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Effects of human-induced environmental changes on benthic macroinvertebrate assemblages of wetlands in Lake Tana Watershed, Northwest Ethiopia

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Abstract Wetlands of Lake Tana Watershed provide various ecological and socioeconomic functions. However, they are losing their vigor at alarming rate due to unwise management. Hence, there is an urgent need to monitor and assess these resources so as to identify the major drivers of its degradation and to provide information for management decisions. In this context, we aimed to assess the effects of human activities on macroinvertebrate assemblages of wetlands in Lake Tana Watershed. Biotic and abiotic data were collected from 46 sampling sites located in eight wetlands. A total of 2568 macroinvertebrates belonging to 46 families were recorded. Macroinvertebrate metrics such as Biological Monitoring Working Party score, Shannon diversity index, Ephemeroptera and odonata family richness, and total family richness portrayed a clear pattern of decreasing with increasing in human disturbances, whereas Family biotic index score, which is an indicator of organic pollution, increased with increasing in human disturbances. The regression analysis also revealed that livestock grazing, leather tanning, and eucalyptus plantation were important predictors of macroinvertebrate metrics ($p < 0.05$). In conclusion, human activities in and around the wetlands such as farming, leather tanning, solid waste dumping, and effluent discharges were contributed to the degradation of water quality and decreasing in the macroinvertebrate richness and diversity. These alterations could also reduce the availability of wetland products (sedges, craft materials, etc.) and the related ecosystem services. This in turn has an adverse effect on food security and poverty alleviation with considerable impact on communities who heavily depend on wetland products for their livelihood. Therefore, it is essential to formulate wetland policy for achieving wise use goals and necessary legal and institutional backup for sustainable wetland management in Ethiopia.

Keywords Family richness · Human disturbance · Leather tanning · Macroinvertebrates · Wetlands

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Introduction

Historically, wetlands were designated as breeding places for disease vectors and as impediments to civilization (Day et al. 2006). However, wetlands are now well recognized for their ecological functions and services they provide to human society (Dixon and Wood 2007). Wetlands perform a wide variety of ecological functions including provision of habitat for wildlife, purification of catchment surface water, floodwater attenuation, groundwater recharge, climate regulation, and erosion control (Mitsch and Gosselink 2000; Adhikari and Bajracharaya 2009; Jacobs et al. 2009; Justus et al. 2010). Furthermore, wetlands play a vital role in providing a wide range of ecosystem services for millions of people mainly living in developing countries (Teferi et al. 2010).

In spite of its critical role in providing countless ecological and socioeconomic benefits to humans, wetlands all over the world are under heavy pressure (Wolfson et al. 2002; Finlayson and D'Cruz 2005). A conservative estimate indicates that approximately 50% of the world's wetlands have been lost in the last century due to rapid expansion in human population and urbanization, which are demanding increased resources (Xu et al. 2011). The loss and degradation of wetlands have been driven by expansion of human settlement, irrigation agriculture, water withdrawal, industrial pollution, overexploitation, and introduction of invasive alien species (MEA 2005; McCartney et al. 2010).

The Lake Tana, Ethiopia's largest lake and the source of Blue Nile River, is endowed with a large number of wetlands that are among the largest and ecologically most important ones of the country and the Horn of Africa (Wondie 2010). The wetlands around Lake Tana are home to a large number of endangered migratory and several endemic bird species, whose habitats are threatened by development for irrigation, farming, and livestock grazing (Aynalem and Bekele 2008). Studies have shown that erosion and heavy use of fertilizers in the uplands have led to high sedimentation and eutrophication of Lake Tana (Wondie 2010). Furthermore, untreated effluents from Bahir Dar City administration are released into the wetlands leading to a reduction in the water quality and biodiversity (Wondie 2010; Atnafu et al. 2011).

The recent emphasis on wetland protection and management has created an urgent need to develop bioassessment tools to monitor human impacts on wetland ecosystems in order to prioritize wetlands management actions (Cole 2006; De Troyer et al. 2016). In this regard, macroinvertebrates have long been recognized as bioassessment tools for wetland ecosystems (Karr and Chu 1999; Rader and Shiozawa 2001; Mereta et al. 2013). Several reasons could be mentioned for the wide use of macroinvertebrates as bio-indicators of aquatic ecosystems. Firstly, benthic macroinvertebrates hold a central position in aquatic food chains by linking the lower and higher trophic levels; thereby, their taxonomic richness and diversity could indicate the overall condition of an aquatic ecosystem. Secondly, they are omnipresent (Kasangaki et al. 2006, 2008) and vary in their sensitivity to various human-induced stressors (Steinman et al. 2003; Hepp et al. 2010; Lunde and Resh 2012; Von Bertrab et al. 2013). Thirdly, benthic macroinvertebrates are relatively immobile and live in close contact with both bottom sediments and the water column, thereby having the potential for exposure to stressors via both sediment and aqueous pathways (Feio et al. 2007; Von Bertrab et al. 2013). Furthermore, macroinvertebrate communities can respond to nutrient enrichment (Lücke and Johnson 2009), oxygen availability (Saloom and Duncan 2005), food quantity and quality (Cross et al. 2006), and changes in habitat structure (Steinman et al. 2003).

Despite its popularity in monitoring running waters worldwide, the use of macroinverrebrates as a tool for ecological assessment of wetlands in Ethiopia is incipient (Yimer and Mengistou 2009; Atnafu et al. 2011; Getachew et al. 2012; Mereta et al. 2012, 2013). Hence, there is lack of comprehensive information on how intensifying human activities have been deteriorating ecological condition of wetlands in Ethiopia. Therefore, the aim of this study was to assess the impacts of human activities on macroinvertebrate assemblages and water quality of wetlands in Lake Tana Watershed, Northwest Ethiopia.

Methods and materials

Study area

The data used in the present study were collected from wetlands located in Lake Tana Watershed. Lake Tana Watershed is situated within a range of 10°58′–12°47′N latitude and 36°45′–38°14′E longitude in Amhara National Regional State, Northwest of Ethiopia. Eight wetlands (Yiganda, Welala, Fidiamba, Infruanz, Legdia, Kurtbahir, Lakeshore 1, and Lakeshore 2) were included in this study (Fig. 1). Yiganda and Welala Wetlands are connected to Lake Tana during rainy season. Fidiamba is flooded by out bank flow of Little Abay River during rainy seasons, while Infraunz Wetland is connected to Infruanz River. These two rivers flow into Lake Tana. Legdia Wetland and Kurtbahir Wetland are depressional wetlands. Lakeshore 1 and Lakeshore 2 Wetlands are lacustrine wetlands interface with Bahir Dar city administration. These lacustrine wetlands receive both solid and liquid wastes generated from Bahir Dar City (Wondie 2010). The major anthropogenic activities observed in and around the study wetlands were farming, leather tanning and processing, intensive grazing, drainage, vegetation

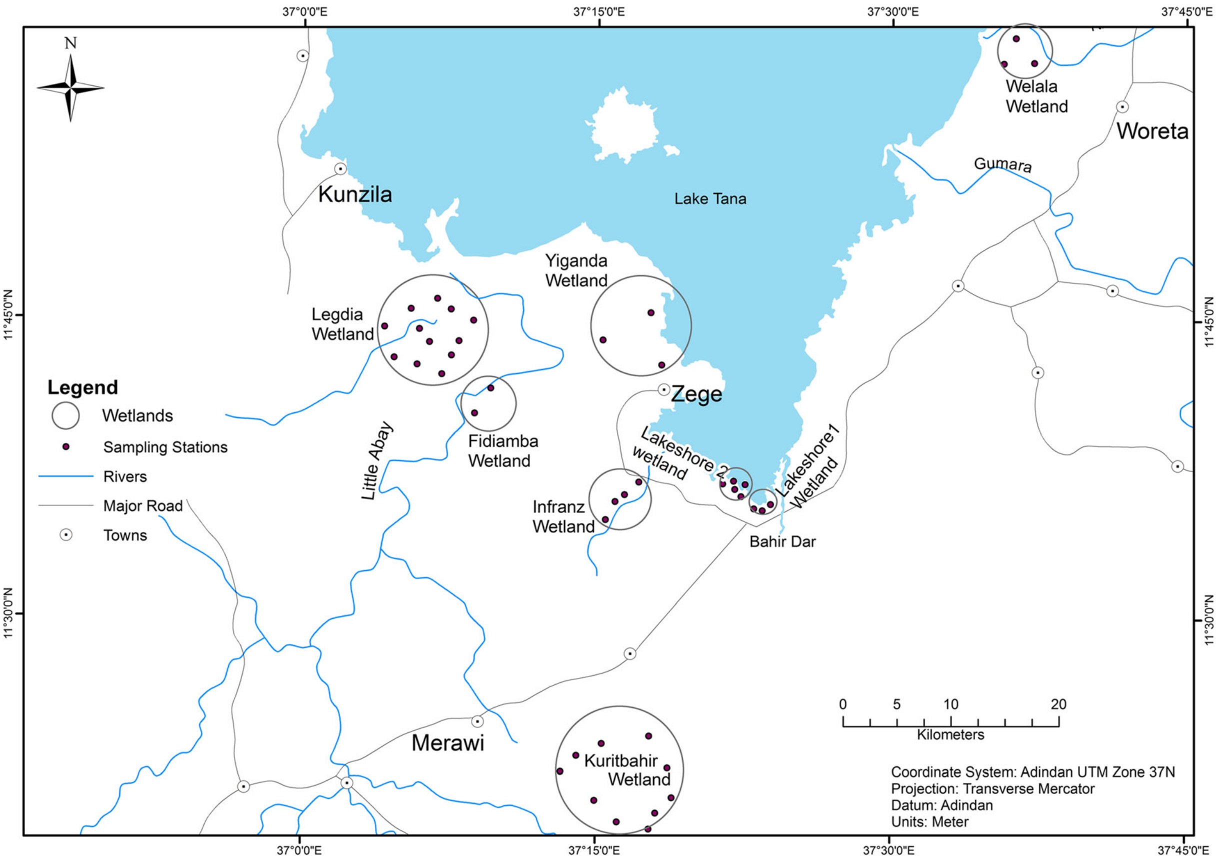


Fig. 1 Location of wetlands and sampling locations (wetland represented by *circle* and sampling location represented by *point*) in Lake Tana Watershed

clearance, water abstraction, waste dumping, and eucalyptus plantation.

Data collection

Data were collected from 42 sampling stations located in eight wetlands in Lake Tana Watershed Northwest Ethiopia from April to May in 2015. Sites were selected within each wetland along a gradient of visible disturbance including both nearly less disturbed and heavily disturbed sites. The number of sampling sites was evenly distributed among the wetlands depending on their size, with the smallest wetlands having a lower number of sampling sites. The accessibility of the wetland was also taken in to consideration. Habitat characteristics in each sampling site were assessed following USEPA wetland habitat assessment protocol (Baldwin et al. 2005). A measure of human disturbance was obtained by assessing hydrological modifications, habitat alteration, and land use practices. Hydrological modifications included ditching or draining, filling, and abstracting of water in the wetland. Habitat alteration included grazing, tree plantation, and vegetation removal. Land use practices in the wetlands included farming, waste dumping, and leather tanning.

We used the protocol described by Hruby (2004), which was modified by Mereta et al. (2013) so as to quantify human disturbance. A score of 1 was assigned to no or minimal disturbance, 2 to moderate, and 3 to high disturbance. The overall disturbance for each site was calculated by summing the individual values of disturbance factors (eight different factors in total). The overall human disturbance score ranges from 8 to 24. The score of 8–11 was assigned to very low, 12–14 to low, 15–17 to moderate, 18–20 to high, and 21–24 to very high disturbance.

Water depth and sludge layer thickness were measured at multiple locations ($n = 42$) at each observation site using a graduated stick. Conductivity, pH, daytime dissolved oxygen concentration, and water temperature were measured in the field using a multi-probe meter (HQ30d Single-Input Multi-Parameter Digital Meter, Hach). In vivo chlorophyll *a* concentration was used as a proxy of phytoplankton biomass and was measured in the field using a handheld fluorometer (Turner Design Aqua fluor). A water sample (200 ml) was taken from each site and subsequently filtered through a 0.45-μm filter paper in the field for the determination of nitrate, ammonia, and orthophosphate concentration. Unfiltered water (500 ml) was used to determine the chemical oxygen demand (COD), total organic nitrogen (TON), and total phosphorous (TP) concentrations in the laboratory. Water samples were kept cool in the dark during transportation to the laboratory. Ammonia was analyzed using direct nesselerization method (APHA 1998). Total phosphorus samples were first digested in a block digester using ammonium persulfate and sulphuric acid reagent (APHA 1998). Samples for COD and TON were also digested and measured with photometric kits (HACH LANGE) using a Hach DR5000 spectrophotometer. Prati index was computed using concentration of ammonium, chemical oxygen demand, and percent oxygen saturation (Prati et al. 1971) as a measure of chemical water quality of each sampling station. According to Prati et al. (1971), a Prati index value less than one is considered as very pure water, value less than two considered as acceptable water quality, value less than four considered as slightly polluted water, and value less than eight considered as polluted, whereas a value greater than eight considered as heavily polluted water. The percentage of vegetation cover was visually estimated within a 500-m radius around each observation site (Baldwin et al. 2005).

Macroinvertebrate samples were collected from each of the 42 sampling locations. Samples were collected from different meso-habitats such as emergent vegetation, sediment, and open water. A rectangular frame net (20 × 30 cm) with a mesh size of 300 μm was used to kick for 5 min along a 10-m stretch (Gabriels et al. 2010). Benthic macro-invertebrates were collected by disturbing the bottom sediment by foot. All collected macroinvertebrates were sorted in the field and stored in 80% ethanol. Afterward, all macroinvertebrates were transported to the laboratory and examined using a stereomicroscope (×10 magnification). Identification was conducted to family level using the identification key of Bouchard (2012). Moreover, total family richness, abundance, richness of EO taxa, and family biotic index (FBI) were calculated to characterize a sampling site.

Data analysis

Detrended correspondence analysis (DCA) was applied using CANOCO 4.5 (ter Braak and Šmilauer 2002) to determine the appropriate response model (linear or unimodal) for both the macroinvertebrate metrics and the environmental data. Since DCA yielded gradient lengths less than two standard deviations, redundancy analysis (RDA) was used to investigate the relationship between macroinvertebrate metrics and environmental variables. For the RDA analysis, data were $\log(x + 1)$ transformed and divided by the standard deviation to standardize the ordination diagram (ter Braak and Šmilauer 2002). Significance was tested using Monte Carlo tests with 999 permutations (ter Braak and Šmilauer 2002).

Box and whisker plots were made in STATISTICA 7.0 (Statsoft, Inc.) to visualize the relationships of the biotic metrics with chemical water quality and human disturbances. A nonparametric Kruskal-Wallis test was used at a significance level of 0.05, to determine whether significant differences was observed between biotic metrics and water quality and human disturbances. In addition, Spearman rank-order correlation was performed to examine the extent of correlations between the selected biological attributes with environmental variables.

A stepwise multiple regression was used to investigate the relationships between biotic metrics and human disturbances. In the preliminary analysis, human disturbance factors with an inflation factor greater than 5 were removed from the analysis to ensure that none of the models exhibited multicollinearity (Marquardt 1970). Models were compared using ANOVA to determine whether there was a difference in the amount of variance explained by the independent variables. R^2 values of each model were also compared to gain the relative importance of each model. Statistical analysis was performed using SPSS version 20 statistical software (SPSS Inc., Chicago, IL).

Results

Macroinvertebrate abundances and occurrences

A total of 2568 macroinvertebrates belonging to 46 families and 13 orders were recorded (Table 1). The

Table 1 Overview of relative abundance of macroinvertebrates taxa in the study wetlands

Taxa	Lakeshore 1	Lakeshore 2	Welala	Fidiamba	Kurtbahir	Infruanz	Legdia	Yiganda
Coleoptera	43	185	125	52	91	48	195	92
Hemiptera	16	49	195	11	154	106	153	34
Odonata	11	56	0	2	178	65	56	6
Diptera	4	54	84	31	5	4	102	0
Lymnaeoidea	30	14	0	1	10	6	40	0
Ephemeroptera	3	4	0	8	23	35	13	0
Gastropoda	13	27	0	7	12	22	24	0
Veneroida	0	0	0	0	18	2	12	0
Hirudinea	0	1	0	0	1	2	2	0
Rhynchobdellida	0	0	0	1	0	7	3	0
Oligochaeta	1	0	2	3	1	5	1	0
Trombidiformes	0	0	0	6	0	0	0	0
Megaloptera	0	0	0	0	0	0	1	0
Relative abundance	121	390	406	122	493	302	602	132

most dominant order was Coleoptera consisting of nine families with a relative abundance of 32%. Among the Coleopterans, Dytiscidae was the most frequently occurring family, which was found in 93% of the study sites. The second dominant order was Hemiptera consisting of seven families with a relative abundance of 28%. Corixidae was the most frequently occurring family in the order Hemiptera, which was found in the 62% of the study sites. Odonata was the third dominant order consisting of seven families with a relative abundance of 15% (Table 1).

As shown in Table 2, average values of benthic macroinvertebrate metrics varied across different wetlands. Infruanz Wetland had relatively higher family richness and diversity as compared to other wetlands. In addition, BMWP score and family richness of sensitive taxa such as Ephemeroptera and Odonata were higher in Infruanz Wetland. In contrast, Yiganda and Welala Wetlands had lower BMWP score, family richness, and diversity. On the other hand, FBI score was higher in Yiganda and Welala Wetlands.

Environment variables

The mean values of water physicochemical variables of different wetlands are shown in Table 3. Chemical oxygen demand, dissolved oxygen, total phosphorous, pH, and chlorophyll a concentrations were higher in Welala Wetland. The higher electric conductivity values were recorded in Lakeshore 1, Lakeshore 2, and Welala Wetlands (>559 μS/cm), while lower concentrations were recorded in Kurtbahir and Infruanz Wetlands (<225 μS/cm).

Table 2 Average values of macroinvertebrate metrics in the study wetlands

Biotic metrics	Study wetlands							
	Lakeshore1	Lakeshore2	Welala	Fidiamba	Kurtbahir	Infruanz	Legdia	Yiganda
Family richness	7.00	8.60	4.33	11.00	6.70	14.25	9.33	4.67
EO family richness	1.33	1.80	0.00	2.00	1.50	4.25	2.33	1.00
Shannon diversity index	1.60	1.60	1.22	1.98	1.26	2.23	1.76	1.09
BMWP	49.00	62.80	34.67	88.00	60.90	114.00	69.58	37.33
FBI	6.81	6.27	7.28	4.79	4.70	3.38	5.20	7.18

BMWP Biological Monitoring Working Party, *FBI* Family Biotic Index, *EO* Ephemeroptera and Odonata

Table 3 Average values and standard deviation of environmental variables measured in the wetlands of in Lake Tana Watershed, Northwest Ethiopia

Variables	Study wetlands							
	Lakeshore 1 (mean ± SD)	Lakeshore 2 (mean ± SD)	Welala (mean ± SD)	Fidiamba (mean ± SD)	Kurtbahir (mean ± SD)	Infruanz (mean ± SD)	Legdia (mean ± SD)	Yiganda (mean ± SD)
COD (mg/l)	66.87 ± 13.89	113.99 ± 43.17	367 ± 2.52	58.1 ± 16.3	119.7 ± 17.92	57.48 ± 16.11	38.88 ± 4.89	195 ± 42.78
TON (mg/l)	14.43 ± 3.72	17.77 ± 0.46	18.32 ± 0.04	17.88 ± 0.525	15.36 ± 1.31	13.83 ± 1.55	16.73 ± 1.4	16.52 ± 1.81
NH_4 (mg/l)	2.16 ± 1.4	1.8 ± 1.1	2.63 ± 1.2	0.53 ± 0.2	1.23 ± 0.4	0.43 ± 0.5	0.23 ± 0.3	1.23 ± 0.8
TP (mg/l)	1.11 ± 0.44	0.39 ± 0.08	1.94 ± 0.14	0.27 ± 0.05	0.26 ± 0.05	0.31 ± 0.11	0.29 ± 0.03	1.01 ± 0.66
Chl a (μg/l)	12.6 ± 0.2	14.9 ± 1.32	53.66 ± 8.9	12.81 ± 0.48	12.52 ± 0.34	12.02 ± 0.21	12.03 ± 0.19	22.88 ± 2.73
pH	7.25 ± 0.01	7.38 ± 0.33	9.23 ± 0.22	8.58 ± 0.33	7.55 ± 0.23	7.07 ± 0.02	6.61 ± 0.33	8.25 ± 0.26
DO (mg/L)	3.03 ± 0.44	4.15 ± 0.8	7.68 ± 0.55	7.06 ± 0.64	4.34 ± 0.29	2.93 ± 0.17	4.09 ± 0.39	5.72 ± 0.21
DO (%)	44 ± 6	50 ± 14	122 ± 17	121 ± 15	68 ± 16	43 ± 6	62 ± 24	82 ± 5
EC (μS/cm)	998 ± 321.5	559.3 ± 85.7	637.7 ± 11.61	487 ± 77	207.6 ± 32.63	225.3 ± 12.36	388.3 ± 29.81	307.9 ± 114.5
WT (°C)	21.45 ± 1.06	30.9 ± 1.31	27.47 ± 1.28	33.05 ± 0.45	24.27 ± 0.56	24.78 ± 0.52	23.41 ± 1.72	22.96 ± 0.22
WD (cm)	30.33 ± 8.09	24.29 ± 4.65	9.67 ± 3.18	14 ± 1	73.02 ± 17.7	43.25 ± 12.89	57.25 ± 17.72	35 ± 2.52
Basic Prati Index (#)	3.96 ± 0.56	5.19 ± 2.02	13.02 ± 0.29	2.58 ± 0.31	5.04 ± 0.58	3.61 ± 0.42	2.69 ± 0.14	7.142 ± 1.48
Vegetation cover (%)	50 ± 0	34 ± 4	0	60 ± 0	54 ± 2.67	50 ± 0	61.67 ± 5.62	50 ± 0
Hydrological modification (#)	6 ± 0	3.6 ± 0.51	6 ± 0	3 ± 1	4.3 ± 0.42	3 ± 0.41	3.42 ± 0.42	3 ± 0
Habitat alternation (#)	5.67 ± 1.33	7.4 ± 0.81	9 ± 0	6 ± 1	6.2 ± 2.66	3.75 ± 0.48	5.67 ± 0.74	7 ± 0
Land use pattern (#)	7.67 ± 1.33	5.2 ± 0.73	8.33 ± 0.67	7 ± 0	5.8 ± 0.59	3.5 ± 0.29	5.42 ± 0.56	7 ± 0

SD standard deviation, *COD* chemical oxygen demand, *DO* dissolved oxygen, *Chl a* chlorophyll a, *WT* water temperature, *TP* total phosphorous, *EC* electric conductivity, *WD* water depth

Table 4 Correlation of macroinvertebrate metrics and environmental variables using Spearman rank order correlation

	Abundance	FBI	BMWP	Family richness	EO richness	Shannon Index	pH	WT	Os	EC	Chl a	WD	TP	COD
Abundance														
FBI	−0.03													
BMWP	0.17	−0.73**												
Family richness	0.35*	−0.66**	0.88**											
EO richness	0.12	−0.69**	0.76**	0.85**										
Shannon Index	0.16	−0.65**	0.84**	0.89**	0.79**									
pH	0.06	0.18	−0.34*	−0.39*	−0.45**	−0.36*								
WT	0.20	0.02	−0.08	−0.08	−0.11	−0.16	0.23							
Os	0.07	0.22	−0.33*	−0.37*	−0.35*	−0.43**	0.76**	0.4**						
EC	0.23	0.52**	−0.24	−0.11	−0.38*	−0.08	−0.04	0.11	−0.11					
Chl a	0.25	0.48**	−0.43**	−0.40**	−0.60**	−0.45**	0.44**	0.18	0.33*	0.44**				
WD	−0.01	−0.45**	0.38*	0.41**	0.52**	0.37	−0.4**	−0.39*	−0.36*	−0.35*	−0.26			
TP	0.03	0.45**	−0.30	−0.25	−0.43**	−0.10	0.37*	−0.02	0.22	0.38*	0.54**	−0.4*		
COD	0.21	0.34*	−0.43**	−0.46**	−0.48**	−0.50**	0.56**	0.05	0.49**	−0.06	0.58**	−0.16	0.30	
NH_4	0.12	0.54**	−0.63**	−0.6**	−0.7**	−0.4*	0.46**	0.05	−0.3*	−0.06	0.58**	−0.16	0.30	0.34*

COD chemical oxygen demand, NH_4 ammonium, *Os* oxygen saturation, *BMWP* Biological Monitoring Working Party, *FBI* Family Biotic Index, *EO* Ephemeroptera and Odonata, *Chl a* chlorophyll a, *WT* water temperature, *TP* total phosphorous, *EC* electric conductivity, *WD* water depth

*Significant at $p < 0.05$; **significant at $p < 0.01$

The average values of Basic Prati Index in the studied wetlands ranged from 2.58 ± 0.31 to 13.02 ± 0.297. According to the Basic Prati Index, Welala Wetland was found to be heavily polluted; Yiganda, Lakeshore2, and Kurtbahir were polluted, and Fidiamba, Legdia, Infruanz, and Lakeshore 1 were slightly polluted.

Relationships of macroinvertebrate metrics with water quality

The correlation between water quality variables and macroinvertebrate metrics is depicted in Table 4. Spearman rank-order correlation portrayed most water quality parameters that were significantly correlated with macroinvertebrate metrics. Oxygen saturation, pH, NH_4, chlorophyll a, chemical oxygen demand, and electric conductivity were negatively correlated with EO richness, total family richness, Shannon diversity index, and BMWP score ($p < 0.05$). However, electric conductivity, chlorophyll a, and total phosphorous were positively correlated with FBI (Table 4).

Box and whisker plots indicated that BMWP score and Shannon diversity index decreased with decreasing in water quality ($p < 0.05$). In contrast, the FBI score was significantly increased with decreasing in water quality. However, there was no statistically significant difference in abundance, total family richness, and EO family richness among the different water quality classes ($p > 0.05$) (Fig. 2).

Relationships of macroinvertebrate metrics with human disturbances

The box and whisker plots indicated that EO richness, BMWP score, family richness, and Shannon diversity index significantly decreased with increasing in human disturbances ($p < 0.05$), whereas FBI score was significantly increased with increasing in human disturbances ($p < 0.05$). However, there was no statistically significant difference in abundance among the different disturbance classes ($p > 0.05$) (Fig. 3). Among the disturbance factors, grazing and leather tanning were important predictors of family biotic index ($R^2 = 0.647$, $p < 0.001$) and EO family richness ($R^2 = 0.513$, $p < 0.05$), whereas grazing alone was best predictor of BMWP ($R^2 = 0.415$, $p < 0.001$) and Shannon diversity index ($R^2 = 0.341$, $p < 0.001$). In addition, farming and tree plantation were important predictors of macroinvertebrate family richness ($R^2 = 0.453$, $p < 0.05$) (Table 5).

Multivariate analysis

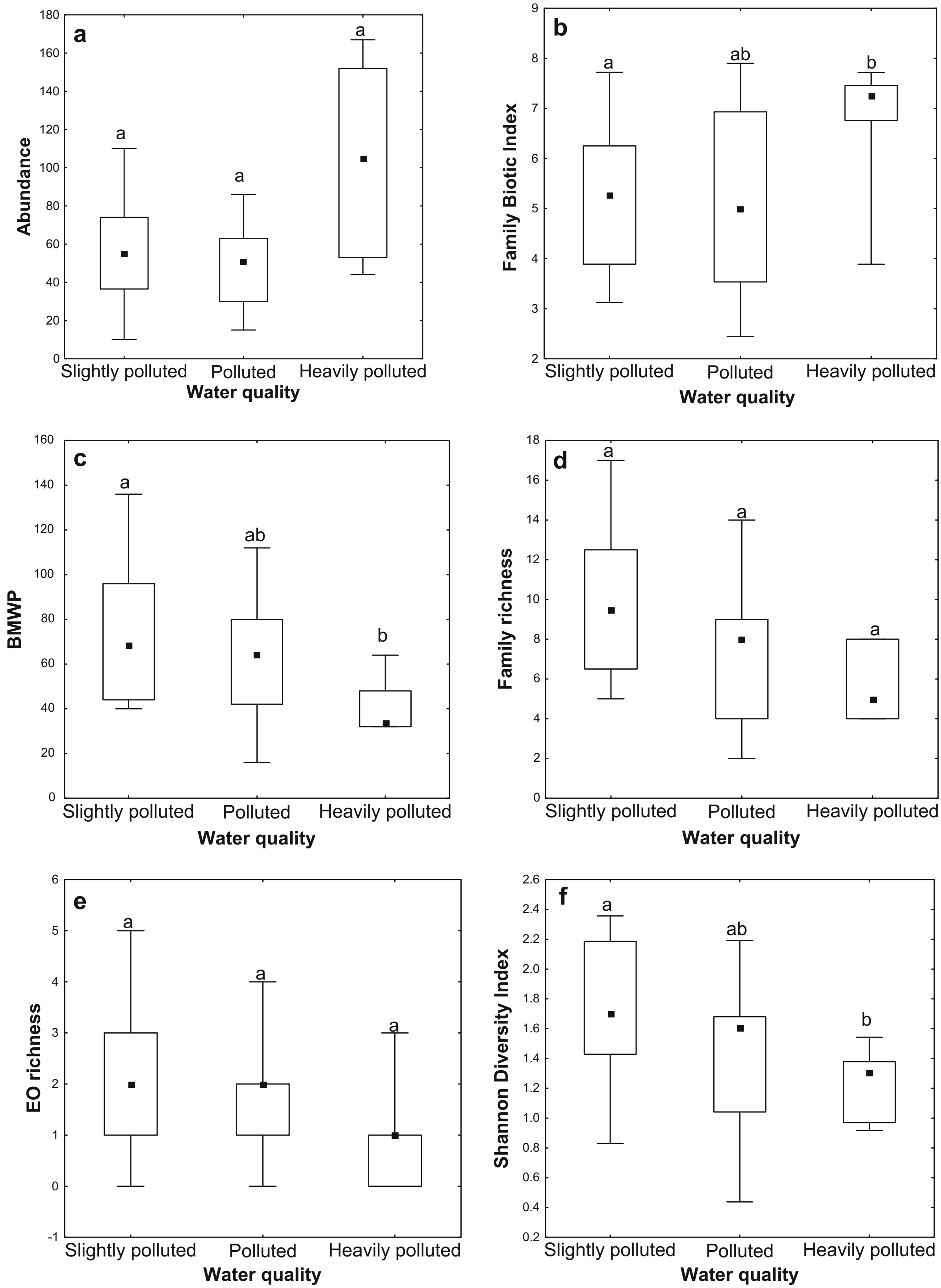
The variance of the RDA-biplot of macroinvertebrate metrics and environmental variables based on the first two axes explained 49% of the variance. Axes 1 and 2 explained 40 and 9% of the variation in macroinvertebrate assemblages, respectively. The first axis of the RDA ordination revealed a gradient primarily associated with human disturbances. This axis was negatively correlated with percent vegetation cover and macroinvertebrate metrics except FBI score (Fig. 4).

Discussion

This study revealed that low disturbed wetlands support a higher diversity of macroinvertebrates than highly disturbed wetlands. Furthermore, low disturbed wetlands had higher family richness and dominated by pollution sensitive orders such as Ephemeroptera and Odonata. For example, Infruanz Wetland, which falls under very low human disturbance category (disturbance score of 11), had the highest total and EO family richness, BMWP score, and Shannon diversity index. Ephemeroptera families are widely used in biomonitoring of wetland ecosystems (Hepp and Santos 2009; Arimoro and Muller 2010; Getachew et al. 2012; Mereta et al. 2013), and they have been usually found in good water quality with submerged vegetation (Mereta et al. 2012). Likewise, odonates are strongly related to the vegetation present in wetlands as they are carnivores that mainly look for food around roots and leaves of plants (Shelly et al. 2011).

On the other hand, the highly disturbed Welala Wetland had the lowest total family richness, BMWP score, and Shannon diversity index. Welala Wetland was completely devoid of ephemeropterans and odonates. Draining and pumping of water for small scale irrigation and livestock grazing are major threats for Welala

Fig. 2 *Box* and *whisker plots* of macroinvertebrate metrics. *Small black squares* represent median numbers, *boxes* represent interquartile ranges (25–75% percentiles), and *range bars* show maximum and minimum values. *a*, *b*, and *c* indicate statistically significant differences shown by Kruskal-Wallis tests ($p < 0.05$). *EO* Ephemeroptera and Odonata; *BMWP* Biological Monitoring Working Party, *FBI* Family Biotic Index ▶


a
Abundance
180
160
140
120
100
80
60
40
20
0
a
a
a
Slightly polluted
Polluted
Heavily polluted
Water quality
b
Family Biotic Index
9
8
7
6
5
4
3
2
a
ab
b
Slightly polluted
Polluted
Heavily polluted
Water quality
c
BMWP
160
140
120
100
80
60
40
20
0
a
ab
b
Slightly polluted
Polluted
Heavily polluted
Water quality
d
Family richness
18
16
14
12
10
8
6
4
2
0
a
a
a
Slightly polluted
Polluted
Heavily polluted
Water quality
e
EO richness
6
5
4
3
2
1
0
-1
a
a
a
Slightly polluted
Polluted
Heavily polluted
Water quality
f
Shannon Diversity Index
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
a
ab
b
Slightly polluted
Polluted
Heavily polluted
Water quality

Wetland (Atnafu et al. 2011). Human activities such as farming and grazing were responsible for the loss of riparian vegetation in Welala Wetland, causing a decline in pollution sensitive taxa such as Ephemeropteran and odonates. Vegetation can provide shelter against water current and predation, can provide more food resources, and is important as oviposition site (Couceiro et al. 2007). Vegetation has been shown to decrease the efficiency of fish predation and provides a refuge for benthic macroinvertebrates against visual predators (Habib and Yousuf 2015). Mereta et al. (2013) demonstrated that vegetation clearance had profound effects on both physical and biological structures of wetlands.

The stepwise regression analysis also revealed that cattle grazing was negatively correlated with Shannon diversity index, BMWP, EO, and total family richness. The effects of livestock grazing on wetland ecosystems can be both direct and indirect. Direct effects may include vegetation trampling and removal, and fecal and urine inputs which decrease water quality and reduce habitat availability (Steinman et al. 2003). Cattle feces and urine decrease water dissolved oxygen, wetland plant richness, and percent cover, and increase algal productivity (Croel and Kneitel 2011). Indirect effects result from shifts in vegetation communities which induce changes throughout higher trophic levels and affect wetland productivity (Silver and Vamosi 2012). The results of this study demonstrated that livestock grazing negatively affects the wetland macroinvertebrate assemblages by reducing the total and EO family richness and diversity of macroinvertebrate communities. Foote and Hornung (2005) indicated that cattle grazing caused a significant decrease in odonate abundance and reproductive effort by reducing vegetation height both within and adjacent to wetlands and a reduction in odonate species richness and diversity with complete vegetation removal.

The higher FBI scores of Lakeshore1 and Lakeshore2 Wetlands could be ascribed to the release of organic wastes from Bahir Dar City and the leather tanning activities in these wetlands. FBI portrays the status of organic pollution (Hilsenhoff 1988). Leather tanning has been widely applied in these wetlands to remove flesh and furs (Wondie 2010). It poses serious environmental impact on water since it releases high concentration of biodegradable organic materials such as proteins and carbohydrates, which causes depletion of the dissolved oxygen concentration of the wetlands as a result of microbial decomposition (Mwinyihija et al. 2006).

In this study, wetlands located adjacent to Bahir Dar City administration had higher water conductivity and chemical oxygen demand mainly due to the inflow of untreated wastewater from domestic, commercial institutions and industries. Several studies have shown that urbanization increases levels of conductivity and decreases dissolved oxygen in freshwater ecosystems, as urban residues contain high concentrations of contaminants and organic matter thereby increasing conductivity, and increasing chemical oxygen demand and decreasing dissolved oxygen in the water bodies (Roy et al. 2003; Hepp et al. 2010). The level of water conductivity recorded in this study area was higher than the study done in Cheffa Wetland in Northeast Ethiopia (Getachew et al. 2012) and wetlands in southwest Ethiopia (Mereta et al. 2012). The high electric conductivity level of wetlands in this study area might be due to high influxes of nutrient ions from croplands or high inputs of ions such as chloride from animal manure and contaminants from urban and suburban areas since Lake Tana Watershed is highly populated and intensively cultivated region (Setegn et al. 2008; Wondie 2010; Atnafu et al. 2011).

On the other hand, the high chemical oxygen demand and high concentration of total phosphorus observed in Welala and Yiganda Wetlands were probably due to agricultural waste products and litter decomposition. Welala and Yiganda Wetlands are situated in areas with intensive agricultural activity, and they are often used as agricultural field or grazing land during the dry season. Cattle can deposit significant amounts of excrements in these fields. When these areas become inundated during the rainy season, the dead organic material from crops and cattle excrements can be decomposed and results in an increase of the concentration of total phosphorus and an increase in chemical oxygen demand (Croel and Kneitel 2011).

In conclusion, human activities in and around the wetlands such as farming, overgrazing by domestic livestock, eucalyptus plantation, vegetation clearance, water abstraction, drainage, leather tanning, and effluent discharge from domestic and industrial plants particularly

Fig. 3 *Box* and *whisker plots* showing the relationships between macroinvertebrate metrics and disturbance classes. *Small black squares* represent median numbers, *boxes* represent interquartile ranges (25–75% percentiles), and *range bars* show maximum and minimum values. *a*, *b*, and *c* indicate statistical significant differences shown by Kruskal-Wallis tests ($p < 0.05$). *EO* Ephemeroptera and Odonata, *BMWP* Biological Monitoring Working Party, *FBI* Family Biotic Index

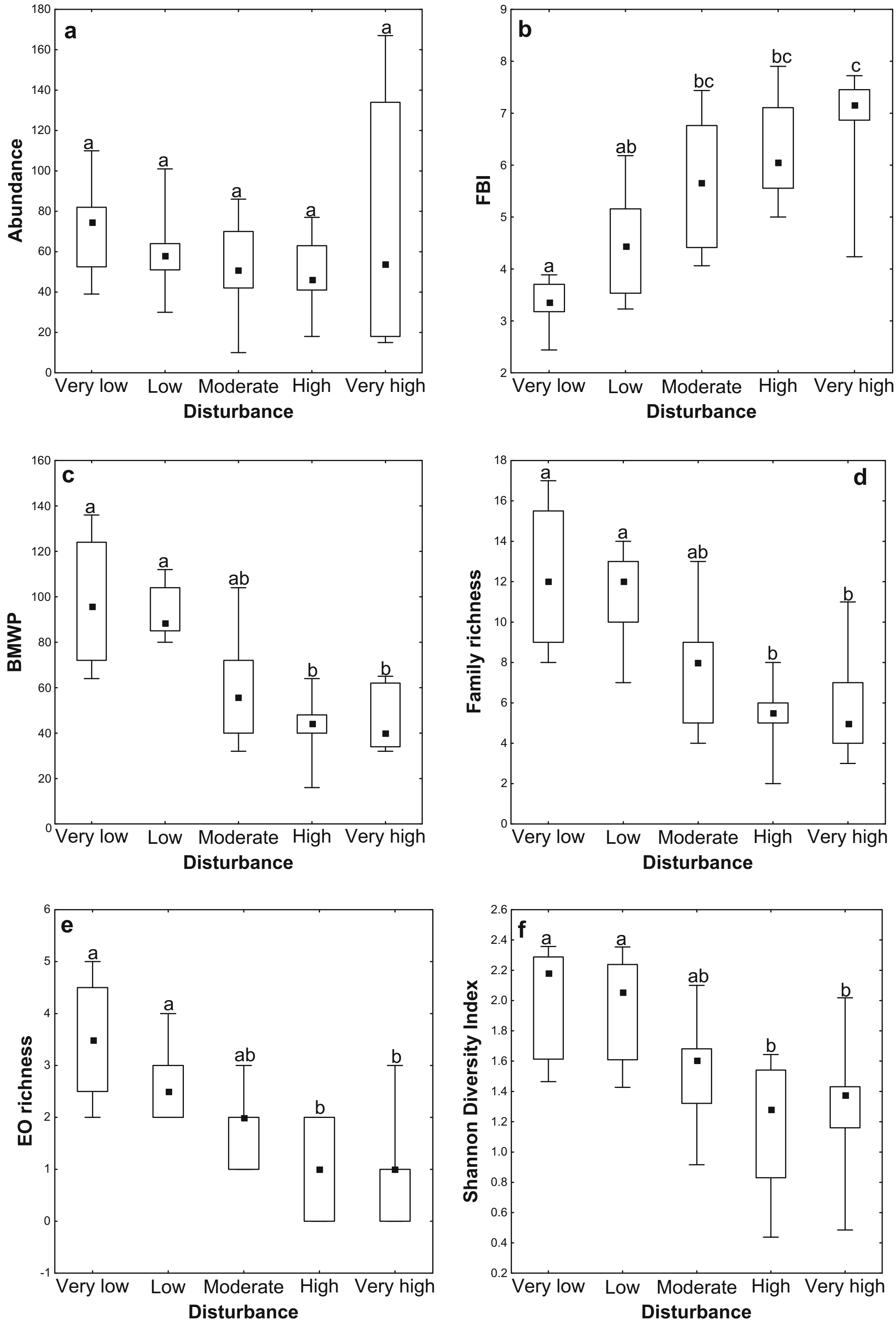

a
Abundance
180
160
140
120
100
80
60
40
20
0
a
a
a
a
a
Very low
Low
Moderate
High
Very high
Disturbance
b
FBI
9
8
7
6
5
4
3
2
a
ab
bc
bc
c
Very low
Low
Moderate
High
Very high
Disturbance
c
BMWP
160
140
120
100
80
60
40
20
0
a
a
ab
b
b
Very low
Low
Moderate
High
Very high
Disturbance
d
Family richness
18
16
14
12
10
8
6
4
2
0
a
a
ab
b
b
Very low
Low
Moderate
High
Very high
Disturbance
e
EO richness
6
5
4
3
2
1
0
-1
a
a
ab
b
b
Very low
Low
Moderate
High
Very high
Disturbance
f
Shannon Diversity Index
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
a
a
ab
b
b
Very low
Low
Moderate
High
Very high
Disturbance

Table 5 Stepwise regression models showing the relationships between environmental variables and macroinvertebrate metrics in wetlands of Lake Tana Watershed, Northwest Ethiopia

Biotic metric	r^2	*p* value	Predicator	Partial correlation	*p* value
Shannon diversity index	0.341	<0.001	Grazing	−0.585	<0.001
BMWP	0.415	<0.001	Grazing	−0.645	<0.001
FBI	0.647	<0.001	Leather tanning	0.584	<0.001
			Grazing	0.539	<0.001
EO family richness	0.513	<0.05	Grazing	−0.542	<0.001
			Leather tanning	−0.351	<0.05
Total family richness	0.453	<0.05	Plantation	−0.447	<0.001
			Farming	−0.241	<0.05

BMWP Biological Monitoring Working Party, *FBI* Family Biotic Index, *EO* Ephemeroptera and Odonata

to wetlands adjacent to Bahir Dar City administration were contributed to the degradation of water quality and decrease in the richness and diversity of maroinvertebrate taxa. These alterations could also reduce the availability of wetland products (sedges, craft materials, and medicinal plants) and the related ecosystem services. This in turn has an adverse effect on food security and poverty alleviation with considerable impact on communities who heavily depend on wetland products for their livelihood. Therefore, the rapid loss and degradation of wetlands and its resources and associated ecological and socioeconomic impact call for an urgent need for the conservation and wise use. It is essential to formulate wetland policy for achieving wise use goals and necessary legal and institutional back up for sustainable wetland management in the region. This study was conducted during the dry season, when the wetlands had low water level and were under high human pressure, and hence, we recommend wet season sampling so as to analyze the effects of season on human disturbances, which in turn influences macroinvertebrate assemblages.

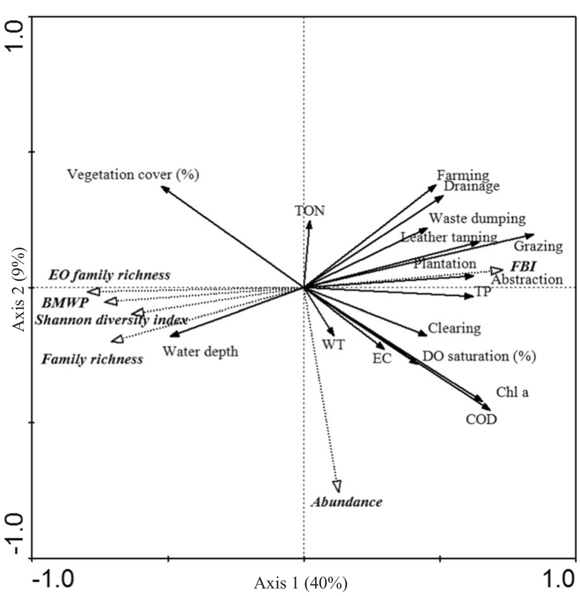


Fig. 4 Redundancy analysis (RDA) biplot of macroinvertebrate metrics, human disturbance, and environmental variables. *COD* chemical oxygen demand, *TON* total organic nitrogen, *TP* total phosphorous, *WT* water temperature, *Chl a* chlorophyll a, *EC* electric conductivity, *FBI* Family Biotic Index, *EO* Ephemeroptera and Odonata, *BMWP* Biological Monitoring Working party

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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