Wetlands
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ORIGINAL RESEARCH

Using Macroinvertebrates and Birds to Assess the Environmental Status of Wetlands across Different Climatic Zones in Southwestern Ethiopia

Selamawit Negassa Chawaka[1,2] · Pieter Boets[1,3] · Seid Tiku Mereta[4] · Long T. Ho[1] · Peter L. M. Goethals[1]

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Abstract
We investigated the variation in macroinvertebrate and bird fauna of 12 different freshwater wetlands located in three different climatic zones of southwestern Ethiopia. Data on macroinvertebrates, birds, physico-chemical water quality variables, human disturbance and vegetation cover were collected from 62 sampling sites during the dry and wet season of 2015. Generalized linear mixed models (GLMMs) were used to identify the most important variables explaining the variation in macroinvertebrates and birds. Twenty four percent of the variation in macroinvertebrate richness was explained by a combination of vegetation cover and dissolved oxygen, whereas 34% of the variation in macroinvertebrate abundance was explained by a combination of dissolved oxygen saturation, electric conductivity, total phosphorus and vegetation cover. A combination of water depth, dissolved oxygen, human disturbance and macroinvertebrate abundance explained about 34% and 31% of variation in bird species richness and abundance, respectively. Richness and abundance of macroinvertebrate and wetland dependent birds were significantly ($P < 0.05$) different between wetlands. When investigating the ecological status of wetlands, local environmental conditions of wetland should be taken into account for the development of wetland conservation strategies.

Keywords Generalized linear mixed model · Physico-chemical water quality · Species richness · Taxa abundance · Vulnerable species

Introduction

Wetlands are among the most productive ecosystems on earth and provide many ecological services and socio-economic benefits (Keddy et al. 2009**;** Lavoie et al. 2016). Wetlands are responsible for water quality regulation (Daneshvar et al. 2017), climate change mitigation (Roulet 2000) and ground water recharge (Hayashi et al. 2003). An important contribution of wetlands to the livelihood of people and many functions in agriculture such as livestock grazing, water supply and wood production have been reported (Schuyt 2005; Getachew et al. 2012). Furthermore, wetlands are considered as biodiversity hotspots and provide habitat for numerous species of waterfowl (Beatty et al. 2014), macroinvertebrates (Balcombe et al. 2005) and fish (Clavero et al. 2015).

Despite their high ecosystem and economic value, wetlands and their associated species have been rapidly declining during the past decades due to anthropogenic disturbances (Millennium Ecosystem Assessment 2005). Around 64–71% of the global wetland area has disappeared during the 20th and early twenty-first century (Davidson 2014). Agriculture is considered one of the main causes for gradual loss of wetlands since the 1950s (Teferi et al. 2010; Davidson 2014). One of the countries in sub-Saharan Africa that suffers from continuous degradation and loss of wetlands due to anthropogenic activities is Ethiopia (Gebresllassie et al. 2014). As a result,

✉ Selamawit Negassa Chawaka
selamnegassa@yahoo.com;
SelamawitNegassa.Chawaka@UGent.be

1 Laboratory of Environmental Toxicology and Aquatic Ecology, Ghent University, Coupure Links 653, Building F, B-9000 Ghent, Belgium

2 Department of Natural Resource Management, Jimma University, P.O. Box 370, Jimma, Ethiopia

3 Provincial Centre of Environmental Research, Godshuizenlaan 95, 9000 Ghent, Belgium

4 Department of Environmental Health Science and Technology, Jimma University, P.O. Box 378, Jimma, Ethiopia

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the species richness, abundance and distribution of wetland biological communities is highly affected in different parts of the country (Abebe and Geheb 2003; Mooney et al. 2009; Getachew et al. 2012).

Ethiopia is a country harbouring many different habitats including enormous wetland ecosystems and is divided in 11 climatic zones based on Koeppen's classification method (Gonfa 1996; Abebe and Geheb 2003). Except coastal and marine related wetlands and extensive swamp-forest complexes, all types of wetlands are found in Ethiopia including alpine formations, riverine, lacustrine and palustrine wetlands (Abebe and Geheb 2003). A large number of freshwater wetlands are found in southwestern Ethiopia, which support a high number of bird species and macroinvertebrates (Mereta et al. 2013). However, these wetlands are prone to degradation due to over grazing, clay mining, disposal of domestic sewage and farming (Mereta et al. 2013).

Wetland biological communities can be used to assess wetland conditions and to develop appropriate wetland conservation methods (Seilheimer et al. 2009). Various studies have been conducted using different biological communities such as macroinvertebrates, fish or birds (Green and Figuerola 2005; Larsen et al. 2012; Guareschi et al. 2015). Macroinvertebrates and birds are considered major bio-indicators of ecosystem health (Reid et al. 2014; Gebrehiwot et al. 2017; Gezie et al. 2017). Macroinvertebrates are used in wetland bio-assessment because of their short life cycle, their influence on nutrient and energy flows and their response to oxygen availability and habitat structure (Covich et al. 1999; Steinman et al. 2003; Saloom and Duncan 2016). Wetland birds are also considered as important ecological indicators as they are sensitive to environmental change, can be sampled easily and their taxonomy is well-known (Timothy et al. 2000; Gregory et al. 2003; Herrando et al. 2014). Moreover, macroinvertebrates and wetland birds are interacting with each other for example via the trophic web structure (Tomankova et al. 2014) or via dispersal interactions (Green and Figuerola 2005).

It is reported that local environmental conditions and human disturbance structure biodiversity of freshwater ecosystems (Al-shami et al. 2013; Heino 2013; Hawkins et al. 2015). In addition to local environmental conditions, temporal variability such as season and regional (spatial) determinants such as dispersal, geology and climate play a role in the biodiversity patterns observed in freshwater biological communities (Dolédeca et al. 2017; Baselga et al. 2012). An in-depth investigation of wetland biodiversity across climatic zones plays a crucial role for effective conservation of wetlands and its biodiversity (Erwin 2009). It has been reported that climatic conditions of wetlands affect the ecosystem structure and functioning through a change in precipitation and temperature (Erwin 2009; Ruhí et al. 2013). However, previous studies conducted on wetlands found in south-western Ethiopia, have been focusing on the development of biological indices (Yimer and Mengistou 2009; Mereta et al. 2013), on environmental characterization and composition of macroinvertebrate communities (Mereta et al. 2012) and on the perception of humans to wetland management (Moges et al. 2016). To our knowledge, no studies are present on how the composition of macroinvertebrates and birds vary between different climatic zones and how human disturbance interferes with the natural variation of wetlands in southwestern Ethiopia. Albeit interesting and important, using multiple biological communities to assess the status of wetland ecosystems has only been performed for the north-eastern part of the country (Getachew et al. 2012). The aim of this study was (1) to investigate the spatial differences in macroinvertebrate and bird fauna of wetlands located in three different climatic zones of southwestern Ethiopia and (2) to identify important environmental variables affecting these biological communities. To investigate this, we selected wetlands situated in a tropical rainforest climate, a warm temperate rainy climate and a tropical rainy climate based on the climatic classification of Ethiopia as reported by Gonfa (1996). We expected differences in diversity and abundance of macroinvertebrates and wetland birds due to climatic differences and varying local environmental conditions. We also expected differences in species richness and abundance of macroinvertebrates and birds between different wetlands. The results of this study can help to assess the status of wetlands in Ethiopia and therefore can be used to support the conservation and management of wetlands in an understudied area.

Materials and Methods

Study Area

This study was carried out in wetlands located in the southwestern part of Ethiopia in three different climatic zones. Several wetlands situated in a warm temperate rainy climate, a tropical rainforest climate and a tropical rainy climate were selected (Fig. 1). In the warm temperate rainy climate, six different wetlands were investigated: Awetu; Boye; Kofe; Bulbul; Kito and Haro, which are located in the Gilgel Gibe watershed situated between latitudes 7°37’ N and 7°45’ N and longitudes 36°47′ E and 37°15′ E. All of these wetlands are freshwater wetlands according to the wetland classification of Cowardin et al. (1979). Four of them, however, are totally covered by vegetation (Awetu; Boye; Kofe and Kito), whereas Bulbul and Haro are wetlands characterized by open water

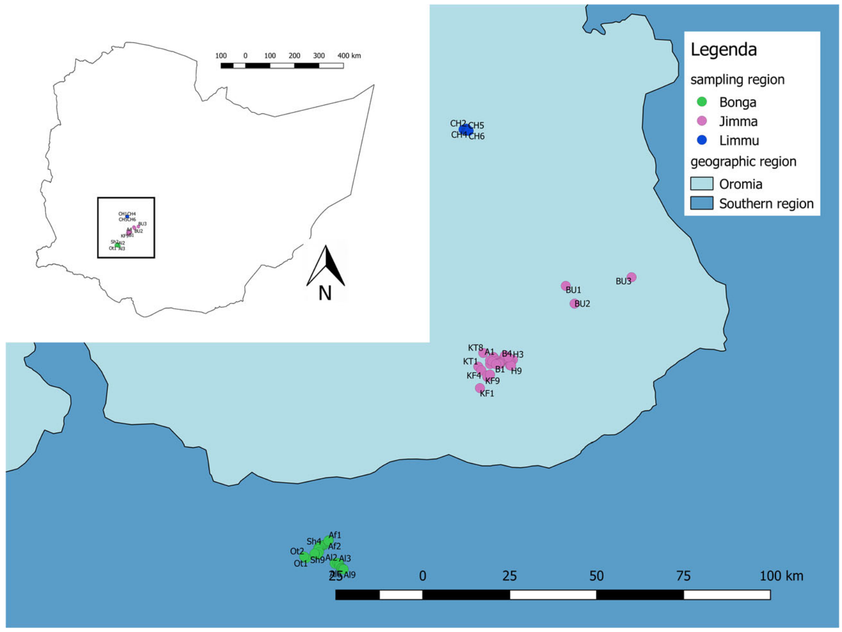

Fig. 1 Overview of the study area in Ethiopia and detailed location of the study area and wetland sampling stations. The different colors indicate different regions in Ethiopia

(Mereta et al. 2013). The average annual temperature of the area ranges between 22 and 32 °C (National Meteorological Agency 2015). The mean annual precipitation ranges between 1000 mm and 2800 mm (Gonfa 1996; National Meteorological Agency 2015). The dominant soil types in this region are Nitisols, Acrisols, Ferralsols, Vertisols and Planosols (Van Ranst et al. 2011). The altitude in the catchment varies between 1096 and 3259 m a.s.l.. The land use includes cultivation, clay mining, plantation, disposal of domestic sewage and grazing (Table 1). In the tropical rainforest climate, five wetlands were sampled: Shimbira; Alemgono; Afala; Ottra and Nech Wuha which are situated between 7°19' N and 07°24' N and 36°12′ E and 36°14′ E. All selected wetlands in this climatic zone are classified as freshwater wetlands and they are almost totally covered by vegetation. According to Gamachu (1977) this region is the most humid part of the country, with only two to four dry months per the year. The area has an average annual rainfall of 1200–2800 mm and mean temperature of 19.4 °C (Gonfa 1996; National Meteorological Agency 2015). The region is characterized by Afromontane cloud forests and rainforests, which contain wild *Coffee Arabica*, bamboo forests, grasslands and shrublands (NABU 2015). The dominant soil types occurring in this area are dystric nitisols (WBISPP 2004). The altitude in this region varies between 1500 and 2600 m a.s.l.. Chalalaki wetland, which is found in tropical rainy climate, is situated between latitude 08°14' N and longitude 37° 01′ E and is characterized as a freshwater wetland with open water. The mean temperature in this region is 26 °C and the annual rainfall ranges between 680 mm and 2000 mm (Gonfa 1996; National Meteorological Agency 2015). The dominant soil type in this region is Chromic, Pellic, Vertisols, Orthic Acrisols and Dystric Nitisols (Tegegn 2017). The altitude ranges between1573–1577 m a.s.l.. The main land use practice around this wetland is grazing. A summary of the human impact, climatic condition, size and number of sampling locations monitored in the studied wetlands can be found in Table 1.

Macroinvertebrate Sampling and Identification

Macroinvertebrate samples were collected twice from a total of 62 sampling locations, once during January to April 2015 (dry season) and once during September to November 2015 (wet season). The sampling locations were selected based on previous research, the distance between sites, the level of human disturbance and based on the confluence of rivers. Equal sampling effort was ensured in all sites by allotting proportional time to cover different meso-habitats such as open water or emergent vegetation (Mereta et al. 2013). A rectangular frame net (20 × 30 cm) with a mesh size of 300 μm was used to sample for 10 min along a 10 m stretch. The net was swept while the bottom sediment was disturbed by foot in order to collect the benthic macroinvertebrates. Then the sample was emptied into a rectangular tray in order to sort macroinvertebrates. All collected macroinvertebrates were sorted according to broad taxonomic groups in the field and stored in 80% ethanol. Afterwards, all macroinvertebrates were transported to the laboratory and examined using a stereomicroscope (10×

Table 1 Description of the human impact, climatic condition, size and number of sampling locations monitored in the studied wetlands

Region	Climatic condition	Name of wetland	Number of sites monitored	Size of wetland (ha)	Human impacts
Jimma	Warm temperate and rainy climate	Awetu	5	12	Disposal of domestic sewage, drainage, grazing and vegetation removal
		Kito	7	92	Clay mining, drainage, grazing, clearing, plantation and domestic sewage
		Kofe	6	87	Clay mining, grazing, vegetation removal and plantation
		Boye	5	111	Disposal of domestic sewage and plantation
		Bulbul	3	20	Grazing
		Haro	6	76	Cultivation and grazing
Bonga	Tropical rainforest climate	Alamgono	9	390	Grazing
		Shimbira	9	170	Grazing and farming
		Nech Wuha	2	9	Grazing
		Afala	2	8	Grazing and plantation
		Ottra	2	10	Grazing
Limmu	Tropical rainy climate	Chalalaki	6	40	Grazing

magnification). Identification was conducted to family level using the identification key of Bouchard (2004). Identification to a lower taxonomic level was impossible due to the lack of proper identification literature and reference collections for Ethiopia.

Bird Survey

A bird survey was conducted twice a year during the wet and dry season similar to the macroinvertebrate sampling period. Surveys were carried out between 6 and 10 am and between 4 and 6 pm local standard time. The point count method was used to collect data within a 100 m radius of the site where macroinvertebrates and environmental conditions were sampled (Lee and Marsden 2008). This method was justified as we mainly visually observed birds near open grassland and not dense forest. All species visually observed during 15 min were recorded using binoculars (Kite, 10 × 42) and identified using the key of Van Perlo (2009). The first 5 min were used to allow birds to settle and return to their natural behavior, whereas the remaining 10 min were used to record all bird species seen (Ralph et al. 1995). The recorded bird species were classified as wetland dependent and wetland associated birds based on Almaw (2012). Birds that flew over were not included. The number of species as well as the abundance of each particular species was recorded at each site.

Environmental Variables

To assess the hydro-morphological habitat characteristics of each site, the United States Environmental Protection Agency (USEPA) wetland habitat assessment protocol was used (Baldwin et al. 2005), which was modified by Mereta et al. (2013) for specific conditions present in Ethiopian wetlands. 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 clay mining. The degree of intensity of land use practices, which was indicated as human disturbance, was quantified based on the protocol described by Hruby (2004), which was modified by Mereta et al. (2013). A score of 1 was assigned to no or minimal disturbance, 2 to moderate and 3 to high disturbance. The overall human disturbance for each site was calculated by summing the individual disturbance values of land use activities (9 different activities in total). Each of the 9 scores were summed to calculate the overall human disturbance at each site, so the minimum disturbance score was 9 and the maximum disturbance score was 27. The percentage of vegetation cover was visually estimated at each sampling site within a radius of 100 m from the sampling site. Dissolved oxygen, electrical conductivity (EC), pH, turbidity and water temperature were measured in the field using a multi-probe meter (HQ30d Single-Input Multi-Parameter Digital Meter, Hach). Total nitrogen (TN), total phosphorus (TP) and chemical oxygen demand (COD) were analyzed in the laboratory using NANOCOLOR® test kits. Step by step instructions provided with the test kits were followed for all chemical analyses. Physical variables such as sediment and water depth were measured at each site.

Data Analysis

Richness and abundance were calculated at family level for macroinvertebrates and at species level for birds. The total richness per site was obtained for macroinvertebrates by counting the number of recorded families at each site, whereas for birds the number of species per site was counted. The total abundance was obtained by summing all individuals at each site. Total family richness, total family abundance, number of Ephemeroptera, Odonata and Trichoptera (EOT) taxa, abundance of EOT taxa and percentage of Chironomidae was calculated to characterize a sampling site. These metrics were selected as these are the sub-metrics used to calculate the biotic index developed by Mereta et al. (2013) for natural wetlands in Ethiopia. The relative abundance (%) was calculated by dividing the abundance of individual taxa by the total abundance and multiplying the outcome by 100.

Normality was checked for richness and abundance of macroinvertebrates and birds first, using a Shapiro Wilk Normality test. Since the data were not normally distributed we used a non-parametric Kruskal-Wallis test to determine significant differences in richness and abundance of macroinvertebrates and birds between wetlands. All analyses were performed in R (R Development Core Team 2015). Boxplots were used to visualise richness and abundandance of macroinvertebrate families and bird species.

Generalized linear mixed models (GLMM) were built to identify the response of richness and abundance of macroinvertebrates and birds to environmental variables. Season was set as random variable, whereas fixed variables included: climatic zone (warm temperate and rainy climate, tropical rainforest climate and tropical rainy climate), water depth, sediment depth, water temperature, ambient temperature, dissolved oxygen saturation, electrical conductivity (EC), pH, total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), human disturbance, abundance of macroinvertebrates (for wetland birds) and vegetation cover. Prior to the development of the GLMM, strongly correlated predictor variables were identified using the pairs function in R to avoid problems of correlation (Zuur et al. 2009). If variables were strongly correlated, only one of the variables in the pair was included in the model. Also, the spatial autocorrelation was checked for locations to identify if data in the same wetland was spatially auto-correlated using a correlogram (Zuur et al. 2009). If positive spatial autocorrelations were observed, the variable was set as a random variable. All possible models were constructed and the model with the lowest Akaike Information Criterion (AIC) was selected. GLMMs were run using a Poisson error distribution. The model was considered reliable if the residuals were normally distributed and rejected if not.

Results

A total of 14,480 individuals from 82 macroinvertebrate families were collected from the three climatic zones. The most commonly found macroinvertebrate families were Chironomidae and Dytiscidae followed by Coenagrionidae with a relative abundance of 10.3%, 9.7% and 8.5%, respectively. For a complete list of recorded macroinvertebrates we refer to Appendix Table 4.

Based on the correlation analysis, climatic zone showed a strong correlation with temperature ($R = 0.7$) and water temperature ($R = 0.8$), so we removed both ambient temperature and water temperature, as we considered climatic zone as a variable of interest. No spatial autocorrelation was observed between sampling locations. The GLMM model did not select climatic zones, pH and COD as important variables for both richness and abundance of macroinvertebrates and wetland birds.

Based on the GLMM we found that taxa richness of macroinvertebrates was positively correlated with vegetation and dissolved oxygen (Table 2). Taxa abundance of macroinvertebrates was negatively correlated with dissolved oxygen, EC and vegetation cover, whereas positively correlated with TP (Table 2). Twenty four percent of the variation in macroinvertebrate richness was explained by a combination of vegetation cover and dissolved oxygen, whereas 34% of the variation in macroinvertebrate abundance was explained by a combination of dissolved oxygen saturation, electric conductivity, total phosphorus and vegetation cover.

Variation in richnes and abundance of macroinvertebrates was observed between wetlands. Total taxa richness did not significantly differ ($P = 0.14$) between wetlands. Total taxa abundance was significantly higher ($P = 0.02$) in Chalalaki and Otra wetland compared to other wetlands. EOT richness and EOT abundance were significantly higher ($P = 0.01$ and $P < 0.001$, respectively) in Chalalaki and Nech Wuha wetland, whereas the percentage of Chironomidae was significantly higher ($P = 0.01$) in Awetu wetland followed by Afala and Otra wetland (Fig. 2).

Table 2 Output of GLMM for richness and abundance of macroinvertebrates taxa for all climatic zones together

	Variables	Estimate	Std. error	Z value	*P*-value
Richness	DO saturation	0.0020	0.0009	2.164	0.030
	Vegetation cover	0.0036	0.0016	2.222	0.020
Abundance	DO saturation	−0.0009	0.0003	−3.10	0.001
	EC	−0.0010	0.0002	−3.54	<0.001
	TP	0.2062	0.0417	4.94	<0.001
	Vegetation	−0.0022	0.0004	−4.81	0.004

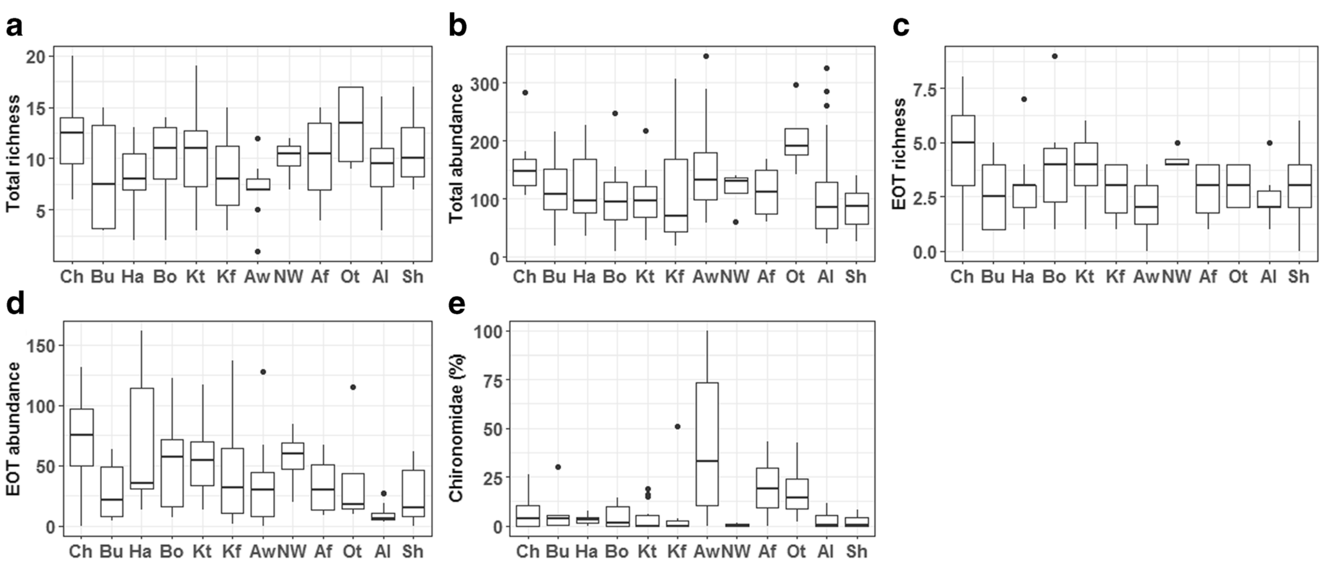

Fig. 2 Box plots of taxa richness and abundance of macroinvertebrates for the different wetlands studied in southwestern Ethiopia: (**a**) total richness, (**b**) total abundance, (**c**) EOT richness, (**d**) EOT abundance, (**e**) percentage of Chironomidae. Where: Ch = Chalalaki, Bu = Bulbul, Ha = Haro, Bo = Boye, Kt = Kito, Kf = Kofe, Aw = Awetu, NW = Nech Wuha, Af = Afala, Ot = Otra, Al = Alamgano and Sh = Shimbira

A total of 168 bird species were recorded in the three climatic zones, of which 59 species were categorized as wetland dependent birds and 109 as wetland associated birds. The most common wetland dependent bird was the Cattle Egret, followed by the Yellow-billed Duck with a relative abundance of 11% and 6.64%, respectively. The highest species richness and abundance of wetland dependent birds was observed for wetlands found in the tropical rainy climate. The most common wetland associated bird was the Hadada Ibis and Bronze Mannikin with a relative abundance of 11.5% and 9.31%, respectively. For a complete list of recorded bird species, we refer to Appendix Table 5.

Based on the GLMM we found that water depth, dissolved oxygen saturation and macroinvertebrate abundance were positively correlated with species richness and abundance of wetland dependent birds, whereas human disturbance was negatively correlated with both bird abundance and richness (Table 3). A combination of water depth, dissolved oxygen, macroinvertebrate abundance and human disturbance explained about 34% and 31% of variation in bird species richness and abundance respectively.

Wetlands with open water such as Chalalaki, Bulbul and Haro were characterized by a higher species richness and abundance of wetland dependent birds compared to wetlands totally covered by vegetation. Species richness and abundance of wetland associated birds appeared to be more or less similar in wetlands with open water and wetlands totally covered by vegetation (Fig. 3).

Discussion

Our model results indicated that several environmental variables were important for describing the occurrence of macroinvertebrates. Vegetation cover was positively correlated with macroinvertebrate richness and negatively correlated with abundance. This result is in contrast with the result of Michaletz et al. (2005) who reported no relation of macroinvertebrate abundance with vegetation. However, our results seem in agreement with the result of Oyague Passuni and Maldonado Fonken (2014) who reported a negative correlation of total vegetation cover with macroinvertebrate assemblages occurring in Andean peatland systems. Electric conductivity negatively correlated with abundance of macroinvertebrates. Although the maximum values recorded in our study area were rather low, our result is in agreement with the result of Kefford (1998), who reported a decrease in abundance of macroinvertebrates at higher electric conductivities. Our model indicated that total taxa richness of macroinvertebrates is positively correlated to dissolved oxygen, suggesting that conditions favouring a high dissolved oxygen concentration promote a higher macroinvertebrate richness. Abundance of macroinvertebrates on the other hand, was negatively correlated with DO saturation and positively correlated with total phosphorus. This might be explained by the higher relative abundance (10.3%) of Chironomidae taxa in our study area. The majority of Chrironomidae was collected at Awetu wetland which receives high amounts of domestic waste and is characterised by a higher nutrient concentration and lower dissolved oxygen. It has been

Table 3 Output of GLMM for species richness and abundance of wetland dependent birds

	Variables	Estimate	Std. error	Z value	*P* value
Richness	Water depth	0.0051	0.0009	5.2	< 0.001
	DO saturation	0.0091	0.0009	9.4	< 0.001
	Human disturbance	−0.078	0.0019	−40.1	< 0.001
	Macroinvertebrate abundance	0.1440	0.0600	2.4	0.016
Abundance	Water depth	0.0071	0.0024	2.9	0.003
	DO saturation	0.0121	0.0025	4.777	< 0.001
	Human disturbance	−0.115	0.0337	−3.4	0.006
	Macroinvertebrate abundance	0.2702	0.0923	2.92	0.003

reported that some genera of this taxon can thrive well at sites with a high organic enrichment due to anthropogenic activity (Silva et al. 2009). Moreover, this taxon is often characterized by a fast colonization allowing it to reach high abundances (Silveira et al. 2013). However, our result needs further styudy as identification was only performed at family level and there are also pollution sensitive Chironomidae species.

The average richness and abundance of macroinvertebrate taxa differed between wetlands. Higher total taxa richness, total taxa abundance, EOT richness and EOT abundance was observed in wetlands with a low human disturbance such as Chalalaki and Otra. Gezie et al. (2017) also reported a high macroinvertebrate richness in wetlands with a low human disturbance. Nech Wuha wetland, was characterized by a high EOT richness and abundance. This might be due to the high dissolved oxygen concentration present in this wetland compared to others. It has been reported that EOT taxa benefit from high dissolved oxygen concentrations (Hofmann and Mason 2005; Narangarvuu et al. 2015).

Our study revealed that dissolved oxygen concentration was, besides for macroinvertebrates, an important variable explaining the variation observed in birds. Dissolved oxygen concentration was positively correlated with richness and abundance of wetland dependent birds. This finding is consistent with the finding of Patra et al. (2010) who reported a positive influence of dissolved oxygen on water birds. The positive correlation of water depth with the richness and

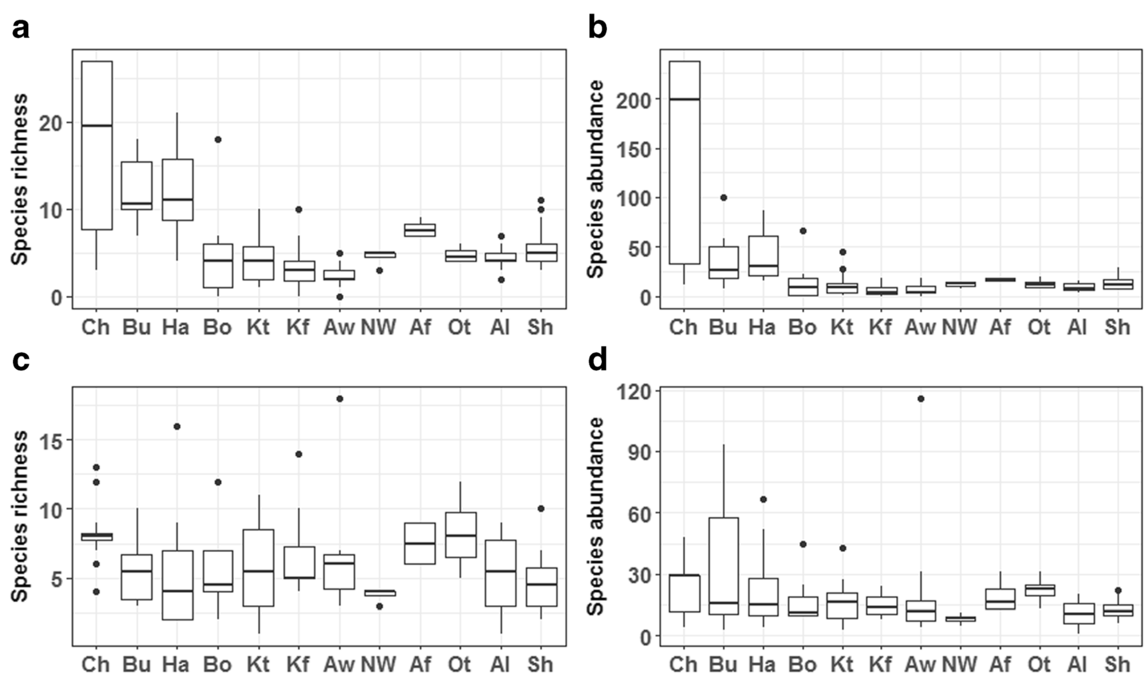

Fig. 3 Box plots of species richness and abundance of wetland dependent and wetland associated birds for the different wetlands studied in southwestern Ethiopia: (**a**) species richness of wetland dependent birds (**b**) species abundance of wetland dependent birds, (**c**) species richness of wetland associated birds and (**d**) species abundance of wetland associated birds. Where: Ch = Chalalaki, Bu = Bulbul, Ha = Haro, Bo = Boye, Kt = Kito, Kf = Kofe, Aw = Awetu, NW = Nech Wuha, Af = Afala, Ot = Otra, Al = Alamgano and Sh = Shimbira

abundance of wetland dependent birds found in our study could be ascribed to the high number of wading and diving birds in our study sites, which prefer open water. Next to the effect of physico-chemical variables on birds, we found a negative correlation of human disturbance (physical variable) and a positive correlation of macroinvertebrate abundance (biotic variable) with species richness and abundance of wetland dependent birds. Previous studies reported a low bird species diversity in high disturbed wetlands (DeLuca et al. 2004; Ntongani and Andrew 2013) and a high bird abundance at sites with greater macroinvertebrate diversity and abundance Getachew et al. (2012). Furthermore, high species richness and abundance of wetland dependent birds was observed in wetlands with a high percentage of open water such as Chalalaki, Haro and Bulbul which are also characterized by a high macroinvertebrate richness and abundance. In our study area, wetlands totally covered by vegetation were characterized by a higher level of human disturbance, a lower availability of food such as fish (Mereta et al. unpublished data) and consequently also a lower richness and abundance of wetland dependent birds.

In contrary to our hypothesis, the GLMM model did not select climatic zones as important variable to explain variation in richness and abundance of both macroinvertebrates and birds. In contrast, local environmental conditions seem more important than climatic conditions in explaining the variation in richness and abundance of macroinvertebrate and birds in our study area. Previous studies investigating birds or macroinvertebrates support our results. Zhang et al. (2014) reported that especially local environmental conditions affect the macroinvertebrate assemblage. Whereas, Hiley et al. (2016) reported that the diversity of birds was affected by habitat modification in different climatic zones in Mexico.

Despite the importance of freshwater wetlands as biodiversity hot spots, they are continuously under pressure due to expanding human activities. The record of 169 bird species including IUCN red list and endemic species and 82 macroinvertebrate taxa indicates that the wetlands in the study area are an important biodiversity hotspot. Previous studies reported that local environmental conditions such as change in habitat or water quality affect the occurrence of macroinvertebrates (Mereta et al. 2012; Gezie et al. 2017) and that regional and global factors such as climate affect bird diversity and abundance (Valiela and Bowen 2003). The present study indicates that local environmental conditions are important when assessing the richness and abundance of birds and macroinvertebrates, rather than the spatial differences between different climatic zones. Therefore, the selected environmental variables can be considered important when monitoring wetland ecosystems and assessing the wetland status. These results could help to inform decision-makers and stakeholders, when developing wetland conservation strategies, since local environmental conditions should be taken into account. Moreover, further study is needed on the composition and structure of biological communities in these wetlands, as species richness and abundance alone is not enough to measure ecosystem health and function.

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Appendix

Table 4 List of recorded macroinvertebrates in the three climatic zones of south western Ethiopia

Family name of macroinvertebrates	Relative abundance
Aeshnidae	5.68
Ancylidae	0.01
Belostomatidae	3.99
Caenidae	0.74
Calopterygidae	0.21
Ceratopogonidae	1.24
Chironomidae	10.35
Chlorocyphidae	0.04
Chlorolestidae	1.59
Chrysomelidae	0.03
Cicadellidae	0.05
Coenagrionidae	8.54
Corbiculidae	0.19
Corduliidae	0.15
Corixidae	3.82
Corydalidae	0.07
Crambidae	0.06
Culicidae	0.91
Dixidae	0.06
Dolichopodidae	0.01
Dryopidae	0.01
Dytiscidae	9.74
Ecnomidae	0.40
Elmidae	3.38
Empididae	0.04
Ephemerilidae	0.89
Erpobdellidae	0.00
Gelastocoridae	0.01
Gerridae	1.01
Gomphidae	6.85
Gyrinidae	0.85
Haliplidae	0.01
Helodidae	3.12

Table 4 (continued)

Family name of macroinvertebrates	Relative abundance
Heptagenidae	0.58
Hirudinea	1.82
Hydraenidae	0.06
Hydrometridae	0.17
Hydrophilidae	6.93
Hydropsychidae	1.55
Hydroptilidae	0.08
Isotomidae	0.05
Lebullidae	0.18
Leptoceridae	0.06
Leptophlebiidae	0.11
Lestidae	0.84
Lumbricidae	0.01
Lymnaeidae	4.37
Lymnephiliidae	0.01
Mesoveliidae	0.11
Naucoridae	0.12
Nepidae	0.39
Noteridae	0.12
Notonectidae	6.50
Nymphulidae	0.01
Oligochaete	1.40
Perlodidae	0.39
Philopotamidae	0.08
Physidae	0.56
Pisulidae	0.03
Planorbidae	0.47
Pleidae	0.37
Potomanautidae	0.28
Psephinidae	0.01
Psychodidae	0.12
Pyralidae	0.06
Rhagionidae	0.07
Salpingidae	0.08
Scirtidae	0.04
Simulidae	0.53
Siphlonuridae	0.19
Sphaeriidae	6.18
Stratiomyidae	0.01
Syrphidae	0.04
Tabanidae	0.08
Teloganodidae	0.37
Tetragnothidae	0.04
Thiaridae	0.30
Tipulidae	0.09
Unionidae	0.07

Table 5 List of recorded bird species in the three climatic zones of southwestern Ethiopia

Name of bird species	Relative abundance
Wetland dependent birds	
African Black Duck	0.03
African Darter	0.13
African Fish Eagle	0.39
African Jacana	3.68
African Snipe	0.05
African Spoonbill	0.49
Black Crake	0.13
Black-crowned Crane	4.79
Black-headed Heron	1.03
Black-necked Grebe	0.1
Black-tailed Godwit	0.05
Blue-breasted King-fisher	0.13
Cattle Egret	11.51
Common Bittern	0.21
Common Mohooren	0.15
Common Sandpiper	0.39
Common Stilt	0.15
Egyptian Goose	1.9
Eurasian Spoonbill	0.05
Eurasian wigeon	2.53
Fan-tailed Widow-bird	5.74
Fulvous Whistling Duck	0.1
Giant King-fisher	0.13
Glossy Ibis	0.05
Great Egret	1.26
Great White Pelican	0.05
Grey Headed Kingfisher	0.15
Grey Heron	0.62
Hamerkop	0.75
Hottentot Teal	0.15
Knob-billed Duck	0.9
Lesser Moorhen	0.03
Little Egret	0.23
Long-tailed Cormorant	0.98
Malachite King-fisher	0.23
Mallard	0.1
Marabou Stork	0.15
Marsh Sand-piper	0.72
Northern Pin-tail	1.47
Northern Shoveler	0.44
Pied King-fisher	0.21
Pied Wagtail	0.08
Pink-backed Pelican	0.33
Purple Heron	0.05
Rouget's Rail	0.64
Sacred Ibis	4.04
Spur-winged Lapwing	0.82

Table 5 (continued)

Name of bird species	Relative abundance
Squacco Heron	0.64
Wattled Crane	0.51
Wattled Ibis	1.42
White-backed Duck	0.88
White-faced Duck	4.02
Wood Sandpiper	0.05
Yellow-billed Duck	6.64
Yellow-billed Stork	0.62
Yellow Wag-tail	0.18
Yellow-mantled Widow-bird	0.18
Wetland associated birds	
Abyssinia Orioles	0.61
Abyssinia Ground Horn-bill	0.2
Abyssinia Long-claw	0.25
Abyssinian Slaty Flycatcher	0.25
Africa Paradise Monarch	0.3
African Dust Fly-catcher	0.05
African Fire Finch	0.25
African Mourning Dove	2.08
African Olive Pigeon	0.15
African Paradise Fly-catcher	1.17
African Rook	0.41
African Striped Cuckoo	0.15
African Trush	1.47
African Wattled Lap-wing	2.58
Augur Buzzard	0.1
Barn Swallow	1.77
Black Bishop	0.1
Black Crow	0.15
Black-cuckoo Shrike	0.1
Black-headed Oriole	0.05
Black-headed Weaver	1.88
Black Kite	0.35
Black-tailed Godwit	0.1
Black-winged Lap-wing	0.2
Blue-headed Coucal	1.67
Blue-spotted Dove	0.25
Bronze Mannikin	9.63
Brown Babbler	0.81
Brown-throated Wattle Eye	0.25
Brown Snake Eagle	0.3
Brown-throated Martin	0.76
Cape Rook	3.04
Cardinal Wood Pecker	0.15
Common Bulbul	1.01
Common Chitchat	0.15
Common Fiscal	0.46
Common Green Shank	0.2
Common Ringed Plover	0.05

Table 5 (continued)

Name of bird species	Relative abundance
Common Waxbill	0.3
Copper Sunbird	0.15
Crested Frankolin	0.3
Crowned Hornbill	0.41
Eastern Grey Plantain-eater	1.82
Ethiopian Swallow	1.32
European Bea-eater	0.1
Glossy Ibis	0.05
Greater Blue-eard Starling	1.67
Greenbul	0.1
Grey-backed Camaroptera	1.17
Grey-backed Fiscal	1.22
Grey Wood Picker	0.15
Greyish Eagle Owl	0.05
Hadada Ibis	11
Helmeted Guineafowl	1.98
Hemprich’s hornbill	0.15
Hooded Vulture	2.03
Lesser Blue-eared Glossy Starling	0.41
Little Bee Eater	0.76
Little Greenbul	0.1
Long Crested Eagle	0.2
Mountain White Eye	0.1
Northern Black Flycatcher	0.1
Olive Trush	0.25
Pin-tailed whydah	0.35
Red-backed Shrike	0.05
Red-billed Fire-finch	0.56
Red-billed hornbill	0.3
Red-chested cuckoo	0.3
Red-cheeked Cordon Blue	0.05
Red-eyed Dove	2.94
Red-tailed Wheatear	0.05
Red-winged Lark	0.15
Richard Pipit	0.35
Ring-necked Dove	0.41
Rupees Rubin Chat	0.46
Silvery-cheeked hornbill	0.15
Singing Bush Lark	0.3
Southern Black Flycatcher	0.1
Speckled Mouse Bird	1.67
Speckled pigeon	0.35
Spectacled Weaver	0.1
Splendid Starling	0.46
Swainsons Sparrow	0.46
Tacasse Sunbird	0.46
Tambourine Dove	0.81
Tawny Flanked Prinia	0.51
Thick-billed Raven	1.12

Table 5 (continued)

Name of bird species	Relative abundance
Tropical Boubou	1.47
Variable Sun Bird	1.42
Village Indigo Bird	0.05
Village Weaver	0.2
White-billed Bustard	0.35
White-cheeked Turaco	0.35
White-colored Pigeon	3.29
White-eyed Slaty Fly-catcher	0.05
White-headed Mouse Bird	0.76
White-ramped Babbler	0.1
White-tailed Swallow	0.41
White-throated Bee-eater	0.2
Woolly-necked Stork	0.51
Hooded Vulture	1.52
Woodland King-fisher	0.51
Yellow Billed Kite	0.51

Table 6 Physico-chemical parameters used to develop the generalized linear mixed model, with indication of the mean and standard deviation

Parameters	Mean	Standard deviation
Water depth (m)	63.6	45.1
Sediment depth (m)	37.8	30.8
Water temp (°C)	22.4	4.4
pH	6.5	0.8
Dissolved oxygen (mg/l)	63.7	38.1
Electric conductivity (μS/cm)	103.6	67.8
Total nitrogen (mg/l)	1.4	2.4
Chemical oxygen demand	24.4	24.5

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