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RESEARCH ARTICLE

DIVERSITY AND ABUNDANCE OF FISHES IN TEKEZE RESERVOIR, TEKEZE BASIN, ETHIOPIA

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ABSTRACT: The diversity and relative abundance of fishes from Tekeze Reservoir, Ethiopia, was studied from January 2016 to December 2017. Samples were collected from six sites using gill nets with different stretched mesh sizes (0.5–5.5, 6, 8, 10, 12, and 14 cm). Fish were identified to family and species level. Ecological indices such as Shannon-Weaver diversity index, Simpson's diversity index, Species Evenness and Richness were used to analyze the data. All environmental variables were found in the optimum condition for fish production. The fish belonged to 15 species within four families: Cyprinidae, Bagridae, Claridae and Cichlidae. Shannon-Weaver and Simpson's diversity indices ranged from 1.447 to 1.697 and 0.7333 to 0.7925, respectively, and Equitability ranged 0.6957–0.8718. Values for fish species diversity and equitability were higher ($H' = 1.715$; $J' = 0.746$) during the wet and dry-cold seasons, respectively. The index of relative importance (%IRI) in the gill net landings were: *Oreochromis niloticus*, (35.5%), *Bagrus docmak* (22.6%), *Labeobarbus intermedius* (20.5%), *Labeo niloticus* (10.6%) and *Labeo forskalii* (10.2%). The species with low relative importance (< 1%) include *Clarias gariepinus*, *Labeobarbus nedgia*, *Raiamas senegalensis*, *Labeobarbus crassibarbis*, *Heterobranchus longifilis*, *Garra dembeensis*, *Bagrus bajad*, *Labeobarbus bynni*, *Labeo cylindricus*, and *Labeobarbus beso*. The river mouth habitats had more catch composition than the pelagic. Physico-chemical parameters played a key role in the spatial variation of the fish. The study indicated decline of the fish stock in the reservoir, therefore, management plan and strategy should be in place to maintain the fish species and increase their sustainable utilization.

Key words/phrases: Abundance, Diversity, Evenness, Seasons, Tekeze Reservoir.

INTRODUCTION

Reservoirs play a very important role in the geochemical cycling of elements and influence the chemical composition and material transfer of

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river systems (Singh *et al.*, 2005). They have high ecological, economic and recreational importance (Carol *et al.*, 2006). They contribute significantly to fulfilling basic human needs such as water for drinking and industrial use, irrigation, flood control, hydropower generation, fishing and recreation. However, unwise use of reservoirs can cause decline of the aquatic fauna and flora (Basavaraja *et al.*, 2014).

Fish diversity and abundance reflect the quantity and quality of the available habitat. The decline in the abundance of freshwater fish in the world has been a concern for over one hundred years. Since the twentieth century, many fish species have suffered continuing declines in abundance and distribution. Inland commercial fisheries target many smaller species. The decline of the species is commonly attributed to general habitat degradation, reduced water quality and pollution, illegal fishing and commercial overfishing and altered biotic interactions (Gehrke *et al.*, 1995; Mallen-Cooper *et al.*, 1995). Nevertheless, the impact of the anthropogenic activities, habitat degradation, exotic species introduction, water diversions, pollution, and global climate change are the main causative agents for the rapid decline of aquatic species (Barbour *et al.*, 1999).

Due to their easy identification and economic value, fish have been identified as suitable for biological assessment (Siligato and Böhmer, 2001). Fish assemblages have been widely used as ecological indicators to assess and evaluate the level of degradation and health of water bodies at various spatial scales (Vijaylaxmi *et al.*, 2010). As habitat degradation continues on a global scale, maintenance of fish species habitat has become a central issue of conservation biology. This is particularly the case with the fish fauna of inland waters (Pegg and Taylor, 2007). Management of fishery needs scientific information of resources where knowledge of fish stocks is important (Ricker, 1975). Besides, assessing fish biodiversity and their interaction with biotic and abiotic factors would give a broader understanding of the functions and ecological value of ecosystems (Okyere *et al.*, 2012).

Tekeze Reservoir is one of the newly constructed reservoirs in Ethiopia mainly for the purpose of hydroelectric power generation (Mebrahtom Gebrmariam, 2012). It has huge potential fishery resources and other aquatic life forms (Dereje Tewabe *et al.*, 2009; Tsegay Teame *et al.*, 2016). Dereje Tewabe *et al.* (2009) reported eighteen fish species, but Tsegay Teame *et al.* (2016) documented eleven fish species, and the fishery activities in the reservoir plays a significant role in providing income and food supply for the rural families found near the water body. However, no detailed systematic study (in terms of time and space occupation for sampling) was conducted about the diversity and abundance of fishes, and the critical environmental factors that governed fish dynamics. Therefore, the objective of the present investigation was to update recent data regarding fish diversity status and abundance, aiming to contribute to better knowledge of the fish diversity profile and a tool for conservation planning of the aquatic resources in Tekeze Reservoir.

MATERIALS AND METHODS

Study area

The study was conducted in Tekeze Reservoir, found at about 938 km north of Addis Ababa, the capital city of Ethiopia and 155 km west of Mekelle, the capital city of the Tigray Regional State. The reservoir was constructed in 2009 over Tekeze River for hydroelectric generation, and is located at about 1,115 metres above sea level at coordinates of 13°20′ 49″ N and 38°44′ 37″ E. Subsistence and commercial fishing activities are also carried out in the reservoir. It is one of the biggest reservoirs in Ethiopia, with a total water storage capacity of 9,230 million m^3 (Mebrahtom Gebrmariam, 2012). It is fed by Tekeze River, which is one of the longest perennial rivers originating from the highlands of Ethiopia, placed on the eastern side of the Semien Mountains range (Kidane Welde, 2016; Fikru Fentaw, 2018). Maximum length of the reservoir is almost 75 km at full supply level, with two main branches. The reservoir has a considerably large surface area of 147 km^2. It has a catchment area of over 29,404 km^2, with a long-term average annual inflow of 3,750 million m^3 and sedimentation of 30 million m^3 per year (Kidane Welde, 2016). Six sampling sites (Gfrtsatsa, Lmlmo, Tsilare, Kanizu, Seletsa, and Ariqua) (Fig. 1) were selected to represent river mouth, pelagic and littoral habitats of the reservoir.

Environmental variables

The environmental variables of Tekeze Reservoir were recorded in the late morning between 9:00 and 11:00 a.m. (Shukla and Singh, 2013). Chlorophyll a and turbidity were measured *in situ* by aqua-flour or fluorometer/turbidity meter (Model 8000–001), and dissolved oxygen was measured with a portable oxygen meter probe (Model HQ40d), whereas pH and temperature were measured with coupled pH/MV/meter (Model CE 370 pH meter 01186, EU). Total dissolved solids and electrical conductivity were measured simultaneously with conductivity/TDS meter (Model CE 470 conductivity meter 01189). Water transparency of the reservoir was measured with a standard Secchi-disc of 20 cm diameter.

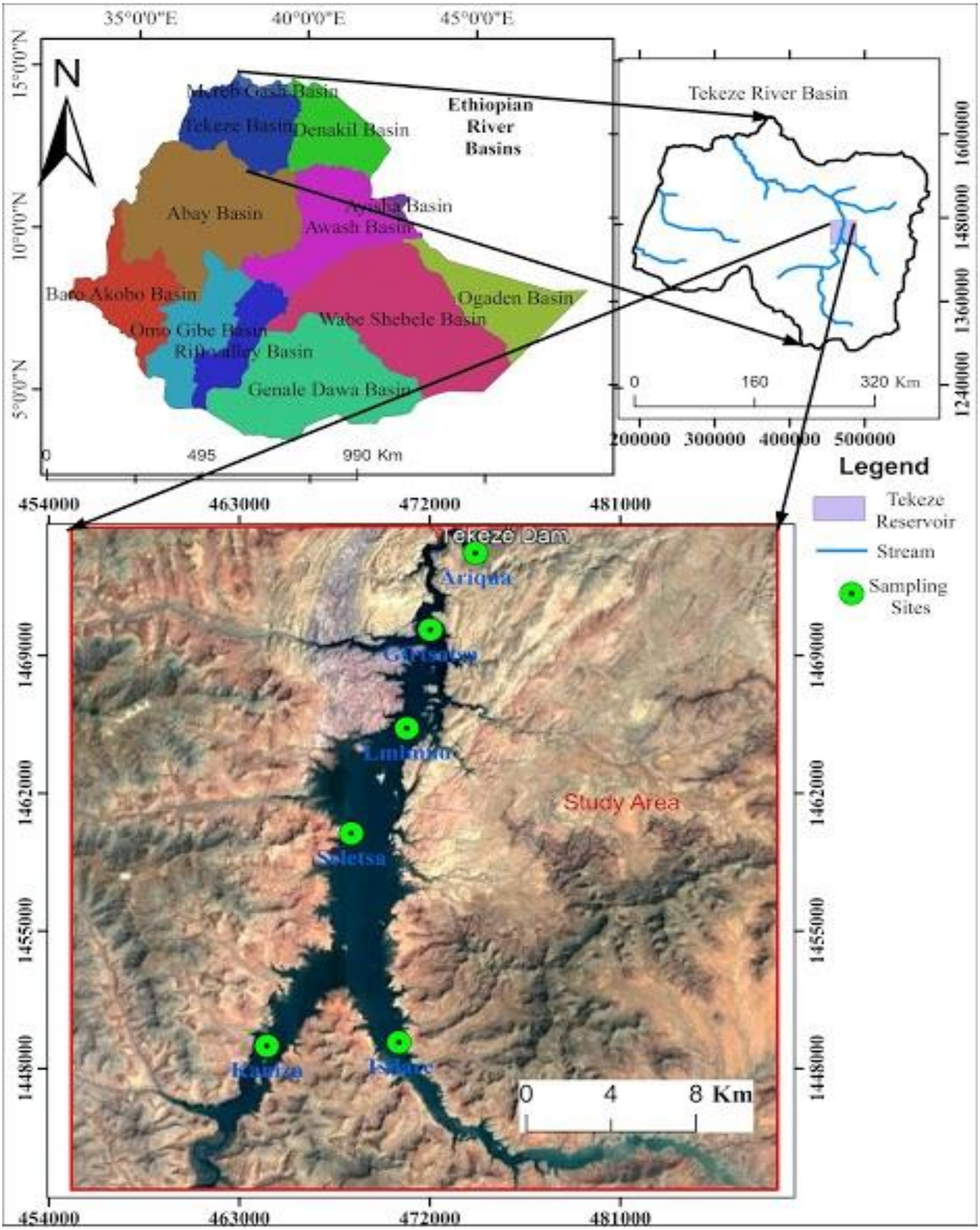

Fig. 1. The Ethiopian main basins, the Tekeze basin and sampling sites in Tekeze Reservoir.

Fish sampling and measuring

Fish specimens were collected from January (2016) to December (2017) using multifilament gill nets with a stretched mesh size of 6, 8, 10, 12, and 14 cm and monofilament gillnet with a stretched mesh size of 0.5 to 5.5 cm from six sampling sites in Tekeze Reservoir. The six panels were combined to form one multi-mesh gill net. The various mesh sizes of the gill nets were chosen to be able to catch the whole range of size classes and species. The size of a single mesh panel was 3 m X 50 m. The nets were deployed in the late afternoon (3:00 p.m.) and removed in the following morning (9:00 a.m.). Fish specimens were collected for two consecutive years, two times each during the dry-cold (November-February), dry-hot (March-June), and wet (July-October) seasons. Immediately after capture, identification of the fish specimen was made to species level using relevant taxonomic literature (Shibru Tedla, 1973; Nelson, 2006; Redeat Habteselassie, 2012). The total length (TL) and standard length (SL) of each fish specimen was measured to the nearest 0.1 cm. Total weight of each fish specimens was also taken using a digital balance and measured to the nearest 0.1 g. Diversity, abundance, and temporal and spatial distribution of the fish species in the reservoir were determined with routine methods.

Data analysis

The collected data were analyzed using statistical software and simple descriptive statistics. SPSS version 24, PAST version 3.25, Canoco for windows 4.5, and Pasgear II were used to analyze the data. The environmental variables were analyzed and tested using Post Hoc multiple comparison LSD model and the comparisons between the sampling sites were taken using one-way ANOVA (tested at $P = 0.05$).

The species diversity was calculated using different indices. The commonly used indices such as Shannon diversity index (H′) (Shannon and Weaver, 1963) and Simpson’s dominance or diversity index (Simpson, 1959) were used to evaluate the species diversity. Calculation of fish diversity using Shannon-Weaver index depends on both the number of species present and the abundance of each species. Simpson’s index measures the diversity of species. The value of Simpson’s dominance index (D) ranges between zero and one. With this index, zero represents infinite diversity and one represents no diversity; hence the bigger the value of D, the lower the diversity. It measures the probability that two individuals randomly selected from a sample will belong to the same species. The value of Simpson's index of diversity (B) also ranges between zero and one, but the greater the value, the greater the sample diversity. In this case, the index represents the probability that two individuals randomly selected from a sample will belong to different species (Simpson, 1959). The different diversity indices were used in the discussion of the spatial and season patterns in the reservoir.

Shannon-Weaver Index:

$$H' = -\sum Pi \times \ln(Pi)$$ Where $Pi = \frac{ni}{N}$, H′ = diversity index and ni = number of individuals within species and N= total number of individuals

Simpson's Index of Dominance:

$$D = \frac{\Sigma n(n-1)}{N(N-1)}$$ Where D = Simpson's index of dominance

Simpson's Index of Diversity

$$B = 1 - \frac{\Sigma n(n-1)}{N(N-1)}$$ Where B = Simpson's index of diversity

The species evenness (J′) and richness (R) of the reservoir was calculated using Pielou's Evenness Index (Pielou, 1969) and Margalef's Index (Margalef, 1958). Evenness is a measure of the relative abundance of the different species making up the richness of an area. The number of species per sample is a measure of richness. The more species present in a sample, the 'richer' the sample.

Pielou's evenness index:

$$J' = \frac{H'}{H' \max}$$ Where $H'max = lnS$, H′ is the value derived from Shannon-Weaver index

Margalef's richness index:

$$R = \frac{S-1}{\ln N}$$ Where S = number of species and N is total number of individuals

Index of Relative Importance (IRI) was used to measure the relative abundance based on number and weight of individuals in catches, and their frequency of occurrence (Kolding, 1989). This was calculated as:

$$\%IRIi = \frac{(\%Wi + \%Ni)\%Fi}{\sum_{j=1}^{i=1}(\%Wj + \%Nj)\%Fj} X100$$

Where *%Wi* = percentage weight of each fish species in total catch

%Ni = percentage number of each fish species in total catch

%Fi = percentage frequency of occurrence of each species in total number of settings

%Wj = percentage weight of total species of total catch

%Nj = percentage number of total species of total catch

%Fj = percentage frequency of occurrence of total species in total number of settings

The percentage composition by number and weight of every fish taxa during dry-cold, dry-hot and wet seasons as well as for each landing site were computed. The significance of differences in species relative abundance during the sampling seasons was analyzed using the T-test. One-way ANOVA was used to determine the significance of differences in species diversity between sites and sampling seasons. A paired T-test was also used to determine if there exist significant differences between the sampling seasons of mean total abundance of the fishes.

The association between fish species distribution and physico-chemical variables was evaluated by canonical multivariate analysis using Canoco for windows 4.5-version software (Lepš and Šmilauer, 2003). Detrended Correspondence Analysis (DCA) was employed to check the response of the data, and it was found that the length of the longest gradient was 0.316. According to Lepš and Šmilauer (2003), redundancy analysis (RDA) should be used only if the length of the longest gradient is shorter than 3. Redundancy analysis was performed to observe the relation of species abundance data to environmental factors. Therefore, the RDA was used as the fish species data showed a linear response to the environmental variables.

RESULTS

Physico-chemical parameters

The spatial variation of the environmental variables of the Tekeze Reservoir is given in Table 1. There was no statistically significant variation ($p>0.05$) in all parameters between all sampling sites of the reservoir.

Table 1. Spatial variation of abiotic parameters (mean ± SE) of Tekeze Reservoir.

	Sampling sites					
Variables	**Gfrtsatsa**	**Lmlmo**	**Tsilare**	**Kanizu**	**Seletsa**	**Ariqua**
Chl. (mg/l)	41.28±4.62	45.93±7.05	58.55±14.27	56.56±11.68	50.22±10.62	47.49±7.70
TRB (NTU)	6.31±1.73	7.67±1.66	6.07±1.53	7.05±1.68	6.98±1.38	8.11±1.80
DO (mg/l)	4.32±0.82	5.27±0.86	6.21±0.32	6.37±0.51	5.64±0.61	4.99±0.97
Temp. (°C)	27.27±1.00	27.45±0.39	26.93±0.53	28.53±0.46	28.50±0.71	27.70±0.73
pH	7.72±0.30	8.13±0.19	8.19±0.19	8.00±0.10	7.94±0.20	8.07±0.23
TDS (ppm)	128.92±10.54	126.65±11.52	144.08±21.45	138.67±17.01	136.93±16.33	131.42±12.94
EC (µS/cm)	198.33±16.21	194.83±17.72	221.67±33.01	213.33±26.16	210.67±25.12	202.17±19.91
WT (cm)	212.50±14.76	211.67±23.90	209.17±16.45	203.33±17.26	201.67±19.90	195.00±17.27

Note: Chl. – chlorophyll a, TRB – turbidity, DO - dissolved Oxygen, Temp. - Temperature, TDS - total dissolved solids, EC – electrical conductivity and WT - water transparency (secchi disk)

Fish species composition

A total of 2,110 fish specimens, belonging to three orders, four families, eight genera, and fifteen species were collected from six sampling sites, which represent river mouth, open water, and littoral habitats (Table 2). Three Orders: Cypriniforms, Siluriforms, and Perciforms were represented in the reservoir.

Order Cypriniformes was the most diverse taxa represented by one family, four genera, and ten species. The fish species found under this order were *Labeo niloticus* (Linnaeus, 1758), *Labeo forskalii* (Rüppell, 1835), *Labeo cylindricus* (Peters, 1852), *Labeobarbus beso* (Rüppell, 1835), *Labeobarbus intermedius* (Rüppell, 1835), *Labeobarbus bynni* (Forsskål, 1775), *Labeobarbus nedgia* (Rüppell, 1835), *Labeobarbus crassibarbis* (Nagelkerke and Sibbing, 1997), *Raiamas senegalensis* (Steindachner, 1870), and *Garra dembeensis* (Rüppell, 1835).

Order Siluriformes was also represented by two families, three genera, and four species. *Bagrus bajad* (Forsskål, 1775) and *Bagrus docmak* (Forsskål, 1775) were from the family Bagridae, and *Clarias gariepinus* (Burchell, 1822) and *Hetrobranchus longifilis* (Valenciennes, 1840) were from the family Claridae. However, only one family, one genus and one species (*Oreochromis niloticus* (Linnaeus, 1758)) represented the order Perciforms. *Labeo cylindricus* was a new record for the reservoir. Generally, the taxonomic classification, common and local (Amharic) names of the identified fish species from Tekeze Reservoir is given in Table 2.

Table 2. Fish species composition and their local names (Amharic) from Tekeze Reservoir.

Order	Family	Genera	Scientific name	Local name	Common name
Cypriniformes	Cyprinidae	Labeo	*L. niloticus*	Gebsma	Nile labeo
			L. forskalii	Tiqurie	Not available
			L. cylindricus	Not available	Redeye labeo
		Labeobarbus	*L. beso*	Not available	African scraping feeder
			L. intermedius	Nech asa	Ethiopia barb
			L. bynni	Nech asa	Nile/Niger barb
			L. nedgia	Nech asa	Not available
			L. crassibarbis	Nech asa	Not available
		Raiamas	*R. senegalensis*	Shilm	Senegal minnow
		Garra	*G. dembeensis*	Not available	Dembea stone lapper
Siluriformes	Bagridae	Bagrus	*B. bajad*	Qey ambaza	Bayad
			B. docmak	Nech ambaza	Semutundu
	Claridae	Clarias	*C. gariepinus*	Qey ambaza	African catfish
		Hetrobranchus	*H. longifilis*	Qey ambaza	Sampa
Perciformes	Cichlidae	Oreochromis	O. niloticus	Qereso	Nile tilapia

Fish diversity indices

The diversity indices of fishes in different sampling sites of the Tekeze Reservoir are given in Table 3. The Simpson's dominance index (D) shows the higher value at Ariqua (0.2667), but low at Tsilare (0.2061) and Seletsa (0.2075). That is, the bigger the value of D, the lower the diversity. However, the value of Simpson's index of diversity (B) for the sampling sites of Tsilare (0.7939) and Seletsa (0.7925) were high. The lowest values of Shannon-Weaver species diversity index (H′) was recorded at Ariqua (1.447) and Lmlmo (1.562) sampling sites, which are the pelagic zones of the reservoir. Conversely, high values were recorded at the littoral (Gfrtsatsa and Seletsa) and river mouth (Tsilare and Kanizu) habitats. The value of species richness index ranged from 0.9004 to 1.683 at Lmlmo and Gfrtsatsa sampling sites, where the highest and lowest numbers of species were obtained, respectively.

Table 3. Fish diversity indices from different sampling sites of the Tekeze Reservoir.

Parameters	Sampling sites					
	Gfrtsatsa	**Lmlmo**	**Tsilare**	**Kanizu**	**Seletsa**	**Ariqua**
Number of species (S)	10	6	9	9	9	8
Number of individuals (N)	243	258	429	525	429	226
Simpson's dominance index (D)	0.2234	0.2232	0.2061	0.2197	0.2075	0.2667
Simpson's diversity index (B)	0.7766	0.7768	0.7939	0.7803	0.7925	0.7333
Shannon-weaver index (H′)	1.683	1.562	1.674	1.636	1.697	1.447
Margalef's richness index (R)	1.638	0.9004	1.32	1.277	1.32	1.291
Pielou's evenness (J′)	0.7308	0.8718	0.762	0.7448	0.7723	0.6957

The diversity indices of fishes in different sampling seasons are also given in Table 4. The value of B was high in the wet season (0.7978), but low in the dry-hot season (0.7661). Similarly, the lowest value of H′ was recorded in the dry-hot season (1.592), but high value was recorded in the wet season (1.715). The value of R ranged from 1.285 to 1.596 in the dry-cold and wet seasons, respectively. The overall value of the diversity indices in the reservoir were 0.7901 (B), 1.688 (H′), 1.826 (R), and 0.6232 (J). The overall values of the diversity indices in the reservoir were 0.7901 (d), 1.688 (H′), 1.826 (R), and 0.6232 (J).

Table 4. Fish diversity indices in different sampling seasons of the Tekeze Reservoir.

Parameters	**Sampling seasons**			**Overall values**
	Dry-cold	**Dry-hot**	**Wet**	
Number of species (S)	9	10	12	15
Number of individuals (N)	506	621	983	2110
Simpson's dominance index (D)	0.216	0.2339	0.2022	0.2099
Simpson's diversity index (B)	0.784	0.7661	0.7978	0.7901
Shannon-weaver index (H′)	1.639	1.592	1.715	1.688
Margalef's richness index (R)	1.285	1.399	1.596	1.829
Pielou's evenness index (J′)	0.746	0.6916	0.69	0.6232

Relative abundance of fishes

The catch composition and index of relative importance are given in Table 5. Five fish species; such as *O. niloticus, L. intermedius, L. forskalii, B. docmak* and *L. niloticus* were dominant in number, weight, frequency, and index of the relative importance of the total catch. In the case of numerical percentage (%No), *O. niloticus* (26.9%) was the most dominant in the catch and followed by *L. forskalii* (24.8%), *L. intermedius* (21.5%), *B. docmak* (14%), and *L. niloticus* (10.1%). However, *B. docmak* (28.1%) dominated the catch by weight (%W) followed by *O. niloticus* (27.1%, *L. intermedius* (14%), *L. niloticus* (13%) and *L. forskalii* (11.7%). *Oreochromis niloticus* (91.7%), *L. intermedius* (80.6%), *B. docmak* (75%), *L. niloticus* (63.9%), and *L. forskalii* (38.9%) were the most frequently occurring fish species in the total setting. According to the index of relative importance (%IRI), *O. niloticus* (35.5%) was the most dominant species, followed by *B. docmak* (22.6%), *L. intermedius* (20.5%), *L. niloticus* (10.6%) and *L. forskalii* (10.2%) in descending order of their importance.

Table 5. Catch composition and index of relative importance (IRI) of fish species in Tekeze Reservoir.

Spp.	No	%No	W (kg)	%W	F	%F	IRI	%IRI
O. niloticus	567	26.9	132.103	27.1	33	91.7	4945	35.5
B. docmak	295	14.0	137.115	28.1	27	75.0	3156	22.6
L. intermedius	454	21.5	68.516	14.0	29	80.6	2865	20.5
L. niloticus	214	10.1	63.626	13.0	23	63.9	1481	10.6
L. forskalii	523	24.8	57.218	11.7	14	38.9	1420	10.2
C. gariepinus	7	0.3	19.077	3.9	3	8.3	35	0.3
L. nedgia	12	0.6	0.953	0.2	7	19.4	15	0.1
R. senegalensis	13	0.6	0.259	0.1	4	11.1	7	0.1
L. crassibarbis	7	0.3	0.945	0.2	5	13.9	7	0.1
H. longifilis	2	0.1	5.206	1.1	2	5.6	6	0.0
G. dembeensis	10	0.5	0.046	0.0	4	11.1	5	0.0
B. bajad	1	0.0	2.145	0.4	1	2.8	1	0.0
L. bynni	2	0.1	0.392	0.1	2	5.6	1	0.0
L. cylindricus	2	0.1	0.077	0.0	1	2.8	0	0.0
L. beso	1	0.0	0.204	0.0	1	2.8	0	0.0
Total	2110	100.0	487.882	100.0	-	-	13947	100.0

Note: Spp. – species, No. – catch number, %No – numerical percentage, W – catch weight, %W – percentage of catch weight, F - frequency of occurrence, %F – percentage of frequency of occurrence, IRI – index of relative importance, and %IRI – percentage of index of relative importance.

Spatial and temporal distribution of fishes

The total percentage distribution of fish caught by number and weight in each sampling site during the research period is shown in Fig. 2. The highest percentages of the catch were observed at Kanizu, Tsilare, and Seletsa sampling sites. However, the lowest catch was recorded at Lmlmo and Gfrtsatsa sampling sites. The result showed spatial differences in the catch among the habitats of the reservoir. As indicated in Fig. 2, Kanizu contributed 24.88% (catch by number) and 23.33% (catch by weight) followed by Tsilare that contributed 20.33% (catch by number) and 21.99% (catch by weight). Seletsa sampling site also contributed 20.33% and 15.58% of the catch by number and by weight, respectively. However, Lmlmo, Gfrtsatsa, and Ariqua sampling sites had low catch composition. This might be due to the high fishing pressure in the areas (personal observation).

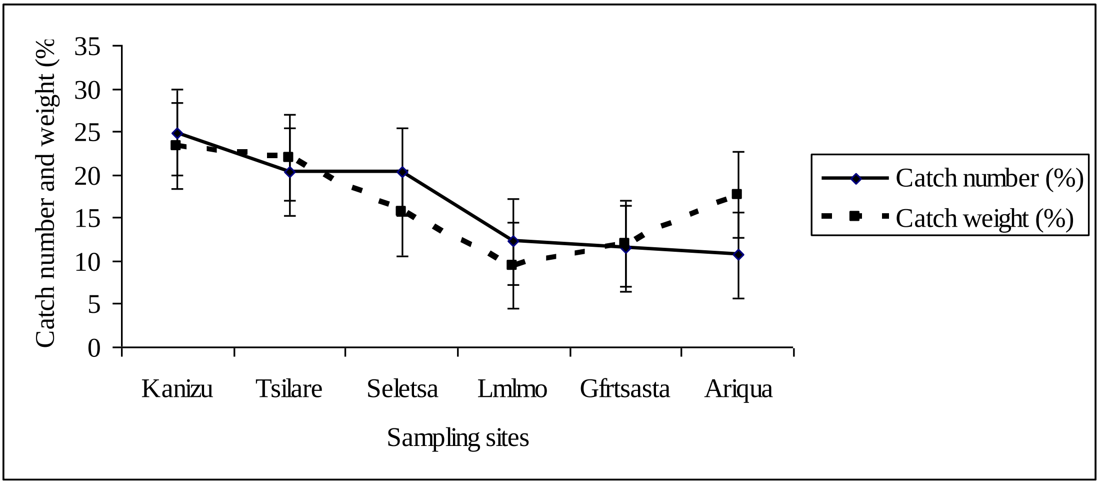

Fig. 2. Percentage of catch by number and weight of fish species in each sampling site of Tekeze Reservoir (2016 to 2017).

Of the total specimens, 983 (46.59%) were caught during the wet, 621 (29.43%) in the dry-hot, and 506 (23.98%) in the dry-cold seasons. Similar to catch number, high proportion of catch by weight (51.72%) was recorded in the wet season. The remaining 26.56% and 21.72% were caught in the dry-hot and dry-cold seasons, respectively. The result showed significant temporal variation in number and weight between seasons. *Oreochromis niloticus*, *L. forskalii*, *L. intermedius*, *B. docmak* and *L. niloticus* were the dominant fish species in all seasons. *Oreochromis niloticus* was the most abundant species in number in the dry-cold and wet seasons, but *L. forskalii* dominated the dry-hot season of the sampling period (Table 6). *Oreochromis niloticus*, *L. intermedius*, *B. docmak*, *L. niloticus*, *L. forskalii*, *R. senegalensis*, and *L. crassibarbis* were caught in all seasons during the study period. *Labeobarbus nedgia* and *G. dembeensis* were obtained in both the dry-hot and wet seasons. *Clarias gariepinus*, *H. longifilis*, and *B. bajad* were collected in the wet, *L. cylindricus* in the dry-hot, *L. beso* and *L. bynni* in the dry-cold seasons.

Table 6. Catch distributions of the species in different sampling seasons of the study period in Tekeze Reservoir.

Species	**Sampling seasons**					
	Dry-cold		**Dry-hot**		**Wet**	
	%No	**%W**	**%No**	**%W**	**%No**	**%W**
Oreochromis niloticus	25.89	28.4	24.64	28.3	28.79	25.9
Labeobarbus intermedius	25.3	15.4	23.99	16.7	18.02	12.1
Bagrus docmak	12.25	28.6	12.08	25.1	16.07	29.4
Labeo niloticus	9.29	14.4	5.8	7.2	13.33	15.5
Labeo forskalii	24.7	12.5	31.24	22.1	20.75	6.1
Clarias gariepinus	-	-	-	-	0.71	7.6
Labeobarbus nedgia	-	-	0.65	0.2	0.81	0.3
Raiamas senegalensis	1.78	0.1	0.48	0.1	0.1	0.0
Garra dembeensis	-	-	0.48	0.0	0.71	0.0
Labeobarbus crassibarbis	0.2	0.1	0.32	0.2	0.41	0.2
Hetrobranchus longifilis	-	-	-	-	0.2	2.1
Bagrus bajad	-	-	-	-	0.1	0.9
Labeobarbus bynni	0.4	0.4	-	-	-	-
Labeo cylindricus	-	-	0.32	0.1	-	-
Labeobarbus beso	0.2	0.2	-	-	-	-
Total	23.98	21.72	29.43	26.56	46.59	51.72

Distribution of fish species in relation to the environmental variables

The RDA ordination of the species-environment association indicated that chlorophyll, dissolved oxygen, temperature, total dissolved solids, electrical conductivity, and pH were positively correlated with the first axis, which contributed 90.4% of the total variance. However, the first five environmental variables were strongly correlated with the axis. The abundances of *O. niloticus*, *B. docmak*, and *L. niloticus* were positively-strongly related to chlorophyll, TDS, electronic conductivity, and dissolved oxygen. *Labeo forskalii*, *L. nedgia*, *L. crassibarbis*, *L. cylindricus*, *G. dembeensis* and *L. intermedius* were also positively associated with axis 1. The remaining environmental factors (turbidity and water transparency) and fish species (*L. beso*, *C. gariepinus*, *H. longifilis*, and *L. bynni)* were negatively correlated with this axis (Fig. 3; Table 7).

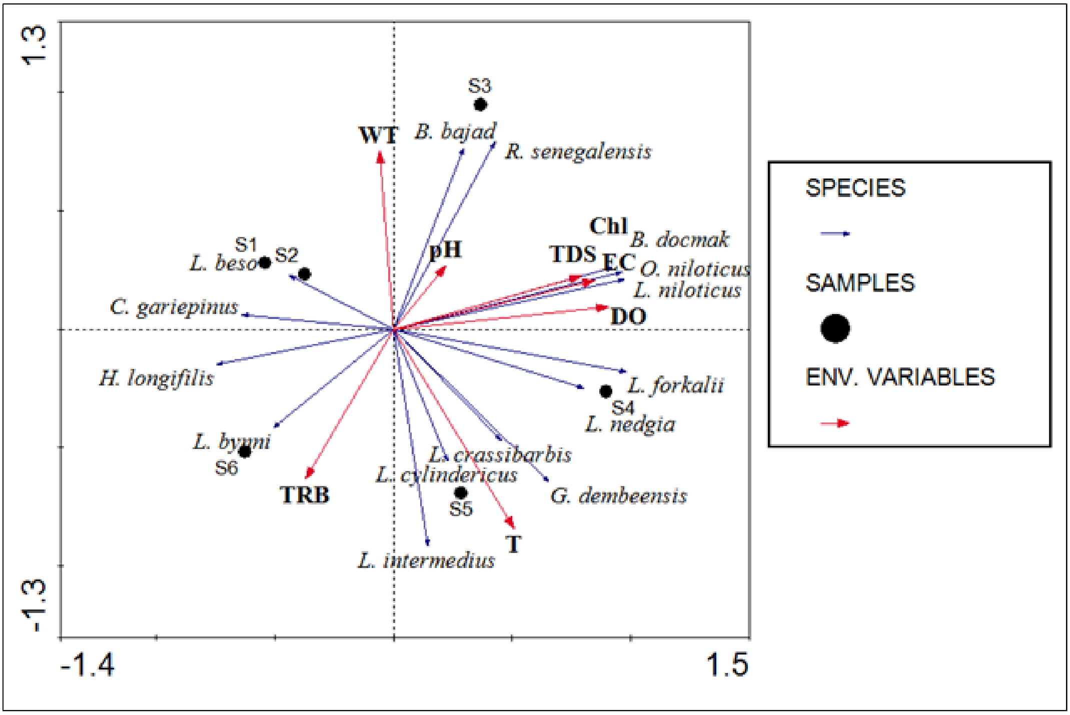

Fig. 3. Tri-plots of the first two axes of the redundancy analysis showing the association of samples, fish species and environmental variables in Tekeze Reservoir.

The second axis was positively correlated with the environmental variables such as chlorophyll, dissolved oxygen, pH, total dissolved solids, and electronic conductivity. Water transparency showed strongly positive correlation, but turbidity and water temperature were negatively correlated with this axis. Chlorophyll, electronic conductivity, total dissolved solids, and dissolved oxygen were positively associated with the relatively high abundance of *B. docmak*, *O. niloticus*, and *L. niloticus*. Similarly, *R. senegalensis*, *B. bajad*, *L. beso*, and *C. gariepinus* were positively correlated, but *L. forskalii*, *L. nedgia*, *L. crassibarbis*, *L. cylindricus*, *G. dembeensis*, *L. intermedius*, *L. bynni*, and *H. longifilis* were negatively correlated to the axis. Particularly, *H. longifilis* and *L. bynni* were negatively correlated with the two axes of the environmental variables such as turbidity. Both axes explained 97.9% of the cumulative percentage variance of the species-environment relationship (Table 7).

Table 7. Canonical coefficients of the first two axes showing the correlation of species abundance and environmental variables in Tekeze Reservoir.

Variables	**Canonical coefficients**	
	Axis 1	**Axis 2**
Eigen values	0.904	0.075
Cumulative percentage variance of species-environment relation	90.4	97.9
Chlorophyll	0.8487	0.2074
Turbidity	-0.3707	-0.632
Dissolved oxygen	0.9066	0.0963
Temperature	0.5078	-0.8409
pH	0.2208	0.2706
Total dissolved solids	0.7913	0.2252
Electric conductivity	0.7912	0.2252
Water transparency	-0.0591	0.7527

DISCUSSION

The optimum fish production is very dependent on the physical, chemical, and biological qualities of water. Fish do not like changes in their environment beyond their limit. Any change can cause stress to the fish. The larger the changes the greater the stress could be on fishes (Bhatnagar and Devi, 2013). The physico-chemical parameters of Tekeze Reservoir varied between sampling sites, but statistically there was no significant difference and was not much deviated from the required ranges for survival and growth of fishes. Therefore, all of the values in the reservoir were found in the optimum condition for fish production. Dereje Tewabe *et al*. (2009) have also previously reported similar values in Tekeze Reservoir.

Fifteen fish species belonging to three orders, four-families, and eight genera were collected in the study. The fish families recorded include Cyprinidae, Bagridae, Claridae, and Cichlidae. The family Cyprinidae dominated the catch composition of the species and contributed more than 66% (10 species) of the total species. Tsegay Teame *et al*. (2016) have also reported a similar number of families and orders but listed 11 fish species from the reservoir. The authors also confirmed that family Cyprinidae was the highest contributor to the composition of the fish catch.

The fish species that were recorded in the present study, but not in the list of Tsegay Teame *et al*. (2016) were *L. niloticus*, *L. cylindricus*, *L. bynni*, and *L. crassibarbis.* Relatively, a wider range of habitats and seasons were sampled for two consecutive years during this study. Therefore, this might be the reason for more species to be caught in the present study that were not reported in previous studies. However, previous fish survey by Dereje Tewabe *et al.* (2009) reported eighteen fish species, five orders, seven families, and thirteen genera are found in Tekeze Reservoir. The family

Malapteruridae, Mormyridae, and Characidae, which represented the fish species of *Malapterurus electricus, Mormyrus kannume,* and *Hydrocynus forskahlii*, respectively reported by Dereje Tewabe *et al*. (2009) were not collected during this study. Conversely, *L. cylindricus* was a new record for the present study, which was not reported by the previous authors. Fishing pressure and other anthropogenic activities have negatively affected the fishing activities of the fisheries (Solomon Tesfay and Mekonen Teferi, 2017; Ayalew Assefa *et al*., 2018). Therefore, this might be the cause for the declining of fish species in the reservoir.

During the survey of Dereje Tewabe *et al.* (2009), the reservoir was new and full-time fishing activity had not yet started. Therefore, the fish species that entered into the reservoir through the tributaries may have contributed to the higher diversity of the species at the time. Currently, legal and illegal fishing activities are high in the reservoir (Tsegay Teame *et al*., 2016; Ayalew Assefa *et al*., 2018). These activities could cause decline in the number and type of species. As in many parts of the world, population growth, agricultural development and industrialization contribute to the loss of species diversity of freshwater fishes in Ethiopia (Abebe Getahun and Stiassny, 1998; Gashaw Tesfaye and Wolff, 2014). The diversity of the fishes mainly depends upon the biotic and abiotic factors and type of the ecosystem, age of the water body, mean depth, water level fluctuations, morphometric features and bottom types (Thirumala *et al*., 2011).

Based on the result of diversity indices, the fish species diversity in the Tekeze Reservoir was low. The reservoir has an outlet, so low diversity is common in reservoirs that have such kinds of outflow (Wandera and Balirwa, 2010). This may have contributed to the low species diversity in the reservoir. Washing out accumulated nutrients in water bodies could result in low nutrients (Burlakoti and Karmacharya, 2004). Besides, all parts and sampling sites of the reservoir are rocky with no vegetation and almost uniform morphometric features (personal observation). The difference between the sampling sites was due to the depth and anthropogenic activity (fishing pressure) in the reservoir. Therefore, the absence of more significant heterogeneity among the sampling habitats can induce a low diversity of fishes. It is evident that homogeneity of habitats favours a lower diversity of fishes (Wandera and Balirwa, 2010). According to the review of Golubstov and Mina (2003), Tekeze-Atbara system has lower fish species diversity compared to the Nile River Basin within the limits of Ethiopia. This could be because of the remarkable seasonal variation of water discharge in the system (Golubtsov and Mina, 2003). Therefore, the seasonal tributaries of Tekeze Reservoir, may contribute for the low species diversity of the reservoir.

A few species dominated the fish compositions of Tekeze Reservoir. Five species (*O. niloticus*, *B. docmak*, *L. intermedius*, *L. niloticus* and *L. forskalii*) comprised 99.4% IRI of the reservoir's fish composition. Relative importance of *O. niloticus* ranked first followed by *B. docmak, L. intermedius, L. niloticus* and *L. forskalii.* All the remaining fish species contributed below 1% IRI of the total catch composition of the fishes. Although the highest contributions of *O. niloticus* and *L. intermedius* were previously reported, *B. docmak* and *L. forskalii* were listed under the least dominant of the catch composition in the reservoir (Dereje Tewabe *et al.*, 2009; Tsegay Teame *et al.*, 2016). *Labeobarbus nedgia* which was the lowest in the present study is the third dominant species in the reservoir (Tsegay Teame *et al.*, 2016). Besides, it was reported that *G. dembeensis* was one of the dominant fish species in the reservoir (Dereje Tewabe *et al.*, 2009). Environmental variables play a key role in the abundance and composition of aquatic flora and fauna in freshwater ecosystems (Matveev and Steven, 2014; Manish *et al.*, 2018).

The spatial distribution of the fish species was different in different sampling habitats of the reservoir. In the present study, the river mouth habitats such as Kanizu and Tsilare sampling sites contributed to most of the total fish catch. The offshore (Gfrtsatsa and Seletsa) sampling habitats ranked second and the inshore (Lmlmo and Ariqua) habitats third. This variation might be due to the difference in the preference of the species for spawning grounds (Shibabaw Gebru *et al,* unpublished part of PhD dissertation). During the spawning period, different fish species move towards the river mouth and littoral area of the reservoir. Other authors recorded similar findings that various fish communities exhibit some patterns in migration and hence show defined variation in the space they occupy over time and space (Gehrke *et al.*, 1995; Jackson and Harvey, 1997).

Seasonal variations in the relative abundance of fish species were observed in this study. Higher numbers of fish specimens were caught during the wet season as compared to the other sampling seasons. This could be related to the breeding time of the species that have a high chance of vulnerability to fishing gears (Assefa Tessema *et al.*, 2011). Variation in available nutrients, water level, turbidity, fish behaviour, size and life stages of fishes might also contribute to variations in the catches (Kolding *et al.*, 2003).

The present investigation revealed that the environmental variables play a key role in the distribution of fishes in the reservoir. Habitat alteration brings about threats to freshwater fish fauna (Manish *et al.*, 2018). Among the physico-chemical attributes, chlorophyll a, total dissolved solids, dissolved oxygen, electrical conductivity, temperature, and water transparency were strongly correlated with fish assemblages and influenced the fish distribution. Similarly, Manish *et al*. (2018) reported similar finding in Haro Reservoir (India).

CONCLUSION AND RECOMMENDATION

Based on the results obtained in this study, the physico-chemical parameters of the reservoir were found to be in the optimum condition for survival, growth and production of freshwater fishes. Only five species (*O. niloticus*, *L. forskalii*, *L. intermedius*, *B. docmak*, and *L. niloticus)* dominated the catch composition of the reservoir. The highest catch composition of the fishes was recorded in the river mouth habitats of the reservoir and the wet season of the sampling period. Environmental variables play a key role in the distribution of fishes in the reservoir.

More detailed assessment of water quality including nitrate, phosphate, silicate, CO_2, biological and chemical oxygen demand, etc, and their potential impacts on the aquatic resources should be done. Further investigation on diversity and abundance of fish species in the downstream sites of the reservoir is required. Detailed study on the composition, relative abundance and distribution of plankton, micro- and macro-invertebrates is needed.

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