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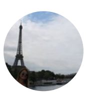
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Research Article

Zoobenthos of Lake Uluabat, a Ramsar Site in Turkey, and Their Relationship with Environmental Variables

The numerical and proportional distributions of zoobenthos in lake Uluabat, which is located in the Northwestern part of Turkey and having international importance according to the Ramsar Convention, were determined from August 2004 to July 2005 at monthly intervals (except for December 2004, January and February 2005) at 12 different stations. Thirty-three taxonomic groups were recorded. It was found that the zoobenthos consisted of 35.6 % Oligochaeta, 27.7 % Nematoda, 12.3 % Chironomidae larvae, 10.7 % Gastropoda, 3.6 % Ostracoda, and 10.1 % Varia by numbers (Bivalvia, Ceratopogonidae, Hirudinea, Odonata, Ephemeroptera, Asilidae, Hydraacarina, Hemiptera, Argulidae, and Gammaridae). The average number of invertebrates was 160 individuals for 33 taxa at the 12 different stations. Also some environmental parameters of the lakewater were analyzed (temperature, pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, NO_2-N, NO_3-N, NH_3-N, PO_4^{-3}, fecal coliform, and total coliform). The relationships between the dynamics of the Oligochaeta and the physicochemical variables were supported by the Pearson correlation index and the canonical correspondence analysis (CANOCO). It was found that the relation between the average number of *P. hammoniensis* and *P. albicola* ($p < 0.05$, $r = 0.590$ and 0.593, respectively) and *L. hoffmeisteri* ($p < 0.01$, $r = 0.777$) was directly proportional while the relation between the average number of some taxa *Trichodrillus* sp., *Rhyacodrilus coccineus*, *Nais communis*, *N. variabilis*, and *N. barbata* and NO_3-N ($p < 0.05$, $r = -0.685$) was inversely proportional.

Keywords: Oligochaeta; Water; Zoobenthos

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1 Introduction

Turkey has been recognized as one of the most important countries in Palearctic due to its important bird areas (IBA) and wetland [1]. Turkey encompasses an area of 779.452 km^2 and has 97 IBAs covering a total of 29.978 km^2 or 4 % of the total land area [2]. Among them is lake Uluabat (also known as Apolyont Gölü) which has tectonic origin and a large turbid, shallow, and eutrophic freshwater lake on the southern side of the Sea of Marmara [1]. Unfortunately, along with those in other circum-Mediterranean xeric habitats, many Turkish wetland stations are under increasing pressure through anthropogenic impacts (water abstraction, pollution) coupled with the (possibly increasing) effects of climatic aridity [3, 4]. In 1998, lake Uluabat and its surrounding area were included in the Ramsar List that was established in response to Article 2.1 of the Convention on Wetlands held in Ramsar, Iran, in 1971.

As is known, zoobenthos is defined as a group of invertebrates, whose existence for the greater part of their life cycle is related to bottom substrates of water bodies. Bottom communities of most freshwater bodies are represented by three major groups: *(i)* chironomid larvae, *(ii)* Oligochaetas and *(iii)* mollusks [5]. Oligochaetas that permanently live at the bottom are broadly distributed worldwide and frequently are the most abundant group in many freshwater ecosystems. Certain species show ecological adaptations, in ecosystems at different trophic levels, to extreme environmental situations related to high temperature, pH, organic matter content in the sediment, and low dissolved oxygen (DO) in the water-sediment interface [6].

Scientific studies with regards to lake Uluabat are very limited. Although few researchers have studied lake Uluabat from faunistic or ecological points of view at different times [4, 7 – 9], to date there has been no comprehensive study of the oligochaete fauna communities in the lake. The purposes of this study were to establish quantitative characteristics of zoobenthos in the lake Uluabat which plays an important role in both national and international bird area (see Section 2.1), determine the distribution of Oligo-

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Abbreviations: BOD, biochemical oxygen demand; **CCA**, canonical correspondence analysis; **COD**, chemical oxygen demand; **DO**, dissolved oxygen; **Fc**, fecal coliform; **IBA**, important bird areas; **SWI**, Shannon-Wiener index (average)

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chaeta species and identify correlative relationships between physicochemical features and the dynamics of the oligochaete fauna.

2 Materials and Methods

2.1 Study Area

Lake Uluabat is located in the western part of Turkey (40°10(N, 28°35(E) at an altitude of 9 m above sea level, and is a eutrophic lake (mean depth = 2 m; maximum depth = 6 m) with a surface area of 156 km^2 (see Fig. 1) [1]. The lake is fed principally by the river Mustafakemalpasa from the southwest and has its only outlet in the northwest, where it drains into the river Kocaçay. Deposits of incoming silt from the river Mustafakemalpasa have formed an inland delta covering an area of 3747.6 ha that is under agricultural use [7].

The lake's area includes a series of marshes, wetlands, and islands, and these contribute substantially to the station's importance as a wintering station for waders and waterfowl, and as a breeding station for species [1]. Its rich biodiversity, its location on the migratory bird route, and its vast areas of suitable habitats for many bird species makes the lake important not only for Turkey but also for Europe and the Middle East [7].

Furthermore, in 1998, lake Uluabat and its surrounding area were included in the Ramsar List that was established in response to Article 2.1 of the Convention on Wetlands held in Ramsar, Iran, in 1971. The lake is currently considered to show a typical eutrophication character. Domestic and industrial waste discharges affect its water quality. The locations of the sampling stations are shown in Fig. 1 and the descriptions of the stations are given in Tab. 1.

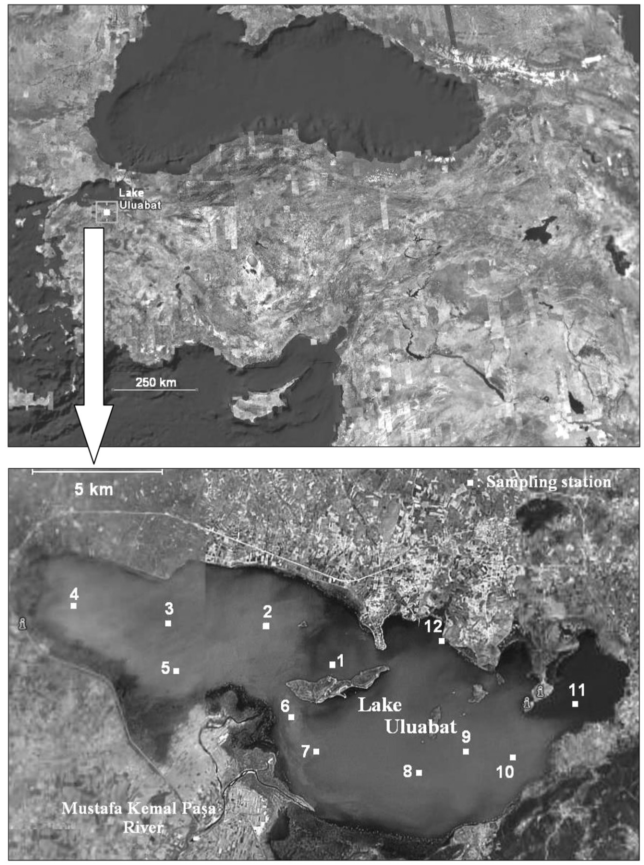

Figure 1. Geographical situation of the study area and locations of sampling stations.

2.2 Sampling

Two replicate benthic samples were collected using an Ekman grab (two sample-units per station and invertebrates sampled from macrophytes were collected by washing the leaves and stems of the plants), monthly from August 2004 to July 2005 at 12 sampling stations in lake Uluabat (see Fig. 1). Because of bad weather condition, in some months, December 2004, January and February 2005, samples could not be taken. Samples were washed in situ using a 200 μm mesh size. The material was preserved in 4% formalin in the field, taken to the laboratory and sorted under a stereomicroscope. All samples were identified to family, ordo or clasis level preserved in 70% alcohol.

Taxa were grouped as Oligochaeta, Nematoda, Chironomidae larvae, Gastropoda, Bivalvia, Ostrocoda and included only few numbers of Ceratopogonidae, Hirudinea, Gammaridae, Odonata, Ephemeroptera, Asilidae, Hydraacarina, and Hemiptera which were grouped as "Varia" and only Oligochaeta samples were identified to genera or species level. Oligochaeta specimens were either studied as whole mounts in glycerine or mounted in polyvinyl lactophenol (for chaetal characters), and finally mounted as a whole in Canada Balsam after dehydration. The identification of the Oligochaeta species was done using ref. [6, 10, 11].

2.3 Environmental Parameters

During each sampling period, the water temperature, hydrogen ion concentration (as pH) and DO were measured in the field with a water quality checker (TOA WQC 22A). The water samples were analyzed in the laboratory for biochemical oxygen demand (BOD), chemical oxygen demand (COD), phosphate-phosphorus (PO^{3-}), NH_3 – N, NO_2 – N, NO_3 – N, fecal coliform (Fc), and total coliform.

The minimum, maximum, and average values of the environmental parameters for lake Uluabat in the period of investigations from August 2004 to July 2005 are shown in Tab. 2. The results were classified by Turkish Standarts [12].

2.4 Data Processing

Faunistic and environmental data were analyzed by canonical correspondence analysis (CCA), CANOCO. The data were not transformed and species were not down-weighed. The relationship between the selected Oligochaeta species, which had shown a wide distribution and/or high abundance, and the selected environmental variables (such as BOD, temperature, DO, pH, nitrate-nitrogen, phosphate-phosphorus, Fc, and vegetation) were evaluated using the CANOCO program for Windows [13 – 15].

Four BODs ($\leq$4 mg/L = B(1), 4.1 to 8.0 mg/L = B(2), 8.1 to 20.0 mg/L = B(3), $\geq$20 mg/L = B(4)); two temperatures (10.0 to 19.9°C = t(1), 20.0 to 29.9°C = t(2)); four DOs ($\geq$8.1 mg/L = DO(1), 6.1 to 8.0 mg/L = DO(2), 3.1 to 6.0 mg/L = DO(3), $\leq$3 mg/L = DO(4)); two pH values 7.70 to 8.35 = pH(1), 8.36 to 9.10 = pH(2)); three nitrate-nitrogens (0.002 to 0.010 mg/L = N(1), 0.011 to 0.05 mg/L = N(2), $\geq$0.05 mg/

Table 1. Description of the sampling stations in lake Uluabat (S: sampling station).

S	Substrate	Macrophytes	Coordinates	Depth (m)
1	Organic mud	No	40°10′45 N-28°35′42 E	1
2	Organic mud	No	40°12′02 N-28°33′51 E	2.1
3	Organic mud	Reedbed	40°11′55 N-28°31′09 E	1.7
4	Organic mud	Reedbed	40°12′08 N-28°28′26 E	1.8
5	Organic mud	Reedbed	40°11′08 N-28°30′15 E	1.2
6	Fine sand and mud	Reedbed and submerged macrophytes	40°09′58 N-28°34′10 E	1
7	Organic mud	No	40°08′20 N-28°35′11 E	1.2
8	Fine sand and mud	Reedbed	40°08′09 N-28°38′43 E	1.8
9	Organic mud	Reedbed	40°09′26 N-28°38′31 E	1.4
10	Fine sand and mud	No	40°08′31 N-28°40′21 E	1.2
11	Fine sand and mud	Abundant, reedbed	40°10′23 N-28°42′54 E	1.6
12	Fine sand and mud	Abundant, emerged and submerged macrophytes and white water-lily	40°11′36 N-28°38′12 E	0.6

Table 2. Minimum, maximum, and average values of the environmental parameters of lake Uluabat during the period of investigation from August 2004 to July 2005 (number in parantheses and roman numbers indicate average value and class of water quality, respectively; S: sampling station).

	Parameters										
S	Temperature (°C)	pH	DO (mg/L)	BOD (mg/L)	COD (mg/L)	NO_2–N (mg/L)	NO_3–N (mg/L)	NH_3–N (mg/L)	PO_4^{-3} (mg/L)	Fecal coliform	Total coliform
1	12–27.3 (20.4)	8.2–9 (8.4)	4.1–18.2 (8.5)	6–36 (13.8) III	10–91 (62.3) II	0.01–0.06 (0.03) III	0–1.58 (0.53)I	0–1.32 (0.4) II	0.06–1.31 (0.36) II	0–40 (4) I	0.0–1500 (302)
2	12.3–25.2 (19.9)	8.1–8.9 (8.4)	5.5–13.3 (8.5) I	3–16 (7.6) II	14.6–100 (48.5) I	0.01–0.12 (0.04) III	0.2–1.2 (0.85) I	0–0.51 0.17) II	0.06–0.91 (0.3) III	4–40 (4.4)I	0.0–440 (72)
3	11.5–24.8 (19.5)	7.9–8.9 (8.4)	5.2–13.5 (9.3) I	2–17 (7.5) II	15–80 (47.8) I	0.02–0.18 (0.06) IV	0.3–2.02 (1.07) I	0.04–0.34 (0.15) II	0.157–0.9 (0.56) III	0-0(0) I	0.0–930 (171)
4	11.2–24.5 (19.4)	7.8–9 (8.3)	3.6–13.7 (7.7) III	2–27 (8) II	30–90 (60.5) II	0.01–0.05 (0.025) II	0.2–3.92 (1.11) I	0.03 –0.25 (0.23) II	0.04–1.92 (0.37) III	0-0(0) I	0.0–1500 (233)
5	11.8–24.7 (19.7)	8.1–8.9 (8.4)	7.5–14.6 (9.2) I	2–16 /7.8) II	25–101 (56.3) II	0.01–0.11 (0.05) IV	0.3–1.78 (1.01) I	0–0.34 (0.12) II	0.06–0.72 (0.28) III	0–9 (1) I	0.0–430 (99)
6	11.1–25.6 (19.6)	8–8.6 (8.3)	6.5–10 (8.2) I	1–15 (7.3) II	12–52 (34.5) I	0.01–0.1 (0.05) IV	0–1.19 (0.94) I	0–0.73 (0.18) II	0.06–2.68 (0.52) III	0–4600 (1112) III	9–11 000 (2343)
7	10.9–25.4 (20)	7.8–8.6 (8.3)	5.1–13 (7.5) II	1–18 (8.1) III	20–145 (51.5) II	0.02–0.1 (0.03) III	0.05–2.35 (1.1) I	0.01–0.59 (0.18) II	0.1–0.65 (0.31) III	0–430 (110) II	0.0–4600 (741)
8	11.3–26.7 (19.7)	8.2–8.8 (8.4)	5–14 (7.4) II	2–23 (8.8) III	18–115 (51.8) II	0.01–0.1 (0.03) III	0.03–1.95 (1.23) I	0–1.03 (0.3) II	0.06–0.64 (0.35) III	0–43 (4.7) I	0.0–1500 (224)
9	12.8–26.7 (20.9)	8.1–9 (8.3)	3.1–19.4 (7.6) II	4–40 (15.3) III	6–56 (37.4) I	0.005–0.15 (0.04) III	0.04–1.5 (0.89) I	0.02–0.88 (0.27) II	0.07–1.87 (0.53) III	4–930 (110.7) I	9–1100 (335)
10	12–26.6 (20.3)	8–9.1 (8.3)	4–14.3 (6.5) II	8–23 (12.1) III	25–134 (63) II	0.01–0.34 (0.07) IV	0.6–2.29 (1.19) I	0–0.69 (0.2) II	0.1–2.17 (0.47) III	0–140 (37.7) I	0.0–640 (237)
11	27.1–13.9 (21.5)	8.2–9 (8.4)	3–44.8 (10.9) I	6–42 (16.1) III	40–55 (47.2) I	0.01–0.1 (0.03) III	0.06–2.25 (1.13) I	0.03–0.95 (0.3) II	0.09–2.05 (0.57) III	6–2400 (804.5) III	11–11 000 (4146)
12	13–23.3 (18.8)	7.9–8.9 (8.3)	3.9–13.8 (5.4) III	3–11 (6) I	35–109 (73.6) IV	0–0.05 (0.01) III	0.9–1.4 (0.71) I	0.07–0.16 (0.07) I	0.07–1.01 (0.3) III	0–90 (17.5) II	0.0–960 (286)

L = N(3)); two phosphate-phosphorus (0.27 to 0.37 mg/L = Pht(1); 0.38 to 0.59 mg/L = Pht(2)); three Fcs (≤10 MPN/100 mL = Fec(1), 10 to 200 MPN/100 mL = Fec(2), ≥(200 MPN/100 mL = Fec(3)); and two vegetation (moderate vegetation: V(1); dense vegetation V(2)) classes were treated as supplementary variables in the analysis.

Species diversity (H') values calculated according to the Shannon-Wiener species diversity index and the Bray-Curtis similarity index were determined to obtain statistical data about the distribution of the Oligochaeta species. The correlation and statistical significance of the relationship between the selected Oligochaeta species and environmental parameters were evaluated using Pearson's correlation coefficient.

3 Results

3.1 Zoobenthos and Oligochaeta Species Composition

Studies at lake Uluabat revealed the presence of 33 invertebrate taxa, 19 of these belonging to Oligochaeta (16 of them were determined to the species level and unidentified Lumbricidae, Lumbriculidae and Branchiobdellidae members). Except the Oligochaeta members, the composition of the zoobenthic fauna identified as Nematoda, Chironomidae larvae, Gastropoda, and Ostrocoda included only few numbers of Bivalvia, Ceratopogonidae, Hirudi-

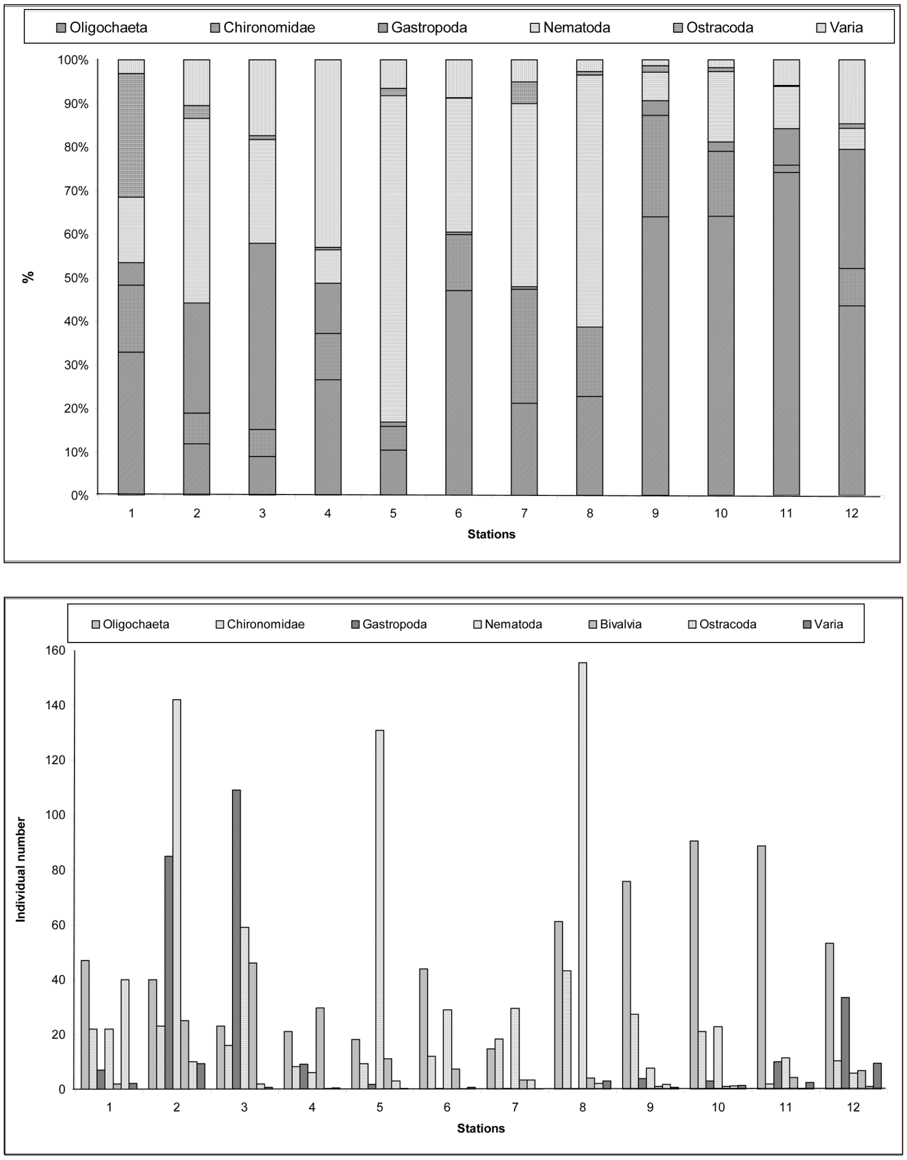

Figure 2. (a) Distribution of zoobentos group types in lake Uluabat. (b) Quantitative characteristics of zoobenthos in lake Uluabat.

nea, Odonata, Ephemeroptera, Asilidae, Hydraacarina, Hemiptera, Argulidae, and Gammaridae which were grouped as Varia. The taxa proportions of the total zoobenthic abundance are shown in Fig. 2a. The amount and diversity of zoobenthos in the lake Uluabat was not appreciable (see Fig. 2a). The average number of invertebrates was 160 individuals for 33 taxa at the 12 different stations between August 2004 and July 2005. The average number of individuals for the 33 taxa is shown in Fig. 2b. The greater part of zoobenthos was represented by oligochaetes, nematoda, and chironomid larvae.

The ten taxa of the group of Varia had the lowest abundance with 10.1 %. Ceratopogonidae in this group had the highest abundance (0.4 %) while Gammaridae in the varia had the lowest abundance (0.01 %). The number of taxa belonging to Varia was the highest at station 12 and in November.

At the end of the study, 19 Oligochaeta taxa (16 of them were determined to the species level and identified as Lumbricidae, Lumbriculidae and Branchiobdellidae members) of the families Tubificidae, Lumbriculidae, and subfamily Naidinae were identified.

A monthly abundance of the total Oligochaeta in the 12 sampling stations showed considerable fluctuations during the study period ranging from 0 (station 3, June 2005) to 449 individuals (station 11, November 2004). In addition, the average number of individuals of Oligochaeta at 12 sampling stations was significantly different from each other ($p < 0.05$). The highest average number of Oligochaeta observed at stations 11 and 10 were 89 and 88 individuals, respectively, and the lowest number of individual observed at stations 7 and 5 were 15 and 18 individuals, respectively. Occurrences of taxon at each sampling station are shown in Tab. 3.

The most common species at lake Uluabat was the eutrophic species, *Potamothrix hammoniensis* (Michaelsen, 1901) (12 stations, 61.4 %) followed by *Tubifex tubifex* (Müller, 1774) (12 stations, 15 %), *Psammoryctides albicola* (Michaelsen, 1901) (12 stations, 5.8 %), *Limnodrilus hoffmeisteri* (Claparede, 1862) (nine stations, 3 %). Except *Dero digitata*

Table 3. List of Oligochaeta taxa recorded and average number of individuals at the stations (number in parantheses indicates their proportion in%). Abbreviations: A, average; Nt, number of taxa; Im. Tub. wths, immature tubificidae without hair setae; Im. Tub. wts, immature tubificidae with hair setae; Branc, Branchiobdellidae.

		Sampling station												
	Species	1	2	3	4	5	6	7	8	9	10	11	12	A
1	*T. tubifex*	12 (16.5)	4 (16)	6 (19.4)	4 (25.1)	4 (18.6)	7 (17.6)	1 (10.5)	29 (23)	13 (15.8)	6 (11.4)	14 (5.3)	5 (4)	9 (15.2)
2	*L. hoffmeisteri*	–	–	–	1 (2.8)	–	2 (6.1)	1 (7.8)	1 (0.2)	1 (0.1)	2 (3)	4 (9.2)	11(8.7)	2 (3.1)
3	*L. profundicola*	–	–	–	–	–	1 (0.6)	–	–	–	–	–	–	1 (0.05)
4	*P. hammoniensis*	30 (75)	36 (81.1)	12 (65.6)	12 (55.9)	13 (76.6)	18 (49.5)	9 (60.6)	28 (58.7)	46 (72.6)	66 (68.3)	27 (34)	18 (47.2)	27 (62)
5	*P. albicola*	4 (6.9)	1 (2.8)	4 (13)	1 (2.1)	1 (1.8)	1 (1.8)	1 (2.6)	12 (14.4)	7 (7.1)	9 (8.1)	10 (6.7)	2 (5.2)	5 (6)
6	*R. coccineus*	1 (0.1)	–	–	–									1 (0.008)
7	*P. frici*	–	–	–	–	–	2 (2.1)					1 (0.2)		1 (0.2)
8	*U. uncinata*	–	–	–	–	–	–	–	1 (0.2)					1 (0.01)
9	*S. lacustris*										1 (0.7)	1 (0.4)	5 (1.4)	1 (0.2)
10	*N. communis*	–	–	–	1 (0.5)	–	–	–	–	–	–	–	–	1 (0.04)
11	*N. variabilis*	–	–	–	–	–	–	–	–	–	–	1 (0.1)	–	1 (0.008)
12	*N. pardalis*	–	–	–	–	–	–	–	1 (0.5)	–	–	2 (2.3)	1 (1.1)	1 (0.3)
13	*N. barbata*				–	–	–	–	–	–	–	1 (0.03)	–	1 (0.002)
14	*P. aequiseta*	–	–	–	–	–	–					1 (0.02)	–	1 (0.001)
15	*D. digitata*	1 (0.2)	–	–	1 (1.6)	–	1 (1.4)	–	–	1 (3.7)	2 (2.8)	20 (11)	3 (1.7)	3 (1.9)
16	*Trichodrilus* sp.	–	1 (0.1)	–	–	–	–	–	–	–	–	–	–	1 (0.08)
17	*Lumbricidae* spp.	–	–	1 (1.5)	1 (2.6)	–	–	1 (4.8)	1 (0.5)	–	–	1 (0.2)	–	1 (0.8)
18	*Lumbriculidae* sp.						1 (2.2)					1 (7.1)	(25.5)	1 (2.9)
19	Branc. sp.	–	–	1 (0.5)	–	–	–	–	–	–	–	–	–	1 (0.04)
	Im. Tub. wths	1 (0.8)	–	–	0.22 (4.4)	1 (3)	1 (1.3)	1 (5.1)	–	–	1 (2)	1 (1)	–	1 (1.5)
	Im. Tub. wts	1 (0.5)	–	1 (0.2)	2 (5)	–	10 (17.4)	2 (8.6)	1 (2.5)	1 (0.7)	1 (3.3)	8 (22.3)	6 (5.1)	3 (5.4)
	Nt	6	4	3	6	3	7	4	6	5	6	11	7	
	SWI	0.35	0.20	0.41	0.49	0.12	0.58	0.56	0.61	0.50	0.56	0.74	0.77	0.49
	Evenness	0.29	0.29	0.37	0.36	0.32	0.46	0.06	0.4	0.39	0.42	0.46	0.39	

(Müler, 1773), all other species occurred at <4 sampling stations (i.e., <0.3 %).

As can be seen from the Tab. 3, there were considerable differences as to species composition in the sampling stations, species richnesses ranged from 3 to 11. Notable was station 11 which had the highest species richnesses: Seven naidin species were recorded here and three of these, *Nais variabilis*, *Nais barbata*, and *Pristina aequiseta*, were not recorded from other sampling stations. As can be seen from Tab. 3, the richnesses of Oligochaeta species recorded in the stations could be ordered as 11 > 12 = 6 > 10 = 8 = 4 > 1 = 9 > 7 = 2 > 3 = 5. In addition, stations 11 and 12 have shown the highest invertebrates taxa diversity (see Figs. 2a and b).

The oligochaeta species diversity was evaluated according to the Shannon-Wiener index. According to this index, the species diversity in Uluabat lake was found to be 0.49 on average; in November station 11 was determined to have the highest diversity (1.49) while station 3 in June (0) was determined to have the lowest diversity (see Tab. 3).

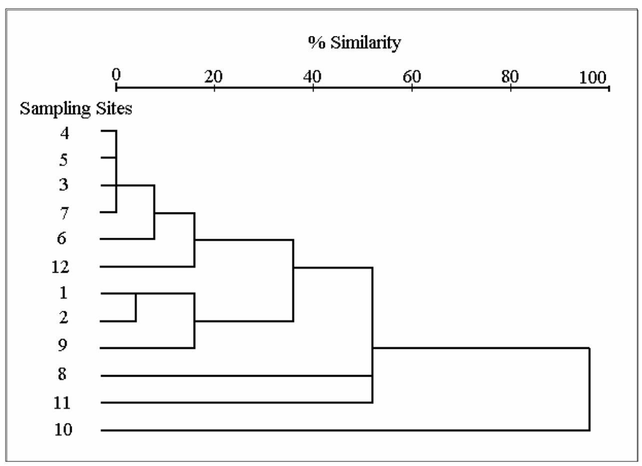

Figure 3. The dendrogram of similarity of the stations in lake Uluabat with respect to Oligochaeta species.

3.2 Statistical Analysis

For each sampling station % similarities were calculated using the Bray-Curtis analyses (see Fig. 3), to the Oligochaeta species abundance. According to the Bray-Curtis analyses the stations 3, 4, 5, and 7 were found to be the most similar to each other while station 10 (also 8 and 11) was found to be the most different from all the other stations for the dynamics of the oligochaete fauna.

CCA was used to extract the species-environmental relationship; eight selected taxa which showed wide distribution and/or high abundance, and selected eight environmental parameters in 108 samples were evaluated (see Fig. 4). The statistical significance of environmental variables was assessed by the Pearson's coefficient test. CCA showed significant correlations between the abundance of some Tubificid species *T. tubifex*, *P. hammoniensis*, *P. albicola*, and aquatic macrophytes (V1), temperature (t1), phosphate-phosphorus (Pht1) and BOD (B1), and abundance of *L. hoffmeisteri* and phosphate-phosphorus (Pht2), aquatic macrophytes (V2) (see Fig. 4).

The species of Oligochaeta was not equally responding to the physicochemical parameters of the water. With regard to the Pearson correlation index between the average number of Oligochaeta species and the paramaters, the relation between the number of Tubificidae and BOD ($p < 0.05$ for *P. hammoniensis* and *P. albicola*; $p < 0.01$ for *L. hoffmeisteri*) was directly proportional while the relation between the number of some taxa *Trichodrillus* sp., *Rhyacodrilus coccineus* (Vjdeovsky, 1875), *Nais communis* (Piguet 1906), *N. variabilis*

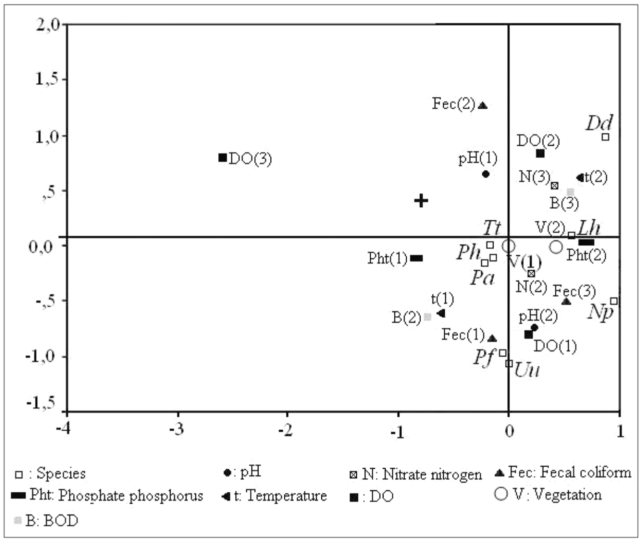

Figure 4. CCAs of selected water parameters with selected Oligochaeta species in lake Uluabat.

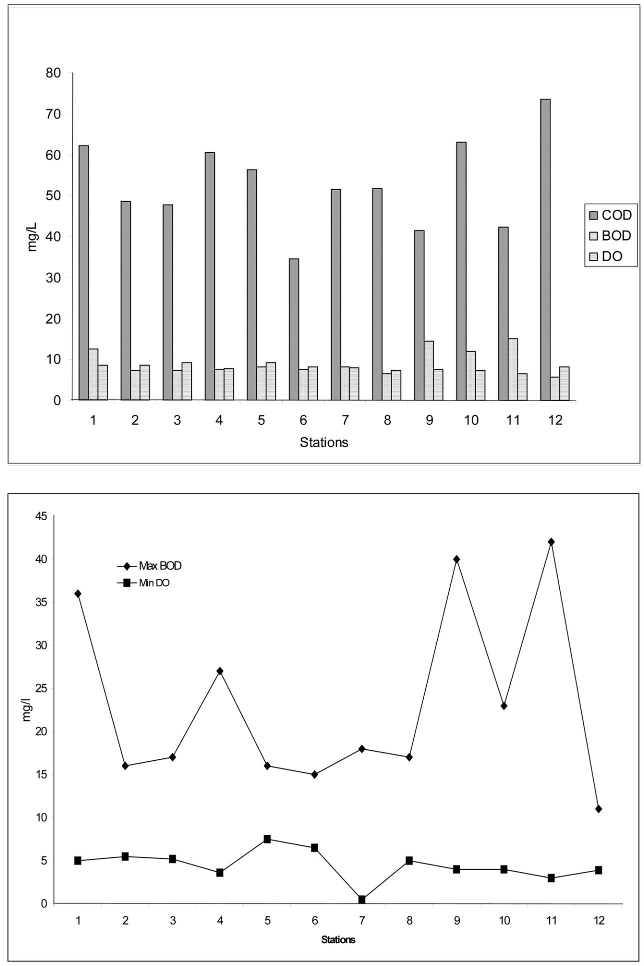

Figure 5. (a) Average value of DO, BOD, and COD in the water of lake Uluabat. (b) Variation of the minimum concentration of DO and maximum BOD.

(Piguet 1906), and *N. barbata* (Müler, 1773) NO_3-N ($p < 0.05$) was inversely proportional.

3.3 Water Quality

In all the samplings, the temperature did not vary along the lake, and a normal seasonal variation was observed (see Tab. 2). As can be seen from Tab. 2, along the lake, the pH of the water varied between 7.8 and 9.1. According to the average value of the bottom water parameters, NO_3-N was found at first quality level (the highest level, 3.92 mg/L, was recorded at station 4 in October 2004); NO_2-N was generally found at third-fourth quality level (the highest levels 0.12 and 0.11 mg/L were recorded at stations 2 and 5, respectively); NH_4-N was found at second quality level (the highest level, 1.32 mg/L, was recorded at station 1 in August 2004); PO^{-3}_4-P was found at third quality level (except station 1). BOD was found at second or third quality level (except station 12) while DO was found at first or second quality level. COD was found at first or second quality level (except station 12) (see Figs. 5a and b). The maximum Fc level was found at station 11.

As is well known, the high amount of organic matter in waste effluents is potentially one of the most important environmental problems. The variations of these parameters are represented in Tab. 3. Once again, the behavior of the sampling stations number 1, 4, 7, 9, 10, and 11 are clearly different from the others with respect to DO, probably due to the high consumption of DO in the wastewater and to the processes involved in the degradation of nutrients. In addition, at these stations the BOD values are supposed to contain a considerably load of organic matter (see Fig. 5b).

4 Discussion

4.1 Zoobenthos and Oligochaeta Species Composition

A total of 33 taxa were found in lake Uluabat. The Nematoda, Oligochaeta, and Chironomidae larvae were the most plentiful while Gastropoda and Ostrocoda were particularly abundant. The fauna of Oligochaeta consists mainly of taxa with wide ecological tolerances and extensive geographical ranges. The oligochaetes were mainly represented by *P. hammoniensis*, which was found all year round, *T. tubifex*, *P. albicola*, and *L. hoffmeisteri* while the naidin species, *N. variabilis*, *N. communis*, *P. aequiseta* (Piguet 1906) 06, *Uncinais uncinata* (Orsted, 1842), lumbriculid *Trichodrilus* sp., and tubicifid *R. coccineus*, were found at only one station (see Tab. 3).

All of these species, especially tubificidae members, are known to live in a range of water bodies, including eutrophic waters [6]. At lake Uluabat, only one species belonging to the family Lumbruculidae (*Trichodrilus* sp.) was found at the apparent tectonic origin of the lake. The species richest sampling stations were 11 and 12 with 11 and 7 Oligochaeta species, respectively, while stations 3 and 5 showed the lowest values of the diversity and taxa richness with a *P. hammoniensis*'s dominating proportion over 55 %. It is known that all Tubificid species found in lake Uluabat occur within a wide range of environmental conditions [6].

If we consider only the Tubificidae species composition and distribution on 12 selected sampling stations, they do not differ significantly. The distribution, species composition, and development of aquatic Oligochaeta depends on many factors such as water temperature, chemical and physical properties of the water [16], sediments, bottom microflora, and vegetation cover. In the lake investigated, there are no significant differences (except for stations 11 and 12) from the point of view of the substrate type. However, the main and important differences between the sampling stations were the vegetation. High diversity and taxonomic richness of the stations 11 and 12 may be partly due to their rich vegetation (especially reedbed) and substrate types (see Tab. 1). Pieczynska [17] and Banziger [18] indicated that reedbed offers a broad range of organic substrates (young and old reed stems, senescent reed leaves, periphytic algae on the stems), but they comprise also soft sediments underlying the reedbed which are inhabited by burrowing taxa. This could explain the similarity of all stations based mainly on the high densities of the Oligochaeta, Chironomidae, and the Nematoda.

4.2 Water Quality

The Uluabat lake water quality was evaluated according to Turkish Standarts [12]. It is important in water management to know the concentrations of the various constituents (natural or pollutional) of water. In the most commonly met form of pollution, by organic biodegradable wastes, the physicochemical assessment of the water quality is usually based on five parameters: BOD, ammonia, nitrate, phosphates, and DO.

The oxygen uptake is due to the activity of microorganisms breaking down the organic matter present in the sample. The greater the rate of loss of DO the greater is the amount of organic matter present. Thus the test provides a useful general measure of the level of contamination of the sampled water by biodegradable wastes [19]. As is well known, the high amounts of organic matter in waste effluents are potentially one of the most important environmental problems. DO concentrations ranged from 3 to 19.4 mg/L (see Tab. 2 and Figs. 5a and b). In general, the highest DO concentrations were recorded in cooler months (especially November 2004 and March 2005). As mentioned above, November and March were determined to have the highest diversity in terms of both Oligochaeta and other groups. During these relatively cooler months, it appears the DO levels are suitable to support many benthic invertebrates. According to the average value of DO, the behavior of the sampling stations 1, 4, 7, 9, 10, and 11 are clearly different from others with respect to DO, probably due to the high consumption of DO into the wastewater and to the processes involved in the degradation of nutrients. In addition, at these stations the BOD values suggest a considerable organic matter load to be present (see Fig. 5a).

According to the average value of bottom water parameters, NO_3-N was found at first quality level, NO_2-N was generally found at three-fourths quality, and NH_3-N was found at second quality level (see Tab. 2). The use of fertilizers in agriculture and urban sewage is believed to increase nitrate and nitrite concentrations. Furthermore, except for some sampling stations such as 11 and 12 lacking of macrophyt may cause an increase in the nitrogen ion cencentration in the lake. The maximum ammonium concentrations were found at stations 1 (1.32 mg/L), 4 (1.11 mg/L), 6 (0.731 mg/L), 8 (1.03 mg/L), and 11 (0.957 mg/L) where the center of the population and companies are located (see Fig. 1). It is important to mention the high levels of ammonia measured at these stations, where domestic and industrial effluents flow into the lake. It is known that especially high nitrite concentrations are a limiting factor for the life of living organisms. The highest levels of nitrite concentrations were found at stations 2 (0.12 mg/L) and 5 (0.11 mg/L) in September 2004 and June 2005, respectively. Furthermore, on the same date for station 2, the lowest level of DO was recorded (5.5 mg/L). In addition to Oligochaeta, Nematoda, is a known eutrophic taxon in the lentic systems [18], which was the dominant zoobenthic taxon for these two stations.

Phosphate was found at third quality level (except station 1) and its concentrations ranged from 0.04 (in April at station 4) to 2.68 mg/L (in September at station 6). The highest level of phosphate concentration was recorded at station 6 through which the Mustafakemalpasa river flows. According to the value established for polluting nutrients in surface water by the Turkish government [12], the concentrations of PO_4-P surpass in station 6 the upper limits (upper limits for $PO_4-P > 0.65$ mg/L). Although mandatory phosphate limits of 0.02 to 0.65 mg/L PO_4-P are specified in the Surface Water Regulations, these values relate to the suitability of water for treatment and have no environmental significance. Sustained values of even one-tenth of these would be expected to give rise to eutrophication in surface waters and would be particularly undesirable in rivers and streams which flow into lakes.

Sewage and agriculture are the main sources of phosphate in surface waters. The high levels of phosphate concentration are thought to be mainly a result of the use of dung in agriculture and detergents including phoshate. This result is evident from the fact that the Mustafakemalpasa river has runoff high levels of phosphate to the lake. As can be seen from Fig. 2b, generally three taxa (Oligochaeta, Chironomidae, and Nematoda) were dominant at station 6. A high level of phosphate and also other parameters such as NO_2-N and NH_3-N may cause reductions in zoobenthos.

The temperature of the sampling stations reflected the seasonal changes. Temperatures ranged from 11.2 to 27.3°C (see Tab. 2). The results of total coliform and Fc are shown in Tab. 2. As can be seen, the maximum total and Fcs were found in stations 6 and 11. In general, total and Fcs are commonly used as indicators of bacteriological quality of the water. Bacterial groups indicate the contamination process occurring in aquatic environments.

As the most representative variations, those observed for DO, BOD, and nutrients, especially for ammonium and coliform, which, as is well known, is indicative of recent pollution, can be mentioned.

4.3 Statistical Analysis

CCA considered eight environmental variables (vegetation, temperature, pH, DO, BOD, phosphate-phosphorus, nitrate-nitrogen, and Fc) and selected Oligochaeta species which showed a common distribution or high abundance and analysis produced two factors. The eigenvalues for the two factors were 44 % (0.4483) and 39 % (0.3990). The eigenvalue for the first factor explained 44 % (0.4483) of the species environment relations and the eigenvalue for the second factor explained 39 % (0.3990) of the species environment relations. The first factor contained vegetation, DO, NO_2-N, and PO_4-P; second factor contained BOD, temperature, Fc, and pH (discrimination measures per variable per dimension is shown in Tab. 4).

As can be seen from Fig. 4, a relationship was recorded between the abundance of some Tubificid species *T. tubifex*, *P. hammoniensis*, *P. albicola* and the first level of aquatic macrophytes (V1), temperature (t1), and phosphate-phosphorus (Pht1) and the second level of BOD (B2). In addition, abundance of *L. hoffmeisteri* and second level of phosphate-phosphorus (Pht2) and aquatic macrophytes (V2) was also recorded. It is clear that vegetation, which is the highest parameter contributing to factor 1 (see Tab. 4), was the most important factor for oligochete species. Similarly, a relationship was recorded

Table 4. Factor analysis using selected Oligochaeta species and selected parameters (discrimination measures per variable per factor).

	Factor 1	Factor 2
Variables		
Vegetation	0.839	0.014
BOD	0.141	0.194
DO	0.829	0.658
PH	0.107	0.523
Temperature	0.269	0.453
Fc	0.190	0.932
NO_2-N	0.817	0.152
PO_4-P	0.451	0.049
Variance explained, %	0.4483	0.3990

between abundance of selected naidin taxa, *D. digitata* and second level of temperature, DO and vegetation, third level of BOD and nitrate-nitrogen. In addition, a relationship was recorded between abundance of *Paranais frici* and *U. uncinata* and first level of fecal coliform (Fec1).

With regard to the Pearson correlation index between the average number of Oligochaeta species and the paramaters, the relation between the number of Tubificidae and BOD (for *P. hammoniensis* and *P. albicola*, $p < 0.05$; for *L. hoffmeisteri*, $p < 0.01$) was directly proportional while the relation between the number of some taxa (*Trichodrillus* sp., *R. coccineus*, *N. communis N. variabilis*, and *N. barbata* NO_3-N ($p < 0.05$), was inversely proportional. The species of Oligochaeta was not equally responding to the physicochemical parameters of the water. It was found that the abundance of *D. digitata* showed a significant positive correlation to the temperature of the water ($p < 0.01$) and positive correlation to the NO_2-N level ($p < 0.05$). The abundance of *Trichodrilus* sp., *P. albicola*, *L. profundicola*, *R. coccineus*, *P. aequiseta*, *N. communis*, *N. variabilis*, and *N. barbata* showed a positive correlation to the NH_3-N ($p < 0.05$). Furthermore, a significant positive correlation with abundance of *U. uncinata*, *P. frici* and *D. digitata* and Fc was recorded ($p < 0.01$). In the present study, the dominant species are: *P. hammoniensis*, *T. tubifex*, *P. albicola*, and *L. hoffmeisteri* which are known as most common oligochaete species in eutrophic lakes [6, 20]. Most of the naidin taxa recorded in this study was found at stations 12 and 11 which contain a high density of aquatic vegetation. The subfamily Naidinae contains species with a wide variety of environmental preferences. Särkkä [21] indicated that *D. digitata* is an indicator of organic loading in lakes. All our results support these findings.

According to the Bray-Curtis analyses, the stations 3, 4, 5, and 7 were found to be most similar to each other while station 10 (as well as 8 and 11) was found to be the most different from all the other stations for the dynamics of the oligochaete fauna (both the numbers and species). The hydromorphological structures, habitat, and physicochemical features were similar at all sampling stations, but the most significant habitat charecteristics of the first four stations was vegetation composition while this characteristic was not observed at station 10.

5 Conclusions

The diversity and taxa richness of the zoobenthic communuties found in the whole area were not quite diverse. The impression gained from the water-quality measurements made and considering the Turkish Standart study area, lake Uluabat is generally polluted by organic wastes. It was found that Oligochaeta, Chironomidae larvae, and Nematoda were dominant, while taxa were absent as is typical of lentic systems. High nutrient enrichments are known to favor Oligochaeta, Chironomidae larvae, and Nematoda. The lower density or minimum values of the other zoobenthic taxa were due to the dominance of oligochaetes, chironomids, and nematodes in most of the sampled stations, and not due to a decrease in the number of taxa. The dominance of these three taxa was controlled by soft sediments and available food resources. In addition, they are known to be benthic groups very tolerant to extreme conditions and high concentrations of organic pollution.

In an earlier study [8], it was found that heavy metal residues (Fe, Mn, Cu, Zn, Cr, Pb, Ni, and Co) in the Uluabat lake water were lower than the maximum allowable levels in drinking water established by WHO [22]. However, they indicated that lead and cadmium concentrations were relatively higher than in the sediment samples. High levels of Pb, Cd, Zn, and Fe in the sediments of Uluabat lake reflect the presence of lake polluting activities arround the lake. Moreover, Barlas et al. [9] detected considerable amounts of organochlorine pesticides in water and sediment samples of Uluabat lake.

Consequently, nutrients such as nitrogen are important for life in all aquatic systems. In the absence of human influence, aquatic systems contain a background level of nitrogen that is essential to the survival of the aquatic plants and animals in those systems. However, during the last several hundred years, the amount of nitrogen in many lake systems, including lake Uluabat, has increased, as a result of anthropogenic influences such as agricultural runoff, wastewater discharge, and urban/suburban nonpoint sources. Excessive nitrogen loading may lead to the eutrophication of the water body.

The structure of the benthic macrofauna in the lake changes with the effects of environmental variables. In the future, similar studies should be repeated periodically to determine the future of the Uluabat lake.

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