Turk J Zool
2012; 36(1): 59-74

doi:10.3906/zoo-1002-39

Research Article

Distribution of aquatic oligochaetes (Annelida, Clitellata) of high-elevation lakes in the Eastern Black Sea Range of Turkey

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Received: 11.02.2010

Abstract: Many large and small lakes of varying depths are present in the Eastern Black Sea Range of Turkey, the nation's third most important glacial region following the Ağrı and Cilo-Sat mountain ranges. During the present study, 6 expeditions to collect aquatic oligochaetes from these lakes were conducted in July and August of 2005, 2006, and 2007; qualitative and quantitative samples were collected from 59 glacial lakes. We present and analyze the dominancy and distribution of aquatic oligochaete assemblages and their relation to environmental factors (temperature, dissolved oxygen, pH, electrical conductivity, salinity, turbidity, PO_4^{-3}-P, HCO_3^-, organic carbon, hardness, Ca^{2+}, Mg^{2+}, Si, water depth, and altitude) using classification and ordination techniques. Canonical correspondence analysis (CCA) was used to characterize the relationship between oligochaetes and the environmental variables. As a result, we determined the 4 most important environmental variables (elevation, water depth, dissolved oxygen, and temperature) affecting species distribution in general. Sampling localities were clustered into 8 groups with the unweighted pair-group method with arithmetic mean (UPGMA) based on physicochemical characteristics. The relationships between the total number of individuals and environmental measurements were determined by a simple analysis of variance (ANOVA) test. The results of our analyses suggest a significant positive correlation between altitude ($P < 0.05$; $F = 2.994$) and the total number of individuals.

Key words: Oligochaeta, Clitellata, Haplotaxidae, Naididae, Enchytraeidae, Lumbriculidae, Tubificinae, Naidinae, Eastern Black Sea Range, Turkey, glacial lakes

Türkiye'nin Doğu Karadeniz Sıradağları üzerindeki yüksek rakımlı göllerde sucul Oligoket (Annelida, Clitellata) türlerinin dağılımı

Özet: Ağrı ve Cilo-Sat Dağları'ndan sonra Türkiye'nin 3. büyük buzul bölgesi olan Doğu Karadeniz Sıradağları'nda çeşitli derinliklerde büyüklü küçüklü bir çok göl vardır. Bu çalışma boyunca, bölgedeki sucul oligoket topluluklarının dağılım ve baskınlıkları analiz edilmiş ve sınıflandırma sıralama (derecelendirme) teknikleri kullanılarak çevresel faktörlerle ilişkileri sunulmuştur. Oligoketlerle çevresel faktörler arasındaki ilişkiyi ortaya çıkarmak için kanonik korrespond analizi (CCA) kullanılmıştır. Türlerin dağılımını etkileyen 4 önemli çevresel faktör, önem sırasıyla rakım, su derinliği, çözünmüş oksijen ve sıcaklık olarak belirlenmiştir.

Örnekleme yapılan lokalitelerde ölçülen fiziko-kimyasal analiz sonuçlarına göre yapılan UPGMA analiz sonucunda, lokaliteler 8 gruba ayrılmıştır. Toplam birey sayıları ile çevresel faktörlerin ilişkisi basit ANOVA testi ile belirlenmiştir. Buna göre toplam birey sayısı ile rakım arasında önemli pozitif bir ilişki ($P < 0.05$; $F = 2.994$) olduğu saptanmıştır.

Anahtar sözcükler: Oligoket, Clitellata, Haplotaxidae, Naididae, Enchytraeidae, Lumbriculidae, Tubificinae, Naidinae, Doğu Karadeniz Sıradağları, Türkiye, buzul göller

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Introduction

Lakes in high mountains and on glaciers are unique habitats in terms of faunal composition, because they constitute isolated environments. Our knowledge of oligochaete fauna is still very limited in some parts of Turkey, especially in the mountain ranges. This study aims to explore the ecological and faunistic features of mountain lakes in the Eastern Black Sea Range.

Although various Oligochaeta studies have been conducted at easily accessible lowland lakes, according to Arslan (2006), only a few studies have focused on the oligochaete fauna associated with the high-elevation glacial and tectonic lakes in the mountains of Turkey. Among these, a pioneering study by Yıldız et al. (2005) investigated macroinvertebrate fauna of Eğrigöl in the Taurus Mountains; a second study by Yıldız et al. (2007) addressed the oligochaete fauna of 16 lakes located in the Taurus Range. Ustaoğlu et al. (2008) investigated the limnology and fauna of glacial lakes and streams on Mount Uludağ in western Anatolia. More recently, Yıldız et al. (2010) presented the results of their study on the distribution of oligochaetes (Lumbriculidae and Enchytraeidae) in the littoral zones of glacial and tectonic lakes in the mountains of the Eastern Black Sea Range of Turkey.

This study was part of a larger investigation focused primarily on: 1) the littoral, profundal, and pelagic aquatic macroinvertebrate communities; 2) the general limnology; and 3) the chemical and physical parameters of high-elevation lakes occurring in 6 drainage basins in the Eastern Black Sea Range. The objectives of this study were to determine the range of distribution of oligochaete species in the area and to document the relationships between the species and environmental variables.

Study area

The Eastern Black Sea Mountains are a range rising along the Black Sea coast in northeastern Turkey. The highest peak is Kaçkar Mountain (3937 m), and the plateaus at about 3000 m above sea level are the highest parts of the range. The mountains are partially glaciated and alpine in character, with steep rocky peaks and numerous mountain lakes. Extensive glacial and water erosion has given these mountains their craggy, rugged look. Powerful streams and rivers rush down to the lower elevations. Locality information for the 59 lakes in the 6 drainage basins studied during this project, and the characteristics of the sampling sites on those lakes, are presented in Table 1 and Figure 1.

Materials and methods

Sampling procedures and environmental variables

Due to the high elevation of these lakes, most of the study sites are covered by ice and snow for 8-9 months of the year, with ice-free conditions usually present only during the warmest months of July and August. To collect aquatic oligochaetes from these lakes, 6 expeditions were conducted in July and August of 2005, 2006, and 2007. Some physicochemical features and the oligochaete fauna of the 59 lakes (3 replicates per site) belonging to the basins of 6 rivers (Çoruh River, Fırtına Stream, İyidere, Kabisra Stream, Solaklı Stream, and Maçka Stream) were determined for the first time. Water samples were taken from the littoral zone of each lake, and 6 environmental variables, temperature (°C), dissolved oxygen (DO, mg L^{-1}), pH, electrical conductivity (COND, µs cm^{-1}), salinity (S, mg L^{-1}), and water transparency, were measured in situ with a WTW pH meter (model 330), WTW oxygen meter (model 330), YSI SCT meter (model 30), and Secchi disk. Other variables (PO_4^{-3}-P, HCO_3^-, organic carbon, hardness, Ca^{2+}, Mg^{2+}, and Si) were measured in the laboratory following the standard methods of the American Public Health Association (1989).

Benthos samples were collected from different parts of the littoral zone (between 0 and 50 cm) of the lakes by hand-net (mesh size: 180 µm), disturbing the substrate for 3 min. In addition, an Ekman-Birge grab was used in deeper parts of the lakes. Benthic samples were fixed on site with 4% formaldehyde. After sorting the material, Oligochaeta samples were preserved in 70% ethanol until identification to the species level. After a temporary mounting of sorted oligochaete samples on slides in Amman's lactophenol, the worms were identified using a stereomicroscope and a binocular microscope. The reference materials were kept in the collection of the first author as permanent whole mounts on slides

Table 1. Locality information for and dates of sampling at 59 stations in high-elevation lakes in the Eastern Black Sea Range of Turkey, where surveys for aquatic oligochaetes were conducted in 2005, 2006, and 2007. Trophic scale: UO = ultraoligotrophic, O = oligotrophic, M = mesotrophic.

Station numbers	Code	Sampling dates	Lakes	Basins	Altitude (m)	Coordinates	Substratum types	Trophic scale
1	Ç08	06.07.2005 19.08.2005	Adalıgöl	Çoruh River	3020	40°38′43″N, 40°53′10″E	hard, gravel	O
2	Ç07	19.08.2005	Üstgöl	Çoruh River	3030	40°38′51″N, 40°52′54″E	hard, gravel	O
3	Ç09	06.07.2005 19.08.2005	Ortagöl	Çoruh River	3010	40°38′53″N, 40°53′18″E	hard, gravel	UO
4	Ç10	06.07.2005 19.08.2005	Büyükgöl	Çoruh River	2980	40°38′45″N, 40°53′36″E	hard, gravel	UO
5	Ç11	19.08.2005	Altgöl	Çoruh River	2950	40°38′53″N, 40°53′40″E	hard, gravel	UO
6	F08	08.07.2005 21.08.2005	Lake Atmeydan	Fırtına Stream	2910	40°43′11″N, 40°54′01″E	peat	UO
7	F10	08.07.2005 21.08.2005	İncegöl	Fırtına Stream	2915	40°43′06″N, 40°54′23″E	peat	UO
8	F09	08.07.2005 21.08.2005	Kumlugöl	Fırtına Stream	2860	40°43′22″N, 40°54′17″E	peat, ground soft	UO
9	F12	21.08.2005	Lake Altkapılı	Fırtına Stream	3000	40°43′11″N, 40°54′57″E	peat	O
10	F11	21.08.2005	Lake Büyük Kapılı	Fırtına Stream	3000	40°43′00″N, 40°54′54″E	hard, vegetation	UO
11	F03	09.07.2005 22.08.2005	Lake Çermeş	Fırtına Stream	2780	40°44′58″N, 40°52′09″E	gravel, stones	UO
12	F02	22.08.2005	Çermeş Karagöl	Fırtına Stream	2990	40°44′37″N, 40°52′04″E	gravel, stones	UO
13	F01	22.08.2005	Lake Keçi	Fırtına Stream	3070	40°44′25″N, 40°51′50″E	gravel, stones	UO
14	F16	11.07.2005 24.08.2005	İsimsizgöl	Fırtına Stream	2890	40°52′28″N, 41°09′46″E	mud, stones	UO
15	F14	11.07.2005 24.08.2005	Lake Büyükdeniz	Fırtına Stream	2900	40°52′09″N, 41°09′42″E	mud, stones	O
16	F15	24.08.2005	Lake Meterez	Fırtına Stream	2990	40°51′49″N, 41°09′45″E	stones, sand	M
17	F17	24.08.2005	Lake Karadeniz	Fırtına Stream	2770	40°52′42″N, 41°10′03″E	stones	O
18	F18	29.07.2006	Lake Ceymakcur	Fırtına Stream	2650	40°53′44″N, 41°11′30″E	stones	O
19	F19	30.07.2006	Büyükgöl	Fırtına Stream	2670	40°56′13″N, 41°12′02″E	stones, in places sand	O

Table 1. Continued.

Station numbers	Code	Sampling dates	Lakes	Basins	Altitude (m)	Coordinates	Substratum types	Trophic scale
20	F13	31.07.2006	Lake Kıblekaya	Fırtına Stream	2870	40°49′24″N, 41°06′06″E	sand-mud	O
21	F06	01.08.2006	Lake Sırpal	Fırtına Stream	2940	40°49′21″N, 40°53′40″E	sand-mud-gravel-stones	O
22	F07	01.08.2006	Lake Çahberik	Fırtına Stream	2810	40°49′17″N, 40°54′09″E	sand-mud	O
23	Ç02	19.08.2005	Lake Dağbaşı	Çoruh River	2710	40°37′02″N, 40°46′47″E	hard, gravel	M
24	İ07	02.08.2006	Lake Akçaağıl	İyidere	2940	40°31′19″N, 40°30′40″E	sand-mud-gravel, in places stones	O
25	İ10	03.08.2006	Lake Çitrik	İyidere	2850	40°39′31″N, 40°46′59″E	sand-mud-gravel-stones	O
26	İ11	03.04.2006	Lake Salar	İyidere	2820	40°43′28″N, 40°52′09″E	sand-mud-gravel-stones	O
27	Ç03	04.08.2006	Lake Batıaksu	Çoruh River	3050	40°39′13″N, 40°50′39″E	sand, stones	O
28	Ç04	04.08.2006	Lake Kuzeyaksu	Çoruh River	3070	40°39′19″N, 40°50′57″E	sand, stones	O
29	Ç05	04.08.2006	Lake Doğuaksu	Çoruh River	3120	40°39′09″N, 40°51′06″E	sand, stones, rock	O
30	İ01	20.08.2006	Dipsizgöl	İyidere	2670	40°33′28″N, 40°28′25″E	gravel, stone, in places mud	O
31	İ04	20.08.2006	Lake Hatalan	İyidere	2810	40°33′11″N, 40°29′24″E	silt, mud, stones,	UO
32	İ03	20.08.2006	Lake Küçükhatalan	İyidere	2800	40°33′16″N, 40°29′22″E	silt, mud, stones,	UO
33	İ06	20.08.2006	Lake Sivrinin	İyidere	2700	40°33′39″N, 40°29′52″E	rock, silt	UO
34	İ05	20.08.2006	Lake Küçüksivri	İyidere	2710	40°33′36″N, 40°29′50″E	rock, silt	UO
35	İ08	21.08.2006	Lake Katreç	İyidere	2700	40°34′06″N, 40°34′51″E	rock, silt	O
36	İ09	21.08.2006	Lake Küçükkatreç	İyidere	2690	40°34′13″N, 40°34′58″E	rock, silt	UO
37	Ç12	23.08.2006	Lake Deniz	Çoruh River	3370	40°49′07″N, 41°09′39″E	rock, silt, stones	UO
38	Ç13	24.08.2006	Lake Kartal	Çoruh River	2940	40°50′20″N, 41°18′04″E	in places rock	UO
39	Ç14	24.08.2006	Lake Devise	Çoruh River	2935	40°50′22″N, 41°18′12″E	silt, stones	UO

Table 1. Continued.

Station numbers	Code	Sampling dates	Lakes	Basins	Altitude (m)	Coordinates	Substratum types	Trophic scale
40	K01	25.08.2006	Arhavi Karagöl	Kabisra Stream	2660	41°09′28″N, 41°24′19″E	rock, silt	O
41	S01	26.08.2006	Uzungöl	Solaklı Stream	1100	40°37′14″N, 40°17′44″E	mud	O
42	İ02	25.07.2007	Lake Koyun	İyidere	3010	40°31′34″N, 40°28′58″E	rock, stones, pieces of rock	UO
43	Ç06	26.07.2007	Ortagöl	Çoruh River	2960	40°38′51″N, 40°52′09″E	stones, mud, sand	O
44	S05	27.07.2007	Lake Aygır	Solaklı Stream	2710	40°31′39″N, 40°23′28″E	mud, sand, stones	M
45	S04	27.07.2007	Lake Balık	Solaklı Stream	2570	40°31′54″N, 40°23′01″E	mud	UO
46	S09	28.07.2007	Lake Buz	Solaklı Stream	3040	40°31′58″N, 40°27′36″E	mud	O
47	S07	28.07.2007	Büyükyayla Karagöl	Solaklı Stream	2930	40°31′41″N, 40°27′03″E	mud	UO
48	S08	28.07.2007	Lake Pirömer	Solaklı Stream	2870	40°32′00″N, 40°27′09″E	mud	UO
49	S03	29.07.2007	Multat Karagöl	Solaklı Stream	2800	40°31′30″N, 40°21′46″E	mud	UO
50	S06	29.07.2007	Lake Sarıçiçek	Solaklı Stream	2880	40°31′15″N, 40°24′21″E	mud	UO
51	S02	30.07.2007	Lake Kırklarcami	Solaklı Stream	2740	40°31′46″N, 40°20′06″E	mud, coarse rock	UO
52	Ç01	30.07.2007	Göloba	Çoruh River	2540	40°30′36″N, 40°19′12″E	mud	UO
53	F20	22.08.2007	Lake Tobamızga	Fırtına Stream	2620	41°02′19″N, 41°15′37″E	sand-mud	UO
54	F21	22.08.2007	Lake Küçük Tobamızga	Fırtına Stream	2630	41°02′08″N, 41°15′39″E	sand-mud	UO
55	F22	23.08.2007	Büyük Çiftegöl	Fırtına Stream	2600	40°59′24″N, 41°15′41″E	sand-mud, in places rocks	UO
56	F23	23.08.2007	Küçük Çiftegöl	Fırtına Stream	2550	40°59′36″N, 41°15′49″E	sand-mud, in places rocks	UO
57	F05	25.08.2007	Lake Büyük Balıklı	Fırtına Stream	2990	40°49′28″N, 40°52′51″E	mud, few stones	UO
58	F04	25.08.2007	Lake Kayakaynak	Fırtına Stream	3080	40°49′17″N, 40°52′43″E	stones, mud	UO
59	M01	26.08.2007	Lake Çakır	Maçka Stream	2530	40°34′34″N, 39°41′26″E	sand-mud, in places rocks, gravel, many macrophytes	UO

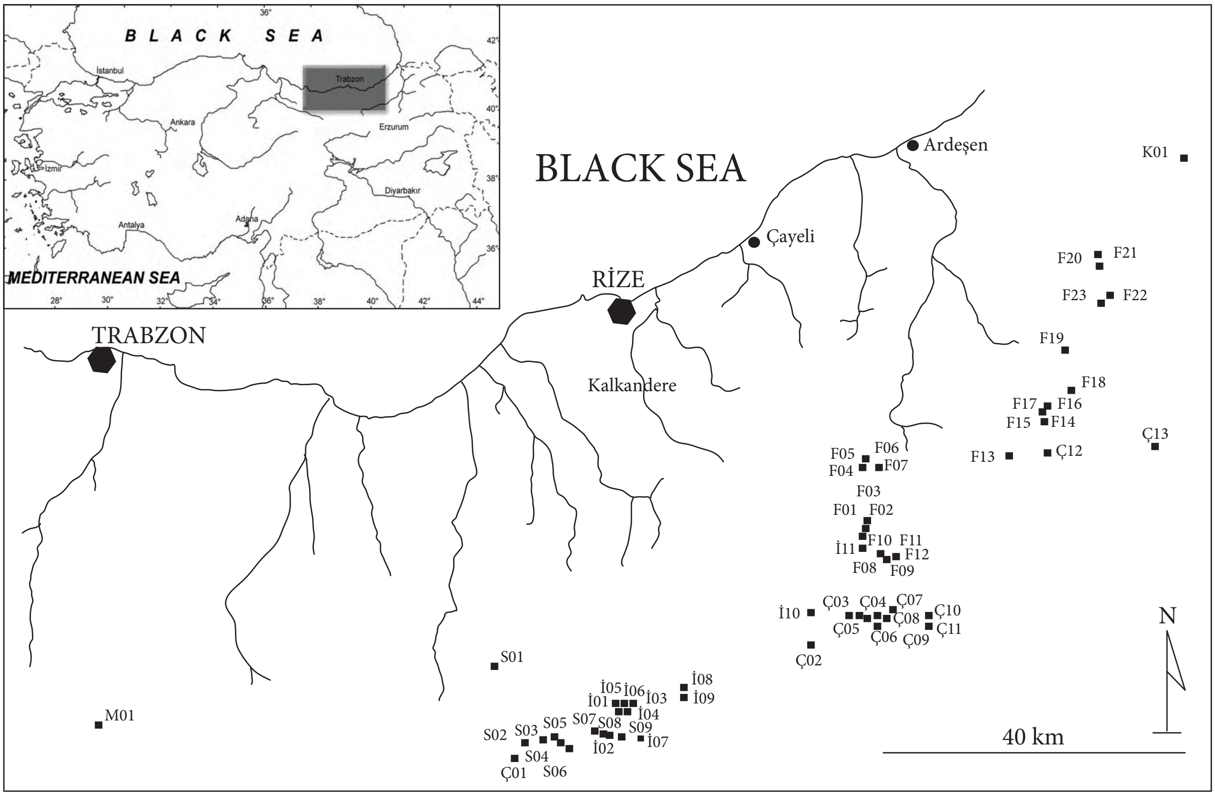

Figure 1. Map of 59 sampling stations associated with **6** drainage basins in the Eastern Black Sea Range in Turkey, where surveys for aquatic oligochaetes were conducted in 2005, 2006, and 2007. Ç = Çoruh River Basin, F = Fırtına Stream Basin, İ = İyidere Basin, K = Kabisra Stream Basin, S = Solaklı Stream Basin, M = Maçka Stream Basin.

in CMCP 10 solution. Specimens were identified using the keys and other distributional information presented by Brinkhurst and Jamieson (1971), Brinkhurst and Wetzel (1984), Sperber (1948, 1950), Nielsen and Christensen (1959), Timm (1999), and Timm and Veldhuijzen van Zanten (2002).

Data analyses

Faunistic and environmental data were analyzed by canonical correspondence analysis (CCA) after testing the data with detrended correspondence analyses (DCA). During the CCA progress in the CANOCO program (ter Braak, 1989), we selected 59 stations, those from which species had been collected at least twice during this study. This method permits the construction of theoretical variables (ordination axes) that best fit the species data according to a unimodal method of ordination (ter Braak, 1987). In order to eliminate or reduce the effect of the skewness of the data, we log-transformed [ln (x + 1)] all environmental variables, with the exception of pH. The statistical significance of the relationship between all species and all variables was tested with a Monte Carlo permutation test using 199 permutations. Rare species were downweighted, and taxa encountered in only one sample were excluded to reduce multicollinearity (ter Braak and Barendregt, 1986; ter Braak, 1995). A clustering analysis of the unweighted pair-group method with arithmetic mean (UPGMA) was conducted using the MultiVariate Statistical Package (MVSP) version 3.1 (Kovach, 1998), in order to identify different taxonomic assemblages among the species at each sampling site. The relationship between the total number of individuals and environmental measurements was determined by a simple analysis of variance (ANOVA) test.

Results

Qualitative analysis

During the 2005, 2006, and 2007 sampling periods, 8721 individuals belonging to 15 genera and 28 taxa

[19 taxa from Naididae, 9 of which are in subfamily Tubificinae (according to Erséus et al., 2008); 5 taxa from Enchytraeidae; 3 species from Lumbriculidae; and 1 species from Haplotaxidae] were collected. A list of the 28 oligochaete taxa collected from the study area is given in Table 2. *Spirosperma ferox* (in 6 basins at 48 stations), *Tubifex tubifex* (in 6 basins at 33 stations), and *Stylodrilus parvus* (in 6 basins at 21 stations) were the dominant species. Among these, 20 taxa were new records for the study area. In all samples, the Naididae dominated (68% of the specimens; subfamily Naidinae, 36%, and subfamily Tubificinae, 32%) (Table 2).

Regarding the species diversity of the stations, station 44 (Lake Aygır) had the highest species richness (9 species), followed by stations 11, 20, 31, 41, and 52 (Lake Çermeş, Lake Kıblekaya, Lake Hatalan, Uzungöl, and Göloba, respectively), each with 8 species. There were no oligochaete species observed at stations 2, 13, 29, or 55.

Environmental variables

Some physicochemical measurements, according to station, are presented in Table 3.

Statistical analysis

In the ordination procedure, 7 environmental variables were used. Variables affecting species distribution were, in order of importance according to CCA, elevation, water depth, dissolved oxygen, and temperature (Figure 2).

The CCA involved 7 environmental variables with 1 nominal variable (habitat type) and 6 selected taxa that showed wide distribution in 59 samples (Figure 2). Accordingly, CCA was able to explain 90.6% of the species-environment relationships with about 48.4% variance (Table 4).

The first ordination axis reflected a gradient mostly related to temperature (Figure 2). Forward selection with Monte Carlo permutation tests indicated that elevation was the main environmental variable associated with assemblage composition ($P < 0.05$; $F = 5.99$). The second ordination axis indicated that water depth, as the second most important factor ($P < 0.05$; $F = 1.84$), had the next largest effect on the occurrence of species. The remaining environmental variables had relatively small effects on species composition. The species related to temperature are seen in the lower right quadrant of the ordination diagram in Figure 2.

According to the UPGMA analysis, the studied lakes were clustered into 8 groups. The most important ecological parameter in determining these groups seemed to be elevation, because the montane lake was placed toward the upper side while the alpine lakes were toward the lower side (Figure 3).

According to ANOVA test results for the data collected during surveys of aquatic oligochaetes at 59 stations, a significant correlation was found between the total numbers of individuals and altitude ($P < 0.05$; $F = 2.994$).

Discussion

Alpine lakes are among the most remote and undisturbed aquatic environments in Europe. In general, those at higher elevations are considered to be pristine, as they are less influenced by pollution from agriculture and wastewater than those at lower elevations (Füreder et al., 2006).

Glacial and tectonic lakes on mountains of high elevation are difficult to reach because of the rough terrain. Consequently, the studied lakes are not yet exposed to anthropogenic pollution.

Oligochaete communities in high mountain lakes and ponds include species with various ecological demands, both narrow and wide (Dumnicka and Galas, 2002). Dumnicka and Galas determined that oligochaete species from high mountain ponds and lakes can be grouped ecologically as follows: 1) species known almost exclusively in high elevation lakes and ponds, 2) opportunistic species, 3) cold-stenothermic species, and 4) semiaquatic species. While oligochaetes are common invertebrates in high mountain streams, they are rarely the dominant group in ponds and lakes located immediately adjacent to these streams (Lencioni et al., 2004).

Due to the high elevation and cold water temperatures of the lakes investigated during this study, overall species diversity was low; a similar distribution pattern was observed for oligochaete communities in these lakes. Oligochaete species found in the Eastern Black Sea Range show similarities to those found in previous studies of other European

Table 2. List and mean individual numbers m^{-2} of aquatic oligochaete species collected from 59 stations in high-elevation lakes in the Eastern Black Sea Range of Turkey in 2005, 2006, and 2007.

Taxa **Station**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Nais simplex Piguet, 1906								29															12					
Nais elinguis Müller, 1774											6									1			4					
Nais pardalis Piguet, 1906																							4					
Nais pseudobtusa Piguet, 1906																							4					
Nais communis Piguet, 1906																									2	1		
Nais sp.								3															4					
Ophidonais serpentina (Müller, 1774)																												
Uncinais uncinata (Ørsted, 1842)																												
Chaetogaster diaphanus (Gruithuisen, 1828)																												
Chaetogaster sp.																												
Spirosperma ferox (Eisen, 1879)	117		10	3	445	293	136	305	5	3	77			51	47	155			43	28	20	44	168	2	10	116	365	30
Limnodrilus hoffmeisteri Claparede, 1862																												
Ilyodrilus templetoni (Southern, 1909)	5						10				5																	
Tubifex tubifex (Müller, 1774)	15					2		7			4	3			38	15			338	46		3			5	1		1
Tubifex montanus Kowalewski, 1919						8										13			26									
Tubifex nerthus Michaelsen, 1908																												
Tubifex sp.																			45	62								
Aulodrilus pluriseta (Piguet, 1906)								11	1					29			1			62		8	12					
Aulodrilus pigueti Kowalewski, 1914																												
Stylodrilus parvus (Hrabe & Cernosvitov, 1927)				1																1								
Stylodrilus heringianus Claparede, 1862	1						1							5														
Lumbriculus variegatus (Müller, 1774)			1	9		15	1	11			2	2		3	3	5					3	2			2	1		1
Cognettia sphagnetorum (Vejdovsky, 1878)			1																	5								1
Cognettia glandulosa (Michaelsen, 1889)						1	9	3			6			4				2		13				1				1
Mesenchytraeus armatus (Levinsen, 1884)											1																	
Mesenchytraeus sp.											4								2			2				9		2
Henlea sp.																												

Table 2. Contunied.

	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
Nais simplex Piguet, 1906			1							3																					
Nais elinguis Müller, 1774			2	1													9						72	8							
Nais pardalis Piguet, 1906																															
Nais pseudobtusa Piguet, 1906																5															
Nais communis Piguet, 1906																															
Nais sp.																															
Ophidonais serpentina (Müller, 1774)													3																		
Uncinais uncinata (Ørsted, 1842)													3																		
Chaetogaster diaphanus (Gruithuisen, 1828)																14															
Chaetogaster sp.																5	9														
Spirosperma ferox (Eisen, 1879)	155	9	135	385	97		26	1		39	15	246	6	3	311	229	408	58	173	111	41	186		145	2	27		59		34	43
Limnodrilus hoffmeisteri Claparede, 1862							2						386																		
Ilyodrilus templetoni (Southern, 1909)										3													15	8							
Tubifex tubifex (Müller, 1774)	15	45	8						6	18	9	45	5		2	23	130		66	19		21		6		2		18		2	46
Tubifex montanus Kowalewski, 1919	13									3							1		88	12						2				2	
Tubifex nerthus Michaelsen, 1908							1			1																					28
Tubifex sp.																															
Aulodrilus pluriseta (Piguet, 1906)		1	27	17								18	31									4		21	2						
Aulodrilus pigueti Kowalewski, 1914																															
Stylodrilus parvus (Hrabe & Cernosvitov, 1927)											4	3	11	1	23	32	200	4		6	12	17		123		12		16	10	2	28
Stylodrilus heringianus Claparede, 1862															33	5								18				6			
Lumbriculus variegatus (Müller, 1774)	5	11	2	2	14		2								15									60					10	12	
Cognettia sphagnetorum (Vejdovsky, 1878)							2																							9	
Cognettia glandulosa (Michaelsen, 1889)			3		13	7	18							158	69	5		2		12											
Mesenchytraeus armatus (Levinsen, 1884)			1																												
Mesenchytraeus sp.							1														2	8	2					3	6		
Henlea sp.							1							14																	
Haplotaxis gordioides (Hartmann, 1821)																	17														

Table 3. Physicochemical features of stations in 2005, 2006, and 2007. Temp. = temperature, Cond. = conductivity, DO = dissolved oxygen, nd = not detected.

Sta. no.	Temp. (°C)	Water depth (m)	pH	DO (mg L^{-1})	Cond. (µs cm^{-1})	HCO^{-3} (mg L^{-1})	T. hard. (mg L^{-1})	Ca^{+2} (mg L^{-1})	Mg^{+2} (mg L^{-1})	NO_2^--N (µg L^{-1})	NO_3^--N (µg L^{-1})	NH_4^--N (µg L^{-1})	PO_4^{-3}-P (µg L^{-1})	SiO_2 (µg L^{-1})
1	2.5	8.1	8.02	9	36.7	67.1	40	8.02	4.86	1.12	58.7	6.13	5.47	1108.11
1	20.9	8.1	9.82	7.9	46	54.9	40	8	4.9	0.37	6.9	47	0	915
2	18.7	4.4	9.44	5.3	72	61	40	8	4.9	0.7	9.4	46.3	8.76	1203.2
3	2.5	4.1	7.92	9.3	33.2	61	40	8.02	4.86	0.74	42.5	0.68	1.09	1033.84
3	20.3	4.1	9.11	6	43	61	60	8	9.7	0.74	31.9	34	4.38	790.2
4	3	1.0	7.77	10.1	43	54.9	40	8.02	4.86	0	43.75	10.89	1.09	1117.02
4	18.2	1.0	8.86	6	46	61	40	8	4.9	0.74	17.5	53.8	3.28	861.5
5	18.7	2.8	8.94	6.6	64	61	60	8	9.7	0.74	10	49.7	3.28	1351.7
6	12.5	3.7	7.72	9.7	17.8	42.7	40	8.02	4.86	1.49	20.62	33.35	4.38	1604.2
6	16.3	3.7	9.34	5.8	30	54.9	60	8	9.7	1.49	8.1	33.3	5.47	1604.2
7	13.6	3	7.61	9.7	22.4	48.8	40	8.02	4.86	2.23	49.37	18.38	4.38	1185.35
7	11	3	8.85	6.6	44	48.8	60	8	9.7	1.86	56.9	47.6	3.28	1628
8	17.1	0.8	7.62	7.6	18.6	54.9	40	8.02	4.86	2.6	25.62	25.86	3.28	1330.92
8	15	0.8	9.04	6.2	33	61	60	16	4.9	0.74	43.7	27.2	9.85	1841.9
9	14.2	8.5	9.24	6.3	31	48.8	40	8	4.9	1.49	41.9	40.2	8.76	903.1
10	14.9	3.7	8.96	5.7	59	48.8	40	8	4.9	1.12	35	23.1	4.38	998.2
11	8.7	6.2	7.53	10.1	40.7	54.9	40	8.02	4.86	3.35	40.62	0	4.38	1657.71
11	6.3	6.2	8.82	6.3	44	48.8	60	8	9.7	2.98	30	49	5.47	2516.3
12	13.8	32.7	8.3	5.5	39	42.7	60	16	4.9	2.23	33.1	32	4.38	2251.9
13	17.2	12.3	9.25	5.7	34	61	40	8	4.9	1.49	60	51.7	3.28	2121.2
14	19.6	3.1	7.96	6.6	13.5	48.8	40	8.02	4.86	2.23	6.87	8.85	3.28	796.17
14	19.5	3.1	8.2	5.6	12	54.9	60	16	4.9	1.49	6.90	12.90	4.38	805.1
15	12.6	15.1	7.76	8.7	48.5	54.9	40	8.02	4.86	3.35	51.25	2.04	10.95	1336.86
15	16.5	15.1	8.51	6.3	51	67.1	60	16	4.9	1.49	49.40	23.10	5.47	1592.3
16	16	0.5	9.08	7.2	79	48.8	60	8	9.7	2.23	38.1	11.6	9.85	1666.6
17	17	11.5	9.71	7.1	29	73.2	60	16	4.9	0.74	88.1	9.5	5.47	1642.9
18	6.1	1.5	8.09	9.4	45.4	36.6	60	16	4.9	1.12	75.6	6.8	6.57	923.9
19	12.2	10.2	8.05	8.4	37.6	42.7	40	8	4.9	nd	95	44.2	6.57	1363.6
20	16.5	3.2	7.84	8	33.7	42.7	60	16	4.9	nd	40	32.7	6.57	1693.4
21	18	0.7	8.12	7.6	77.5	61	80	24	4.9	nd	33.1	8.2	5.47	1574.5
22	18.1	0.5	8.14	8	82.5	61	60	16	4.9	0.74	26.9	20.4	5.47	1925.1
23	17.4	2.9	8.74	5.8	86	48.8	60	16	4.9	0.37	13.7	44.2	9.85	1429
24	16.1	2.5	6.9	6.8	56.5	24.4	60	16	4.9	1.49	73.1	10.9	5.47	2281.6
25	15.1	14	7.63	7.8	49.2	24.4	80	24	4.9	2.23	30.6	nd	7.66	1672.6

Table 3. Contunied.

Sta. no.	Temp. (°C)	Water depth (m)	pH	DO (mg L^{-1})	Cond. (µs cm^{-1})	HCO^{-3} (mg L^{-1})	T. hard. (mg L^{-1})	Ca^{+2} (mg L^{-1})	Mg^{+2} (mg L^{-1})	NO_2^--N (µg L^{-1})	NO_3^--N (µg L^{-1})	NH_4^--N (µg L^{-1})	PO_4^{-3}-P (µg L^{-1})	SiO_2 (µg L^{-1})
26	17	2.5	8.1	8	37.2	36.6	80	24	4.9	1.49	33.1	24.5	7.66	2225.1
27	16.7	7.5	7.76	7.3	38.2	36.6	100	24	9.7	5.21	79.4	106.9	6.57	1601.3
28	17.9	3	7.65	7.1	37.2	30.5	100	32.1	4.9	3.35	20.6	23.8	6.57	1785.5
29	17.8	20	6.95	6.9	14.6	24.4	100	32.1	4.9	2.23	105	23.1	7.66	724.9
30	15.9	2	7.45	7.3	44	30.5	80	16	9.7	0.37	nd	61.3	9.85	258.5
31	15.5	4	6.96	6.8	32	30.5	80	16	9.7	nd	27.5	29.9	3.28	701.1
32	14	0.8	7.14	7.6	33	30.5	80	24	4.9	nd	27.5	27.9	2.19	805.1
33	13.1	1.5	7.34	8.4	39.3	30.5	80	16	9.7	nd	25.6	49	3.28	918
34	12.4	1	7.5	8.4	30.5	30.5	80	24	4.9	nd	24.4	19.1	2.19	790.2
35	11.4	6.5	7.4	8.6	99.1	30.5	60	40	4.9	1.49	79.4	19.1	7.66	745.7
36	12.3	1	7.41	9	35.7	24.4	80	24	4.9	0.37	86.2	10.9	3.28	745.7
37	14.3	49	7.34	7,3	36.3	24.4	80	24	4.9	0.74	66.9	8.8	3.28	466.4
38	18	2.8	7.93	7.5	56.9	30.5	60	16	4.9	0.37	5	nd	3.28	1185.3
39	20.5	1	7.54	6.6	19.7	24.4	40	8	4.9	0.37	7.5	10.2	4.38	534.7
40	19.7	9	7.55	6.1	60.7	18.3	60	16	4.9	nd	2.5	nd	5.47	677.3
41	20.8	6.9	7.54	8.3	106.6	73.2	80	16	9.7	nd	50.6	104	7.66	1758.7
41	18.3	6.9	7.64	6.3	108.0	61.0	140	16.03	24.32	2.60	18.12	34.71	4.38	674.32
41	18.6	6.9	7.92	6.8	121.8	73.2	140	16.03	24.32	2.60	18.12	37.43	6.57	698.09
42	13.6	10	7.43	7.7	24.9	36.6	60	8.02	9.73	2.23	74.37	11.57	2.19	362.41
43	14.7	10	7.73	6.4	33	42.7	60	8.02	9.73	2.6	52.5	28.58	5.47	493.12
44	18	13	7.44	6.1	27.2	48.8	60	16.03	4.86	2.6	57.5	21.78	9.85	591.15
45	19.4	4.5	8.01	6.5	25.4	42.7	80	8.02	14.59	1.86	52.5	25.18	3.28	629.76
46	13.3	13.8	7.63	7	24.7	42.7	100	24.05	9.73	2.98	45.62	24.5	7.66	341.62
47	15.1	16.5	7.31	6.9	23.8	42.7	80	24.05	4.86	5.21	56.87	25.86	1.09	350.53
48	17.2	16.5	7.53	6.5	26.4	36.6	80	24.05	4.86	4.09	30	23.14	1.09	442.62
49	14.6	24.9	7.41	7.3	48.9	36.6	60	8.02	9.73	4.84	38.12	36.07	1.09	353.5
50	17.2	5.2	7.48	6.5	25.4	36.6	60	8.02	9.73	3.72	23.12	49.68	2.19	653.53
51	8.3	4.1	7.96	8.1	46.6	42.7	40	8.02	4.86	2.6	31.87	33.35	2.19	552.53
52	21	3	7.22	5.9	36.8	42.7	60	8.02	9.73	2.98	79.37	39.47	4.38	751.56
53	18	3.5	7.37	5.9	26.9	36.6	80	8.02	14.59	1.12	13.75	63.29	5.47	273.29
54	19.1	1	6.75	6.2	18.3	36.6	80	8.02	14.59	1.12	18.12	64.66	4.38	570.35
55	10.5	6.5	7.53	7.1	36.6	36.6	80	8.02	14.59	2.23	24.37	14.97	3.28	555.5
56	11.5	6	7.59	6.8	39.4	36.6	100	16.03	14.59	1.86	21.87	34.03	2.19	305.97
57	13.5	11	9	6.3	66.5	36.6	100	16.03	14.59	1.86	25	23.14	2.19	404
58	14	1	7.82	6	43	36.6	100	8.02	19.46	1.49	13.75	27.22	4.38	380.23
59	13.5	10	7.85	6.7	58.8	24.4	80	16.03	9.73	1.86	18.75	23.14	4.38	626.79

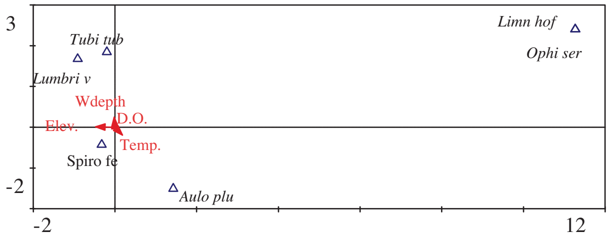

Figure 2. CCA diagram with selected environmental variables and the dominant oligochaetes present at 59 stations associated with high-elevation lakes in the Eastern Black Sea Range of Turkey in 2005, 2006, and 2007.

high-mountain lakes (Dumnicka and Galas, 2002; Milbrink et al., 2002; Lencioni et al., 2004; Kownacki et al., 2006; Krno et al., 2006).

Using the trophic scale based on mean concentrations of total phosphorus (TP) measured in the study area (Catalan et al., 2006), 56% of the lakes (33 lakes) could be classified as ultraoligotrophic (TP < 4.7 µg L^{-1}) [see Materials and Methods; units were for L^{-1}], 36% oligotrophic (23 lakes) (4.7 < TP < 9.3 µg L^{-1}), and 8% mesotrophic (3 lakes) (9.3 < TP < 31

Table 4. Results of canonical correspondence analysis (CCA) from data collected during surveys for aquatic oligochaetes at 59 stations in high-elevation lakes in the Eastern Black Sea Range of Turkey in 2005, 2006, and 2007.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.353	0.145	0.090	0.057	2.726
Species-environment correlations	0.906	0.673	0.444	0.457	
Cumulative percentage variance					
of species data	13.0	18.3	21.6	23.7	
of species-environment relations	48.4	68.2	80.5	88.4	
Sum of all eigenvalues					2.726
Sum of all canonical eigenvalues					0.730

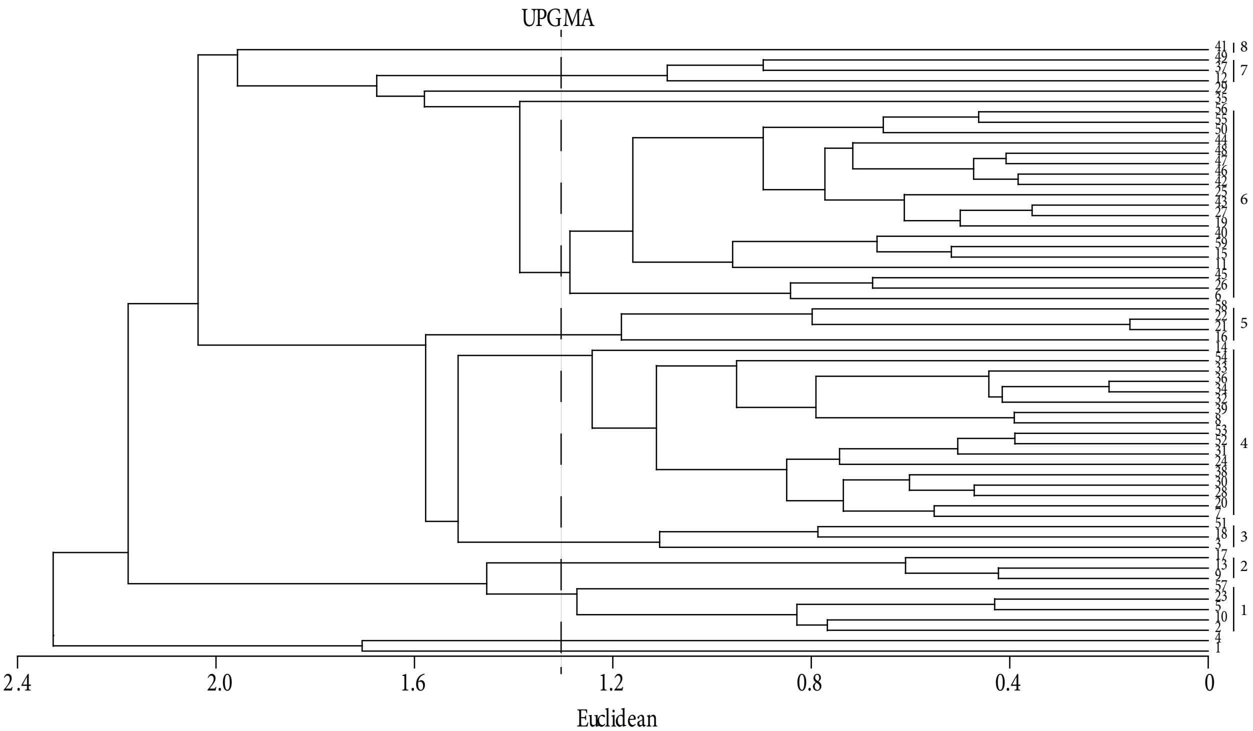

Figure 3. UPGMA dendrogram illustrating the relationship of aquatic oligochaetes at 59 stations in high-elevation lakes in the Eastern Black Sea Range of Turkey, where surveys were conducted during 2005, 2006, and 2007.

µg L^{-1}). Low values of chlorophyll-a measured in the studied lakes also confirm these findings.

Naididae, the dominant family by number of taxa in this study, is one of the most important groups of aquatic Oligochaeta. Most naidids are cosmopolitan and occur throughout the world (Martin et al., 2008). Species of the subfamily Naidinae inhabit the water column, submerged vegetation, and the surface of sediments, and they can be fairly active swimmers. The tubificoid Naididae (especially those taxa in subfamily Tubificinae) represent the most diverse and widely distributed group of aquatic microdriles. They are commonly associated with sediments in aquatic habitats.

Spirosperma ferox (Naididae, Tubificinae), present at 48 stations in 6 basins, was the dominant species in this study. It is a freshwater form widely distributed throughout the Holarctic region, and it is common particularly in northern cool-water bodies (Timm and Veldhuijzen van Zanten, 2002). This species is an indicator of oligotrophy (Milbrink, 1987), most commonly associated with very fine sandy to silty substrates with a high organic matter content (Verdonschot, 2001). Dumnicka and Galas (2002) found this species to be dominant in the small high-mountain ponds in the Tatra Mountains of Poland. These authors defined *S. ferox* as an opportunistic species. This species was also frequently found in small, shallow lakes and in the deep littoral areas of mountain lakes of the mountain pine zone in the Western Tatras (Šporka, 1992) and other mountainous areas, including the Pyrenees (Juget and Giani, 1974), Alps (Wagner, 1987), and Rila Mountains (Uzunov and Varadinova, 2000). According to Milbrink et al. (2002), in the profundal zones of lakes characterized as oligotrophic, *S. ferox* is dominant, either alone or together with *Tubifex tubifex* in about equal proportions. The same authors noted that, in oligotrophic situations, *T. tubifex* is generally a dominant species, often together with *S. ferox* and *Stylodrilus heringianus*, and occasionally with a few additional species. This species community is particularly common in waters at high elevations. In this respect, the results of the present study are similar to those of previous studies.

Tubifex tubifex (present at 33 stations in 6 basins) is a characteristic species indicating oligotrophy in western and northern Sweden, as well as in most of Norway and Iceland, from lowland to high-elevation habitats (Milbrink, 1980, 1994). It is mainly known as a species characteristic of heavily polluted waters, where it can reach very high densities (Poddubnaya, 1980). Milbrink (1983) claimed that *T. tubifex* occurs in environments in which competition or predation is weak (in Dumnicka and Galas, 2002). This cosmopolitan species, although not commonly encountered, is locally abundant in habitats of varying water quality, including pristine alpine and subalpine lakes (Klemm, 1985); the bottoms of large, unproductive, oligotrophic lakes; grossly polluted and organically enriched sites with low oxygen tensions; and aquatic habitats supporting few other species (Brinkhurst, 1996). In oligotrophic situations, *T. tubifex* is generally a dominant species, occurring together with *S. ferox* (Milbrink, 1980). Timm (1996) also found this species in a small oligotrophic lake in Estonia with *Spirosperma ferox*. Our findings are consistent with these results.

Lumbriculidae is a thermophobe family of the northern temperate zone (Timm, 1980). It was represented by 3 species in this study (*Lumbriculus variegatus*, *Stylodrilus parvus*, and *S. heringianus*). *S. parvus*, the third most dominant species in this study (present at 21 stations in 6 basins), is a Palearctic species. It lives in various types of water bodies, including lake bottoms, and is also common in mountain streams (Lencioni et al., 2004). In a study of the oligochaete communities in mountain streams of Poland, Dumnicka (1994) found that a third group of 5 streams was characterized by an oligochaete fauna dominated by the Lumbriculidae. Among the determined taxa, *S. parvus* was the dominant species along the entire length of the studied streams. According to Dumnicka and Galas (2002), the genus *Stylodrilus*, and probably also *L. variegates*, are cold-stenothermic species in the Tatra Mountains. *L. variegatus* has very wide ecological valence (Timm, 1970).

Stylodrilus heringianus, which was recorded as a new species for Turkey in one of the most recent studies (Yıldız et al., 2010), is considered to be the most reliable indicator of oligotrophic conditions in the Palaearctic region (Milbrink, 1980). It is a clean-water (Probst, 1987; Timm et al., 2001) and cold-stenothermic species (Lang and Lang-

Dobler, 1980; Dumnicka and Galas, 2002). It is also an oligosaprobic species (Timm et al., 2001). *L. variegatus* and *S. heringianus* seem to have wider ecological requirements; hence, they were also encountered in other types of water bodies sampled in this study.

Enchytraeidae is a cosmopolitan family. They are found from the polar regions to the tropics, from the bottom of lakes and rivers to the bottoms of the oceans, in permanent ice (glaciers) or snow, and in permafrost soils. They also exist in abundance in sewage trickle filter beds and pristine marine sands, and they occur in large numbers in water-logged soils and throughout the range of soil types, in all but dry deserts (Wetzel et al., 2000). Enchytraeidae was the best represented family in a recent study of the Eastern Black Sea Range (Yıldız et al., 2010). Similarly, this family was most common in other studies connected to high-mountain lakes (Manca et al., 1998; Rieradevall et al., 1998; Lencioni et al., 2004). According to Dumnicka and Galas (2002), members of this family were considered semiaquatic species, especially some species from the genera *Mesenchytraeus*, *Cognettia*, and *Henlea.*

There have been very few attempts to define the major variables affecting macroinvertebrate distribution. Wathne et al. (1995), Fjellheim et al. (2000), and Boggero et al. (2005) identified elevation as the most important factor influencing the distribution of species in remote alpine lakes across Europe. Our findings correspond very well to this pattern. In addition to the effect of elevation, other environmental parameters influenced the distribution of littoral macroinvertebrates in these lakes. Similar to previous studies, our study found that elevation is the most important factor influencing the distribution of oligochaete species in the Eastern Black Sea Range (Figure 2).

The distribution of species along the first axis reflects requirements associated with elevation and temperature. The distribution of *Spirosperma ferox* is positively correlated with elevation and negatively correlated with water depth and dissolved oxygen. *Tubifex tubifex* and *Lumbriculus variegatus* are negatively correlated with temperature and positively correlated with water depth (Figure 2). *Aulodrilus pluriseta* is positively correlated with temperature and negatively correlated with water depth and dissolved oxygen. *Limnodrilus hoffmeisteri* and *Ophidonais serpentina* are negatively correlated with elevation (Figure 2).

The width and depth of the water body appeared to be the most important factors in the distribution of oligochaete species (Nijboer et al., 2004). Many researchers showed relationships between the oligochaete community and water depth (Collado and Schmelz, 2001; Nijboer et al., 2004). In our study, multivariate analysis (CCA) showed that the distribution patterns of oligochaete species assemblages are significantly correlated with depth. Probst (1987) and Särkkä (1987, in Peralta et al., 2002) noticed that while *L. hoffmeisteri* diminishes in density with depth, *T. tubifex* increases in density in deeper water.

In the UPGMA diagram (Figure 3), the percentage of habitat similarity in environmental data from each sampling station was the highest between stations 22 and 21. Stations 58 and 16 were also found to be similar to each other. In contrast, the oligochaete fauna associated with station 41 (Uzungöl) was the most different from the other stations (Figure 3), and because the elevation of this lake is lower than the others, it can be classified as a montane lake; the other lakes are subalpine and alpine lakes (Oertli et al., 2008).

This study represents a pioneering contribution to the research of oligochaete communities in the glacial lakes of Turkey. Further research is needed, in Turkey and in other glacial regions, to address the lack of information on the taxonomy and ecology of this group of animals.

Acknowledgements

This project was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK, Project 104/Y/183). We are deeply grateful for their support. We would also like to thank Dr Süleyman Balık, Dr Hasan M. Sarı, Dr Cem Aygen, Dr Ali İlhan, Dr Esat T. Topkara, and Mesut Kaptan for their invaluable support and help with technical issues. We also thank Dr Mark J. Wetzel (University of Illinois at Urbana-Champaign, Illinois, USA) for the linguistic revision of the manuscript.

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