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Long-term macrobenthic community structure changes in the Upper Sakarya River System (1995–2015)

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Abstract

The Upper Sakarya River System (USRS) is one of the most important river systems in Turkey. Its primary drainage is provided by the Porsuk Seydi and Bardakçı Rivers and their tributaries. Long term benthic invertebrate community structure in the USRS was investigated from 1995–2015 (with sampling conducted every five years) in order to assess changes in their composition and in relation to water quality. Oligochaete specimens sorted from samples were identified to the species level when possible; all other invertebrate specimens sorted from samples were identified to order and family level. In addition, some environmental parameters (e.g., dissolved oxygen, temperature, and hydrogen ion concentration as *p*H) were measured *in situ*.

Although Ephemeroptera-Plecoptera-Trichoptera fauna were the most abundant group in fauna of USRS during the years 1995, 2000 and (in part) 2005 (18.80, 17.69, and 14.07%, respectively), this ratio decreased to 7.90% during the more recent years of monitoring. In 1995, 2000 and 2005, *Nais bretscheri*, *Chaetogaster diastrophus*, *Chaetogaster langi*, *Pristinella jenkinae*, *Aulodrilus pigueti*, *Aulodrilus pluriseta*, *Potamothrix hammoniensis*, and *Psammoryctides albicola* were the dominant oligochaete taxa. After 2005, tubificine species became more prevalent in samples. While 6 stations had high BMWP (Biological Monitoring Working Party) value in 1995, 2000 and 2005, only 1 station had high value after 2005. Values of Shannon Diversity Indices ranged from 2.00 to 3.05 for the years 1995–2000, 1.87 to 2.24 for the years 2000–2005, 1.06 to 1.85 for the years 2005–2010, and 0.97 to 1.80 for the years 2010–2015. In USRS, while values of dissolved oxygen were measured as 8.00 mg/l and 9.00 mg/l in 1995 and 2000, this high value was measured only at one station in 2015. It was found that numerical and proportional distributions of benthic invertebrates in the USRS have changed considerably between 1995 and 2015. It is obvious that these changes are the result of anthropogenic habitat degradation.

Key words: Upper Sakarya River, zoobenthos, Oligochaeta

Introduction

The Sakarya River Basin—which encompasses 3.4% of the riverine habitat of Turkey—constitutes approximately 7% (5800 ha) of the surface area of the country. The basin includes in total 13 provinces including mainly Eskişehir, Sakarya and Bilecik—either partially or completely. The basin is consisted of 3 sub-basins, namely Upper, Central and Lower Sakarya sub-basins. The headwaters of the upper Sakarya River drainage emanate from five different springs in a region called "Sakaryabaşı", all located in the southern areas of Çifteler District of Eskişehir Province. The waters originating from these springs flow into Bardakçı, Seydi and Sarısu Creeks, draining in a southeasterly direction, eventually becoming the political boundary between Ankara and Eskişehir provinces near the village of Çakmak. This drainage continues to flow in a northerly direction towards its confluence with Porsuk Creek. Porsuk, Seydi and Bardakçı Creeks are included in Upper Sakarya River System (USRS). The Sakarya River basin includes 16 reservoirs, the most important being the

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Porsuk, Çatören, Kunduzlar, Gökçekaya reservoirs. Additionally, Balıkdamı wetland, which is under protection, in located in Upper Sakarya sub-basin.

Water pollution due to the anthropogenic elements—and the decrease in and destruction of aquatic biological diversity as a result of that pollution—is not a problem specific to Turkey but a worldwide problem. Therefore activities were initiated to reveal the aquatic biodiversity, to determine the pollution level in surface waters, to execute biological monitoring, to identify reference sites in order to take measures, and to draft river basin management plans among European Union Member States in accordance with Water Framework Directive (WFD) (2000) with which Turkey aligns the national legislation. Numerous activities were carried out within this scope in Turkey, many of which continue today. One of the most important components of these activities is to determine five biological quality indicators (macroinvertebrates, fish, macrophytes, diatoms, and phytoplankton), identifying the organisms to the species level when possible. Among those components, macroinvertebrates have critical importance in terms of maintaining the aquatic life and sustainable use of the environment. Moreover, various species have bioindicator characteristics and they form an early warning mechanism for short term changes. Due to the fact that their population density is high and that they can occur in almost all types of waters in every period, it is critical to document changes through biological monitoring (Rosenberg and Resh 1993; Metcalfe-Smith 1994). In recent years, ecological quality assessments based on benthic macroinvertebrates were applied by numerous researchers in different river systems in Turkey (e.g., Duran *et al.* 2003; Kazancı *et al.* 2008; Camur-Elipek *et al.* 2006; Topkara *et al.* 2011; Arslan *et al.* 2016). Among the benthic macroinvertebrate groups, oligochaete species are considered one of the more important indicator taxa used for biological monitoring and to set the pollution levels of surface waters (Rosenberg and Resh 1993). Because tubificine taxa have ability to replace less tolerant groups of macroinvertebrates in organic polluted surface waters (Schenková and Helešic 2006), they are used as indicators of organic pollution in surface waters (Lin and Yo 2008).

Although extensive historical and recent research focusing on the water quality and fauna the in Upper Sakarya River System—one of the most essential river systems in Turkey—has been conducted, the assessment of water and habitat quality is performed for the first time in this present study by using physico-chemical variables along with biotic indices (Biological Monitoring Working Party (BMWP), Shannon Wiener and Margalef Index, Ephemeroptera-Plecoptera-Trichoptera% (EPT) and Oligochaeta%), and by monitoring macroinvertebrate fauna and their changes over time for a long time period of 20 years.

The objectives of this study were: i) to determine the fauna diversity of benthic invertebrates on the level of ordo-family in Upper Sakarya River System, ii) to identify the oligochaete fauna to the species level, iii) to determine the changes in fauna structure from 1995 to date (especially EPT% and Oligochaeta%), iv) to make an assessment of the fauna structure with biotic indices, and v) to reveal the changes in water quality with benthic invertebrates which are among the ecological quality elements. Thus, a river system was assessed in terms of ecological quality for 20 years and the structure of benthic invertebrates and their biodiversity were revealed for the first time in Turkey. The results of this study include data summarized past studies associated with the WFD (2000), providing substantive information that can be used during planning of future river basin activities.

Material and Methods

Study area

The Sakarya River (824 km) is the third largest river in Turkey, it is 810 km long and ranges from 60–150 m wide. It rises from five different springs, called Sakaryabaşı, all of which are located in the western Anatolian Plateau. Upper Sakarya River System includes the Porsuk River—one of the biggest tributaries in this system, and also the Sakarya, Seydi and Bardakçı Rivers and their tributaries. All the rivers are being used presently for irrigation and industrial water supply.

Sampling

Thirteen sampling stations (Figure 1) in the Upper Sakarya River System (USRS) and its tributaries were studied between 1995–2015; each station was sampled once every five years, and always during Autumn. Four stations initially surveyed in 1995 and again in 2000 were later eliminated from further study due dewatering and eventual desiccation due to road construction; data generated from samples collected from these four stations during the early years of this study were not included in the calculations. Benthic macroinvertebrates were collected using a hand net (500 µm mesh size) from different habitats present at each of the 13 stations in USRS: three stations on the Sakarya River, six stations on the Porsuk River and four stations on the Seydi River. After collection, samples were washed through a series of sieves (1.5 mm, 0.7 mm, and 0.3 mm mesh net sieves, respectively) then preserved in 80% ethyl alcohol.

In the laboratory, macroinvertebrate specimens were sorted from the raw, preserved samples under stereo dissecting microscopes, separated to order or family level, and then enumerated. The oligochaete specimens were mounted on microscope slides and identified to species level using the keys presented in Sperber (1948, 1950), Brinkhurst and Jamieson (1971), and Timm (1999). Several physico-chemical parameters were measured during each sampling period—water temperature, hydrogen ion concentration (as *p*H), dissolved oxygen (DO), biological oxygen demand (BOD), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonium nitrogen (NH_4-N) and sulfate ($S0_4$). The values resulting from field and laboratory analyses of water samples collected during this study were compared with values and limits established by inland water quality management in Turkey (Republic of Turkey Ministry of Environment and Forest 2015).

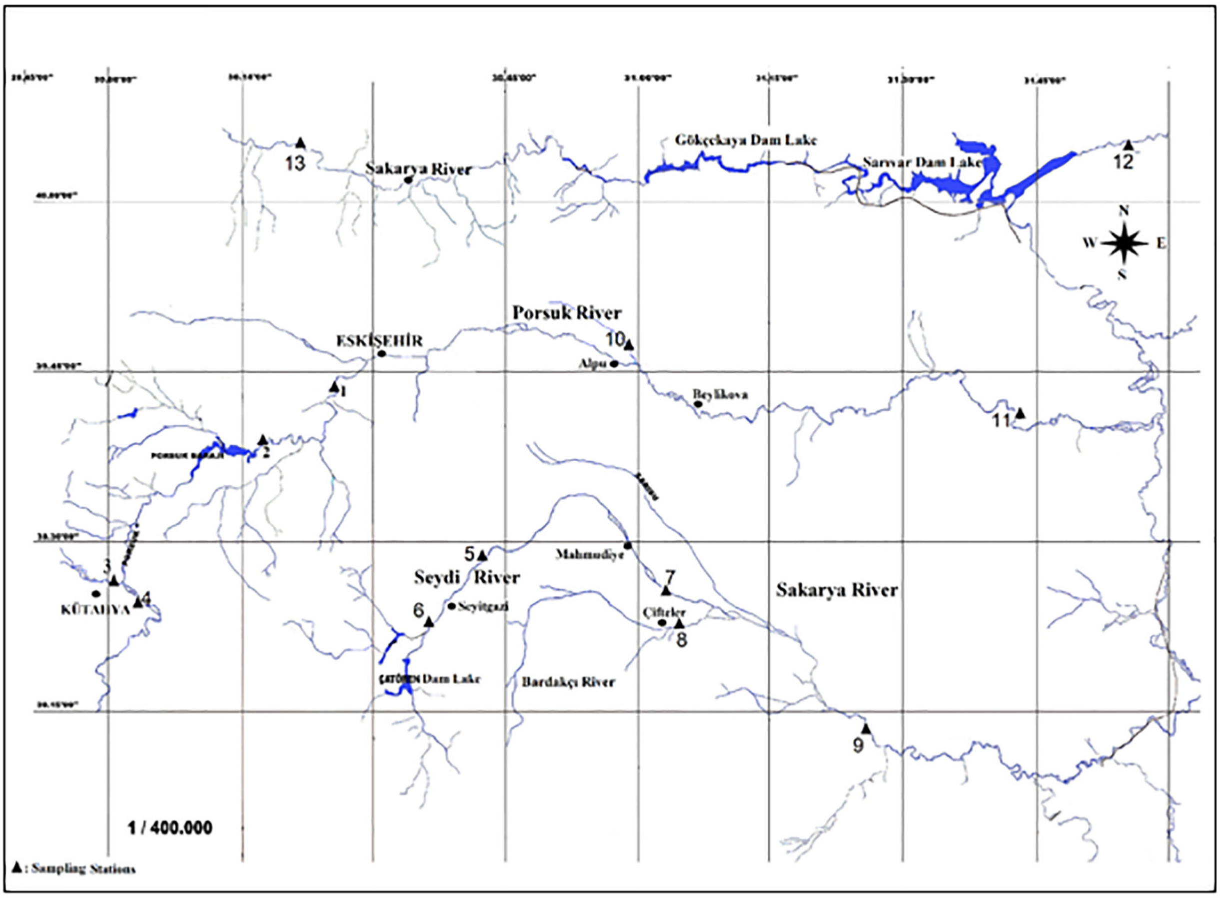

FIGURE 1. The Upper Sakarya River System in Turkey, noting 13 sampling stations surveyed during the research period (1995–2015) discussed in this paper.

Results

Sixty taxonomic groups of aquatic macroinvertebrates were present in samples collected from 13 stations during this study in the USRS. With the exception of the oligochaetes, all taxa were identified to class, order and family level (Table 1); in total, 53 oligochaete species were identified in samples collected during this study (Table 2). Shannon Wiener index values varied between 0.93–2.57 during the research period in the basin. The highest values were recorded from stations 1 and 7 on the sampling dates between 1995 and 2015. Shannon Wiener index values were recorded as 2.31, 2.58 and 2.53 at Station 1 in the years 2000, 2005 and

2015, respectively (Table 3). Values at Station 7 were recorded as 2.49 and 2.07 in the years 1995 and 2010, respectively (Table 3). The lowest value was reported at Station 3 (1.04 and 0.74, respectively) in the years 1995 and 2000, and at Station 10 (1.08 and 1.37) in the years 2005 and 2010, respectively (Table 3).

TABLE 1. Dominance values of taxa individual numbers by years which were identified in the sampling stations during the research period (1995-2015) in the Upper Sakarya River System (as %).

	Years				
Taxa	**1995**	**2000**	**2005**	**2010**	**2015**
Turbellaria	0.40	0.20	0.20	0.04	0.03
Total Gastropoda	11.80	8.90	7.50	12.20	8.40
Planorbidae	2.40	3.60	2.30	3.10	4.20
Physidae	3.60	2.10	3.90	7.40	3.50
Melanopsidae	3.40	2.30	1.10	0.90	0.20
Lymnaeidae	2.40	0.90	0.20	0.80	0.50
Total Bivalvia	4.05	3.02	4.10	6.09	5.10
Unionidae	2.40	2.10	1.30	2.30	0.70
Dreissenidae	0.20	0.40	1.60	2.70	3.50
Sphaeriidae	1.40	0.70	1.20	1.10	0.90
Oligochaeta	27.40	33.70	27.80	32.20	33.80
Total Hirudinae	1.60	0.70	1.10	1.40	1.90
Erpobdellidae	0.70	0.20	0.20	0.10	0.10
Glossiphoniidae	0.70	0.00	0.30	0.20	0.30
Hirudinidae	0.20	0.50	0.40	0.80	1.20
Erpobdellidae	0.00	0.00	0.20	0.30	0.30
Hydracarina	0.40	0.50	0.90	0.60	0.80
Nematoda	5.20	2.30	5.60	4.50	3.90
Total Ephemeroptera	11.90	13.10	8.90	6.70	5.70
Baetidae	1.10	2.10	3.20	2.80	4.20
Oligoneuriidae	2.30	2.70	0.70	0.50	0.20
Heptageniidae	2.20	3.20	1.10	0.60	0.10
Ephemerellidae	1.80	1.50	1.30	1.30	0.60
Caenidae	1.80	1.20	1.10	0.40	0.20
Ephemeridae	1.60	1.30	0.70	0.40	0.30
Potamantidae	1.10	1.10	0.80	0.70	0.10
Total Odonata	2.40	2.00	0.80	1.20	1.30
Calopterygidae	0.80	1.10	0.50	0.60	0.80
Coenagrionidae	0.40	0.00	0.20	0.00	0.10
Platycnemididae	0.30	0.00	0.10	0.20	0.20
Aeshnidae	0.50	0.30	0.00	0.30	0.10
Gomphidae	0.40	0.20	0.10	0.10	0.00
Libellulidae	0.00	0.40	0.00	0.00	0.10

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TABLE 1. (Continued)

	Years				
Taxa	**1995**	**2000**	**2005**	**2010**	**2015**
Total Hemiptera	0.70	0.40	0.30	0.40	0.10
Gerridae	0.20	0.20	0.10	0.20	0.10
Corixidae	0.10	0.10	0.20	0.10	0.00
Notonectidae	0.20	0.10	0.00	0.00	0.00
Pleidae	0.10	0.00	0.00	0.10	0.00
Isonychiidae	0.10	0.00	0.00	0.00	0.00
Total Coleoptera	4.10	1.10	5.06	0.80	1.07
Dytiscidae	0.30	0.20	1.30	0.30	0.40
Haliplidae	0.50	0.30	0.60	0.00	0.10
Hydraenidae	0.70	0.40	1.20	0.10	0.20
Hydrophilidae	0.40	0.10	1.40	0.00	0.30
Gyrinidae	2.20	0.10	0.50	0.40	0.00
Chironomidae	9.80	17.30	18.40	13.10	19.40
Tipulidae	0.20	0.20	0.34	0.59	0.30
Simuliidae	4.30	1.80	2.50	1.10	0.70
Culicidae	0.06	0.51	0.23	0.17	0.05
Tabanidae	1.00	1.40	0.80	0.50	0.60
Ceratopogonidae	0.87	1.73	1.09	2.06	1.09
Psychodidae	0.01	0.07	0.10	0.20	0.10
Ephydridae	0.01	0.02	0.04	0.00	0.02
Dixidae	0.02	0.02	0.01	0.01	0.01
Stratiomyidae	0.00	0.00	0.11	0.06	0.04
Total Trichoptera	5.60	4.10	4.60	4.50	2.10
Hydropsychidae	2.20	3.20	3.10	2.90	1.90
Hydroptilidae	0.70	0.40	0.90	0.90	0.10
Rhyacophilidae	0.80	0.40	0.30	0.10	0.10
Sericostomatidae	1.00	0.00	0.20	0.40	0.00
Limnephilidae	0.90	0.10	0.10	0.20	0.00
Total Plecoptera	1.30	0.40	0.40	0.20	0.07
Capniidae	0.20	0.00	0.10	0.00	0.07
Nemouridae	0.30	0.00	0.10	0.00	0.00
Perlidae	0.80	0.40	0.20	0.20	0.00
Total Megaloptera	0.10	0.07	0.20	0.01	0.00
Sialidae	0.10	0.07	0.20	0.01	0.00
Asellidae	2.10	0.80	1.50	2.60	3.60
Gammaridae	3.60	4.30	6.40	8.00	9.10
Decapoda	0.30	0.50	0.20	0.10	0.07

TABLE 2. Minimum, maximum and mean dominance values of Oligochaeta species' individual numbers in 13 stations during the research period (1995-2015) in the Upper Sakarya River System in Turkey (as %).

	1	2	3	4	5	6	7	8	9	10	11	12	13
Cognettia sphagnetorum	-	-	-	-	-	-	-	-	(0.0-2.6) 0.5	-	-	-	-
Cognettia sp.	-	(0.0-2.7) 0.5	-	-	-	(0.0-3.0) 0.6	-	-	-	-	-	-	-
Enchytraeus albidus	-	-	-	-	-	(0.0-3.4) 0.7	-	-	-	-	-	-	-
Enchytraeus buchholzi	-	(0.0-4.1) 1.6	-	(0.0-2.5) 0.5	(0.0-11.2) 3.3	(0.0-2.2) 0.4	-	-	(0.0-3.2) 0.6	-	-	-	-
Henlea ventriculosa	-	-	-	-	(0.0-3.7) 1.0	-	-	-	-	-	-	-	-
Henlea perpusilla	-	-	-	-	(0.0-3.4) 0.7	-	-	-	(0.0-3.8) 1.2	-	-	-	-
Henlea sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Mesenchytraeus sp.	-	-	-	-	(0.0-5.6) 1.4	-	-	-	-	-	-	-	-
Haplotaxis gordioides	-	-	-	-	(0.0-4.1) 1.5	-	-	-	(0.0-1.3) 0.3	-	-	-	-
Lumbriculus variegatus	-	(0.0-0.7) 0.1	-	-	(0.0-11.2) 4.4	(0.0-5.1) 2.3	(0.0-13.8) 3.7	(0.0-8.6) 2.5	-	-	(0.0-2.4) 0.48	(0.0-2.7) 0.7	-
Lumbriculus sp.	-	-	-	-	-	-	(0.0-2.9) 1.1	-	-	-	-	-	-
Trichodrilus sp.	(0.0-4.6) 2.0	-	-	-	-	(0.0-9.0) 1.8	-	(0.0-8.2) 2.5	-	-	-	-	-
Rhynchelmis sp.	(0.0-3.3) 1.4	-	-	-	-	-	-	-	(0.0-5.2) 1.0	-	-	-	-
Chaetogaster diaphanus	(0.0-10.5) 3.8	-	-	-	(0.0-10.6) 4.4	-	(0.0-6.2) 4.0	-	-	-	-	(0.0-4.0) 1.5	-
Chaetogaster diastrophus	-	-	-	-	-	(0.0-10.2) 2.0	-	-	-	-	-	-	-
Chaetogaster langi	(0.0-5.9) 2.2	-	-	-	-	(0.0-5.7) 3.2	-	-	-	-	-	-	-
Dero digitata	-	(0.0-8.1) 1.8	-	(0.0-2.1) 0.7	-	-	-	-	(0.0-14) 4.5	(0.0-11.4) 2.3	-	-	-
Dero furcatus	-	(0.0-8.9) 4.8	(0.0-9.1) 4.8	-	-	-	-	-	(0.0-10.4) 2.8	(0.0-20.0) 5.1	-	-	-
Dero obtusa	-	(0.0-6.1) 1.2	-	(0.0-2.6) 0.5	-	-	-	-	-	-	(0.0-8.3) 3.1	-	-
Nais barbata	(0.0-10.5) 6.0	-	-	-	(2.5-9.4) 5.4	(0.0-6.1) 1.8	(1.2-9.9) 5.3	(0.0-5.9) 2.3	(0.0-5.1) 1.7	-	-	(0.0-9.2) 5.2	(0.0-12.0) 5.8
Nais bretscheri	(0.0-22.2) 9.6	-	-	-	(0.0-18.8) 9.0	(0.0-12.8) 5.3	(0.0-19.8) 4.7	(0.0-8.8) 4.8	-	-	-	(0.0-4.7) 2.3	(0.0-7.1) 3.5
Nais communis	-	(0.0-19.3) 7.6	(0.0-6.9) 2.7	(0.0-12.0) 5.0	(4.7-22.1) 11.6	(0.0-11.5) 3.9	(0.0-8.5) 3.0	(0.0-6.1) 2.3	(6.6-14.6) 8.9	-	(0.0-4.2) 0.83	(5.0-16.0) 8.0	(0.0-20.7) 7.8
Nais elinguis	-	(2.1-10.5) 6.9	(0.0-24.2) 11.3	(2.3-14.4) 8.6	-	-	(0.0-18.1) 6.5	-	(9.8-17.9) 14.5	(0.0-20.0) 5.1	(0.0-21.9) 9.71	(5.0-16.0) 8.0	-
Nais pardalis	(7.9-11.0) 12.2	(2.3-30.0) 12.9	-	(0.0-10.1) 3.7	(7.6-23.9) 12.5	(12.6-28.4) 21.6	(0.0-15.8) 9.7	(0.0-48.9) 9.8	(0.0-17.3) 8.3	-	(0.0-2.4) 0.48	(4.9-10.3) 7.7	(7.8-22.8) 14.4
Nais pseudobtusa	(0.7-4.4) 2.4	-	-	-	(0.0-7.1) 2.1	(0.0-9.1) 2.7	(0.0-4.7) 1.1	(9.2-34) 23.2	(0.0-15.4) 3.1	-	-	-	(0.0-3.7) 1.2
Nais variabilis	-	(0.0-1.1) 0.2	-	-	-	(0.0-4.9) 1.0	-	-	-	-	-	-	-
Ophidonais serpentina	-	(0.0-15.4) 4.0	(0.0-4.4) 0.9	(0.0-7.4) 2.6	-	(0.0-4.5) 1.5	-	-	(0.0-10.3) 4.7	-	(0.0-4.8) 0.95	(0.0-5.1) 1.7	(0.0-4.9) 1.4

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TABLE 2. (Continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Paranais frici	(0.0-8.5) 4.6	(0.0-4.1) 1.3	-	(0.0-5.1) 1.7	-	(0.0-4.8) 1.2	(0.0-4.7) 2.8	-	(0.0-13.9) 6.8	(0.0-2.9) 0.6	-	(0.0-9.0) 3.9	(0-2.2) 0.8
Pristina aequiseta	-	-	-	-	(0.0-12.4) 4.4	-	(0.0-6.8) 3.7	(0.0-6.1) 1.2	-	-	-	(0.0-3.0) 1.4	-
Pristina proboscidea	(0.0-13.8) 6.8	-	-	-	(0.0-4.7) 1.7	(0.0-5.1) 1.9	(0.0-8.2) 2.8	(0.0-12.3) 4.3	-	-	-	(0.0-3.0) 0.8	-
Pristinella jenkinae	(3.7-10.5) 6.9	(0.0-11.3) 2.5	-	(0.0-3.1) 0.6	(3.2-11.0) 6.8	(0.0-29.1) 9.1	(7.8-17.8) 13.6	(0.0-12.2) 4.2	(0.0-2.6) 0.5	-	-	(0.0-8.8) 3.4	(0.0-5.4) 2.0
Slavina appendiculata	-	(0.0-4.5) 0.9	-	(0.0-6.7) 1.5	-	-	-	-	-	(0.0-8.6) 2.5	-	-	-
Spericaria josinae	-	(0.0-0.8) 0.2	-	(0.0-9.5) 3.0	-	(0.0-2.0) 0.4	(0.0-3.7) 1.4	-	-	-	-	(0.0-5.0) 2.3	-
Stylaria lacustris	(3.2-12.1) 8.2	(0.0-8.8) 4.6	-	(0.0-35.4) 13.3	(0.0-15.0) 6.6	(0.0-6.4) 1.3	(2.3-10.4) 6.9	(0.0-14.3) 5.1	(0.0-15.7) 6.8	-	(0-11.8) 5.33	(7.2-14.6) 10.5	(8.9-38.4) 19.5
Uncinais uncinata	(0.0-3.2) 1.8	(0.0-2.7) 0.5	-	(0.0-6.7) 3.1	-	-	-	-	(0.0-18.7) 6.9	-	(0-7.8) 2.85	(0.0-7.0) 1.7	(0.0-2.0) 0.7
Aulodrilus pigueti	(0.0-4.2) 1.9	-	-	-	-	-	-	-	-	-	-	-	-
Aulodrilus pluriseta	(0.0-5.1) 2.4	-	-	-	(0.0-8.9) 3.4	(0.0-6.4) 4.4	(0.0-7.0) 3.4	-	-	-	-	-	-
Haber speciosus	(0.0-2.8) 1.0	-	-	-	(0.0-0.9) 0.2	-	-	(0.0-23.6) 12.3	-	-	-	(0.0-2.0) 0.6	-
Limnodrilus claparedeianus	-	-	-	(0.0-11.9) 3.8	-	-	-	-	-	-	-	-	-
Limnodrilus hoffmeisteri	(0.0-19) 3.9	(0.0-12.0) 5.8	(26.1-74.0) 47.5	(3.2-27.0) 15.4	(0.0-2.8) 0.6	-	-	-	(0.0-11.6) 6.6	(28.6-76.8) 52.5	(12.7-35.4) 24.88	(0.0-8.6) 3.1	-
Limnodrilus udekemianus	-	(0.0-4.5) 1.3	(0.0-14.5) 9.4	(0.0-15.6) 6.0	-	-	-	-	(0.0-11.5) 4.0	(0.0-64.7) 26.5	(3.1-22.5) 12.52	(0.0-3.1) 0.6	-
Potamothrix bavaricus	(0.0-2.9) 0.8	-	-	-	-	-	(0.0-2.3) 0.5	-	-	-	-	(0.0-4.0) 0.8	-
Potamothrix bedoti	-	-	-	-	-	(0.0-4.7) 0.9	-	-	-	-	-	-	-
Potamothrix hammoniensis	(0.0-29.3) 7.1	(5.4-17.5) 12.0	(0.0-16.1) 6.1	(0.0-22.1) 10.5	(0.0-9.9) 4.1	(0.0-23.1) 6.2	(0.0-13.5) 6.6	-	(0.0-12.2) 6.9	(0.0-10.0) 3.1	(0.0-19.8) 9.66	(10.9-19.5) 14.3	(13.0-69.0) 29.9
Psammoryctides albicola	(3.2-7.4) 5.0	(4.1-28.5) 16.3	(0.0-2.3) 0.5	(0.0-9.5) 4.2	(7.0-20.4) 13.6	(11.8-37.2) 20.0	(10.3-26.5) 17.2	(0.0-3.7) 0.7	(0.0-10.3) 2.4	(0.0-5.7) 1.1	(0.0-5.8) 3.03	(10.8-23.9) 15.5	(0.0-20.7) 10.5
Psammoryctides barbatus	-	(0.0-5.4) 1.8	-	(0.0-1.3) 0.3	(0.0-1.2) 0.2	(0.0-7.7) 2.3	(0.0-2.5) 0.9	(0.0-22.6) 8.6	-	-	(0.0-0.8) 0.16	-	-
Psammoryctides moravicus	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhyacodrilus coccineus	-	(0.0-13.6) 6.6	(0.0-8.6) 2.6	(0.0-13.5) 5.9	-	-	(0.0-2.4) 0.5	-	(0.0-7.3) 2.6	-	(7.3-30.2) 15.69	-	-
Spirosperma ferox	-	(0.0-1.4) 0.3	-	-	-	(0.0-2.0) 0.4	(0.0-3.1) 0.8	-	-	-	(0.0-12.5) 2.98	-	-
Spirosperma velutinus	-	(0.0-2.3) 0.5	-	-	-	-	-	-	-	-	-	-	-
Stylodrilus parvus	-	-	-	-	(0.0-1.9) 0.4	-	-	-	-	-	-	(0.0-1.7) 0.3	-
Tubifex tubifex	(0.0-0.9) 0.2	(0.0-7.2) 3.1	(4.6-24.2) 14.3	(0.0-18.8) 8.1	-	-	-	-	(0.0-11.6) 3.9	-	(0.0-13.1) 7.36	(0.0-5.6) 1.7	(0.0-6.6) 1.8
Tubifex spp.	-	(0.0-2.3) 0.5	-	-	-	-	-	-	-	-	-	-	-
Quistadrilus multisetosus	-	(0.0-1.4) 0.3	-	-	(0.0-1.9) 0.4	-	-	-	-	-	-	-	-
Eisenella tetraedra	-	-	-	(0.0-2.5) 1.0	(0.0-2.1) 0.4	-	-	-	(0.0-1.7) 0.6	(0.0-5.7) 1.1	-	-	-

The highest EPT value in the basin were identified in two out of three stations located on Seydi Creek; at Station 5 (44.52 and 44.09) in the years 1995 and 2000, and at Station 6 (46.04, 36.72 and 24.72) in the remaining years (Table 3). EPT values at Station 7, which is another sampling point on Seydi Creek, are higher than the basin-wide values, although they are not as high as the values recorded at those two stations (Stations 5 and 6) (Table 3). The lowest EPT values were identified from samples collected from stations 4 and 10 on Porsuk Creek throughout the entire research period. Those two stations are the sampling areas in which the abundance of %Oligochaeta has the highest values, which is in parallel with %EPT results. Especially in the Station 10, Oligochaeta individuals constitute more than half of the zoo-benthic community. In parallel with the biotic indices, the highest BMWP values were recorded again stations 5, 6, and 7 except for the year 2015 (in 2015, no station was identified having BMWP value 1) (Table 3).

In total, 53 oligochaete species were present in samples collected from stations in the USRS study area; the highest taxonomic diversity (25 species) was reported for Station 6 (Table 2).

The lowest species diversity values were recorded at stations 3 and 10, where only 10 species of oligochaetes were recorded (Table 2). Throughout the study period, *Psammoryctides albicola* (collected from all the stations and *Potamothrix hammoniensis* (collected from 12 of the 13 stations) were the most widespread species. Three other species, *Stylaria lacustris, Nais pardalis,* and *N. communis* were collected from 11 of the 13 stations (Table 2). Except for semiaquatic Enchytraeidae species, *Lumbriculus* sp. (Station 7), *Chaetogaster diastrophus* and *Potamothrix bedoti* (Station 6), *Spirosperma velutinus* (Station 2) and *Aulodrilus pigueti* (Station 1) were detected only in 1 station (Table 2).

The dominance values of for oligochaetes present in the basin varied during this study, dependent primarily on the sampling year and the habitat conditions of the station. The species with the highest population density is as follows in 13 stations: 76.80% of the oligochaete fauna is composed of *Limnodrilus hoffmeisteri* (Station 10 in 2015), 69.00% of the fauna is composed of *Potamothrix hammoniensis* (Station 13 in 2015), 64.70% of the fauna is composed of *Limnodrilus udekemianus* (Station 10 in 2015), 48.90% of the fauna is composed of *Nais pardalis* (Station 8 in 2000), 38.40% of the fauna is composed of *Stylaria lacustris* (Station 5 in 1995), 37.20% of the fauna is composed of *Psammoryctides albicola* (Station 6 in 2005), 23.60% of the fauna is composed of *Haber speciosus* (Station 8 in 2010) (Table 2). Nevertheless, *Chaetogaster diaphanus* and *Chaetogaster langi* have a dense population at stations 1, 5, and 7 in the first 2 sampling periods, the population density decreased in time and no species was detected in the samplings carried out in 2015. The decrease in the population density of *Chaetogaster* species was also observed in two other species—*Aulodrilus pigueti* and *Aulodrilus pluriseta*. *A. pigueti* was only identified in samples from a single station (Station 1) and *A. pluriseta* was only identified in samples from four stations (stations 1, 5, 6, and 7) during the study period (Table 2). The existence and dominance of both species in samples collected from those stations decreased gradually and they were not identified in the last sampling campaign.

In general terms, the tubificine population increased while naidine population decreased in the stations in the basin between 1995 and 2015. The situation is highly dynamic at stations 3, 10, and 13. Naidine dominance was 29.75% in the Station 3 in 1995, however this value dropped to 7.53% in 2015 while it dropped from 61.24% to 24.42% at Station 13. Naidine rate which was 34.00% at Station 10 disappeared completely in 2015.

Minimum, maximum, mean and standard deviation values of several environmental parameters, measured at all 13 stations every five years during the 20-year period of this study, are presented in Table 4. The dominance variations of Naidine-Tubificine given for the above-mentioned stations support the water quality results in those stations. Stations 3, 10, and 13 had the lowest water quality of all sites in the basins. Among the water quality parameters, dissolved oxygen levels were low at Station 6, located on the Seydi River which forms the source of Sakarya River (known as Sakarbaşı). However low levels of DO are associated with the fact that the station is actually a crenal region. As presented in Table 4, BOD values of the same station are also low and it falls under the I. water quality class.

TABLE 3. Index values calculated for 13 stations during the research period (1995-2015) in Upper Sakarya River System in Turkey (Roman numbers indicate water quality for BMWP; H': Shannon Wiener Index, Marg: Margalef Index; EPT: Ephemeroptera-Plecoptera-Trichoptera groups' individual numbers; Olig: Oligochaeta group's individual numbers).

	St 1					St 2					St 3					St 4					St 5				
Index/Year	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**
%EPT	12.83	14.59	11.34	6.90	6.64	8.04	5.56	3.00	0.47	0.00	0.77	0.35	2.30	0.46	0.15	0.00	0.00	0.00	0.00	0.00	44.52	44.09	35.40	21.93	11.23
%Olig	6.36	10.03	19.27	26.74	8.47	26.43	50.90	51.59	26.64	34.20	36.59	75.13	21.67	26.95	25.04	14.37	16.48	16.52	44.83	39.53	15.96	15.18	12.70	25.03	37.97
BMWP	I	I	II	II	III	II	II	IV	IV	V	IV	IV	V	V	V	III	IV	III	IV	V	I	I	II	I	I
H'	2.35	2.31	2.58	2.4	2.53	2.34	1.55	1.67	1.954	1.59	1.04	0.74	1.72	1.835	1.65	1.70	1.42	1.86	1.549	1.75	2.22	1.95	2.20	2.282	2.01
Marg	4.45	3.41	4.42	3.76	3.97	3.53	2.46	2.86	2.42	1.75	1.97	1.10	1.75	1.761	1.75	2.42	2.01	2.42	2.201	2.20	3.98	2.72	3.98	3.751	3.52
	St 6					St 7					St 8					St 9					St 10				
Index/Year	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**
%EPT	31.60	29.67	46.04	36.72	24.72	24.10	27.95	7.97	11.14	8.98	8.78	31.16	17.67	21.33	16.17	39.64	26.13	34.20	7.52	11.09	0.00	0.00	0.00	0.00	0.00
%Olig	16.35	13.34	20.15	24.21	19.28	17.37	40.43	7.79	38.65	41.84	14.45	6.26	2.92	10.97	11.65	23.08	18.12	15.01	48.98	37.88	44.81	70.14	69.05	51.82	59.94
BMWP	I	I	I	I	II	I	I	II	II	II	I	I	I	I	I	II	II	II	III	III	V	V	V	V	V
H'	2.36	1.80	2.14	2.25	2.30	2.49	1.68	2.07	2.067	1.80	1.57	1.62	1.99	1.759	1.93	2.33	1.58	2.01	1.597	1.99	1.38	0.93	1.08	1.368	1.23
Marg	3.99	3.25	3.97	3.78	3.08	3.99	2.92	3.32	3.317	2.65	3.09	2.10	3.10	2.41	2.41	3.07	1.57	3.09	2.647	2.87	1.32	1.10	1.31	1.534	1.32
	St 11					St 12					St 13														
Index/Year	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**	**1995**	**2000**	**2005**	**2010**	**2015**										
%EPT	12.08	13.90	1.17	0.00	0.00	25.76	16.67	4.99	7.17	8.60	37.90	20.77	19.85	35.71	15.85										
%Olig	56.38	51.34	36.26	43.88	40.32	45.00	41.04	53.91	32.78	47.96	39.69	30.10	35.11	17.97	36.19										
BMWP	III	III	IV	V	V	I	I	II	III	III	I	I	I	II	II										
H'	1.26	1.33	1.35	1.38	1.07	1.98	1.81	1.51	1.66	1.69	1.77	1.68	2.00	2.27	2.05										
Marg	1.09	0.97	1.03	1.09	0.87	3.78	2.93	3.54	3.089	2.65	3.09	2.08	2.63	2.63	3.09										

TABLE 4. Minimum-maximum, mean and standard deviation values of several parameters measured between 1995 and 2015 in the Upper Sakarya River System study area in Turkey (mean values are given in brackets. Min-Max(Mean) ± STD; D.O: dissolved oxygen; BOD: biological oxygen demand).

	Temparature (ºC)	*p*H	D.O (mg/l)	BOD (mg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	NH_4-N (mg/l)	SO_4 (mg/l)
1	16.60-25.20 (19.80)±4.60	7.90-8.90 (8.37) ±35.10	3.00-16.00 (8.20) ±6.80	1.00-22.00 (11.50) ±14.80	0.10-0.80 (0.40) ±0.30	0.02-0.04 (0.03) ±0.01	0.07-0.10 (0.09) ±0.02	73.00-105.00 (85.33) ±17.20
2	15.90-24.50 (18.90) ±4.80	8.20-8.50 (8.30) ±0.15	8.80-11.30 (10.07) ±1.25	0.00-16.00 (8.30) ±8.02	0.37-1.40 (0.76) ±0.50	0.01-0.06 (0.03) ±0.02	0.07-0.19 (0.09) ±0.09	148.00-313.00 (204.30) ±94.10
3	14.40-23.00 (17.63) ±4.68	8.20-8.70 (8.37) ±0.29	10.10-11.20 (10.60) ±0.56	0.00-13.00 (7.00) ±6.50	0.70-1395.00 (466.10) ±804.30	0.01-0.10 (0.07) ±0.05	0.00-0.06 (0.06) ±0.00	196.00-267.00 (226.00) ±36.70
4	13.70-21.50 (16.90) ±4.08	8.00-8.20 (8.07) ±0.11	8.90-11.70 (10.10) ±1.40	0.00-6.00 (2.33) ±3.20	0.30-1.80 (1.14) ±0.70	0.01-0.20 (0.09) ±0.10	0.00-0.09 (0.02) ±0.03	95.00-250.00 (178.30) ±78.10
5	12.10-20.50 (15.10) ±4.60	7.90-8.28 (8.06) ±0.20	8.60-9.90 (9.40) ±0.70	1.00-8.00 (4.50) ±4.90	1.70-4.43 (2.80) ±1.40	0.02-0.10 (0.06) ±0.04	0.00-0.17 (0.06) ±0.09	68.00-189.00 (141.30) ±64.40
6	11.80-21.70 (15.30) ±5.50	7.60-7.80 (7.70) ±0.10	2.00-5.00 (3.60) ±1.50	0.00-1.00 (6.60) ±6.50	0.50-2.20 (1.40) ±0.80	0.02-0.06 (0.04) ±0.02	0.60-1.80 (1.20) ±0.62	59.00-159.00 (100.00) ±52.30
7	12.10-26.60 (17.00) ±8.30	8.40-8.70 (8.50) ±0.18	9.30-10.30 (9.90) ±0.50	0.00-5.00 (2.60) ±2.50	0.00-1.40 (0.06) ±0.70	0.01-0.19 (0.07) ±0.10	0.02-0.70 (0.20) ±0.40	87.00-213.00 (148.60) ±63.00
8	19.00-22.40 (20.10) ±1.30	8.10-8.60 (8.30) ±0.20	8.50-11.60 (10.30) ±1.60	0.00-9.00 (3.00) ±5.20	0.10-1.90 (0.90) ±0.90	0.00-0.03 (0.02) ±0.02	0.00-0.08 (0.03) ±0.04	39.00-98.00 (63.30) ±30.80
9	8.10-20.07 (14.20) ±6.30	7.40-8.20 (7.80) ±0.40	9.40-12.10 (10.60) ±1.30	0.00-8.00 (3.60) ±4.04	0.50-1.90 (1.20) ±0.90	0.01-0.02 (0.02) ±0.00	0.02-0.06 (0.05) ±0.01	12.00-132.00 (73.60) ±60.00
10	8.60-21.20 (14.10) ±6.45	7.80-8.10 (7.90) ±0.17	8.50-12.40 (10.03) ±2.08	1.00-7.00 (3.33) ±3.21	0.54-1.90 (1.25) ±0.92	0.01-0.01 (0.01) ±0.00	0.00-0.11 (0.07) ±0.06	48.00-87.00 (66.33) ±19.60
11	14.00-20.00 (17.60) ±3.20	7.90-8.50 (8.10) ±0.30	6.50-8.30 (7.17) ±0.90	0.00-4.00 (1.30) ±2.30	1.10-11.56 (386.30) ±666.50	0.03-0.08 (0.04) ±0.01	0.02-1466.00 (488.60) ±846.30	45.00-154.00 (99.50) ±77.00
12	9.00-16.40 (12.10) ±3.80	7.50-8.00 (7.80) ±0.26	6.30-10.80 (8.60) ±2.20	0.00-3.00 (2.00) ±1.70	0.08-2.10 (1.70) ±0.50	0.01-0.04 (0.04) ±0.01	0.02-0.04 (0.04) ±0.01	61.00-133.00 (107.30) ±40.20
13	14.90-19.70 (16.50) ±2.70	7.50-8.10 (7.80) ±0.30	7.20-9.60 (8.70) ±1.30	0.00-5.00 (2.30) ±2.50	0.08-2.20 (1.30) ±1.20	0.01-0.10 (0.09) ±0.05	0.02-0.10 (0.10) ±0.02	128.20-354.00 (244.50) ±126.50

Discussion and Conclusions

During this study in the Upper Sakarya River System in Turkey (1995–2015), 60 aquatic macroinvertebrate taxa were identified to class, order and family level; in addition, 53 oligochaete taxa were identified to species (Tables 1 and 2). When the zoobenthic community structure is analysed in the sampling years, it is realized that EPT rate, which is high in 1995, decreased each sampling period at Station 2 during this study, and was reduced to zero in samples collected in 2015 (Table 3). Station 2 is situated on the outlet of Porsuk Dam (Figure 1). One of the fundamental ways for providing resources for various purposes such as irrigation, electricity production and domestic use is to construct dams on rivers which are known as fluvial systems (Earthscan 2000). River systems can be physically altered by hydraulic infrastructures, which are regarded as significant components of fluvial habitat degradation (Almeida *et al.* 2013). Hydro morphological alterations such as dams and weirs constitute barriers for migration of aquatic fauna, and natural flow regimes are impacted by those alterations (Nilsson *et al.* 2005). As well, trophic resources of the fauna are disrupted and the abiotic environment is homogenized (Cortes *et al.* 1998). Aquatic ecosystems located upstream and downstream of hydraulic infrastructures such as dams are impacted by those infrastructures, affecting the aquatic ecosystem along the river (McAllister *et al.* 2001).

In 1972, Porsuk Dam was constructed on Porsuk Creek, a tributary of Sakarya River, for the purposes of irrigation, flood control, and municipal and industrial water supplies. The height of the dam from the river bed is 49.70 m. As presented in Table 3, the EPT value at Station 2 (located downstream of the Porsuk Dam)—which was 8.04% in 1995—diminished every five years, and was reduced to 0% in 2005. In addition, % Oligochaeta rate increased in parallel with the decrease in EPT. This rate which was 26.43% in the first sampling campaign was doubled in the years 2000 and 2005, and BMWP value was downgraded from quality level II to quality level V over the years. It is known that several species belonging to the insect orders Ephemeroptera, Trichoptera and Plecoptera are quite sensitive to changing environmental conditions, and that alfa-beta mesosaprobic species replace oligosaprobic species under decreasing environmental conditions, and when these environmental pressures persist, the faunal structure shifts towards dominance by polysaprobic species. Degradation of both habitat and environmental parameters negatively impacted the macroinvertebrate fauna this station. When oligochaete fauna of this station (Station 2) was analysed, the effect of negative change was also reflected in the population structure of species. For instance, the dominance value of *Dero furcatus* increased from 2.00% to 6.10% in 20 years. *Dero* spp. are known to occur in diverse environments—from swampy areas in ponds and rivers to slow moving marshy rivers. Distinctive features of *Dero furcatus* are branchial fossa, a pair of noncontractile palps and 3 pairs of gills—which allow this species to tolerate very low levels of dissolved oxygen concentrations (Brinkhurst & Jamieson 1971).

No EPT species were encountered in two stations (stations 4 and 10) during the whole study period in the basin. Station 10 is a good example of an "artificial or impoverished stream" which is located on Porsuk Creek near Alpu District of Eskişehir. In this region, irrigation water is supplied from Porsuk River by means of secondary ducts for agriculture in Alpu Plain. Running water systems are classified into five categories, namely crenal, rhithral, potamal, artificial or impoverished streams, and intermittent running waters—dependent on the geographical position, habitat structure, and natural or artificial nature of those systems. No taxa other than Oligochaeta, Gastropoda, Bivalvia, Chironomidae and Gammaridae were present in samples collected and identified from this station (Table 1). Relatively high levels of nitrate nitrogen, nitrite nitrogen, and ammonium nitrogen in water samples collected from station 10 during each 5-year sampling period might indicate the perennial presence fertilizers with high nitrogen content used in agricultural practices in this region. This conclusion suggests that this station is not an appropriate habitat for other aquatic macroinvertebrate taxa except for meso- and polysaprobic groups having wide tolerance interval in artificial water systems. This finding is also supported by oligochaete species identified in the same station. The tolerant *Limnodrilus hoffmeisteri* is dominant in this sampling area, followed by *Limnodrilus udekemianus, Dero furcatus, Nais elinguis* and *Dero digitata* (Table 2). Moreover, the naidine rate which was recorded as 34.3% in 1995 dropped to 0 in 2015, with tubificine taxa becoming completely dominant.

Station 4 is situated in a region in the vicinity of an industrial site and industrial facilities in Kütahya province. The river banks in this area are covered with stones, thus habitat structure is typical of a regulated river. Oligochaeta, Gastropoda and Chironomidae are the dominant taxonomic groups in this station. *Rhyacodrilus coccineus* and polysaprobic oligochaete species are dominant in this station, as is also the case at station 10.

Our results note that stations 5, 6, and 7 have the highest Shannon and EPT% values (Table 3). The common features of those stations are that they are positioned in areas which are relatively located some distance from settlements and thus have remained relatively undisturbed sites. Station 7 is an example of a hyporhithral region, and stations 5 and 6 are examples of eupotamal regions. All three stations (in addition to Station 2) are the areas in which the highest number of oligochaete species (23, 25 and 22 species, respectively) were recorded in the basin during this study (Table 2). The dominance rate of *Nais bretscheri, N. barbata* and *N. pardalis,* which are typical species of running waters, is high in every three station (Stations 5, 6, and 7) (Table 2). Moreover they are the stations in which *Haplotaxis gordioides* as well as *Lumbriculus variegatus, Lumbriculus* sp. and *Trichodrilus* sp. are recorded—taxa that have rarely if ever been reported previously, either from this basin or elsewhere in Turkey. Additionally, *Chaetogaster diastrophus* was only recorded from Station 6 in the basin (Table 2). Although *Chaetogaster diastrophus* was reported to cling to Odonata larvae and thus being transported passively (Corbi *et al.* 2004), and that it can occur even in saline waters (Erséus *et al.* 1999), there are only a few records of this species from surface waters in Turkey. Stations 5, 6, and 7 have the highest water quality values. Although water quality fluctuated during the study period, our results suggest that Station 5 is of quality class II., and that stations 6 and 7 in quality class II. until 2010, and later was upgraded to quality class III. in 2015.

The area associated with Station 8, which covers five different springs and their spring run drainages from which Sakarya River originates (known as Sakarbaşı), is the area having near similar taxonomic diversity and water quality (except for minor fluctuations) as that of station 8, and having a huge ponding area. As presented in Table 3, EPT rate which was 8.78% in 1995 did not decrease over the past 20 years in this station. On the contrary, the EPT rate in station 8 increased within past 20 years. Oligochaeta % rate can be projected to remain stable. BMWP value remained within the I. quality class during the entire study period. The two most important features of this site were that water temperature never drops below 16°C, even in winter, and the calcium concentration of the water remains high. Moreover, this area provided critical habitat for extant populations of the commercially important *Palaemonetes turcorum* (Holthuis, 1961) (Decapoda, Palemonidae)—a marine species that has adapted to living in freshwater habitats, and to date is endemic species to Sakarya River in Turkey. Despite the fact that the Sakarbaşı region accommodates picnic areas, restaurants and hotels and is used for recreational purposes, the area has remained the same with few alterations (other than minor changes that can be neglected) for over 20 years, largely because of the preservation activities of Çifteler Municipality of the district covering the area, and the conservation efforts of individuals and groups established for the region to raise the awareness of the public about water pollution and biological diversity.

To summarize, the zoobenthic community structure and water quality in the Upper Sakarya River System has declined, especially in Porsuk Creek—which flows through large settlements and which is used for irrigation purposes, and in which industrial facilities are densely located. Although EPT formed 40–45% of the total zoobenthic community in the years 1995, 2000 and (in part) in 2005, the dominance values for the oligochaete species *Nais bretscheri, Chaetogaster diastrophus, Chaetogaster langi, Pristinella jenkinae, Aulodrilus pigueti*, *Aulodrilus pluriseta*, *Potamothrix hammoniensis* and *Psammoryctides albicola* were high in several stations, the EPT rate decreased to 20–25% in the following years (and to zero in samples collected from several stations), and tubificine taxa replaced naidines. No substantial change was observed, either in water quality or in fauna structure in Seydi River (a tributary of the Sakarya River), during this study.

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