	426.2	93	10.54	9.8	702.5					656	N40°56'429" E31°29'416"	21.09.2012
34	Kastamonu	Sarpunalınca 1*	7.89	0.16	221.3	328.6	75.2	8.87	8.1	663.7	15		50		1281	N41°44'154" E33°48'457"	22.05.2013
35	Kastamonu	Sarpunalınca 2*[1]													1281	N41°44'154" E33°48'457"	22.05.2013
36	Kastamonu	Sarpunalınca 3*	8.03	0.16	216.9	325.5	75.9	9.04	7.5	654.5	14.7		54.6		1281	N41°44'154" E33°48'457"	22.05.2013
37	Kastamonu	Sarpunalınca[e2]	8.14	0.16	220.4	329.3	84.6	10	7.8	657	18		42	5.2	1256	N41°44'166" E33°48'910"	22.05.2013
38	Kastamonu	Kılıçlı *	8.31	0.18	289.3	369.7	82.6	8.41	13.6	739.3	17.3		66.5	2.3	224	N41°41'198" E33°48'673"	22.05.2013
39	Bartın	Gürcüoluk *					18.1	2.07	10.8		16		64		402	N41°43'460" E32°27'849"	23.05.2013
40	Bartın	Sipahiler *[1]									18.1		57.4		161	N41°37'778" E32°29'446"	23.05.2013
		Mean	7.81	0.23	412	441	79.59	8.58	12.5	727	20.8	203.6	64.7	2.9	336.2		
		Maximum	8.36	0.5	1003	830	120	11.9	15.6	762.9	29.2	223.3	88.2	5.2	1281		
		Minimum	7.17	0.11	202.3	265	18.1	2.07	7.5	654.5	14.7	189.8	24.8	2	11		

Table 1: *Environmental charactersitics of 40 stations studied within 22 sampled caves. Abbreviations: Sal (Salinity, ppt), EC (Electrical Conductivity, µS.cm^{-1}), S.EC (Specific Electrical Conductivity, µS.cm^{-1}), DO% (Percent Oxygen Saturation, % sat.), DO (Dissolved Oxygen, mg.L^{-1}), Tw (Water Temperature, °C), Atm. (Atmospheric Pressure, mmHg), Ta (Air Temperature, °C), SHE (Redox Potential, mV), Moist (Moisture, %), Wd (Wind speed, km.h^{-1}), Elev. (Elevation, m). Standard Hydrogen Electrode (SHE) calculated from the field value of the redox potential Eh (mV) as SHE = Eh+207+0.65*(25-Tw°C). * represents inside of the cave, [e] represents entrance of the cave, [e2] represents exit of the cave. Cehennem Ağzı 1 and 2 are also known as Koca Yusuf Cave and Ayazma Cave, respectively. [R], Right branch of the cave, [1] represents insufficient water for measurement.*

	City	Cave	Cc	Cn	Cs	Es	Hs	Ib	Ig	Ii	Is	Pos	Pe	Ps	Pys
1	Zonguldak	Çayırköyü*					1v								
2	Zonguldak	Çayırköyü[e]													
3	Zonguldak	Gökgöl 1*													
4	Zonguldak	Gökgöl 2*													
5	Zonguldak	Cumayanı*													
6	Zonguldak	Cumayanı[e]													
7	Zonguldak	İnağzı*[1]												2c	
8	Zonguldak	Sofular *[1]													
9	Düzce	Aksu*													
10	Düzce	Gökçeağaç*			1c, 2v					2	4c, 8v			1c, 2v	
11	Düzce	Sarıkaya*		3	18v			2			4c, 6v			2c	
12	Düzce	Sarıkaya[e]		21							5c, 6v				2c, 5v
13	Adapazarı	Söğütlü[e]									1v				
14	Adapazarı	Söğütlü*													
15	Adapazarı	Kızılcık R.[e]													
16	Adapazarı	Kızılcık*													
17	Zonguldak	Çayırköyü*													
18	Zonguldak	Cumayanı R.*													
19	Zonguldak	Gökgöl*													
20	Zonguldak	Ilıksu*													
21	Zonguldak	Cehennem Ağzı 1*											2, 13c, 20v		
22	Zonguldak	Cehennem Ağzı 2*			5c, 10v								1c, 10v		
23	Düzce	Fakıllı*									2c, 2v				
24	Adapazarı	Kızılcık*													
25	Adapazarı	Kurumeşe*					2v				1c, 5v				
26	Adapazarı	Söğütlü*			9v										
27	Düzce	Gökçeağaç*													
28	Düzce	Sarıkaya[e]						3, 4c, 5v						2c	4c, 12v
29	Düzce	Sarıkaya*		8j				30							17c, 10v
30	Düzce	Aksu*													
31	Karabük	Mencilis*													
32	Düzce	Kurtsuyu*													
33	Düzce	Saklıkent *													
34	Kastamonu	Sarpunalınca 1*				1v					1v	1v			
35	Kastamonu	Sarpunalınca 2*[1]		1v					4c						
36	Kastamonu	Sarpunalınca 3*									1, 4v				
37	Kastamonu	Sarpunalınca[e2]										2v			
38	Kastamonu	Kılıçlı *	1v		2c										
39	Bartın	Gürcüoluk *													
40	Bartın	Sipahiler *[1]												1	

Table 2: *Summary details of the 13 ostracod taxa recorded within the caves and from the entrance zones of the caves studied. Abbreviations: Cc (Candona cf. candida), Cn (Candona neglecta), Cs (Candona sp.), Es (Eucypris sp.), Hs (Heterocypris sp.), Ib (Ilyocypris bradyi), Ig (Ilyocypris cf. gibba), Ii (Ilyocypris inermis), Is (Ilyocypris sp.), Pos (Potamocypris sp.), Pe (Pseudocandona eremita), Ps (Pseudocandona sp.), Pys (Psychrodromus sp.), c (carapace) and v (valve). See Table 1 for the abbreviations.*

Materials and Methods

Invertebrate samples were collected from 29 sites in 22 caves in six areas/cities: Zonguldak – 8 caves; Düzce – 6 caves; Adapazarı – 3 caves; Kastamonu – 2 caves; Bartın – 2 caves, and Karabük – 1 cave. All sites were visited from 24 September 2010 to 23 May 2013 (Fig.1). Some caves were visited on more than one occasion (Table 1). Ostracods and zooplankton were collected with a hand net of a 150 and 55µm mesh size, stored in 500 and 250ml plastic bottles repectively and fixed in 70% ethanol. Sampling of phytoplankton was undertaken using a plankton net (45µm mesh size) and fixed in 4% formaldehyde *in situ*. All environmental variables were measured before sampling (Table 1). A pH/ORP meter was used to measure pH and redox potential (mV) (Hanna model HI-98150) and a YSI model 85 was used to measure salinity (ppt), electrical conductivity (µS.cm^{-1}), dissolved oxygen (mg.L^{-1}), percent oxygen saturation (% sat.), and water temperature (°C). The Standard Hydrogen Electrode (SHE) (mV) values were calculated from redox potentials measured at each sampling site. The Total Dissolved Solids (TDS) (mg.L^{-1}) was derived by multiplying the values of electrical conductivity by 0.65. Atmospheric pressure (mmHg) was recorded using a YSI-Professional Plus Multi-Probe. Air temperature (°C), wind speed (km.h^{-1}) and air moisture (%) was recorded with a Testo 410-2 anemometer and basic geographical data (elevation, coordinates) were recorded with a geographical positioning system (GARMIN Etrex Vista H GPS).

In the laboratory, ostracods were washed and filtered under tap water through three standard-sized sieves (0.5, 1 and 1.5mm mesh size) and then stored in 70% alcohol for further analysis. Ostracods were sorted from sediments under a stereo-microscope (Olympus Ach 1X) for taxonomic identification. Soft body parts of organisms were dissected in lactophenol solution under a light microscope prior to identification (Olympus BX 51). Samples for algological studies were collected during the summer (8–10 July) of 2011 from 9 caves in the western Black Sea region of Turkey. Phytoplankton were recorded from 7 caves; with two caves (Ilıksu and Ayazma) not supporting any phytoplankton.

The taxonomic key of Meisch (2000) was used for identifying ostracods, Flössner (1972), Smirnov (1996) and Kiefer (1955) for zooplankton and John *et al*. (2002), Komárek and Anagnostidis (1998, 2005) and Krammer and Lange-Bertalot (1991a,b, 1997a,b) used to identify phytoplankton. Ostracoda with damaged soft body parts, single valves (sub-recent) and empty carapaces were not assigned to species level. All of the biological samples are stored in the Limnology Laboratory of Abant İzzet Baysal University Bolu/Turkey and are available for examination upon request.

Results

A total of 13 ostracods, belonging to 7 genera from 3 families, were recorded from the 29 sites (out of 40 sampled stations) from the 22 caves studied (Tables 1 and 2), two zooplankton species (*Diacyclops bisetosus*, *Tropocyclops prasinus*) from Cumayanı cave and 43 phytoplankton taxa from seven caves were recorded (Table 1). Four Ostracoda (*C. neglecta*, *I. bradyi*, *I. inermis*, *P. eremita*) were recorded from three caves, with three (*Candona* cf. *candida*, *Eucypris* sp., *Potamocypris* sp.) representing new records for caves in Turkey and *I.* cf. *gibba* and *Pseudocandona eremita* representing the second records for Turkish caves (Table 2). When these taxa are included with previous records, around 160 cave ostracods have been reported globally to date (Appendix 1). Of these taxa, 68, 38, 32, and 23 are primarily known from freshwater, anchialine, inland-marine caves and the caves with no or limited information regarding the water bodies where they occurred.

When the phytoplankton were examined (Table 3, Fig.2), Bacillariophyta were the dominant group with 22 (51%) compared to the other three groups recorded: Cyanobacteria (30%), Chlorophyta (14%) and Euglenophyta (5%). A total of 28 phytoplankton taxa were recorded from Kızılcık Cave. Most of the phytoplankton taxa display a cosmopolitan distribution. The most important algal groups, with respect to taxon richness, were the diatoms (Bacillariophyta). Centric diatoms comprised 2 taxa (*Aulacoseira* sp. and *Cyclotella* sp.) while pennat diatoms were represented by 20 taxa. Although there were less centric diatom species in the phytoplanktonic algal flora, they were more abundant than the pennate diatoms. *Aulacoseira* filaments were the most common centric diatom encountered. Among pennate diatoms, the genera *Nitzschia* was represented by 4 taxa and *Encyonema*, *Gomphonema*, *Navicula*, *Pinnularia* and *Surirella* by 2 taxa each. Each of the pennate genera *Cymbopleura, Eunotia, Gyrosigma, Hantzschia, Neidium* and *Planothidium* were represented by single taxa. Bacillariophyta taxa were relatively diverse / rich but were recorded at low densities.

	Kızılcık	Fakıllı	Gökgöl	Söğütlü	Cehennem Ağzı	Çayırköyü	Cumayanı
Cyanobacteria							
Chlorogloea sp.	X						
Gloeotrichia sp.		X					
Heteroleibleinia sp.		X					
Jaaginema angustissimum (West & G.S.West) Anagnostidis & Komárek	X	X		X		X	X
Leptolyngbya tenuis (Gomont) Anagnostidis & Komárek	X	X					
Lyngbya sp.	X		X				
Nostoc sp.	X	X					
Oscillatoria sp.		X					
Phormidium sp.					X		
Planktothrix agardhii (Gomont) Anagnostidis & Komárek		X					
Pseudanabaena acicularis (Nygaard) Anagnostidis & Komárek	X		X				X
Pseudanabaena mucicola (Naumann & Huber-Pestalozzi) Schwabe		X					
Romeria sp.	X						
Bacillariophyta							
Aulacoseira sp.	X	X					
Cyclotella sp.	X						
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer					X		
Encyonema minutum (Hilse) D.G.Mann	X						
Encyonema silesiacum (Bleisch) D.G.Mann					X		
Eunotia pectinalis (Kützing) Rabenhorst	X						
Gyrosigma scalproides (Rabenhorst) Cleve		X					
Gomphonema olivaceum (Hornemann) Brébisson	X						
Gomphonema parvulum (Kützing) Kützing	X						
Hantzschia amphioxys (Ehrenberg) Grunow	X						
Navicula sp.		X					
Navicula tripunctata (O.F.Müller) Bory de Saint-Vincent			X				
Neidium sp.	X						
Nitzschia acicularis (Kützing) W.Smith							X
Nitzschia linearis (C.Agardh) W.Smith	X						
Nitzschia palea (Kützing) W.Smith	X						
Nitzschia vermicularis (Kützing) Hantzsch				X			
Pinnularia acutobrebissonii Kulikovskiy, Lange-Bertalot & Metzeltin	X						
Pinnularia viridis (Nitzsch) Ehrenberg	X						
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	X						
Surirella brebissonii Krammer & Lange-Bertalot		X					
Surirella tenera W.Gregory	X						
Chlorophyta							
Chlamydomonas sp.	X	X					
Desmodesmus intermedius (Chodat) E.Hegewald	X						
Monoraphidium arcuatum (Korshikov) Hindák		X	X				
Monoraphidium komarkovae Nygaard	X			X			
Nephrocytium lunatum West	X						
Tetraedron minimum (A.Braun) Hansgirg	X						
Euglenophyta							
Euglena pisciformis Klebs	X		X				
Euglena sp.	X						

Table 3: Taxonomic list of the 43 phytoplankton taxa recorded in the caves sampled in the study. (X, presence of taxa.)

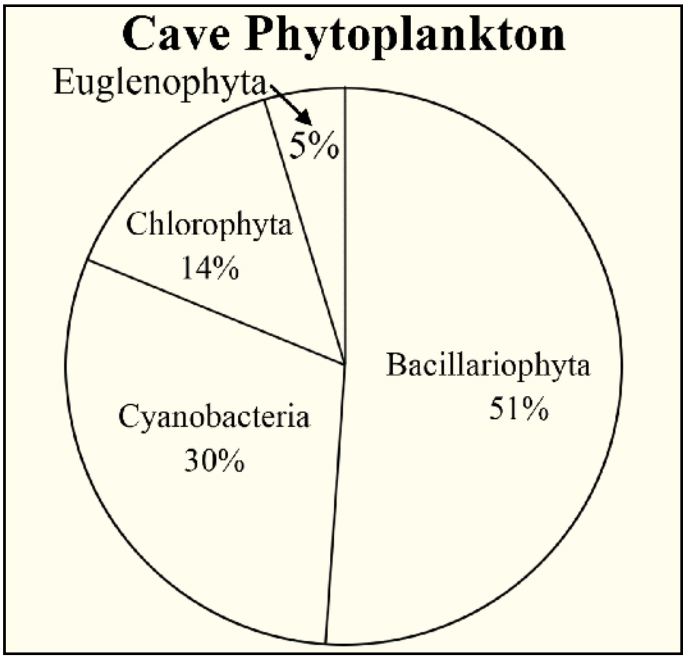

Figure 2: *Percentage of Phytoplankton taxa recorded in Kızılcık, Fakıllı, Gökgöl, Söğütlü, Cehennem ağzı, Cumayanı and Çayırköyü caves. See also Table 3.*

Although Cyanobacteria were less diverse when compared with Bacillariophyta, they were more abundant. The phytoplankton communities of the caves mainly comprised filamentous Cyanobacteria. Of the 13 taxa recorded, one was unicellular / colonial (*Chlorogloea* sp.) and the remaining taxa were filamentous species. When the filamentous Cyanobacteria were considered, *Jaaginema angustissimum* was common within five caves; *Pseudanabaena* species were recorded from 4 different caves, while *Leptolyngbya, Lyngbya* and *Nostoc* were recorded from 2 caves. Chlorophyta was represented by six taxa with each of the genera *Chlamydomonas, Desmodesmus, Nephrocytium* and *Tetraedron* from Chlorophyta being represented by single taxa and the genus *Monoraphidium* by two taxa (*M. arcuatum* and *M. komarkovae*). The most abundant Chlorophyta was *Monoraphidium arcuatum*. Euglenophyta were mainly from the genus *Euglena* with 2 taxa. The highest number of phytoplankton taxa were recorded from Kızılcık (28 taxa) and Fakıllı (14 taxa) caves, while the lowest number of taxa were recorded from Gökgöl (5 taxa), Söğütlü (3 taxa), Cehennemağzı (3 taxa), Cumayanı (3 taxa) and Çayırköyü (1 taxa) caves. No phytoplankton species were recorded in Ilıksu and Ayazma caves. Almost all of the caves studied were characterized by low algal diversity and abundance (except Kızılcık and Fakıllı caves). The characteristics of the water within the caves varied from alkaline and cold fresh to brackish with low to medium level of dissolved oxygen (Table 1). Although the results indicate that the caves studied had relatively low species diversity, it appears that each cave has its own unique characteristics.

Discussion and Conclusion

Low ostracod species diversity was recorded during the present study of the caves compared to other aquatic bodies. The 'harsh' environmental conditions (Creuze des Chatelliers and Marmonier, 1993) and difficulties associated with the colonization of caves by fauna are the reasons hypothesized for the low species diversity (Danielopol and Rouch, 2004). For example, Scharf and Brunke (2013) working in the River Elbe near Coswig (Berlin, Germany) reported 6–11 species around three groyne fields visited from May to September 2000. Similarly, Külköylüoğlu *et al*. (2012) reported five species from a small pond, 1m^2 in size, in Kahramanmaraş (Turkey). Individual sites can support high species diversity, for instance lake Lago Petén Itzá (Guatemala) supported up to eight species at a single site (Perez *et al*., 2010). The ecological characteristics and preferences of species can also play a critical role regarding their adaptation to cave conditions (e.g., for details see Yavuzatmaca *et al*., 2012). Indeed, three of the four species recorded alive in the caves (*C. neglecta*, *I. bradyi*, *I. inermis*) are common in a range of surface water bodies. Despite the lack of ecological information regarding *I. inermis*, the ecological characteristics / preferences of the other two species are well known; with a wide tolerance to a range of environmental conditions over a broad geographical region (Külköylüoğlu, 2013). There are around 68 freshwater ostracods recorded from caves globally to date (see Appendix 1), although this is almost certainly an underestimate of the true biodiversity. Also, the scarcity of cave studies does not represent the true ostracod diversity. The same is also true for the other aquatic cave invertebrates. For example, only two copepod stygoxen species (*Diacyclops bisetosus*, *Tropocyclops prasinus*) were recorded from cave entrance habitats (c. 30m inside the right branch) of Cumayanı Cave (sampled on 25.09.2010). These two are commonly occurring species with cosmopolitan distributions across epigean and hypogean habitats throughout Turkey. The latter has previously been reported from Balıkkaya caves and Kapuz cave entrance (Zonguldak) (Lindberg, 1953).

Among the photosynthetic algae, which are typically found in moist to wet habitats, three groups – Cyanobacteria (blue-green algae), Bacillariophyta (diatoms), and Chlorophyta (green algae) – have been recorded in freshwater hypogean environments (Romero, 2009). All three groups are crucial components of the algal flora developing in caves in many locations globally (Czerwik-Marcinkowska and Mrozińska, 2011; Selvi and Altuner, 2007; Sánchez *et al*., 2002), with similar algal groups / taxa being recorded during the present study. Many studies have shown that the algal communities of caves are commonly dominated by Cyanobacteria (Selvi and Altuner, 2007; Martinez and Asencio, 2010). The presence of filamentous Cyanobacteria in stable conditions of low light intensity and high relative humidity has already been reported from several caves (e.g., Czerwik-Marcinkowska and Mrozińska, 2011; Martinez and Asencio, 2010). Such occurrences probably reflect their broad ecological tolerances to different environmental conditions. In this study, Cyanobacteria were represented primarily by filamentous taxa such as *Jaaginema angustissimum, Pseudonabaena* spp., *Leptolyngbya tenuis, Planktothrix agardhii, Phormidium, Lyngbya, Oscillatoria* and *Nostoc* species. Similar genera were recorded in Ballıca Cave from epilithic samples (Selvi and Altuner, 2007) and Kaklık Cave (Ulcay, 2012) in Turkey and included both planktonic and benthic species.

Bacillariophyta is also frequently recorded within caves. In the present study, members of Bacillariophyta were diverse but were recorded at low densities. Most of the diatom species recorded displayed cosmopolitan characteristics. Among the Bacillariophyta, pennate diatoms were more diverse, with few truly planktonic diatomic taxa. Similar results were reported by Sánchez *et al*. (2002) for phytoplankton of cenotes (sinkholes) and anchialine caves, where pennate (71%) and centric (4%) individuals comprised the largest component of the total diatoms identified. Sánchez *et al*. (2002) also reported that the majority of the diatom taxa were microphytobenthic – except *Cyclotella meneghiniana,* which is a planktonic species found in both fresh and saline environments.

Algae frequently grow in the illuminated parts of cave systems (Mulec *et al*., 2008) and the relative abundance of algal groups varies according to light intensity. In addition to light intensity, algal species within caves are dependent on moisture, nutrient availability and temperature. If the physical and chemical conditions are satisfied (i.e., enough light, moisture and nutrients are available), especially in the entrance zone of caves, relatively diverse algae communities can develop (Selvi and Altuner, 2007). For example, Martinez and Asencio (2010) reported that the primary stress factor influencing the distribution of algal communities in the Gelada Cave was light limitation, followed by humidity, lack of nutrients and temperature.

Overall, the results of this study demonstrate that the caves visited have unique environmental characterisitics that require adaptation for the organisms to live there. However, few species are truly adapted to cave conditons and most of organisms recorded display high tolerances to environmental conditions that enable them to survive and persist in cave environments. However, more studies are required to help quantify cave biodiversity.

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Name of species	a	b	c	d	Location	Reference
Pseudocandona trigonella				1	Slovenia	Klie, 1931
Pseudocandona cavicola				1	Slovenia	Klie, 1935
Cavernocypris subterranea	1				Afghanistan, Austria, Slovenia	Hartmann, 1964; Christian and Spötl, 2010; Mori and Meisch, 2012
Ilyocypris decipiens	1				Turkey	Hartmann, 1964
Ilyocypris gibba	1				Turkey	Hartmann, 1964; This study
Pseudocandona eremita	1				Turkey, Slovenia	Hartmann, 1964, This study; Mori and Meisch, 2012
Psychrodromus olivaceus	1				Turkey, Italy	Hartmann, 1964; Peterson *et al.*, 2013
Potamocypris fallax				1	Britain	Fox, 1967
Candona sp.	1				Texas, USA	Charles D Wise in Maguire, 1960
Batucyprattinae new subfamily	1				West Malaysia	Victor and Fernando, 1981
Batucypretta paradoxa n. gen.n.sp.	1				West Malaysia	Victor and Fernando, 1981
Mixtacandona botosaneanui	1				Romania	Danielopol, 1982
Danielopolina bahamensis		1			Turks and Caicos Islands	Kornicker and Iliffe, 1985
Danielopolina exleyi		1			Bahamas	Kornicker and Iliffe, 1985
Danielopolina exuma		1			Bahamas	Kornicker and Iliffe, 1985
Danielopolina exuma		1			Bahamas	Kornicker and Iliffe, 1985
Danielopolina kakuki		1			Bahamas	Kornicker and Iliffe, 1985
Danielopolina sp.		1			Bahamas	Kornicker and Iliffe, 1985
Deeveya hirpex		1			Bahamas	Kornicker and Iliffe, 1985
Deeveya jillae		1			Bahamas	Kornicker and Iliffe, 1985
Deeveya sp.		1			Bahamas	Kornicker and Iliffe, 1985
Deeveya spiralis		1			Bahamas	Kornicker and Iliffe, 1985
Deeveya styrax		1			Bahamas	Kornicker and Iliffe, 1985
Spelaeoecia barri		1			Bahamas	Kornicker and Iliffe, 1985
Spelaeoecia capax		1			Bahamas	Kornicker and Iliffe, 1985
Spelaeoecia parkeri		1			Bahamas	Kornicker and Iliffe, 1985
Spelaeoecia styx		1			Bahamas	Kornicker and Iliffe, 1985
Anchistracheles hartmanni			1		Bermuda	Maddocks and Iliffe, 1986
Aponesidea iliffei			1		Bermuda	Maddocks and Iliffe, 1986
Argilloecia sp.			1		Bermuda	Maddocks and Iliffe, 1986
Callistocythere sp.			1		Bermuda	Maddocks and Iliffe, 1986
Candona sp.			1		Bermuda	Maddocks and Iliffe, 1986
Cobanocythere sp.			1		Bermuda	Maddocks and Iliffe, 1986
Cyprideis edentata			1		Bermuda	Maddocks and Iliffe, 1986
Cytherella bermudensis			1		Bermuda	Maddocks and Iliffe, 1986
Cytherella kornickeri			1		Bermuda	Maddocks and Iliffe, 1986
Cytherelloidea irregularis			1		Bermuda	Maddocks and Iliffe, 1986
Dolerocypria bifurca			1		Bermuda	Maddocks and Iliffe, 1986
Glyptobairdia cororata			1		Bermuda	Maddocks and Iliffe, 1986
Havanardia keiji			1		Bermuda	Maddocks and Iliffe, 1986
Hemicytherura bradyi			1		Bermuda	Maddocks and Iliffe, 1986
Heterocypris punctata			1		Bermuda	Maddocks and Iliffe, 1986
Jugysocythereis pannosa			1		Bermuda	Maddocks and Iliffe, 1986
Loxoconcha oculocrista			1		Bermuda	Maddocks and Iliffe, 1986
Microcytherura sp.			1		Bermuda	Maddocks and Iliffe, 1986
Myodocopina spp.			1		Bermuda	Maddocks and Iliffe, 1986
Neocaudites navianii			1		Bermuda	Maddocks and Iliffe, 1986
Neonesidea omnivaga			1		Bermuda	Maddocks and Iliffe, 1986
Occultocythereis angusta			1		Bermuda	Maddocks and Iliffe, 1986
Paracypridinae spp.			1		Bermuda	Maddocks and Iliffe, 1986
Paracypris crispa			1		Bermuda	Maddocks and Iliffe, 1986
Paradoxostoma sp.			1		Bermuda	Maddocks and Iliffe, 1986
Paranesidea bensoni			1		Bermuda	Maddocks and Iliffe, 1986
Polycope spp.			1		Bermuda	Maddocks and Iliffe, 1986
Pontocyprididae n. gen. n. sp.			1		Bermuda	Maddocks and Iliffe, 1986
Propontocypris (Ekpontocypris) lurida			1		Bermuda	Maddocks and Iliffe, 1986
Propontocypris minacis			1		Bermuda	Maddocks and Iliffe, 1986
Propontocypris sp.			1		Bermuda	Maddocks and Iliffe, 1986
Xestoloberis spp.			1		Bermuda	Maddocks and Iliffe, 1986
Spelaeoecia bermudensis		1			Bermuda	Angel and Iliffe, 1987
Cavernocypris coreana	1				South Korea	Marmonier *et al.*, 1989
Cypria cavernae	1				Italy	Wagenleitner, 1990
Candona sp.		1			New Caledonia	Maddocks *et al.*, 1991
Cypretta sp.		1			New Caledonia	Maddocks *et al.*, 1991
Darwinula sp.		1			New Caledonia	Maddocks *et al.*, 1991
Dolerocypria n. sp.		1			New Caledonia	Maddocks *et al.*, 1991
Heterocypris sp.		1			New Caledonia	Maddocks *et al.*, 1991
Kennethia major		1			New Caledonia	Maddocks *et al.*, 1991
Mungava sp.		1			New Caledonia	Maddocks *et al.*, 1991
Paracypria n. sp.		1			New Caledonia	Maddocks *et al.*, 1991
Candona sp.	1				Australia	Maddocks and Iliffe, 1991
Candonocypris incosta	1				Australia	Maddocks and Iliffe, 1991
Cypretta minna	1				Australia	Maddocks and Iliffe, 1991
Cypretta viridis	1				Australia	Maddocks and Iliffe, 1991
Cypridopsis sp.	1				Australia	Maddocks and Iliffe, 1991
Gomphodella maia	1				Australia	Maddocks and Iliffe, 1991
Heterocypris incongruens	1				Australia	Maddocks and Iliffe, 1991
Newhamia fenestrata	1				Australia	Maddocks and Iliffe, 1991
Sarscypridopsis cf. *aculeata*	1				Tasmania, New Zealand	Maddocks and Iliffe, 1991
Scottia sp.	1				New Zealand	Maddocks and Iliffe, 1991
Danielopolina elizabethae		1			Jamaica	Kornicker and Iliffe, 1992
Pontopolycope mylax		1			Jamaica	Kornicker and Iliffe, 1992
Spelaeoecia jamaicensis		1			Jamaica	Kornicker and Iliffe, 1992
Danielopolina exuma		1			Bahamas	Kornicker and Iliffe, 1998
Danielopolina sp.		1			Bahamas	Kornicker and Iliffe, 1998
Deeveya exleyi		1			Bahamas	Kornicker and Iliffe, 1998
Spelaeoecia bermudensis		1			Bahamas	Kornicker and Iliffe, 1998
Spelaeoecia capax		1			Bahamas	Kornicker and Iliffe, 1998
Spelaeoecia styx		1			Bahamas	Kornicker and Iliffe, 1998
Trajancandona natura	1				Montenegro	Karanovic, 1999
Trajancandona particula	1				Montenegro	Karanovic, 1999
Genus *Pseudocandona*				1	USA	Culver *et al.*, 2000
Danielopolina kornickeri		1			Australia	Danielopol *et al.*, 2000
Plesiocypridopsis newtoni				1	Italy	Karanovic and Pesce, 2001
Polycope sp.				1	Italy	Karanovic and Pesce, 2001
Pseudolimnocythere hypogea				1	Italy	Karanovic and Pesce, 2001
Cryptocandona brehmi				1	Japan	Namiotko and Danielopol, 2001
Candona candida	1			1	Britain, Italy, Slovenia, Turkey	Proudlove *et al.*, 2003; Peterson *et al.*, 2013; Mori and Meisch, 2012; This study
Pseudocandona sywulai	1				Croatia	Namiotko *et al.*, 2004
Pseudocandona jeanneli				1	Indiana, USA	Indiana Natural Data Center, 2005
Pseudocandona marengoensis				1	Indiana, USA	Indiana Natural Data Center, 2005
Sagittocythere barri				1	Indiana, USA	Indiana Natural Data Center, 2005
Pseudocandona jeanneli				1	USA	Lewis and Lewis, 2005, 2009
Pseudocandona sp.				1	USA	Lewis and Lewis, 2005, 2009
Dolerocypria iliffei		1			New Caledonia	Maddocks, 2005
Mungava woutersi		1			New Caledonia	Maddocks, 2005
Mungava xariessa		1			New Caledonia	Maddocks, 2005
Paracypria ubaris		1			New Caledonia	Maddocks, 2005
Cavernocypris subterranea				1	France	Ferreira *et al.*, 2007
Fabaeformiscandona breuili				1	France	Ferreira *et al.*, 2007
Pseudocandona zschokkei				1	France	Ferreira *et al.*, 2007
Psychrodromus betharrami				1	France	Ferreira *et al.*, 2007
Schellencandona sp. *insueta*				1	France	Ferreira *et al.*, 2007
Schellencandona sp. *schellenbergi*				1	France	Ferreira *et al.*, 2007
Sphaeromicola cebennica cebennica				1	France	Ferreira *et al.*, 2007
Sphaeromicola hamigera				1	France	Ferreira *et al.*, 2007
Sphaeromicola topsenti				1	France	Ferreira *et al.*, 2007
Candona cf. *lindneri*	1				Herzegovina	Petkovski *et al.*, 2009
Candona sp.	1				Herzegovina	Petkovski *et al.*, 2009
Cyclocypris cf. *globosa*	1				Herzegovina	Petkovski *et al.*, 2009
Cypria ophtalmica	1				Herzegovina, Slovenia, Italy	Petkovski *et al.*, 2009; Mori and Meisch, 2012; Peterson *et al.*, 2013
Cypria sketi (carapace)	1				Herzegovina	Petkovski *et al.*, 2009
Cypridopsis vidua	1				Herzegovina, Italy, Slovenia	Petkovski *et al.*, 2009; Peterson *et al.*, 2013; Mori and Meisch, 2012
Heterocypris sp.	1				Herzegovina	Petkovski *et al.*, 2009
Ilyocypris inermis	1				Herzegovina, Turkey	Petkovski *et al.*, 2009; Yavuzatmaca *et al.*, 2012
Ilyocypris sp.	1				Herzegovina	Petkovski *et al.*, 2009
Pseudocypridopsis hartmanni n. sp.	1				Herzegovina	Petkovski *et al.*, 2009
Pseudocypridopsis sywulai n. sp.	1				Herzegovina	Petkovski *et al.*, 2009
Shellecandona cf. *aemonae*	1				Herzegovina	Petkovski *et al.*, 2009
Candona crogmaniana	1				Wisconsin, USA	Anonymous, 2010
Candona lactea	1				Wisconsin, USA	Anonymous, 2010
Cypridopsis sp.	1				Wisconsin, USA	Anonymous, 2010
Ilyocypris bradyi	1				Turkey	Yavuzatmaca *et al.*, 2012; This study
Ilyocypris sp.	1				Turkey	Yavuzatmaca *et al.*, 2012
Candona neglecta	1				Turkey, Italy	Yavuzatmaca *et al.*, 2012; Peterson *et al.*, 2013; This study
Candona sp.	1				Turkey	Yavuzatmaca *et al.*, 2012
Pseudocandona sp.	1				Turkey	Yavuzatmaca *et al.*, 2012
Heterocypris sp.	1				Turkey	Yavuzatmaca *et al.*, 2012
Psychrodromus sp.	1				Turkey	Yavuzatmaca *et al.*, 2012
Potamocypris villosa	1				Slovenia	Mori and Meisch, 2012
Fabaeformiscandona aemonae	1				Slovenia	Mori and Meisch, 2012
Cypria reptans	1				Slovenia	Mori and Meisch, 2012
Notodromas persica	1				Slovenia	Mori and Meisch, 2012
Cypris pellucida	1				Slovenia	Mori and Meisch, 2012
Typhlocypris schmeili	1				Slovenia	Mori and Meisch, 2012
Fabaeformiscandona ex gr. *F. fabaeformis*	1				Italy	Peterson *et al.*, 2013
Pseudocandona albicans	1				Italy, Slovenia	Peterson *et al.*, 2013; Mori and Meisch, 2012
Mixtacandona sp.	1				Italy	Peterson *et al.*, 2013
Prionocypris zenkeri	1				Italy	Peterson *et al.*, 2013
Herpetocypris chevreuxi	1				Italy	Peterson *et al.*, 2013
Heterocypris cf. *H. reptans*	1				Italy	Peterson *et al.*, 2013
Limnocythere inopinata	1				Italy	Peterson *et al.*, 2013
Pseudolimnocythere sp.	1				Italy	Peterson *et al.*, 2013
Candona sp.	1				Turkey	This study
Eucypris sp.	1				Turkey	This study
Ilyocypris sp.	1				Turkey	This study
Heterocypris sp.	1				Turkey	This study
Potamocypris sp.	1				Turkey	This study
Pseudocandona sp.	1				Turkey	This study
Psychrodromus sp.	1				Turkey	This study
Total	**68**	**38**	**32**	**23**		

Appendix 1. *Ostracod taxa previously reported from different cave environments.*
Abbreviations: a: freshwater cave, b: anchialine cave, c: inland marine cave and d: unknown/unrecorded cave type.