POLLUTION MONITORING FOR AQUATIC ECOSYSTEM INTEGRITY USING BIOTIC INDICES BASED ON MACROINVERTEBRATES: CASE STUDY, TONGA LAKE, NORTH-EAST ALGERIA

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DOI: 10.5281/zenodo.14229339

Abstract. The aim of this study was to estimate the diversity of aquatic macroinvertebrates and evaluate the water quality of Tonga Lake (Algeria). Tonga is about 2,700 ha with an average depth of 1.20 m. It is communicating with the Mediterranean Sea through an artificial channel called Messida. The collection of aquatic macroinvertebrates from the seven stations was carried out in the coastal area from March 2017 to February 2018. For this purpose, we used both physicochemical variables and three biotic indices: 1) the FBI (Family Biotic Index); 2) the BMWP (Biological Monitoring Working Party); and 3) the ASPT (Average Score Per Taxon). The indices were calculated using fauna collected from seven stations along the littoral of Tonga Lake. The fauna recorded in this work is composed of seven orders; the most dominant orders were Heteroptera (24.87%), Diptera (21.41%), followed by Coleoptera (19.39%), Ephemeroptera (17.20%), Basommatophora (13.56%), Odonata (3.46%), and Acari (0.12%). The results also revealed that the BMWP index value classified Tonga Lake as having medium biological quality, while the FBI and ASPT indices classified it as having poor biological water quality.

Key words: Aquatic macroinvertebrates, biotic indices, water quality, Tonga Lake

1. INTRODUCTION

Wetlands are essential for the survival of humanity because of the eco-systematic services that they provide, from water resources to food, passing by the exceptional biodiversity where they are a shelter for many animal and plant species, although these are the most productive ecosystems in terms of biomass (Gillet *et al.*, 2011). Despite the enormous ecological and economic services that they provide, unfortunately, these areas continue to deteriorate or disappear from the Mediterranean basin (Chazée, 2012).

Nowadays, the integrity of wetlands is mainly threatened by drainage for agriculture, urbanization, aquaculture, and pollution (Riservato *et al.,* 2009). Algeria is experiencing serious problems with the degradation of these natural zones. The study of physico-chemical variables is widely used to diagnose problems of water pollution and habitat degradation, but it presents limitations because it only gives information about the environment at the time of sampling (Hébert, 1996). For sustainable management of disturbances in aquatic ecosystems, integrity monitoring systems are developed using aquatic organisms (Hart *et al.*, 1999). Biological monitoring is today the most sensitive tool for rapidly and precisely detecting disturbances in aquatic ecosystems. It refers to the ability of organisms or groups of organisms to reveal by their presence, absence, or their demographic behavior the characteristics and the evolution of an environment (Blandin, 1986). Fish, macrophytes, and bacteria can be used as bio-indicators, but benthic macro-invertebrates are known to be a good indicator of the health of aquatic ecosystems (Djamai *et al.*, 2019) because of their reduced movement capacity, so they cannot change their habitats in cases of natural or anthropogenic stress (Türkmen and Kazanci, 2011). They are widely present, abundant, and easily identifiable (Boissonneault, 2006). They react quickly to any change in their environment (Mimeche *et al.* 2019); they have variable sensitivities to pollution; they have relatively long-life cycles; and they are easy to sample (Boggero *et al.*, 2016). In contrast to chemical analyzers, we can use benthic macroinvertebrates to detect disturbances that occur even if they are no longer present at the time of sampling (Chessman, 1995).

Studies on the diversity of macro-invertebrates focused mainly on lotic ecosystems, while very few works dealt with the macro-invertebrate fauna of lentic freshwater ecosystems. The purpose of this study is to increase knowledge about this fauna. Tonga Lake, which is situated in El Kala National Park, was chosen for this purpose also because all the research has been done on birds and vegetation, but not enough research has been done on macroinvertebrates. This study summarizes the benthic macro-invertebrate data collected from 7 stations and evaluates the water quality by using a multitude of biotic indices.

2. MATERIALS AND METHODS

2.1. Study area

Tonga Lake is a freshwater lake; its geographical coordinates are 36°51.511'N and 8°30.100'E, about 3 km from the Algero-Tunisian border to the east; it is located in the National Park of El Kala through the extreme northeast of Algeria (Fig. 1). The lake has been registered since 1982 on the Ramsar list and it's an integral part of the biosphere reserve (Saifouni 2009), which is one of the most important Ramsar wetland sites in north Africa (Boumezbeur 1993). Tonga is about 2700 ha with an average depth of 1.20m. It's communicating with the sea through an artificial channel called Messida. This area has a Mediterranean climate, characterized by a dry season from May to September and a wet season for the rest of the year, with an annual rainfall of 723mm (Djamai, 2020).

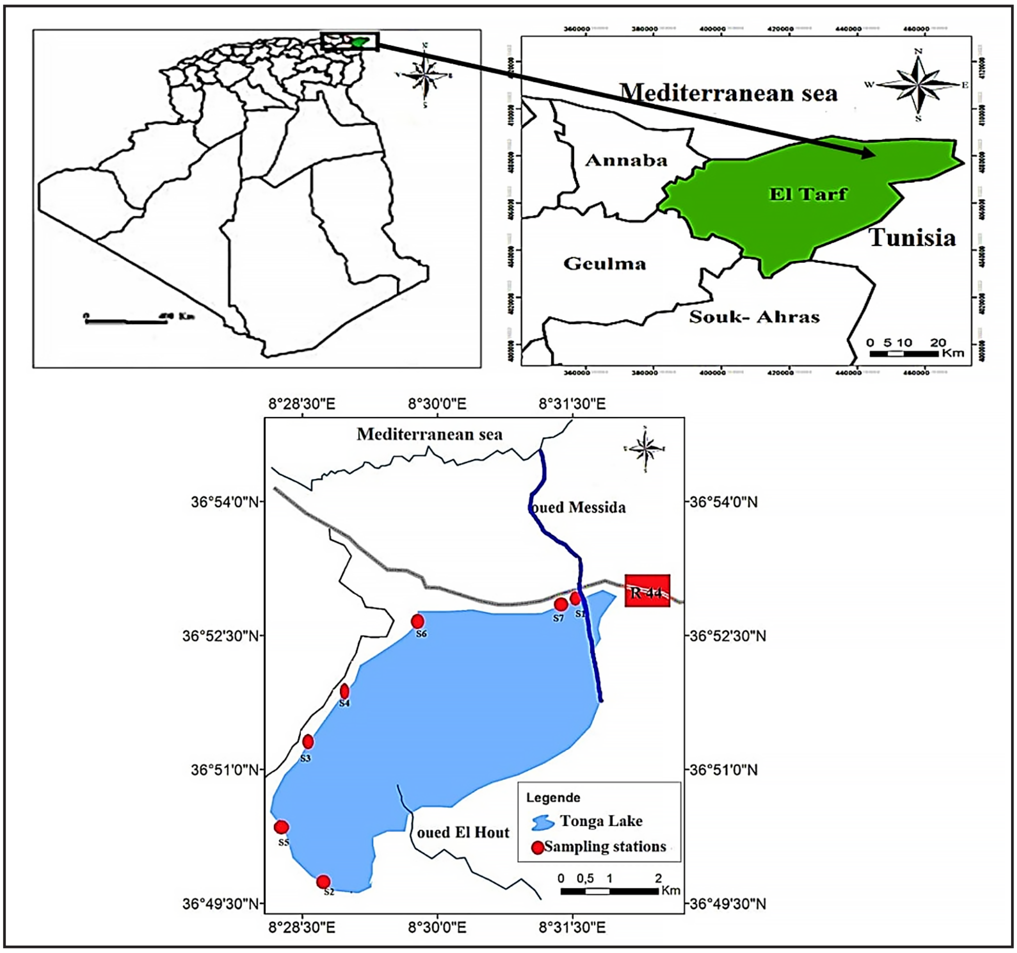

Fig. 1. The sampling stations.

2.2. Sampling method

For each station, air and surface water temperature, pH, conductivity, salinity, and dissolved oxygen in the water were measured in situ immediately after sampling using a multi-parameter device (CONSORT C535). Other variables, NH_4^{+}, NO_3^-, NO_2^-, PO_4^{3-} and biological oxygen demand (BOD), were measured in the laboratory by following the standard methods of AFNOR.

For a more representative sampling, we have chosen seven stations in ways that meet the requirements (site accessibility, presence or absence of urban agglomerations, existence of agricultural activities). The collection of aquatic macro-invertebrates from the seven stations was carried out along the coast from March 2017 to February 2018; three samples were taken at each station using a Haveneau net sampler (0.3 mm mesh), considering the habitat potential where they have been distributed between the vase and the vegetation. The contents of the net, consisting of parts of plants, macro-invertebrates, and a vase, were emptied into a container, and then it was rinsed with water and filtered through a sieve. The captured specimens were collected using flexible entomological forceps and then collected in pill containers filled with 90% ethanol. At the place of sampling, labeling is essential; we mention the date of capture and the sampling station. Samples were taken back to the laboratory for sorting, determination, and analysis.

The identification was done under a binocular loop for large individuals and under a microscope for small parts of the organism, especially to distinguish species of the same family, using the following books, collections, and keys: Freshwater Invertebrates: Systematic, Biology, and Ecology (Tachet *et al.*, 2010), Identification Guide of Freshwater Macro-invertebrates of Spain (Oscoz *et al.*, 2011), and Freshwater Invertebrates in Central Europe (Kriska, 2014).

The data obtained from our sampling were used to assess the water quality of Tonga Lake by using:

The Family Biotic Index (FBI) provides a single tolerance value, which is the average tolerance value of all species within the benthic arthropod community. The FBI was modified to the family level, with tolerance values ranging from 0 (very intolerant) to 10 (highly tolerant) based on their tolerance to organic pollution.

$$FBI = \frac{\sum x_i \times t_i}{n} \quad (01)$$

where:
x_i = number of individuals in the taxon i.
t_i = tolerance value of the i taxon.
n = total number of organisms in the sample.

The family biotic index range of 0 to 3.75 indicates excellent water quality; the range 3.76 to 4.25 shows very good water quality; and good water quality signifies the range 4.26 to 5.00. The range from 5.01 to 5.75 indicates fair water quality; if the index is from 5.76 to 6.50, it signifies fairly poor water quality; 6.51 to 7.25 indicates poor water quality; and a range from 7.26 to 10.00 signifies very poor water quality.

The Biological Monitoring Working Party (BMWP) represents tolerance to pollution by providing a single value at the family level. The greater the tolerance for pollution, the lower the BMWP scores (Mandaville, 2002). The BMWP is one of the most widely used bioassessment indices for assessing the quality of aquatic ecosystems (Ruiz-Picos *et al.* 2017). BWMP was calculated by adding the individual scores of all families and the order Oligochaeta (Friedrich *et al.* 1996). The sensitivity of various insect and other macroinvertebrate families is scored on a scale from 1 to 10, with the highest scores representing species sensitive to organic pollution (Gonçalves and Menezes, 2011).

The Average Score Per Taxon (ASPT) represents the average tolerance score of all taxa within the community. To calculate the ASPT, first we determine the biological monitoring working party (BMWP), and then we divide the BMWP by the number of families represented in the sample (Mandaville, 2002).

$$ASPT = \frac{\text{BMWP Index}}{N} \quad (02)$$

where:
N = number of families present in the sample.

An ASPT score of 6 and above indicates clean water quality; an ASPT score of 5.00 to 5.99 indicates doubtful water quality; a score of 4.00 to 4.99 indicates probable moderate pollution present on the site; and a score below 3.99 indicates that the water suffers from severe pollution.

3. RESULTS

3.1. The physicochemical quality of the water

The analyses of the physico-chemical parameters of water were carried out in parallel with the samples of benthic fauna (Table 1). In all, 11 parameters were the subject of our study, and the results of the analyses obtained during the study period are represented in the table below.

3.2. Macroinvertebrate composition

Following the taxonomic determination made in the laboratory, a faunistic list of macroinvertebrates was established. The results for each station are presented in Table 2.

The analysis of the captured macroinvertebrates shows that only 0.12% of the total fauna belongs to the Arachnida class, 13.56% to the Gastropods class, and the insect class constitutes 6.82%. The most abundant order was Heteroptera (24.87%), Diptera (21.41%), and Coleoptera (19.39%), when Ephemeroptera, Basommatophora, Odonata, and Acarina were respectively 17.20%, 13.56%, 3.46 %, and 0.12%.

Table 1. The physico-chemical quality of the water of the seven stations in Lake Tonga.

Variables	S1	S2	S3	S4	S5	S6	S7
	Mean ± SD (Min-Max)	Mean ± SD (Min-Max)	Mean ± SD (Min-Max)	Mean ± SD (Min-Max)	Mean ± SD (Min-Max)	Mean ± SD (Min-Max)	Mean ± SD (Min-Max)
T°C Water	24.5 ± 2.07 (21.9; 26.6)	29.72±6.51 (22.7; 37.4)	26.2±3.38 (22.4; 28.9)	23.77±1.53 (22.5; 25.9)	23.18±1.92 (21.2; 26)	28.25±0.35 (28; 28.5)	25.84±5.60 (19.2; 31)
T° air	20.3±7.18 (12.4; 28.7)	33.276±2.25 (30.9; 35.88)	24.1±0.95 (23.5; 25.2)	26.65±3.53 (23.6; 30)	23.14±4.80 (17.8; 32)	22.25±0.49 (21.9; 22.6)	24.4±2.08 (21.4; 26.9)
pH	8.26±0.65 (7.23; 8.8)	8.22±0.77 (7.2; 9.49)	7.6±0.71 (6.83; 8.39)	7.5±0.46 (7; 8.1)	8.14±1.02 (6.68; 9.19)	8,25±0,33 (7.87; 8.5)	7.44±0.74 (6.8; 8.88)
EC (µS/cm)	509.2±245.06 (113; 754)	690±346 (124; 974)	431±178 (225; 535)	480± 333.43 (208; 920)	410± 143 (231; 590)	410± 427 (108; 713)	514±219 (311; 731)
O_2 (mg/l)	8.50±0.61 (6.76; 13.02)	7.32±0.59 (5.43; 10.42)	8.71±0.69 (6.73; 13.22)	9.32±0.66 (7.40; 13.32)	6.89±0.21 (5.64; 7.70)	8.17±0.57 (6.37; 12.17)	7.74±0.46 (6.02; 10.36)
NO_3 (mg/l)	4±1.63 (0; 16)	1.25±0.4 (0; 4)	4.30±2.67 (0; 26)	4.73±2.09 (0; 18)	6.10±2.22 (0; 25)	6.55± 1.92 (2; 25)	5.60±0.58 (3; 8)
NO_2 (mg/l)	0.08±0.03 (0; 24)	0.05±0.02 (0; 20)	0.14±0.07 (0.01; 0,61)	0.06± 0.02 (0; 22)	0.08±0.02 (0.01; 0,23)	0.11±0.02 (0.01; 0.23)	0.03±0.01 (0; 0.09)
NH_4 (mg/l)	0.13±0.09 (0; 0.86)	0.12±0.04 (0; 0.36)	0.28±0.20 (0; 2.05)	0.30±0.20 (0; 1.94)	0.39±0.29 (0; 2.25)	0.40±0.25 (0; 2.25)	0.03±0 (0.02; 0.04)
PO_4 (mg/l)	0.01±0 (0; 0.03)	0.01±0.1 (0; 0,04)	0.06±0.05 (0; 0.46)	0.03±0.01 (0; 0.17)	0.05±0.05 (0; 0.53)	0.05±0.06 (0; 0.53)	0.01±0 (0; 0.02)
BOD5 (mg/l)	2.11±0.54 (1; 6)	2.30±0.42 (1; 5)	2.90± 0.80 (1; 8)	2.27±0.59 (1; 7)	2.55±0.93 (1; 10)	3±0.90 (1; 10)	2.20±0.25 (1; 3)
COD (mg/l)	25.44±2.63 (18; 35)	29.90±3.48 (18; 44)	28.10±3.40 (18; 53)	22.27±3.05 (10;44)	25.27±4.33 (10; 53)	31.18±3.81 (18; 53)	26.20±1.79 (18; 35)

Acronyms: SD: standard deviation; **Max:** Maximum; **Min:** Minimum; **T:** temperature; **EC:** electrical conductivity; **pH:** hydrogen potential; **OD:** dissolved oxygen; **NO_3:** nitrates; **NO_2:** nitrites; **NH_4:** ammonium; **PO_4:** orthophosphates; **BOD5:** biochemical oxygen demand; **COD:** chemoxygen demand.

Table 2. The diversity of macroinvertebrates found at Lake Tonga.

Branch	Class	Order	Family	S1	S2	S3	S4	S5	S6	S7
Arthropoda	Insecta	Diptera	Culicidae	*	*	*	*	*	*	*
			Chironomidae		*		*			*
			Ephydridae		*					
			Dixidae		*		*			
			Chaobridae		*	*				*
		Heteroptera	Pleidae	*	*	*	*		*	*
			Corixidae		*	*	*	*	*	*
			Notonectidae			*		*		
			Naucoridae	*	*	*	*	*	*	*
		Odonata	Lestidae			*				*
			Libellulidae				*	*		
			Coenagrionidae		*	*		*		*
			Aeshnidae		*	*				*
			Calopterygidae	*						
		Ephemeroptera	Baetidae	*	*		*	*	*	*
			Siphlonuridea		*	*				
			Caenidae	*				*	*	*
		Coleoptera	Dytiscidae	*	*	*	*	*	*	*
			Hydrophilidae		*	*	*	*	*	*
			Hydrochidae	*		*	*	*		*
			Hylophoridae		*			*	*	*
			Haliplidae					*		
			Elmidae			*		*	*	*
			Hydraenidae		*	*		*	*	*
			Gyrinidae					*		
			Hygrobidae				*			
	Arachnida	Acarina	Hydrachenellae				*		*	
Mollusca	Gastropoda	Basommatophora	Physidae	*	*	*	*	*	*	*
			Liminidi	*						
			Planorbidae	*	*	*	*		*	*

3.3. The Family Biotic Index (FBI)

It is used to indicate a disturbance in the aquatic ecosystem on a scale of 1 to 10 based on the communities of macroinvertebrates present and according to their tolerance to pollution (Table 3). In the present study, a comparison of the FBI across stations showed that the higher FBI value found at station 3 indicates very poor water quality, followed by stations 4 and 6 with poor quality due to the presence of very tolerant taxa such as Diptera. The high pollution in these stations was due to the impacts of anthropogenic activity, in particular the application of synthetic fertilizers and pesticides in agriculture and domestic waste. The FBI of the other stations ranged from 5.69 to 6.63, which indicates fairly poor to poor water quality.

3.4. The Biological Monitoring Working Party (BMWP)

The BMWP is one of the most widely used bioassessment indices for assessing the quality of aquatic ecosystems (Ruiz-Picos 2017). It is a scale from 1 to 10, according to which the sensitivity of different families of insects and other macroinvertebrates is noted. The sum of the scores of the different taxa found on a site is therefore a total score, making it possible to classify this sampling site in one of the five water quality classes (Benetti *et al.* 2012). The values of the used index are mentioned in Table 4. The BMWP index showed that the highest values belonged to the third station with a score of 75, while the lowest values belonged to the first station with a score of 46, and stations S2, S4, S5, S6, and S7 with scores of 71, 48, 57, 50, and 73, respectively.

Table 3. The biological quality assessment of Tonga Lake using the FBI index.

Families	FBI								
	Tolerance Values	S1	S2	S3	S4	S5	S6	S7	Tonga Lake
Culicidae	8	1.29	2.08	2.47	3.14	0.68	2.35	0.4	6.53
Chironomidae	10	0	1.38	0	0.21	0	0	0.17	
Ephydridae	6	0	0.02	0	0	0	0	0	
Dixidae	1	0	0.01	0	0.01	0	0	0	
Chaobridae	8	0	0.02	0.21	0	0	0	0.13	
Corixidae	5	0	0.71	0.03	0.05	0.1	0.07	0.42	
Lestidae	6	0	0	0.04	0	0	0	0.05	
Libellulidae	9	0	0	0	0.28	0.03	0	0	
Coenagrionida	9	0	0.34	0.06	0	0.03	0	0.08	
Aeshnidae	3	0	0.02	0.02	0	0	0	0.65	
Calopterygidae	6	0	0	0	0	0	0	0	
Baetidae	6	2.95	0.51	0	1.85	0.72	2.12	0.5	
Siphlonuridea	4	0	0.67	0.03	0	0	0	0	
Caenidae	7	0.18	0	0	0	0.03	0.41	0.41	
Dytiscidae	5	0.64	0.15	0.13	0.08	1.12	0.37	0.25	
Hydrophilidae	5	0	0.34	0.34	0.05	1.56	0.44	0.13	
Haliplidae	5	0	0	0	0	0.27	0	0	
Elmidae	5	0	0	0.1	0	0.15	0.15	0.08	
Gyrinidae	4	0	0	0	0	0.02	0	0	
Physidae	8	0.68	0.35	3.87	0.7	1.11	0.47	0.93	
Lymnaeidae	6	0.1	0	0	0.03	0	0	0.75	
Planorbidea	6	0.41	0.02	0.2	0.49	0	0.18	0.75	
Total		**6.39**	**6.63**	**7.5**	**7.14**	**5.83**	**6.56**	**5.69**	

Table 4. The biological quality assessment of Tonga Lake using the BMWP index.

Families	Tolerance Values	BMWP							
		S1	S2	S3	S4	S5	S6	S7	Tonga Lake
Culicidae	2	*	*	*	*	*	*	*	
Dixidae	4		*		*				
Chironomidae	2		*		*			*	
Pleidae	5	*	*	*	*		*	*	
Corixidae	5		*	*	*	*	*	*	
Notonectidae	5		*		*				
Naucoridae	5	*	*	*	*	*	*	*	
Lestidae	8			*				*	
Libellulidae	6			*	*	*			
Coenagrionidae	6		*	*		*		*	
Aeshnidae	6		*	*				*	
Calopterygidae	8	*							
Baetidae	4	*	*		*	*	*	*	**60**
Siphlonuridea	10		*	*					
Caenidae	7	*				*	*	*	
Dytiscidae	3	*	*	*	*	*	*	*	
Hydraenidae	5		*	*		*	*	*	
Hydrophilidae	3	*	*	*	*	*	*	*	
Elmidae	5			*		*	*	*	
Gyrinidae	3					*			
Physidae	3	*	*	*	*	*	*	*	
Liminidi	3	*			*			*	
Planorbidea	3	*	*	*	*		*	*	
BMWP		**46**	**71**	**75**	**48**	**57**	**50**	**73**	

When the biotic index was examined in terms of water quality classes, stations S1 and S4 were determined to be polluted with poor quality, while stations S2, S3, S5, S6, and S7 had medium water quality.

3.5. The Average score per taxon (ASPT)

We notice that the ASPT values varied from 5 to 3.4; a comparison across the stations showed that the lowest ASPT found at station 4 is 3.4, indicating probable severe pollution, and the highest is 5 at station 3, indicating doubtful biological quality; stations S1, S6, with a score of 4.2; station 7 with a score of 4.3; and stations S2, S5, with a score of 4.4, which indicated probable moderate pollution (Table 5).

4. DISCUSSION

The physico-chemical analysis of the water reveals that the seven stations have an almost similar hydrology; the samples were collected at a temperature between a minimum of 23 °C in station 4 and a maximum of 29 °C in station 2. Lake Tonga's water is slightly alkaline. The PH values show very low fluctuations; they are generally varying between 8.25 in station 1 and 7.44 in station 7. The conductivity oscillates between extreme values ranging from 690 µs/cm to 410 µs/cm. The highest values are recorded in station 2.

The minimum value (410µs/cm) was recorded at stations 5 and 6. The salinity presents values varying between 3.47g/l and 1.74g/l, which places them in the very salty to salted category.

Table 5. The biological quality assessment of Tonga Lake using the ASPT index.

Stations	ASPT	Water Quality Assessment
S1	4.2	Probable moderate pollution
S2	4.4	Probable moderate pollution
S3	5.0	Doubtful biological quality
S4	3.4	Probable severe pollution
S5	4.4	Probable moderate pollution
S6	4.2	Probable moderate pollution
S7	4.3	Probable moderate pollution
Tonga Lake	4.3	Probable moderate pollution

The dissolved oxygen rates vary between a minimum of 6.89 mg/1 at station 5 and slightly increasing to reach a maximum value of 9.32 mg/1 at station 4. The Lake has a slight variation in nitrate contents between stations; they are between the minimum values of 1.25 mg/l recorded at the S2 station and the maximum value found at the S6 station with 6.55 mg/l, but they remain lower than the eligible value by Algerian standards. This is the same for the results concerning nitrites except at the level of the two S3 and S6 stations with values higher than those of the nitrogen water quality grid, which illustrates notable pollution in these places. The evolution of ammoniacal nitrogen contents is almost similar at all stations. According to the classification of the ANRH (2000), the values of $NH4^+$ recorded in all stations except for station 7 show significant pollution. This observation is also confirmed by the analysis of the phosphorus concentration, where the waters conceal notable pollution.

Biological monitoring is defined as "the systematic use of living organisms or their responses to determine the condition or changes of the environment" (Sedeño-Díaz and Bert, 2012), which is an effective tool to assess the biological quality of water surfaces. Biological water quality assessments use biotic indices, which they are numeric expressions that classify water quality based on the ecological sensitivity of the taxa present and the richness of the taxa (Zeybek *et al.*, 2014). To evaluate the health of aquatic ecosystems, these biotic indices constitute good tools because the distributions of bioindicator taxa are influenced by many factors, such as hydrological characteristics, accessibility to food, substrate type, nutrient supply, predation pressure, natural or anthropogenic perturbations, and variation in water quality itself (Allan, 1995; Buss *et al.*, 2004).

Generally, undegraded water bodies support a variety of living community. With an increase in anthropogenic disturbances, the abundance of pollution-tolerant taxa increases while the abundance of the most sensitive taxa decreases. These changes lead to instability in the structure of the community, which generally results in a reduction in the integrity of the aquatic ecosystem (Djamai, 2020). Among the most popular indicators used in biotic indices are macroinvertebrates, due mainly to their low cost and ease of sampling, relatively easy identification, large size, and long-life cycles (Suleiman and Abdullahi, 2011; Kripa *et al.,* 2013; Rodrigues *et al.,* 2016).

The study of the hydrobiological quality of Tonga Lake was conducted using several biotic indices. The family biotic index across the station ranged between 5.69 and 7.5, which indicates poor to very poor water quality. An average of all the scores among the stations represented the quality of Tonga Lake with a score of 6.53. If we examine this score in terms of water quality class, we can conclude that the lake has poor water quality. The surface water is susceptible to contamination by many kinds of pollutants from anthropogenic activity. In fact, the use of synthetic fertilizer and pesticides by farmers to increase food productivity has negative impacts on the environment (Kartikasari, 2013).

The ASPT index of the studied stations ranged between 3.4 to 5, which indicates probable severe pollution and doubtful biological quality. The average score of all the stations shows a value of 4.3; in terms of quality, this indicates that the lake is included in the category of moderate pollution. The result of the ASPT index saves the result of the FBI index. This was due to the deterioration of water quality as a result of the agro-activities next to the studied stations. Comparing with physicochemical analyses, the BWMP is easy to apply and has greatly reduced costs, which can require sample processing in laboratories (Uherek and Pinto Gouveia, 2014). In our study, Tonga Lake has a score of 60, which indicates medium water quality. It is now inferred that Lake Tonga would have medium to poor quality.

The indices show the same fluctuations at the same station, but despite this, they have different qualities. The difference between the indices could be explained by the quality class levels and the categorization systems being limited by different values. The ASPT quality classes have 4 levels, the BMWP quality classes have 5 levels, and the FBI quality classes have 7 levels.

5. CONCLUSION

The macroinvertebrates are a very heterogeneous taxonomic group, and biological monitoring of this group is now the most sensitive tool for quickly and accurately detecting disturbance in aquatic ecosystems.

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