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RESEARCH ARTICLE

EVALUATION OF MULTI-ASSEMBLAGE METRICS AND TEMPERATE INDICES AS INDICATORS OF HUMAN IMPACT IN LAKE ZIWAY, ETHIOPIA

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ABSTRACT: Lake bioassessment is routinely done using one biological community such as macro-invertebrates, diatoms, macrophytes or fish. The use of at least two assemblages has been suggested as they are believed to be more robust indicators, because each community responds differently to potential stressors in waters. This study aimed to use macroinvertebrate and diatom assemblages to identify metrics and temperate indices that could discriminate between reference and impacted sites of the littoral zone of Lake Ziway, Ethiopia. The Lake Habitat Quality Assessment (LHQA) method was used to categorize the sites in the littoral zone of the lake. Lake water, macroinvertebrate, and diatom samples were collected from 3 reference and 6 impacted sites between September 2015 and April 2016 with standard methods and following the Ontario Benthos Biomonitoring Protocol. A total of 34 macroinvertebrate taxa and 39 diatom species were recorded. 32 macroinvertebrate and 18 diatom indices were tested for their ability to discriminate between the reference, intermediate and multiple-stressed sites using correlations between metrics, similarity values with SIMPER and box-plots overlaps. Further, correlation of the metrics with physico-chemical parameters extracted metrics and indices with high discrimination efficiency (≥ 3). The indices remaining were 5 macroinvertebrate (NT, PTI, PETI, PDT and CLI) and 4 diatom (CEE, PTV, TDI, and IBD) indicators which clearly discriminated between the impacted (intermediate and multiple stressors) and reference sites, but not within the impacted sites, in the lake. These data can also possibly serve as core metrics for multi-assemblage index development for this shallow, tropical lake.

Key words/phrases: Diatom, Discriminatory efficiency, Lake bioassessment, Macroinvertebrate, Multi-assemblage, Omnidia, SIMPER.

INTRODUCTION

Water resources are globally affected by a complex mixture of stressors. Understanding how stressors interfere upon ecosystem services is essential for developing effective management plans (Hering *et al.*, 2006; 2015).

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Most lake monitoring programs document physical and chemical attributes (Coffey and Smolen, 1990), but accurate assessment of water quality requires examination of physical, chemical, and biological components of the ecosystem (Barbour *et al*., 1996; 1999; Jones *et al*., 2007). Therefore, to have meaningful monitoring and management plans, it is recommended to assess the physical, chemical and biological status of the aquatic ecosystems.

Bioassessment of lakes is based on evaluating phytoplankton, phytobenthos, invertebrates, and fish composition and diversity between reference and impaired sites (Delgado *et al*., 2010). Methods to assess the phytobenthos has largely focused on diatoms which form a large part of the algal diversity in freshwaters (Kelly *et al*., 2016), whereas macroinvertebrates have been frequently used in the assessment of rivers (Hering *et al*., 2006). Using macroinvertebrates as indicators of water quality has been getting much attention in tropical countries recently as well as in Ethiopia, although the emphasis has been on lotic systems. In Kenya, Raburu *et al*. (2009) developed IBI for some rivers while Getachew Beneberu (2013) developed IBI for rivers in Ethiopia. Solomon Akalu *et al*. (2011) and Aschalew Lakew and Moog (2015) used macroinvertebrate based biotic scores for the assessment of the health condition of rivers but limited effort was done to use macroinvertebrates and diatoms together for the water quality assessment in Ethiopia, as for instance, Abebe Beyene *et al*. (2009) on Kebena and Akaki rivers. For Lake Ziway, Abnet Woldesenbet and Seyoum Mengistou (2018) reported on the distribution of macroinvertebrate taxa in relation to abiotic factors and habitat quality in the lake.

Since different biological assemblages are sensitive to different impacts related to diversity, life cycle, mobility, and position in the food web (Barbour *et al*., 1999; Mandaville, 2002), use of multiple biological assemblages can enhance the ability to detect different ecological impairments (Karr and Chu, 1999; Solimini *et al*., 2006). Some workers have even suggested the use of at least two assemblages for bioassessment (Yoder and Rankin, 1995) because each assemblage may respond differently to potential stressors. Lake bioassessment has benefitted from multi-biotic indicators and metrics that have been developed from such assemblages (e.g. O'Connor *et al*., 2000). The diversity and abundance of the assemblages may even detect changes in the relative disturbance of ecosystems, especially when the pressure-response relationships are better understood (Brucet *et al*., 2013).

Since the start of this century, many indices have been developed for temperate water bodies to assess water quality conditions and ecological perturbations (Yoder and Rankin, 1995; Barbour *et al.*, 1999). However, studies on the application and suitability of such indices to monitor ecological changes in tropical systems have been limited. Recently, Tarekegn Wondimagegn *et al*. (2019) tested the applicability of European diatom indices for biomonitoring in the tropical Lake Hawassa, and reported that two indices, TDI (Trophic Diatom Index) and IDG (Generic Diatom Index) had the potential to successfully discriminate between test sites in the lake. Clearly, more of such indices need to be tested, and especially, the extension of research into the multimetric indices and multi-assemblage metrics need to be continued, which is one contribution of this study.

This study aimed to evaluate which taxa of macroinvertebrate and diatoms are predominant, and hence can discriminate, between littoral zone of Lake Ziway, exposed to intermediary and multiple stressors. We also tested the suitability of temperate indices to discriminate between reference and impaired sites in the lake. The main research question we wanted to address was whether multi-assemblage indicators can easily discriminate between the ecological condition of reference and non-reference (intermediate and multiple) sites in this large, shallow tropical lake.

MATERIALS AND METHODS

The study area

Lake Ziway is one of the freshwater Rift Valley Lakes of Ethiopia (RVLE). It is between (7° 52′ to 8° 8′ N latitude and 7° 52′ to 38° 56′ E longitude). It is 31 km long and 20 km wide, it has a maximum depth of 9 metres and an average depth of 2.5 metres, is at an altitude of 1636 m above sea level and with a surface area of 434 km^2 (Abnet Woldesenbet and Seyoum Mengistou, 2018). Lake Ziway is fed primarily by two rivers, Meki from the west and Ketar from the east, and is drained by the Bulbula River which empties into Lake Abijata. The town of Batu lies on the lake’s western shore and most of the human-induced pressures are from this direction (Fig. 1).

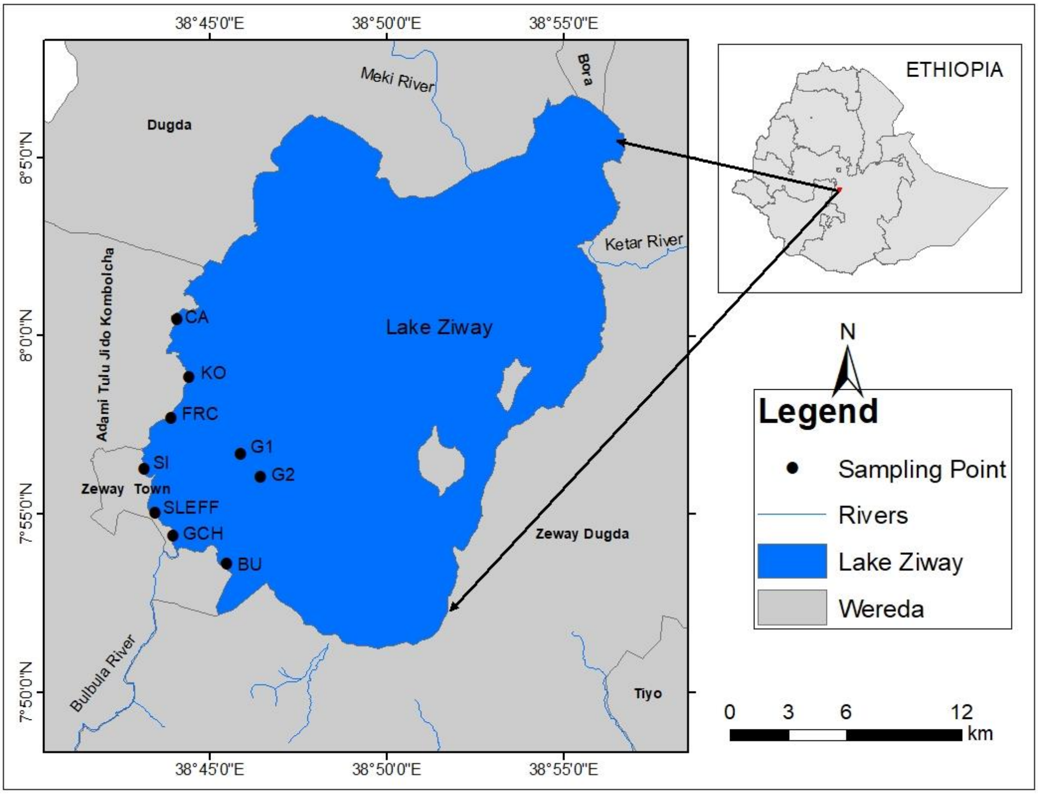

Fig. 1. Map of Lake Ziway showing the lake segment study sites at the western shore.

Selecting reference and non-reference (impacted) sites

The study sites were categorized into different human disturbance gradient using Lake Habitat Quality Assessment (LHQA) methods. The standard 300 meter length of riparian and 20 meter transect of littoral zone was used to record the habitat information following the Ontario Benthos Biomonitoring Protocol Manual (Jones *et al.*, 2007). The Reference Condition Approach (RCA) bio-assessment and a visual-based habitat assessment were implemented to identify reference and non-reference (impacted) sites, as per the recommendation of Rowan *et al.* (2006). Impacted sites were classified only into 2 categories - intermediate and multiple stressors because the focus of this study was not on stressor-specific indicators.

Physico-chemical variables

Dissolved oxygen, pH, temperature, and conductivity were measured *in situ* using a portable digital multi-parameter probe (Model HQ9012 HACH

Instruments) at the end of the month during the study period between September 2015 and April 2016 at each sampling visit. Water samples were collected from each site to analyze for nitrate, nitrite, ammonium, silicon dioxide, soluble reactive phosphorus, and total phosphorus at 0.5 m depth using a one-litre plastic bottle. Analysis of nutrients was done using spectrophotometric method. Nitrate was measured with sodium salicylate method, ammonium with indophenol blue method (APHA, 1995), silica with molybdosilicate method, soluble reactive phosphorus and total phosphorus with ascorbic method (APHA, 1999). The concentration of nitrite was determined by the reaction between sulfanilamide and N-naphthyl-(1)-ethylenediamine-dihydrochloride (APHA, 1995).

Benthic macroinvertebrates sample collection and identification

On the representative lake segments, three replicates with transects were established based on the method outlined in Jones *et al*. (2007). Sampling was done from the water edge to a distance of 20 metres with the multi-habitat approach. A 500 µm mesh D-frame traveling kick (30 x 28 cm in diameter) net was employed. Macroinvertebrate samples were collected actively by physical disturbance of the bottom for 10 minutes in each transect. When 100 animals were collected from the transects, sampling was interrupted and the replicate samples were composited and preserved with 10% buffered formalin. The preservative was replaced with 70% ethanol to prevent hard body parts from dissolving as per the recommendation of Barbour *et al*. (1996; 1999). Macroinvertebrate samples were identified and counted under a dissecting microscope. Taxonomic identification was made to family level using standard keys (Gerber and Gabriel, 2002; Bouchard, 2004).

Benthic diatoms sample collection and processing

Epilithic diatom samples were collected from the upper surface of a cobble (an area of 25 cm^2) with the aid of a toothbrush in a white plastic tray according to Kelly *et al*. (1998). Samples, were preserved with 20% ethanol, diatom frustules were cleaned with concentrated sulfuric acid and acid-cleaned samples were washed with distilled water. Cleaned diatom frustule samples were mounted on permanent slides using Naphrax mounting medium (refractive index 1.73). Diatom frustules were examined with Nikon Eclipse 80i light microscope at 1000x magnification, under oil immersion objective, identified to species level with standard identification manuals and publications (Gasse, 1986; Kelly, 2000; Krammer and Lange-Bertalot, 2000; Krammer, 2003; Taylor and Cocquyt, 2016). Diatom valves were counted using OptiCount and the total count of 400 cells were examined in random microscope fields to determine the relative abundance of each taxon as recommended by Prygiel *et al*. (2002), Diatom analysis was done at North-West University, South Africa.

Metrics and/or indices selection

Several metrics and indices used in the literature (mostly for temperate water bodies) were coded and considered as potential metrics (Table 1). Macroinvertebrate abundance data were used to calculate 32 metrics, and diatom abundance data were used to calculate 18 indices. Biodiversity professional, version 2 and OMNIDIA v.5.3 (Species list version 2009; Lecointe *et al*., 1993) were used to calculate macroinvertebrate and diatom indices, respectively. PAST software v.2.17 was used to calculate the diversity indices. Four metrics were calculated based on the reference diatom and invertebrate taxa: (1) relative abundance (ARSI), (2) richness (RRS), (3) the ratio of reference taxa to the total taxa expressed as percentages of abundance (PARS) and (4) richness (PRRS). The selected metrics and indices were obtained after several tests of elimination based on ecological principles and autecological data.

Table 1. Codes of the macroinvertebrate metrics and indices considered in this study (after several authors).

TNI	Total Number of Individuals .
NT	Number of Taxa (Family) .
NEI	Number of Ephemeroptera Individuals .
NTI	Number of Trichoptera Individuals .
NETT	Number of Ephemeroptera and Trichoptera Taxa .
NETI	Number of Ephemeroptera and Trichoptera Individuals
NOI	Number of Oligochaeta Individuals .
NCI	Number of Chironomidae Individuals .
NDI	Number of Diptera Individuals .
NTTI	Number of Tolerant Taxa Individual.
NITI	Number of Intolerant Taxa Individual .
PEI	% Ephemeroptera Individuals .
PTI	% Trichoptera Individuals
PETI	% Ephemeroptera and Trichoptera Taxa Individuals .
PDI	% Diptera Individuals .
PCOI	% Chironomids and Oligochaeta Individuals
PDT	% Dominant Taxa
PToI	% Tolerant Individuals .
PII	% Intolerant Individuals .
ET/C	Ephemeroptera and Trichoptera /Chironomidae Ratio .
TC/TI	Total Chironomidae/Total Individual Ratio .
MI	Margalef's Index .
H'	Shannon Diversity Index .
D	Dominance Index
FBI	Family Biotic Index .
NETO	Number of Ephemeroptera, Trichoptera and Odonata families .
IBI	Index of Biological Integrity .

CLI	Community Loss Index
ART	Abundance of Reference Taxa Individuals
RRT	Richness of Reference Taxa
PARTI	% Abundance of Reference Taxa Individuals
PRRT	% Richness of Reference Taxa

Table 2. Codes of the diatom metrics and indices tested in this study (after several authors).

CEE	Commission for Economic Community
DESCY	Descy’s pollution metric
EPID	Pollution metric based on diatoms
IBD	Biological Diatom Index
IDAP	Indice Diatomique Artois Picardie
IDP	Pampean Diatom Index
IDSE	Diatom Index of Saprobity-Eutrophication
IPS	Specific pollution Sensitivity Index
PTV	Percent of Pollution tolerant valves
SID	Saprobic Index
SHE	Steinberg and Schiefele trophic
SLA	Sladecek’s pollution index
TDI	Trophic Diatom Index
WAT	Watanabe Index
NRSI	Number of reference species individuals (PS)
RRS	Richness of reference species (PS)
PARS	Percentage abundance of reference species individuals (PS)
PRRS	Percentage richness of reference species (PS)

(Note: PS: Present Study)

Data analysis

Relationships between the environmental variables and biological (diatom and macroinvertebrate) data were evaluated with the Spearman correlation test using SPSS version 20 software program. The SIMPER analysis (Similarity Percentage) was used to estimate similarity between the reference and non-reference samples. Discriminatory efficiencies were judged to evaluate the most suitable metrics/indices that discriminate between the reference and non-reference sites, by examining their distributions using box-and-whisker plots with Sigma Plot 10.0 (Fig. 2 and Fig. 3) and discrimination sensitivity values by correlations with physico-chemical parameters (Tables 3 and 4).

RESULTS AND DISCUSSION

Metrics and/or indices selection

Macroinvertebrate metrics selection

The metrics TNI, NITI, NEI, NETI, NTI, NETT, PTI, NETO, NCI, H′, MI, PEI, and PII were excluded due to their high correlation with others such as PETI, NT, IBI, PDT, PTI, NTTI, PToI, CLI, FBI, PART, and PRRT. For example, NETI was strongly correlated with TNI and NITI (r = 0.845 and

0.993 respectively), IBI with NEI and PETI (r = 0.936 and 0.936, respectively). NDI was strongly correlated with NCI (r = 1.000), PTI was strongly correlated with NTI (r = 0.949), and PDT was strongly correlated with TNI (r = 0.801). D, TC/TI, ET/C, PCOI, and PDI were excluded because they were not strongly correlated with the physicochemical variables (Table 3). The other metrics were selected based on the discrimination efficiency values ≥2: NT, PETI, PTI, IBI, PDT, and CLI. From metrics developed based on the reference taxa, PART and PRRT were selected due to their strong correlation with the physicochemical variables and their higher discriminatory efficiency (Table 3).

Table 3. Spearman correlation among macroinvertebrate metrics and physico-chemical variables, and metrics discrimination sensitivity values (** significant correlation at the level of 0.01 and * at the level of 0.05).

Metrics	**Temp.**	**DO**	**pH**	**EC**	**NO_{3-}**	**PO_4^{3-}**	**TP**	**Sensitivity value**
TNI	-0.168	-0.246*	0.063	-0.364**	0.276**	0.146	0.353**	1
NT	-0.320**	-0.009	0.178	-0.388**	-0.061	0.184	0.293**	3
NEI	-0.219*	-0.230*	0.017	-0.377**	0.125	0.189	0.325**	1
NTI	-0.252*	0.053	0.069	-0.126	-0.342**	0.107	0.083	2
NETT	-0.312**	0.134	0.198	-0.214*	-0.274**	0.019	0.068	2
NETI	-0.219*	-0.230*	0.017	-0.377**	0.125	0.189	0.325**	2
NOI	-0.051	-0.245*	-0.246*	0.204*	-0.215*	-0.214*	-0.228*	2
NCI	-0.139	-0.353**	0.011	-0.328**	0.252*	0.207*	0.368**	1
NDI	-0.139	-0.353**	0.011	-0.328**	0.252*	0.207*	0.368**	2
NTTI	-0.046	-0.224*	0.004	-0.125	0.278**	-0.104	0.082	1
NITI	-0.251*	-0.223*	0.042	-0.401**	0.096	0.195	0.343**	1
PEI	-0.203*	-0.098	0.034	-0.307**	-0.013	0.189	0.245*	2
PTI	-0.223*	-0.024	0.039	-0.128	-0.254*	0.117	0.096	3
PETI	-0.266**	-0.149	0.017	-0.328**	-0.057	0.153	0.219*	3
PDI	-0.022	-0.078	0.026	-0.065	-0.050	0.122	0.132	1
PCOI	-0.110	-0.053	-0.011	0.004	-0.227*	0.098	0.060	0
PDT	0.138	0.435**	0.064	0.318**	-0.332**	-0.115	-0.306**	3
PTI	0.223*	0.127	-0.044	0.341**	0.004	-0.156	-0.237*	2
PII	-0.223*	-0.127	0.044	-0.341**	-0.004	0.156	0.237*	2
ET/C	-0.143	-0.066	-0.034	-0.187	0.067	0.112	0.111	2
TC/TI	-0.016	-0.072	0.043	-0.078	-0.030	0.139	0.161	1
MI	-0.364**	0.063	0.220*	-0.368**	-0.126	0.177	0.260*	0
H′	-0.276**	-0.299**	-0.017	-0.359**	0.085	0.150	0.247*	1
D	-0.001	0.136	0.121	0.015	0.089	-0.113	-0.061	0
FBI	0.197	0.228*	-0.040	0.388**	-0.108	-0.171	-0.315**	2
NETO	-0.271**	0.076	0.142	-0.237*	-0.338**	0.118	0.168	2
IBI	-0.300**	-0.223*	0.000	-0.355**	0.007	0.144	0.250*	3
CLI	0.317**	0.117	-0.144	0.385**	-0.024	-0.232*	-0.322**	3
ARTI	-0.265**	0.025	0.152	-0.314**	-0.231*	0.225*	0.301**	3
RRT	-0.357**	0.095	0.204*	-0.326**	-0.151	0.113	0.150	3
PART	-0.357**	0.095	0.204*	-0.326**	-0.151	0.113	0.150	3
PRRT	-0.288**	0.021	0.119	-0.294**	-0.257*	0.195	0.256*	3

Diatom metrics/indices selection

The indices CEE, DESCY, and EPID were excluded due to their high correlation coefficient with other indices such as IBD, IPS, and TDI. The CEE was strongly correlated with IBD (r = 0.72), DESCY with IPS (r = 0.81), and EPID with IPS (r = 0.86). Similarly, DESCY was strongly correlated with TDI (r = 0.81), and EPID was more strongly correlated with TDI (r = 0.83). IDAP, IDSE, SLA, and WAT indices were excluded because they were not strongly correlated with physico-chemical variables (Table 4). The other diatom metrics were selected based on the discrimination efficiencies value ≥ 2: IBD, IPS, CEE, SHE, PTV and TDI (Table 4). From the metrics developed based on the diatom reference species, PARS and PRRS were selected due to their higher discriminatory efficiency (Table 4).

Table 4. Spearman correlation among diatom metrics/indices and physicochemical variables and indices discrimination sensitivity values (** significant correlation at the level of 0.01; * at the level of 0.05).

Metrics/ Indices	**Temp.**	**pH**	**EC**	**NO_3 -**	**PO_4^{3-}**	**TP**	**Sensitivity value**
CEE	-0.180	-0.039	-0.228*	0.029	0.057	0.207*	3
DESCY	-0.327**	-0.080	-0.294**	0.170	0.106	0.197	1
EPID	-0.237*	-0.083	-0.161	-0.221*	0.111	0.117	1
IBD	-0.257*	0.082	-0.346**	0.009	0.185*	0.281**	3
IDAP	-0.073	-0.204*	0.063	0.189	-0.054	-0.068	1
IDP	-0.222*	-0.020	-0.211*	0.196*	0.089	0.153	2
IDSE	-0.157	0.018	-0.266**	0.028	0.072	0.203*	1
IPS	-0.346**	0.037	-0.276**	-0.263**	0.182*	0.205*	3
PTV	-0.310**	-0.053	0.337**	-0.310**	0.212*	0.228*	3
SID	-0.128	0.167	-0.249**	0.304**	0.215*	0.180*	2
SHE	-0.052	0.134	-0.309**	-0.344**	0.250**	0.278**	2
SLA	0.044	-0.054	0.021	-0.042	-0.099	-0.055	0
TDI	-0.343**	0.049	-0.366**	0.110	0.184*	0.290**	3
TID	-0.136	0.264**	-0.163	-0.058	0.159	0.123	1
WAT	0.056	-0.088	0.022	0.009	-0.114	-0.059	0
NRSI	-0.197	0.200*	-0.332**	0.101	0.151	0.283**	1
RRS	-0.159	0.233*	-0.378**	0.064	0.204*	0.315**	2
PARS	-0.219*	0.233*	-0.359**	0.071	0.186*	0.340**	3
PRRS	-0.221*	0.235*	-0.400**	0.050	0.185*	0.322**	3

Selection of indicator assemblages and metrics

The reference benthic macroinvertebrate taxa and metrics

Hydropsychidae, Polymitarcyidae, Philopotamidae, Naucoridae, and Hydrachnidae, which belong to Orders Ephemeroptera, Trichoptera, and Hemiptera were considered core reference assemblages (Table 5). These taxa were recorded as good water quality indicators (Raburu *et al.*, 2009; Basu *et al*., 2018). Macroinvertebrates taxa those characterized the reference assemblage were dominated by Hydropsychidae, Polymitarcyidae, Hydrachnidae, and contributed 14.43% of the total reference taxa recorded. These three invertebrate taxa of the reference community appeared as well in the non-reference sites, but at lower percent contribution (Table 5), it can be implied that these taxa are moderately sensitive. Philopotamidae and Naucoridae families were absent from all stressed sites, but abundant in the reference sites which suggests that they could conclusively discriminate the reference sites from others.

Table 5. Percentage contribution and accumulative percentage of the macroinvertebrate taxa that characterized the reference and non-reference/test sites.

	Non-Reference group		**Reference group**	
Family	**Percent (%) contribution**	**Percent (%) Accumulative**	**Percent (%) Contribution**	**Percent (%) Accumulative**
Hydropsychidae	0.13	10.00	3.42	90.00
Polymitarcyidae	0.60	11.95	7.41	88.05
Hydrachnidae	0.02	14.28	3.5	85.71
Philopotamidae	0	0.00	0.21	100.00
Naucoridae	0	0.00	1.25	100.00

O’Connor *et al.* (2000) reported that the abundance of tolerant taxa such as Physidae, Sphaeridae, and Chironomidae, and the total absence of sensitive order Plecoptera could be an indication of deterioration of lake water quality, which is supported by this study in Lake Ziway. Moreover, the presence of a few pollution-sensitive (Philopotamidae and Polymitracyidae), and some moderately-sensitive families (Baetidae, Hydropsychidae, and Hydrophilidae) in the reference sites indicates that the reference sites were slightly polluted and were not pristine and close to the near reference condition (NRC) proposed by Rowan *et al*. (2006).

The box plot data in Fig. 2 indicate that many metrics and indices overlapped between the reference and impacted sites. However, NT (No. taxa), IBI (Index of Biotic integrity) and CLE (Community Loss index) showed minimal or no overlap between the reference and impacted sites. The results suggest that dominant taxa and total no. taxa do discriminate reference from impacted sites also in lakes, as was widely documented in rivers (Barbour *et al*., 1996). This implies that many macroinvertebrate taxa and communities are lost from the nearshore areas of lakes where human impact is intensive and the lakeshores are used for activities such as livestock watering, withdrawal for irrigation, washing and other domestic activities (e.g. Tarekegn Wondimagegn *et al*., 2019). Therefore, despite the distinct difference between river and lake typologies with regard to water flow, stratification and spatial patchiness, IBI, NT and CLI could be reliable indicators of human impacts in both ecosystems. CLI was one of the earliest indices to be developed for temperate lotic ecosystems, and its suitability for tropical lake shores is an interesting observation.

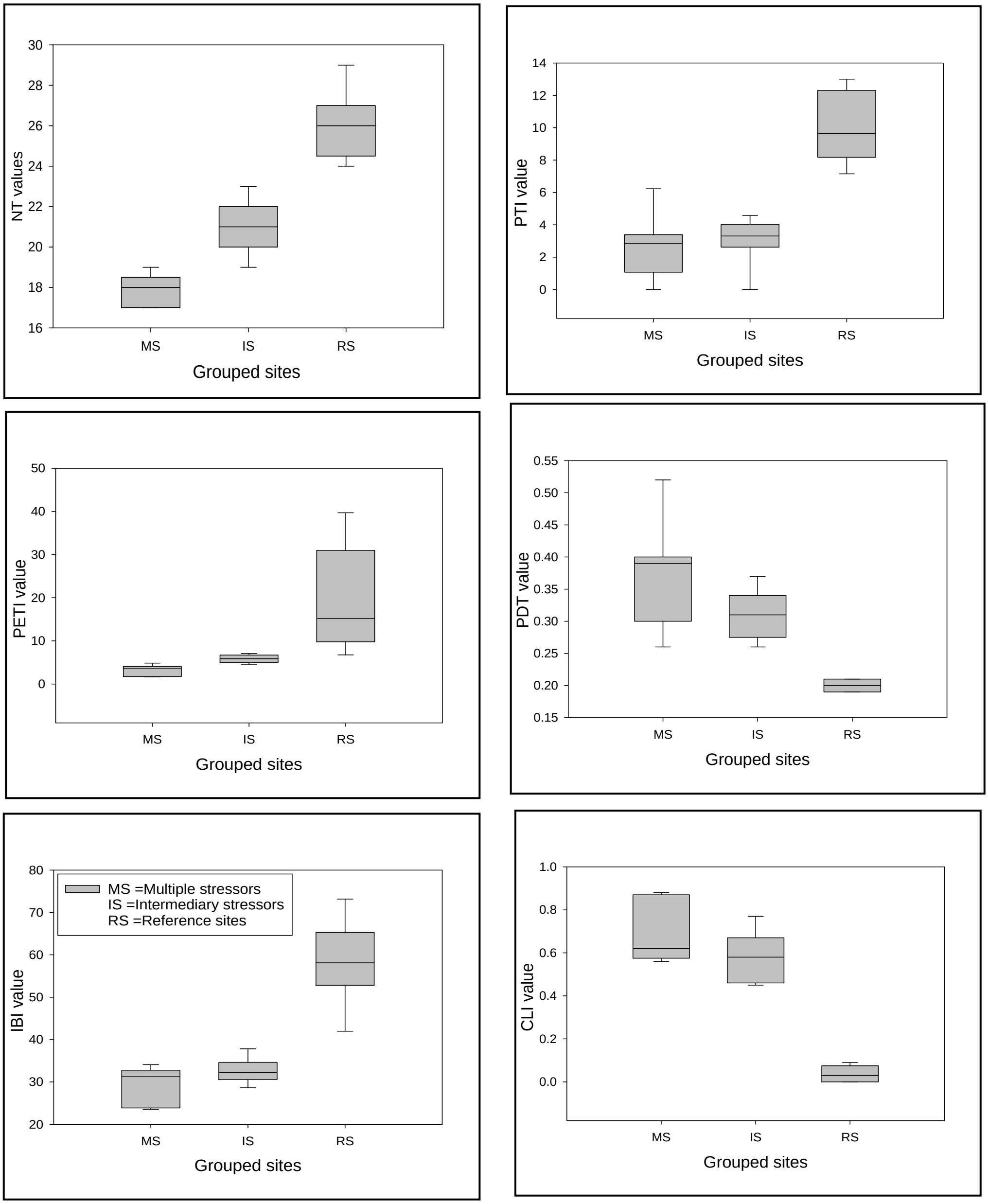

Fig. 2. Distribution of macroinvertebrate index values across the three lakeshore disturbance classes. Horizontal lines represent median values, gray boxes represent 25th and 75th percentiles, and whiskers represent 5th and 95th percentiles.

Although further research is required to corroborate this observation, it appears that these indices can be used reliably for rapid bioassessment of the ecological condition of tropical lakeshores exposed to high human pressure, which is evident in most lakes in Africa and developing countries.

Specimens belonging to families Ephemeroptera and Trichoptera (PTI and PETI) were absent in most of the stressed sites but abundantly present in the reference sites and in the intermediate sites in low numbers. These taxa are indicators of good water quality and are usually incorporated in studies dealing with multimetric index development (Solimini *et al*., 2006; Flores and Zafaralla, 2012; Getachew Beneberu, 2013). Raburu *et al*. (2009), also suggested that separation of individual families will give better results than lumping them since the families in the ET taxa respond differently to degradation. The preponderance of ET taxa in the reference sites (PTI, PETI) suggests that the proportion of ET taxa is more discriminatory in lakes rather than the classical EPT index common in reference sites in rivers. These potential metrics also showed strong correlation with most of the physico-chemical variables and scored high sensitivity value of 3 (Table 3), which suggests that they are reliable macroinvertebrate metrics to discriminate between reference and impacted sites in lake shores.

The reference benthic diatom species and metrics

Aulacoseira ambigua, *Aulacoseira granulata*, *Encyonema volkii*, *Nitzschia acicularis*, *Pinnularia subgibba*, *Stephanodiscus* sp., *Surirella angusta* and *Thalassiosira baltica* were more abundant in reference sites (Table 6). This result is agreeable with the finding of Wang *et al*. (2015) who reported the presence of these species in relatively high abundance in the reference sites for Dongting Lake, China. Reference diatom assemblages were dominated by the species: *Aulacoseira ambigua*, *Aulacoseira granulata*, *Encyonema volkii*, and *Nitzschia acicularis* and contributed 78.74% of the total reference taxa. Four species of the reference community *Aulacoseira ambigua*, *Aulacoseira granulata*, *Encyonema volkii*, and *Thalassiosira baltica* appeared as well in the non-reference sites, but at a lower percentage (Table 6).

Table 6. Percentage contribution and accumulative percentage of the diatom species that characterized the reference and non-reference/test groups.

	Non-Reference group		**Reference group**	
Code*	**% contribution**	**% Accumulative**	**% Contribution**	**% Accumulative**
AAMB	1.5	19.35	6.25	80.65
AUGA	1.0	18.18	4.5	81.82
EVOL	19.5	42.16	26.75	57.84
NACI	0	0.00	3.25	100.00
PSGI	0	0.00	3.0	100.00
STSP	0	0.00	3.5	100.00
SANG	0	0.00	2.75	100.00
TBAL	0.25	12.50	1.75	87.50

*OMNIDIA codes sequence for the diatom species are: *Aulacoseira ambigua, Aulacoseira granulate, Encyonema volkii, Nitzschia acicularis, Pinnularia subgibba, Stephanodiscus* sp., *Surirella angusta* and *Thalassiosira baltica.*

Diatom indices commonly employed in temperate studies were checked for distribution in the reference and impacted sites with box plots (Fig. 3). Interestingly, four indices showed clear discrimination between the reference and impacted sites (IPS, TDI, PTV and CEE) while many other indices showed overlap between even the impacted sites. The IPS, TDI and PTV indices, which are computed from hundreds of diatom species, were equally sensitive in this tropical lake, as in many temperate lakes. This suggests that many diatom taxa have equal contribution in discriminating between impacted and reference sites, both in rivers, and in lakes, which was also supported in an earlier study in another rift valley lake (Tarekegn Wondimagegn *et al*., 2019).

The better discrimination efficiency of TDI in this study might be because the TDI index is based on a suite of 86 taxa selected both for their indicator value and ease of identification (Kelly and Whitton, 1995). Studies done in other African tropical and subtropical regions in East Africa indicated that TDI index was useful to determine the nutrient enrichment of streams near Lake Tanganyika (Bellinger *et al*., 2006) while TDI and IBD indices were useful in most of the South African water bodies (Taylor *et al*., 2007). However, the applicability of these temperate diatom-based indices as reliable bioindicators of ecological impairment in tropical lakes should be further investigated.

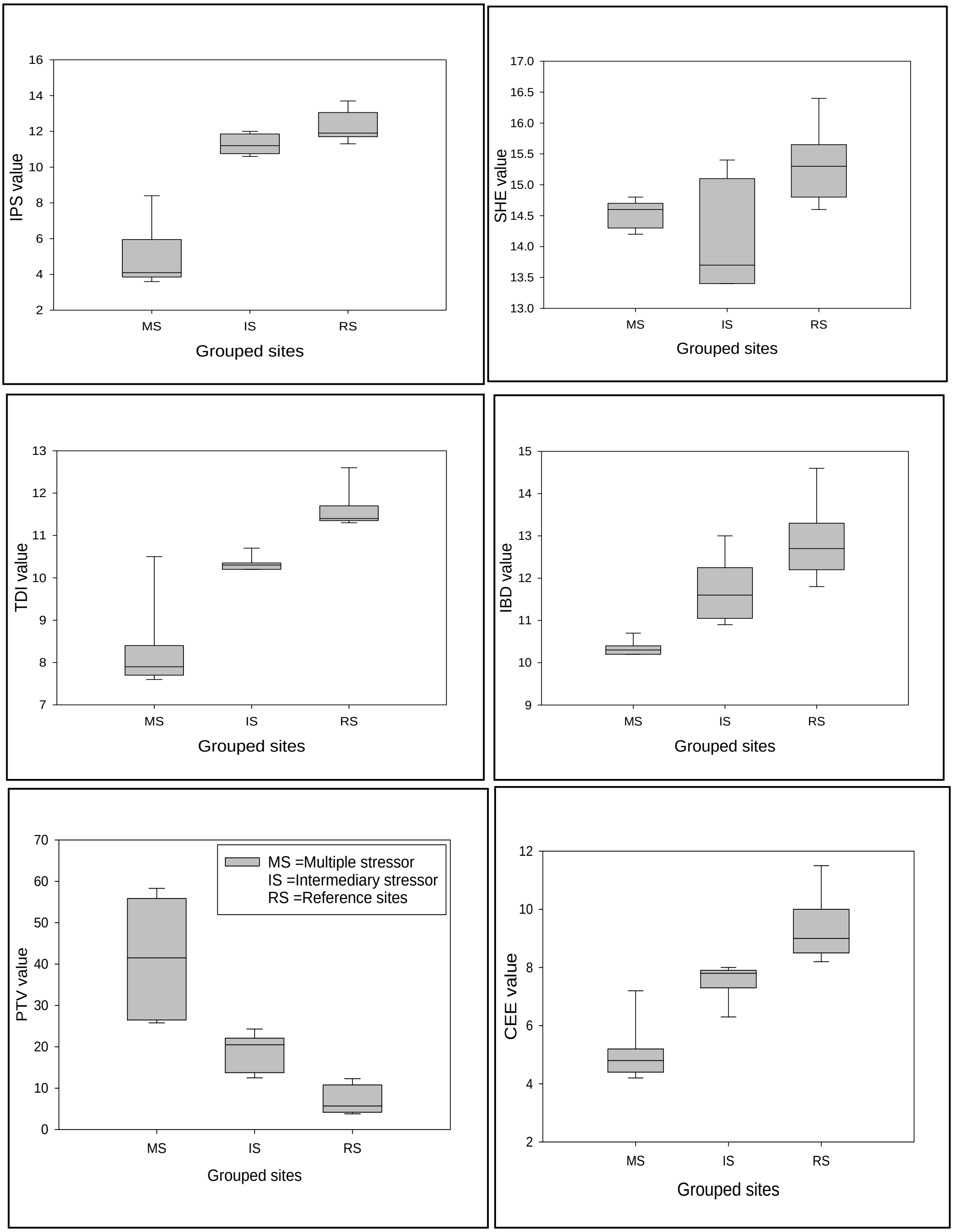

Fig. 3. Distribution of diatom index values across the three lakeshore disturbance classes. Horizontal lines represent median values, gray boxes represent 25th and 75th percentiles, and whiskers represent 5th and 95th percentiles.

Assemblages and metrics in the impacted sites

The overall average dissimilarity between reference and intermediary stressors was 31.09%, and Hydropsychidae, Polymitarcyidae, and Hydrachnidae accounted for 35.46% of the difference between these groups (Table 5). The overall average dissimilarity between reference and multiple stressors was 33.14%, and Hydropsychidae, Philopotamidae, and Polymitarcyidae accounted for 49.81% of the difference. These taxa can represent lake nearshore sites impaired due to multiple stressors, such as habitat degradation, pollution and hydrological changes. The overall average dissimilarity between sites with intermediary stressors and multiple stressors was 24.65%, and Philopotamidae, Polymitarcyidae, and Naucoridae families accounted for 25.55% of the difference. Philopotamidae and Polymitarcyidae contributed large dissimilarity between the impacted groups and could not discriminate between them (e.g. Basu *et al*., 2018). From the SIMPER results, it is suggested that Hydropsychidae, Polymitarcyidae, and Hydrachnidae can be considered as good indicators of reference condition in lake littorals.

When comparison was made for the diatom species between intermediary stressors, multiple stressors and reference groups with the SIMPER routine, the overall average dissimilarity between reference and multiple stressors was high and this dissimilarity was mainly due to the diatom species - *Aulacoseira ambigua*, *Aulacoseira granulata*, *Encyonopsis microcephala*, *Encyonema volkii*, and *Nitzschia acicularis* which accounted for 55.76% of the difference. These species were also useful to distinguish reference and impacted sites in the study of Delgado *et al*. (2010). The average dissimilarity between intermediary and multiple stressors was mainly contributed by *Nitzschia intermedia*, *Achnanthidium* sp. and *Gomphonema affine* which accounted for 65.53% of the difference. Some diatom species were invariably present in the impacted sites, such as *Aulacoseria* spp. *Encyonopsis microcephala* and *Thalassiosira baltica* these appear to be reliable indicators of human impacts of varying magnitude in the nearshore of lakes.

Discrimination between impacted sites

Most of the 50 candidate metrics (32 macrioinvretebrate and 18 diatom metrics) were eliminated because they did not discriminate well among reference and impaired sites (as widely expected in a mixing, shallow lake with similar abiotic conditions over most of the lake). Both benthic macroinvertebrate and benthic diatom assemblages found in Lake Ziway showed high similarity, this could be because of the spatial proximity between the study sites. The within-group percentage of similarity of macroinvertebrates and diatoms was 58.51% and 68.84% in reference site and 42.82% and 48.28% in impacted sites, respectively (Table 5), which suggested that reference sites have high biotic integrity than test sites. Similar result was documented by Kane *et al*. (2009) and Delgado *et al.* (2010). Therefore, we conclude that that the higher dissimilarity between biotic assemblages in impacted sites is due to the particular ecological stressors in the sites.

The overall dissimilarity of diatoms and macroinvertebrates distribution between reference and multiple stressors was higher than with intermediate stressors. Therefore, the highest value of dissimilarity between the reference and multiple stressors sites was possibly because of the multiple ecological stresses experienced in the test sites, which is also reported by the findings of Mabidi *et al*. (2017).

The selected potential metrics showed strong correlation with most of the physicochemical variables. About five macroinvertebrate and diatom metrics/indices showed high discrimination efficiency (≥3.0), which indicated their higher degree of discriminating between the impacted sites (intermediary and multiple stressors). However, some metrics did not conclusively discriminate between the intermediary and multiple stressors sites. This might be because of the low accuracy of the metrics/indices to discriminate the common environmental stressors in the two habitats. Also, some of the indices developed for temperate and other ecoregions might not apply for tropical conditions. Other workers have also reported that individual metrics were better designated to detect specific single stressors in the aquatic environment (e.g. Mandaville, 2002; Ferreira *et al*., 2011).

It is noteworthy that the three major discriminatory macroinvertebrate indices were related to diversity (NT), dominance (PDT) and community loss (CLE) of taxa from impacted sites. Moreover, the general Index of Biotic Integrity (IBI) also successfully discriminated between reference and impacted areas of the lakeshore. However, only Ephemeroptera and Tricoptera taxa were useful to discriminate between the sites in this lake (PTI, PETI), possibly because of the absence of Plecoptera in this lakeshore. For the diatom taxa, indices commonly established for ecological impacts in temperate water (TDI, PTV, IPS and CEE) were equally successful to discriminate between reference and impacted sites in this shallow tropical lake.

CONCLUSION

The selected macroinvertebrate and diatom-based biometrics indicated better ecological quality in reference sites than non-reference sites for the condition of Lake Ziway. Therefore, this study revealed that it is possible to extract discriminating metrics from diatom and invertebrate assemblages within a single lake. However, some of the metrics did not distinguish between the intermediate and multiple stressed sites, as they were developed for other eco-regions with specific sensitivity values. However, to increase the number of potential metrics, there should be an exhaustive investigation on all possible physicochemical factors, habitat stressors, and autecological features that influence the distribution of diatoms and macroinvertebrates in lakes. It can be suggested that by intensive sampling, use of many taxa in two assemblages and broadly-defined stressor sites as used in this study, we can reduce the confounding factors apparent in the design of using many contrasting lakes within an ecoregion for bioassessment studies. It would be interesting to check if these macroinvertebrate and diatom metrics and indices can distinguish between impacted sites in other rift valley lakes. It is also recommended to increase the number of reference sites for better resolutions as the appropriate number of sampling sites would be critical in obtaining more accurate water quality information (e.g. Wang *et al.*, 2015; Giorgio *et al*., 2016).

We also observed that some established temperate indices can be used as potential metrics for rapid bioassessment of human impact in the nearshore of Lake Ziway, and possibly other rift valley lakes in Ethiopia. In particular, the metrics NT, PDT, IBI, PETI and CLE (macroinvertebrate assemblage) and TDI, PTV, CEE and IBD (diatom assemblage) are suggested, based on results from this study.

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