Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 52, No. 1 March 2023

pages (79-89)

sciendo

ISSN 1730-413X

eISSN 1897-3191

Use of biomonitoring tools to detect water quality-dependent ecosystem (macroinvertebrate) responses in lentic systems: the examples of Lakes İznik and Manyas, Türkiye

by

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DOI: **https://doi.org/10.26881/oahs-2023.1.06**

Category: **Original research paper**

Received: **September 5, 2022**

Accepted: **January 12, 2023**

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Abstract

Lakes İznik and Manyas located in Türkiye are important biodiversity resources in the Palearctic region. No studies to date have explored the ecological statuses of these lakes together with their water quality based on biotic indices utilizing benthic macroinvertebrates. In this study, some parameters listed in the SWQMR of Türkiye were measured to determine the ecological quality of the lakes. Biotic indices included in the WFD and bacteriological parameters in terms of human health were also evaluated for these lakes. Sampling was performed at 6 stations in 2018-2019. Results for the zoobenthic community structure indicate that Lake İznik has started to become organically polluted and Lake Manyas is more polluted. Also, the biological index results for Lake İznik also show that the lake water quality has started to decrease and that pollution conditions have occurred, pointing to class III water quality. It is clear that there is pollution pressure in Lake İznik. However, according to the results, the macrozoobenthic community structure, diversity, and water quality of Lake İznik seem to be better than those of Lake Manyas. According to the results of the water qualities in the lakes, precautions should be taken to eliminate the negative pressures seen in both lakes.

Key words: biomonitoring, ecological quality, pollution, Water Framework Directive

online at www.oandhs.ug.edu.pl

1. Introduction

The opening statement of the European Union's Water Framework Directive (WFD) is: "Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such." This is followed by the requirement that "the situation of aquatic ecosystems must be enhanced and hence pollution by emission, discharge or loss of hazardous substances must end or be phased out" (WFD 2000).

Among the various types of aquatic ecosystems, lakes are living systems with ecosystem services from which people benefit, made sustainable by having healthy biota (Schallenberg et al. 2013). For this reason, biological monitoring programs, including those focused on aquatic organisms, should be designed in order to plan the management of lake basins and maintain water quality, as well as analyzing water quality parameters. Determining ecosystem health with biological monitoring programs and taking the relevant precautions has gained importance in the last 15-20 years. The monitoring of biological components, including macroinvertebrates, provides long-term information about the quality of a water source (Grant 2002). In this context, macroinvertebrates may be described as the real living memories of freshwater ecosystems.

In Türkiye, the determination of the status of an aquatic system is based on the water quality parameters listed in the Surface Water Quality Management Regulations (SWQMR 2021). The use of benthic macroinvertebrates from among the biological quality parameters listed in the WFD has also become mandatory as application of the WFD has been added to the agenda (WFD 2000). Benthic macroinvertebrates not only reflect the biological diversity of the aquatic systems in which they live but also have bioecological importance in studies about the determination of the water quality. They are accepted as one of the biological quality elements that can be used in the ecological classification of surface waters and sustainability, improvement, and protection programs according to the WFD because of their characteristics as indicators of biological conditions. European countries have been using benthic macroinvertebrates for many years in the biological assessment of the quality of stream and lake habitats (Hering et al. 2004; Korycińska, Królak 2006; Pastuchova 2006; Višinskienė, Bernotienė 2012; Vitecek et al. 2021). Most studies promoting the use of macroinvertebrates in biomonitoring, however, have focused on stream environments (Hering et al. 2004; Resh, Jackson 1993), with fewer studies addressing the efficacy of employing the macroinvertebrate assemblages of lakes (Johnson et al. 2004, 2007; Brauns et al. 2007).

In recent years, ecological quality assessments based on benthic macroinvertebrates have been widely applied in regard to streams by various researchers in Türkiye, as well (Kazancı et al. 2013; Zeybek et al. 2014; Arslan et al. 2016a; Zeybek 2017; Ertaş, Yorulmaz 2021). However, such studies of lake ecosystems are relatively limited (Çamur-Elipek et al. 2010; Duran, Akyıldız 2011; Yıldız et al. 2015; Arslan et al. 2016b). Until recently, bacteriological components were not considered within the WFD. Bacteria enter lake ecosystems naturally through the soil, air, rivers that discharge into the lakes, and dead plants and organic materials in the water. Only a small part of these bacteria constitute the natural flora of the water and it is possible to detect fecal pollution from sewage water leakages and animal husbandry wastes, which are by-products of anthropogenic activities, using only microbiological parameters such as total fecal coliforms and total coliforms. In aquatic environments, the presence of fecal coliform bacteria is frequently evaluated as a sign of fecal pollution and other contaminants (Gearheart 1999; McMath et al. 1999; Perkins, Hunter 2000). Fecal coliform bacteria are found in the intestinal tracts of warm-blooded animals and contaminate soil and water via animal and human feces (Dickes 2008). As a result of overflowing domestic sewage or nonpoint sources of human or animal waste, fecal coliform pollution can develop in ambient water. In animal and human feces and urine, over 140 different types of viruses and many different bacterial species can be found, including many that are pathogenic to humans. As a result, the presence of fecal contamination indicates a possible health risk for anyone exposed to that water (Tyrrell et al. 1995; Hernandez et al. 1997; Ricca, Cooney 1999; Newman et al. 2000). In studies of aquatic ecosystems, the determination of fecal indicator bacterial distributions is critical, and particularly for coliform bacteria, which are known as indicator microorganisms (Bergstein-Ben Dan, Stone 1991; Pote et al. 2009; Cardak, Altuğ 2010; Koloren et al. 2011). Furthermore, some environmental variables can be altered by their distributions, such as the physicochemical qualities of the water being altered vertically and horizontally or bacterial dispersion being affected by changing environmental conditions (Niewolak, Golas 2000; Anderson et al. 2005; Altınoluk-Mimiroğlu, Çamur-Elipek 2016). For all these reasons, both macroinvertebrates, which are among the important biological quality elements, and water quality parameters together with some microbiological parameters were used in the present study.

In Türkiye, there are about 200 natural lakes (Foreign Relation Office of DSİ 2014). Water management efforts in Türkiye have gained priority in recent years because rapid population growth, urbanization, and industrialization have caused deterioration of the environment (Tanık et al. 1998). Lakes İznik and Manyas are important biodiversity resources in the Palearctic region. No studies to date have explored the ecological statuses of these lakes together with their water quality based on biotic indices utilizing benthic macroinvertebrates. Previous research on these lakes has been related to either the determination of benthic macroinvertebrate fauna or water quality as evaluated by physicochemical parameters (Kırgız, Soylu 1975; Ongan 1982; Özbek et al. 2004; Balık et al. 2005; Arslan, Ahıska 2007; Özyurt, Tanatmış 2008; Gümüş, Akköz 2020; Özbayram et al. 2021). The objectives of the present study were therefore as follows: i) to determine the ecological quality of Lakes İznik and Manyas in terms of some parameters (temperature, pH, conductivity, dissolved oxygen, biological oxygen demand, ammonium nitrogen, nitrate nitrogen, and total phosphorus) listed in the Surface Water Quality Management Regulations of Türkiye; ii) to evaluate bacteriological parameters in terms of human health in these lakes, which are used for irrigation water and recreational purposes; and iii) to evaluate the biotic indices included in the WFD, namely the Biological Monitoring Working Group Scoring System (BMWP), Average Score Per Taxon (ASPT), Shannon diversity index, Margalef diversity index, and dominancy.

2. Materials and methods

2.1. Study area

Samples of water and benthic macroinvertebrates were collected from Lakes İznik and Manyas. With a surface area of 308 km^2, Lake İznik is Türkiye's fifth largest lake, located in the southeast of the Marmara region. It is a deep (maximum depth of 65 m), stratified, alkaline lake with high conductivity (Akçaalan et al. 2014; Özbayram et al. 2021). Since 1959, Lake Manyas, a eutrophic lake in western Türkiye, has been designated as a national park. It is a significant wetland protected under the Ramsar Convention. This lake is shallow, with a maximum depth of 3.4 meters and a surface area of 159 km^2 (Dorak et al. 2017; Özbayram et al. 2021).

2.2. Sampling and data analyses

Samples from a total of 6 stations in Lakes İznik (stations I1-3) and Manyas (stations M1-3) were taken twice in May and September in 2018-2019 (Figure 1). Benthic macroinvertebrate samples, representing biological quality elements, were collected from Lakes İznik and Manyas with an Ekman grab sampler and hand net (Table 1). Samples were washed *in situ* using a series of sieves with decreasing mesh sizes of 2 mm, 1 mm, and 0.5 mm. The material was preserved in 70% ethyl alcohol, taken to the laboratory, and sorted using the Zeiss Stemi 508 stereomicroscope. All macroinvertebrate samples were stored in the ESOGU Hydrobiology Laboratory. At the same time,

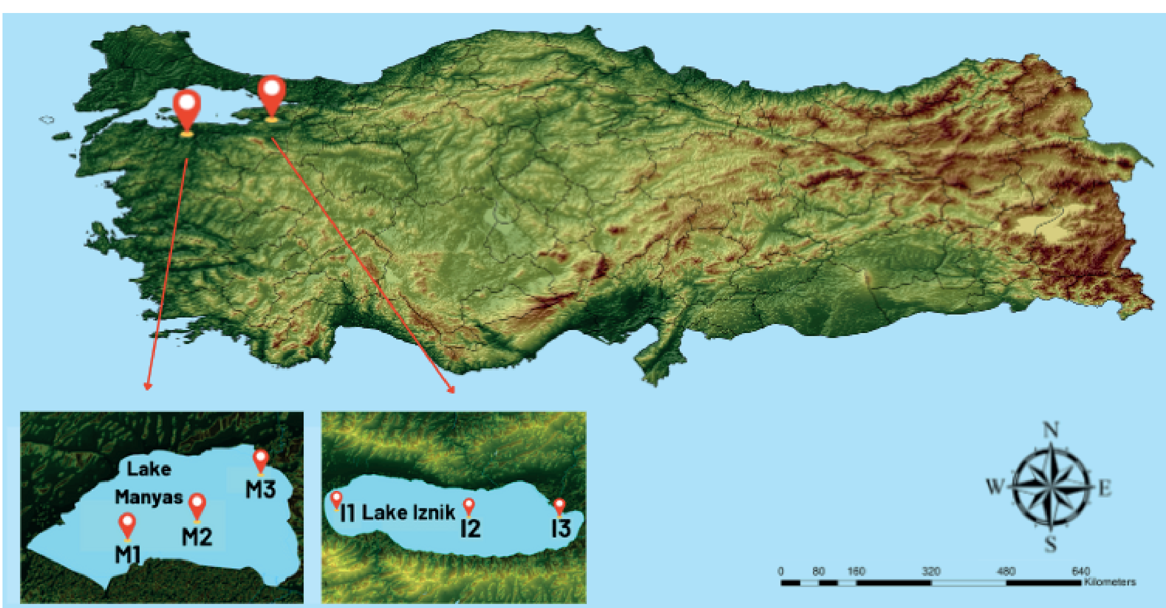

Figure 1

Geographical locations of Lakes İznik and Manyas, and sampling stations in lakes

Table 1

Sampling site details, benthic macroinvertebrate community structures and average dominance, and mean dominance values in Lake İznik and Lake Manyas. Mineral substratum: m – mud; s – sand; p – stones. Vegetation: sa – small aquatic plants; r – reeds.

Station	Lake İznik				Lake Manyas			
	I1	I2	I3		M1	M2	M3	
Latitude and longitude coordinates (X-Y)	29.357483-40.443298	29.541077-40.433289	29.692871-40.436279		27.934875-40.183716	27.989685-40.195923	28.035095-40.226685	
Depth (m)	3	6	2.4		2	4	1	
Vegetation	sa, r	-	sa		sa, r	-	sa, r	
Substratum	m, p	m	m,s		m,s	m	m,s	
	Dominance %			Mean dominance %	Dominance %			Mean dominance %
Phylum: Mollusca								
Class: Gastropoda (total)	18.8	15.04	17.46	17.10	8.23	6.62	6.54	7.13
Subclass: Pulmonata								
Lymnaeidae	4.26	1.77	4.76	3.60	1.32	1.47	-	0.93
Physidae	6.03	3.54	5.56	1.40	6.91	3.68	5.61	0.31
Subclass: Prosobranchia								
Hydrobiidae	-	1.77	2.38	5.00	-	-	0.93	5.40
Valvatidae	8.51	7.96	4.76	7.10	-	1.47	-	0.49
Class: Bivalvia								
Dreissenidae	-	5.31	5.56	3.60	9.21	6.62	8.41	8.08
Phylum: Annelida								
Class: Clitellata								
Subclass: Oligochaeta								
Naididae	6.12	5.15	4.23	5.20	20.6	15.18	30.40	22.06
Tubificidae	2.04	15.2	2.12	6.50	27.1	26.00	21.00	24.70
Subclass: Hirudinea								
Erpobdellidae	-	-	-	-	1.64	-	6.54	2.73
Class: Insecta								
Order: Ephemeroptera (total)	28.01	29.64	19.84	25.83	5.26	9.56	1.87	5.56
Caenidae	5.67	7.96	6.35	6.70	2.96	-	-	0.99
Baetidae	19.86	19.03	11.90	16.90	2.30	8.09	-	3.46
Heptageniidae	2.48	-	1.59	1.40	-	1.47	-	0.49
Ephemerellidae	-	2.65	-	0.90	-	-	1.87	0.62
Order: Odonata (total)	5.32	10.17	15.87	10.45	2.30	5.89	3.74	3.98
Platycnemididae	2.84	5.31	3.17	3.80	1.97	2.21	3.74	2.64
Libellulidae	0.71	-	0.79	0.50	-	0.74	-	0.25
Coenagrionidae	-	1.33	5.56	2.30	0.33	-	-	0.11
Calopterygidae	1.77	0.88	6.35	3.00	-	2.94	-	0.98
Aeshnidae	-	2.65	-	0.90	-	-	-	-
Order: Hemiptera (total)	8.15	8.41	7.15	7.90	3.62	7.36	5.61	5.53
Gerridae	5.67	3.54	5.56	4.90	3.62	3.68	5.61	4.30
Micronectidae	-	3.10	1.59	1.60	-	-	-	-
Nepidae	2.48	1.77	-	1.40	-	3.68	-	1.23
Order: Coleoptera (total)	2.84	0.88	6.35	3.36				
Dytiscidae	1.42	-	6.35	2.60	-	-	-	-
Hydrophilidae	1.42	0.88	-	0.80	-	-	-	-
Order: Diptera (total)	19.52	6.19	16.66	14.12	17.1	14.71	15.88	15.90
Chironomidae								
Tanypodinae	8.87	-	2.38	3.70	-	4.41	-	1.47
Diamesinae	2.13	0.88	-	1.00	-	-	-	-
Ortocladiinae	2.84	2.21	9.52	4.90	2.30	-	2.80	1.70
Chironominae	4.26	-	4.76	3.00	14.80	6.62	13.08	11.50
Tanytarsini	-	3.10	-	1.00	-	3.68	-	1.23
Simuliidae	1.42	-	-	0.50	-	-	-	-
Order: Trichoptera (total)	2.84	0.88	2.38	2.00	1.97	-	-	0.66
Hydropsychidae	2.84	-	2.38	1.70	1.97	-	-	0.66
Hydroptilidae	-	0.88	-	0.30	-	-	-	-
Subphylum: Crustacea								
Class: Malacostraca								
Order: Isopoda								
Asellidae	-	1.33	-	0.40	2.96	2.94	-	1.97
Order: Amphipoda								
Gammaridae	6.38	1.77	2.38	3.50	-	5.15	-	1.72

the parameters of temperature, pH, conductivity, and dissolved oxygen as listed in the Surface Water Quality Management Regulations were measured *in situ* with a Hach Lange DR40D. Biological oxygen demand, ammonium nitrogen, nitrate nitrogen, and total phosphorus, which are also parameters listed in the Surface Water Quality Management Regulations, were evaluated in the laboratory. Total coliforms and total fecal coliforms were also analyzed as bacteriological parameters. All the analyses were performed following standard methods (APHA 1998). For these purposes, water samples were brought to the laboratory by cold-chain transportation for the analysis of total fecal coliforms and total coliforms following the APHA standards (APHA 1998). In the laboratory, benthic macroinvertebrate samples were examined under a stereo binocular microscope and sorted at the family level using the identification keys of Macan (1965; 1977; 1979), Kruse and Pritchard (1982), Brinkhust (1986), Nilsson and Holmen (1995), Mandaville (2002), and Boucherd (2004). The BMWP (Spanish version), ASPT (Armitage et al. 1983), and diversity indices (Shannon-Wiener and Margalef diversity indices) were used to determine the water quality. Biotic indices were analyzed using ASTERICS 3.1 software (AQEM/STAR Ecological River Classification System; AQEM Consortium 2002). In addition, dominancy indices were also used (Bellan-Santini 1969; Soyer 1970).

3. Results

3.1. Benthic Macroinvertebrates

In the benthic macroinvertebrate sampling conducted in Lakes İznik and Manyas in 2018-2019 within the scope of this study, a total of 634 individuals belonging to 5 classes and 27 families in Lake İznik (Table 1) and 547 individuals belonging to 5 classes and 22 families in Lake Manyas (Table 1) were identified.

Table 2

Results for all measured parameters, final classification of parameters, and values of biological and diversity indices in Lakes İznik and Manyas

	Lake İznik			Lake Manyas			SWQMR Classification		
	I1	I2	I3	M1	M2	M3	Class I	Class II	Class III
Water temperature (°C)	16.20	17.40	16.80	15.40	19.30	18.90			
pH	7.80	7.90	8.00	7.40	7.60	7.90	6-9	6-9	6-9
Conductivity (µS cm^{-1})	820	720	850	320	425	390	<400	1000	>1000
Dissolved oxygen (mg O_2 l^{-1})	6.20	7.30	8.10	4.50	5.25	5.75	>8	6	<6
Biological oxygen demand (mg l^{-1})	14.60	11.20	7.96	16.50	18.23	15.32	<4	8	>8
Ammonium nitrogen (mg NH^{4+}-N l^{-1})	0.19	0.18	0.05	0.06	0.06	0.08	<0.2	1	>1
Nitrate nitrogen (mg NO_3^--N l^{-1})	0.11	0.13	0.10	0.13	0.15	0.13	<3	10	>10
Total phosphorus (mg P l^{-1})	0.09	0.17	0.12	0.10	0.13	0.09	<0.08	0.2	>0.2
Bacteriological Parameters									
Total fecal coliforms	200	200	200	460-1100	>1100	460-1100			
Total coliforms	20000	20000	20000	50000-90000	>95000	50000-90000			
Metrics and Indices									
Abundance (ind. m^{-2})	282.00	226.00	126.00	304.00	136.00	107.00			
Number of taxa	21.00	23.00	21.00	14.00	17.00	10.00			
Average score per taxon	5.06 (II-sp)	4.95 (III-mp)	5.00 (II-sp)	4.00 (III-mp)	4.79 (III-mp)	4.13 (III-mp)			
BMWP score	80.00 (II-si)	85.00 (II-si)	81.00 (II-si)	43.00 (III-mi)	63.00 (III-mi)	28.00 (IV-pi)			
Shannon-Wiener index	2.75	2.65	2.89	1.84	2.22	1.66			
Margalef index	3.55	4.06	4.14	2.27	3.26	1.93			
Evenness	0.90	0.85	0.95	0.70	0.78	0.72			
EPT (%)	30.85	30.53	22.22	7.24	9.56	1.87			
Chironomidae (%)	18.09	6.19	16.67	17.11	14.71	15.89			
Oligochaeta (%)	8.16	20.35	6.35	47.70	41.18	51.40			

sp- slightly polluted, hp- heavily polluted, mp- moderately polluted, si- clean but slightly impacted, mi- moderately impacted, pi- polluted or impacte

The highest numbers of families were found at stations I2 and M2 (23 and 14, respectively) and the lowest at I3 and M3 (21 and 10, respectively). Although Lake Manyas generally does not show high diversity in terms of benthic macroinvertebrates, the dominant groups of the lake comprise meso- and polysaprobic taxa such as Oligochaeta, Chironomidae, and Dreissenidae. Lake İznik has higher values than Lake Manyas in terms of its taxonomic diversity and contains oligo-mesosaprobic taxa as well as polysaprobic taxa.

Thirty benthic macroinvertebrate taxa were identified in Lake İznik (Table 1). Among the detected taxa, the highest dominancy rate (16.9%) is seen for the members of the family Baetidae from Ephemeroptera. Baetidae is a common freshwater family and includes mesosaprobic species that can survive in moderately polluted water (Alhejoj et al. 2014). This family was followed by Valvatidae (7.1%), sensitive Caenidae (6.7%), and tolerant Tubificidae (6.9%), respectively. The family Chironomidae also includes highly tolerant species (Popović et al. 2022).

Twenty-four benthic macroinvertebrate taxa were identified in Lake Manyas (Table 1). Among the detected taxa, the highest dominancy rate was seen for oligochaetes, with rates of 24.70% for Tubificidae and 22.06% for Naididae. Oligochaeta contains meso-polysaprobic species that can live in all types of water and species that are highly tolerant. Chironominae and Dreissenidae followed in terms of dominancy with rates of 11.5% and 8.41%, respectively (Table 1).

3.2. Water Quality and Bacteriological Parameters

The results of final classifications according to all measured parameters and the BMWP, ASPT, Shannon-Wiener, Margalef, and evenness indices are provided for Lakes İznik and Manyas in Table 2. In Lake İznik, station I3 has the highest taxonomic diversity, followed by stations I1 and I2. Although stations I1 and I2 have slightly impacted statuses according to their BMWP values, station I3 is moderately impacted. In Lake Manyas, station M2 has the highest taxonomic diversity according to the Shannon diversity index. This lake was found to be class III-IV, which means that it is moderately impacted to polluted or impacted in terms of BMWP values. Total coliform and total fecal coliform bacteria were detected in both lakes. The detection of coliform bacteria and even fecal bacteria in all of the samples that were taken indicates that wastes originating from human and animal feces and/or wastewater originating from slaughterhouses are mixed into Lakes İznik and Manyas (Table 2).

4. Discussion

4.1. Zoobenthic Community Structure

Twenty seven benthic macroinvertebrate families in Lake İznik and 22 families in Lake Manyas were identified in this study (Table 1). Although the numbers of taxa in these lakes seem to be high, it is noteworthy that the density and dominancy rates of groups with high tolerance of adverse conditions, such as meso- and polysaprobic Oligochaeta and Chironomidae, are also high. The dominancy rates of Ephemeroptera and Odonata taxa, which are mostly found in oligo-mesosaprobic zones, are high only in Lake İznik.

Although Lake İznik is rich in benthic macroinvertebrates, the lake largely contains tolerant taxa such as species of Ephemeroptera and Gastropoda. Species of Baetidae from Ephemeroptera and Gammaridae from Malacostraca are typical groups of beta-mesosaprobic and alpha-mesosaprobic zones (Raczynska et al. 2000; Sporka 2006). Freshwater pulmonates from Gastropoda are distributed worldwide with broad environmental tolerance levels (Strong et al. 2008) and they are often indicators of eutrophic environmental conditions (Kebapçı, Yıldırım 2010). They may be dominant in shallow waters where anthropogenic effects such as tourism or fishing activities are present (Yıldırım 2004). Although tolerant pulmonate species were identified in Lake İznik, when their distributions across the lake are examined, it is seen that members of Lymnaeidae and Physidae have a high density in the littoral sections of the lake (stations I1 and I3) and lower density in the middle part (Table 1 and Figure 1). As Yıldırım (2004) stated, such situations may be associated with organic pollution caused by tourism establishments, picnic areas, fishing, and other anthropogenic activities. A similar situation is also seen in Lake Manyas. However, tolerant members of Lymnaeidae and Physidae constitute a large part of the total gastropod population in Lake Manyas. Although they are classified as freshwater snails, they can live in brackish waters and are most often found among highly dense inshore vegetation (Czapski 1977). Lymnaeidae and Physidae species can tolerate a wide range of dissolved oxygen concentrations because their respiratory processes are mostly based on atmospheric oxygen and the aquatic dissolved oxygen level is therefore not essential for them. Their numbers are low or very low in oligosaprobic waters; they generally live in relatively pure waters, namely beta-mesosaprobic waters, and they serve as indicators of the water quality (Michałkiewicz 1993). As seen in Table 1, the bivalve species of Dreissenidae

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are more common in Lake Manyas, with an average dominance rate of 8.8% compared to 3.6% in Lake İznik. Previous studies showed that dreissenid species are sessile and suspension-feeding organisms, and, when in high abundance, they have the potential to negatively impact plankton and benthic communities (Ackerman et al. 2001; Daunys et al. 2006; Minchin et al. 2013). The high taxonomic diversity at station I1, where dreissenids were not detected, and the low taxonomic diversity in Lake Manyas alongside an increasing dreissenid population confirm that this group exerts pressure on the development of the zoobenthic community. The diversity and the population densities of families of the order Ephemeroptera, which include sensitive taxa of low tolerance, in both lakes indicate both negative dreissenid pressure and organic pollution. Mayflies are considered "keystone" species and their presence is believed to be an important environmental indicator of oligotrophic to mesotrophic (i.e., low to moderately productive) conditions in aquatic ecosystems (Barbour et al. 1999; Bauernfeind, Moog 2000). It is seen that the family Baetidae, which includes mesosaprobic species, constitutes a large part of the zoobenthic community at all three stations in Lake İznik, while the dominance ratios of members of the family Caenidae, which includes relatively more sensitive species, are lower. In Lake Manyas, on the other hand, it is remarkable that Ephemeroptera has a lower taxon diversity and population density. It was previously reported that high numbers of individuals and families of Ephemeroptera could be due to the high oxygen concentrations of littoral regions (Rasifudi et al. 2018). In Lake İznik, the stations with both the highest numbers of individuals and highest diversity are the stations in the littoral zone (stations I1 and I3), which are oxygenated by the effect of fluctuations and have vegetation and a substrate structure of stone and mud (m+p) that is suitable for the growth of members of this group.

The dominant taxa of Lake Manyas belong to Oligochaeta and Chironominae, as described above. Both of these groups contain species that have high tolerance levels and can live in all kinds of environmental conditions, and, because of these characteristics, they are used as indicators of organic pollution in regions with high population rates (Behrend et al. 2012; Nicacio, Juen 2015; Abubakr et al. 2018). While the substrate structure of Lake İznik (Table 1) shows higher habitat heterogeneity, the substrate structure of Lake Manyas (mud and particularly sand) and the distribution of aquatic plants are not considered suitable for the development of other zoobenthic community members. This confirms that the littoral parts of Lake Manyas are exposed to organic pollution at a level that supports the development of poly-mesosaprobic species.

The dominancy rates of these benthic macroinvertebrate families show that Lake İznik has moderate water quality that is growing worse. Previous studies on Lake İznik usually focused on determining the zooplankton fauna (Tokat 1975; Toparlak 1975; Altınsaçlı 1998; Gaygusuz et al. 2004; Yağcı, Ustaoğlu 2012). One of those previous studies investigated the Malacostraca fauna of Lake İznik (Özbek et al. 2004). Thus, research on evaluations of the macrozoobenthic fauna of Lake İznik is very limited.

Lake Manyas does not have a high level of benthic macroinvertebrate diversity. In this lake, families of Oligochaeta and Chironomidae constitute a large part of the zoobenthic structure. Oligochaeta and Chironomidae taxa are found in polysaprobic and alpha-mesosaprobic freshwater zones where domestic wastes are discharged, and Chironomidae larvae are ecological indicators in these zones (Raczynska et al. 2000). Similarly, the presence of members of Erpobdellidae, Psychodidae, and Dreissenidae, which are typical groups of mesosaprobic and polysaprobic habitat zones, is compatible with these environmental parameters. The high dominance rates of taxa typical of polysaprobic and alpha-mesosaprobic zones throughout Lake Manyas is a clear indication of pollution pressure. Although many researchers have studied Lake Manyas in terms of macrozoobenthic invertebrate fauna or environmental variables in the last 50 years (Bilgin 1973; Kırgız, Soylu 1975; Ongan 1982; Kinzelbach 1982; Tanatmış 2000; Balık et al. 2005; Karafistan et al. 2005; Berber, Balık 2006; Arslan, Ahıska 2007; Sipahiler 2008), there has been no comprehensive study of its macroinvertebrate fauna and environmental parameters to date.

It is known that the littoral zones of lakes usually support larger and more diverse populations of benthic invertebrates than the sublittoral and profundal zones. The vegetation and substrate heterogeneity of the littoral habitat provide an abundance of microhabitats occupied by varied fauna, which in turn enhances invertebrate production. The littoral habitat is also highly variable due to seasonal influences, land-use patterns, riparian variations, and direct climatic effects producing high-energy areas.

4.2. Water Quality

Analysis of the zoobenthic community structures indicated that Lake İznik has started to become organically polluted and Lake Manyas is more polluted, because the dominant taxa detected in Lake Manyas are meso-polysaprobic species. This may be related to increases in water temperature and decreases in dissolved oxygen concentrations depending on the atmospheric temperature. However, the large number of settlements, recreational areas, and fish production and processing facilities around the lakes are also possible sources of pollution pressure. In addition to the taxonomic data, the biological index results for Lake İznik also show that the quality of the lake water has started to deteriorate and pollution conditions have begun, pointing to class III water quality. The BMWP value was calculated as II (slightly impacted, under pressure) and the ASPT score was found to be III. The diversity index results for this lake also show that the lake currently offers a suitable habitat for macroinvertebrates, but the taxonomic diversity is expected to decrease as a result of the effects of pollution. The lack of diversity among benthic macroinvertebrates might amplify environmental degradation. The values of diversity indices decrease as the environment deteriorates. The level of invertebrate diversity is critical in determining the ecological status of an aquatic habitat (WFD 2000). The Shannon-Wiener and Margalef indices accordingly revealed that the lake's pollution level is unsuitable for zoobenthic life. Previous studies on determining the water quality of Lake İznik with physicochemical parameters are very limited (Akcaalan et al. 2009; Dede 2009; Apaydın Yağcı, Ustaoğlu 2012; Gençoğlu 2017). In those studies, the water quality of the lake was generally found to be good. Our results, however, show that the good water quality of this lake is growing worse. The BMWP and ASPT values for Lake Manyas were lower than those for Lake İznik. The studied environmental parameters also show a parallelism with the biological results. Water temperature and pH were found to be within the normal limits for both lakes. However, the levels of dissolved oxygen and biological oxygen demand, which are the main indicators of organic pollution, were not excessively high. The level of ammonium nitrogen was categorized as class I for Lakes İznik and Manyas. This water classification based on environmental parameters supports the biological results. Özbayram et al. studied Lakes İznik and Manyas, monitoring the physicochemical properties of the two lakes while considering different chemical characteristics and trophic statuses. According to their findings, the bacterial diversity in the lakes is related to environmental factors. They also reported higher diversity in Lake Manyas, a hypereutrophic shallow lake (Özbayram et al. 2021). There is no study to date in which biological indices, diversity indices, and physicochemical parameters were analyzed simultaneously for both of these lakes and analysis was conducted in line with the WFD.

In addition to these findings, although the total amounts of fecal coliforms and total coliforms were not very high, the presence of these species indicates that sewage, fertilizer, and other sources of contamination are mixed into the aquatic environment. The detection of coliform bacteria and even fecal bacteria in the samples taken in the course of this study indicates that human and animal fecal wastes and/or wastewaters that may originate from slaughterhouses are entering Lakes İznik and Manyas. The presence of fecal coliforms indicates the presence of contamination from human excrement and the mixing of sewage waters from settlements and industrial facilities around the lake into rivers (Sarai 1975).

5. Conclusion

According to the results of the macroozoobenthic structure and water quality parameters given in this study, Lake İznik, especially in the littoral zone, seems to be of better condition than Lake Manyas considering the macrozoobenthic community structure, diversity, and water quality. However, it is clear that there is pollution pressure in Lake İznik.

The response of living organisms to negative changes in environmental conditions is reflected by species disappearing from the environments in question. If suitable habitats cannot be maintained, it is inevitable that these taxa will disappear. Therefore, precautions should be taken to eliminate the negative pressures seen in both lakes in this study. As a first step, it is necessary to inform the local people about the importance of biological diversity and its protection, and to explain that surface waters must not be contaminated by anthropogenic activities. In addition, the discharge of domestic and industrial wastes into rivers must be controlled.

Acknowledgment

This study was supported by the Eskişehir Osmangazi University Scientific Research Projects Committee (Project number: 201819D15).

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