Ethiop. J. Biol. Sci. 16(Suppl.): 181–209, 2017

ISSN: 1819-8678

PHYSICO-CHEMICAL CHARACTERISTICS AND MACROZOOBENTHOS ABUNDANCE IN THE GULF OF LAKE TANA

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ABSTRACT: This paper presents results on the investigation of physical and chemical characteristics and macrozoobenthos in the Bahir Dar Gulf of Lake Tana in 2013–2014. Significant changes in the physico-chemical characteristics of water, local sites of nutrients' pollution and seasonal peculiarities of characteristics, linked to the precipitation level were identified. A total of 21 species of macrozoobenthos were registered. Among the six study sites "Infranz river mouth" was found to be most diverse and abundant in macrozoobenthos community. This is probably due to the presence of ample organic matter, which is imported from river catchment, as well as additional microhabitats due to diverse vegetation development. The species diversity, similarity and total number and biomass of macrozoobenthos from the six sites of Bahir Dar Gulf are discussed.

Key words/phrases: Abundance, Ethiopia, Lake Tana, Macrozoobenthos, Species richness, Water chemistry.

INTRODUCTION

Lake Tana is the source of the Blue Nile River and is situated in northwestern highlands of Ethiopia, covering an area of ca 3,050 km^2, with a catchment area of ca 16,500 km^2. It is the largest lake in Ethiopia, containing half of the country's freshwater resources. Many temporary and six large rivers flow into Lake Tana, the largest being Rib, Gumara, Megech, Gelda, Infranz and Gilgel Abay. Bahir Dar city is located on the southern border of the lake; about 180,000 human population live around the lake and about 2 million people in the lake catchment (Vijverberg *et al*., 2009).

The area around the lake has been cultivated for centuries, but recently the local agriculture started to apply mineral fertilizers and pesticides uncontrollably which, coupled with intensified fishing, especially of the large carnivorous barbs, led to changing of food webs in the lake ecosystem. Another important problem for lake is the silt load increasing after the soil

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erosion due to development of dendritic type of drainage network in the catchment area of the lake (Berhanu Teshale *et al*., 2001; Berhanu Teshale, 2003; Ayalew Wondie *et al*., 2007).

Thus, the lake has suffered due to various forms of human activity. Ecosystem of the lake is strongly influenced from top (overfishing of predatory barbs) and from the bottom of food web (reduction of primary phytoplankton production). If these impacts will not be stopped, different scenarios of ecosystem development are possible, such as increasing macrophytes' overgrowth and/or enhanced bacterioplankton dynamics.

Low numbers of Oligochaeta, Chironomidae and *Chaoborus* sp. representatives were previously registered in both inshore and offshore macrozoobenthos (Dereje Tewabe *et al*., 2005; Vijverberg *et al*., 2009). Low abundance of benthic macroinvertebrates is explained by the low content of organic matter in the bottom substrates [near 1.2% in the offshore and 3.8% inshore according to Dereje Tewabe *et al*. (2005)]. Bottom consists of volcanic basalts usually covered by a muddy substratum, transported by the inflowing rivers containing little amounts of organic matter (Vijverberg *et al*., 2009).

The Lake Tana macroinvertebrate fauna includes some endemic and vulnerable taxa. Particularly, endemic molluskan species of the genus *Unio* [*U. elongatulus dembae* (Sowerby), *U. abyssinicus* Martes], which are known in Africa only from Lake Tana (Starobogatov, 1970) are of Palaearctic origin. Species *U. abyssinicus* was widespread in the White Nile until the very late Pleistocene and then was eliminated by rising water temperature as the recent dry conditions developed but survived in the cooler climate of the Ethiopian highlands (Beadle, 1981). This situation in highlands resembles that of islands, which can serve as refugia from continental extinction (Hutsemékers *et al*., 2011). One subspecies *Bellamyia unicolor abyssinica* Bacci, 1951 (Gastropoda, Viviparidae), is also known as the lake's endemic, however its taxonomic status is doubtful and needs revision. The need to preserve these rare and vulnerable species necessitates studying of the communities within their habitats and the lake's ecosystem as a whole.

Estimation of water quality using saprobity scale and assessment of forage resources for bentophagous fish based on the macrozoobenthos abundance is nonexistent in Africa in general, and East Africa in particular. To fill this gap and establish such scale in the future, it is necessary to generate data on macrozoobenthos and nutrient composition – this paper is the first step in this direction, and this can contribute to understand the ecology of such an important water body as Lake Tana.

MATERIALS AND METHODS

Description of sampling sites

Lake Tana is the source of the Blue Nile River, situated in north-western highlands of Ethiopia, covering an area of ca 3,050 km^2, with a catchment area of ca 16,500 km^2. The lake's average depth is 8 m and maximum depth is 14 m. In the main rainy season (July-August) the tributaries carry heavy loads of suspended silt into the lake, increasing the turbidity of water and thereby reducing the primary production (Vijverberg *et al*., 2009). Using nutrient parameters, the lake is mesotrophic (Berhanu Teshale *et al*., 2001), however chlorophyll content and primary production indicate the lake to be oligotrophic (Ayalew Wondie *et al*., 2007).

Sampling was performed three times from November 2013-August 2014. November, March and August represent post-rainy, dry and main rainy seasons, respectively. Macrozoobenthos samples were collected from six sampling sites in Bahir Dar Gulf near the Bahir Dar city, and were different in biotopic characteristics and pollution sources (Fig. 1 & Table 1). All sampling sites, except "Infranz", are located on the lake part, adjacent to the metropolitan area of Bahir Dar city. Bottom substrata in the pelagic zone were represented by gray silt and in the intertidal zone with a dash of large plant residues. In the "Infranz" sampling site the silt was dominated with sand, and, gravel in "Hospital".

The sampling sites are briefly described below.

Fig. 1. Map of Lake Tana (A) and Bahir Dar Gulf (B, C) with abstraction sites: 1 – "Infranz", 2 – "Hospital", 3 – "Gerima", 4 – "Resort", 5 – "St. George", 6 – "Shum-Abo" (Google Earth, Landsat/Copernicus).

1. "Resort" is a small bay within blocks of modern buildings of the city, with the hotels on the banks (Fig. 1, 2). Vegetation is represented by developed belt of plants: *Cyperus papyrus* L., *Phragmites karka* (Retz.) Trin. ex Steud., *Vossia cuspidata* (Roxb.) Griff., *Persicaria senegalensis* (Meisn.) Soják, followed by the belt of submerged *Ceratophylum* sp. Benthic samples sometimes contained mollusks of *Unio* spp.

2. "St. George" is adjacent to the city quay near the port (Fig. 1, 2). Vegetation is represented by *Cyperus papyrus* L., *Phragmites karka* (Retz.) Trin. ex Steud., *Vossia cuspidata* (Roxb.) Griff. There are moored passenger ships and fishing vessels, remains of discarded fish, constantly feeding flock of *Pelecanus onocrotalus* L., 1758 (near 30 ind.), and several other bird species' representatives – *Phalacrocorax africanus* (Gmelin, 1789), *Ardeola* spp. *Egretta* spp., *Threskiornis aethiopicus* (Latham, 1790).

3. "Shum-Abo" is adjacent to a densely populated quarter of rambling one-story buildings ("slum" or "favela") without sanitation, and local vegetable gardens (Fig. 1, 2). Vegetation is represented by developed belt of plants: *Cyperus papyrus* L., *Phragmites karka* (Retz.) Trin. ex Steud., *Vossia cuspidata* (Roxb.) Griff., *Persicaria senegalensis* (Meisn.) Soják.

4. "Infranz" is the mouth of the Infranz River, which drains the network of agricultural lands (Fig. 1, 2). Vegetation is represented by developed belt of plants: *Cyperus papyrus* L., *Cyperus* sp., *Phragmites karka* (Retz.) Trin. ex Steud., *Vossia cuspidata* (Roxb.) Griff. and *Azolla africana* Desv. Developed beds of *Potamogeton thunbergii* Cham. et Schlecht., *Nymphaea lotus* L., *Ceratophylum* sp. are located in the area of river and lake waters mixing. Nests of *Plectropterus* g. *gambensis* (L., 1766), *Alopochen aegyptiaca* (L., 1766) are situated on the banks.

5. "Hospital" is a bay, which fills a large shallow in the period of maximum water level (Fig. 1, 2). Papyrus and wood harvested and accumulated on the shore area from Zegie to Bahir Dar city, which is then transported by pulled mules which serve as an additional source of organic matter. Vegetation is represented by *Cyperus papyrus* L., *Phragmites karka* (Retz.) Trin. ex Steud., *Vossia cuspidata* (Roxb.) Griff., *Nymphaea lotus* L., *Persicaria senegalensis* (Meisn.) Soják, *Ceratophylum* sp. The following species – *Nymphoides* prob. *indica occidentalis* A. Raynal, *Utricularia inflexa* Forssk., *Ipomoea aquatica* Forssk are only found here. In November 2013 the water surface was almost completely covered by *Azolla africana* Desv. This location is inhabited by numerous *Actophilornis africana*

(Gmelin, 1789), *Phalacrocorax africanus* (Gmelin, 1789), *Anhinga rufa* (Dandin, 1802), *Threskiornis aethiopicus* (Latham, 1790), *Varanus* prob. *niloticus* L., 1766.

6. "Gerima" is a wetland which becomes isolated from the shore during the wet season when water volume increases (Fig. 1, 2). Vegetation is represented by *Cyperus papyrus* L., *Phragmites karka* (Retz.) Trin. ex Steud., *Vossia cuspidata* (Roxb.) Griff., *Nymphaea lotus* L., *Azolla africana* Desv. It is the main nesting place for *Plectropterus g. gambensis* (L., 1766), *Alopochen aegyptiaca* (L., 1766), *Balearica regulorum* Bennett, 1834, *Heliaeetus vocifer* (Daudin, 1800), *Actophilornis africana* (Gmelin, 1789), *Ardea alba* L., 1758 and other water and shore birds.

Fig. 2. a – "Infranz" site, b – "Hospital", c – view to "Shum-Abo" from "St. George", d – "Resort", e – "Gerima".

Climatic conditions

During this research, relative humidity, rainfall and minimum air temperatures varied seasonally with no major deviation from the average long-term data (Fig. 3). Humidity (Fig. 3a) was reduced as of November (58.2) to February (41.4), and then gradually increased in August (77.3). The amount of precipitation (Fig. 3b) was 16.6 mm in November 2013, then absent in December-February, and steadily increased from March (65.9) to August (480.8). The minimum monthly air temperature (Fig. 3c) increased from November (7.7) to January (26.4), and then sharply fell to February (8.0), later in the evening being in 13–14ºC range.

Measurement of physico-chemical parameters of water

Dissolved Oxygen (DO), pH, specific electrical conductivity, Total Dissolved Solid (TDS), salinity and temperature were measured *in situ* using YSI 556 multi-probe system. Water transparency was measured using a Secchi disc with a calibrated cable. Measurements of Ammonia (NH_3-N) and Phosphate (PO_4-P) were based on an indophenol and Palintest Phosphate LR method, respectively, in the form of tablet at 640 nm wave length. Nitrate (NO_3-N) measurement was based on Palintest Nitratest method at 570 nm wave length. Nutrient analyses were performed immediately after sampling with water samples filtered through Whatman GF/C.

Macrozoobenthos sampling

The samples were taken twice from each site (littoral zone with vegetation and offshore, outside the vegetation border) using modified Petersen-grab with sampling area of 0.016 m^2. The collected sediment samples were diluted with lake water and sieved using a mesh size of 0.01 mm^2 and screened in a white pan. Macroinvertebrates were preserved in 70% alcohol. Weighing was performed on a torsion balance with an accuracy of 1 mg. Macroinvertebrates were photographed using Nikon D5100 digital camera coupled with microscope Nikon Eclipse 50i at the Papanin Institute for Biology of Inland Waters, Russian Academy of Sciences, Borok, Russia. Identification of the specimens was done at the same institute by expert taxonomists.

Species richness (n), total number (N, ind./m^2) and biomass (B, g/m^2) of macrozoobenthos were estimated, excluding the megazoobenthos representatives, which needs another method for quantitative sampling – bivalves *Unio* (Mollusca, Bivalvia, Unionidae) and crabs *Potamonautes* spp.

(Crustacaea, Decapoda, Potamonautidae). The dendrogram of faunistic similarity was built using the method of single linkage based on calculation of the Bray-Curtis coefficient of faunistic similarities using PAST 3.01 software.

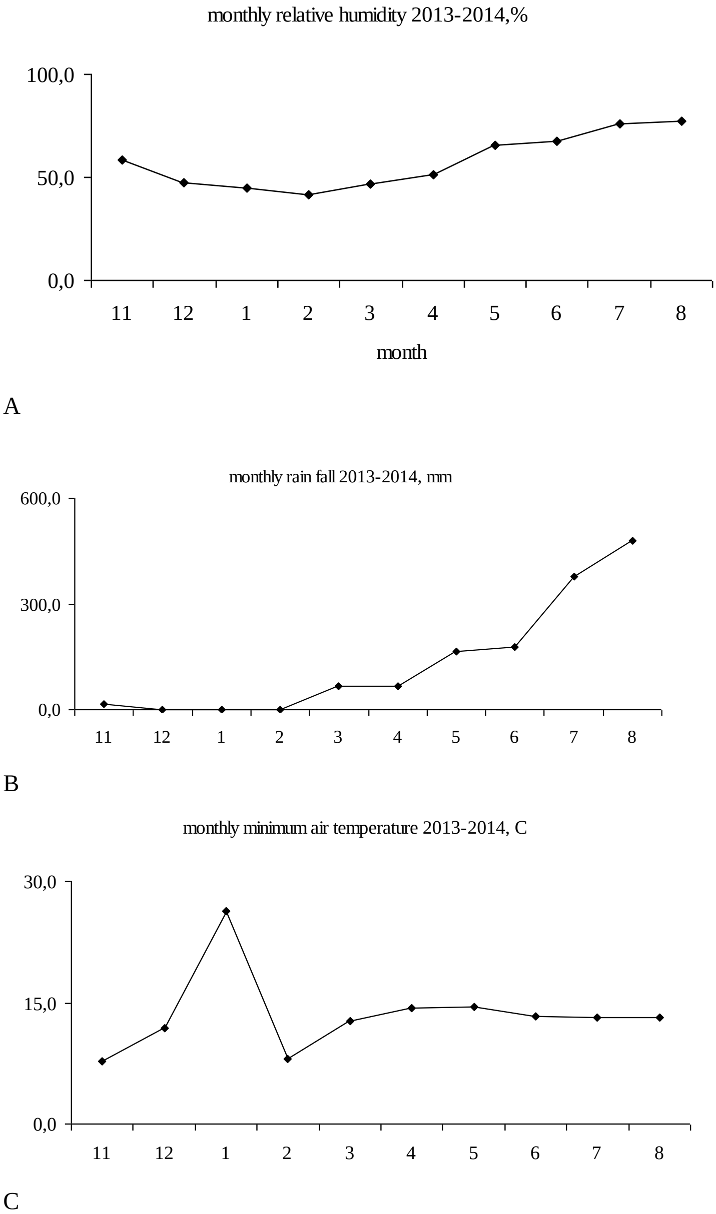

Fig. 3. Meteorological data in Bahir Dar, 11.2013-08.2014: a – monthly relative humidity, %, b – monthly rain fall, mm, c – monthly min. air temperature, ºC.

RESULTS

Physico-chemical characteristics of water

Measured water transparency at different sampling sites ranged from 0.3 to 1.4 m (Table 1). Water transparency during August was lower in the pelagic zone as compared to littoral zone (Table 1). An increase transparency during rainy season in sites "Resort", "St. George" and "Shum-Abo" with increasing precipitation is unlikely. Probably the presence of dense macrophytes in the sites caused the silt to be settled and filtered as compared to the disturbed open area by wind mixing. These sites are characterized by typical lake scenario, when loads of suspended silt from the catchment area are deposited in littoral zone, and phytoplankton has no such development as in the pelagic zone (Vijverberg *et al*., 2009).

Water transparency was minimal at the mouth of Infranz River in comparison with all other studied sites. It was reduced by half in the period from November to August (Table 1). This reduction could be explained by the suspended silt load from the catchment. Less pronounced decrease of transparency was also observed in "Hospital". Like Infranz and Gerima, transparency in the pelagic zone of Hospital site was higher than that in the littoral (Table 1).

Surface daylight water temperature ranged between 22–26ºC during the study season (Table 1). The maximum water temperature both in the littoral and pelagic zones was registered in March at most sites, except ”Hospital”, where it was registered in August, both in the littoral and the pelagic zone, as well as in the pelagic zone of the lake near the mouth of the Infranz River (Table 1).

Conductivity in all cases increased from November to March, and then decreased sharply in August due to the dilution of lake mainly by rainwater. The total range of observed values was 0.098–0.166 mS/cm^3 (Table 1).

Dissolved Oxygen ranged from 4.98 mg/L with 59.8% saturation ("Hospital", March) to 7.49 mg/L with 87.6% saturation ("Shum-Abo", August in littoral). The maximum amount of dissolved oxygen was registered in three pelagic sites ("Resort", "St. George", "Gerima"), and two littoral zones ("Shum-Abo", "Infranz") during August, and the pelagic zone in "Hospital" during November and August (Table 1).

Total Dissolved Solids (TDS) level ranged from 0.065 g/L ("Infranz", August in the pelagic zone) to 0.770 g/L ("Resort", August in the littoral zone). It increased significantly from November to August at "Resort". At the "St. George" seasonal maximum was registered in August in the pelagic zone, while in the littoral zone its value was ten times lower (Table 1). On the contrary, in "Shum-Abo" seasonal maximum occurred in August in the littoral, ten times than in the pelagic (Table 1). In "Infranz", "Hospital" and "Gerima" the rate of TDS was relatively stable during the study period. The maximum values recorded in March coincided with low water level and precipitation inputs.

Salinity in all sites decreased in August to 0.05 g/L both in the littoral and the pelagic zone (Table 1), following the dilution of lake water by rain. The maximum value (0.08) was recorded in most sites in March, and (0.07) in ("Shum-Abo", "Gerima") during November and March.

Phosphate concentration varied between 0.1 ("Hospital" and "Gerima" in November) and 1.42 mg/L ("Shum-Abo", August in the pelagic zone). Maximum values at most sites, except "Hospital" and "Gerima", were recorded in August, with a significant difference in the pelagic and littoral zones (Table 1). In "Resort" during August, phosphate rate in littoral was 2 times higher, and in "Infranz" and more than 3 times higher than in the pelagic zone (Table 1). On the contrary, in "St. George" and "Shum-Abo" phosphate concentration was higher in the pelagic zone, three and ten times higher at both sites, respectively (Table 1). Phosphate concentration did not exceed 0.3 g/L in "Gerima" and "Hospital" showing seasonal minimum in November (Table 1).

Nitrate concentration varied in the range from 1.06 ("Resort", March) to 5.28 mg/L ("Infranz", August in the pelagic zone). In all sites, it increased in August with maximum values in the pelagic zone. The exceptions were sites "Resort", where the maximum values were recorded in November and "Shum-Abo", where the concentration of nitrate in November, equalled that in August in the littoral zone (Table 1).

The concentration of nitrite from March to August 2014 was in the range between 0.003–0.04 mg/L (Table 1). The maximum concentrations in most sampling sites were registered in August in the littoral zone, including a lake’s maximum in "Shum-Abo" (0.036). In "St. George" the maximum value was recorded in August in the pelagic zone, but maximum value for “Infranz” was recorded in March (Table 1). This indicates that nitrite runoff co-occurred with farming fertilizers during the wet season. In most sampling sites nitrites were accumulated in the littoral zone. Nitrite concentration was higher in the pelagic zone of "St. George", which is situated in the city recreation area and has fish waste damped by the fishery cooperatives.

Maximum content of nitrite around Infranz River mouth indicated evidence of receiving them from the fields, as the river water was minimally diluted by rainwater in this period.

Ammonia was detected during the study period only twice (Table 1) in March at sites "Shum-Abo" (0.012) and "Gerima" (0.072). Unfortunately, we measured the concentration of hydrogen sulfide only in August in the littoral zone. During this period, the maximum value was recorded in "Hospital" Bay (0.042 mg/L). In other cases, values were in the range of 0.0210–0.0318 mg/L (Table 1).

Macrozoobenthos

During this study period a total of 21 species were recorded: Oligochaeta – 3, Hirudinida – 1, Bivalvia – 1, Gastropoda – 1, Odonata – 1, Trichoptera – 1, Ceratopogonidae (Diptera) – 1, Chaoboridae (Diptera) – 1, Chironomidae (Diptera) – 11 (Table 2). Photographs of characteristic morphological details of most species are shown in Figures 5-10.

Table 1. Coordinates of sampling sites and physico-chemical characteristics of water in Bahir Dar Gulf of the Lake Tana in Nov. 2013-Aug. 2014.

		Sampling site					
Name		**"Resort"**	**"St. George"**	**"Shum-Abo"**	**"Infranz"**	**"Hospital"**	**"Gerima"**
Latitude N		11º36,291'	11º35,812'	11º35,957'	11º38,887'	11º36,700'	11º37,030'
Longitude E		037º22,698'	037º23,381'	037º23,714'	037º18,951'	037º22,366'	037º22,885'
Depth, m (shore-open)		3.13–5.26	2.95–4.40	4.00–5.21	3.50–3.40	3.44–4.00	2.5–4.32
Transparency (Secchi depth), m	Nov. 2013	0.56	0.53	0.59	0.55	1.00	0.60
	March 2014	0.63	0.52	0.67	0.43	1.00	0.55
	Aug. 2014 (shore)	1.40	0.87	0.86	0.30	0.79	0.55
	Aug. 2014 (open)	0.76	0.74	0.74	0.36	0.83	0.72
Temperature, ºC	Nov. 2013	23.15	23.10	23.24	23.80	24.20	23.67
	March 2014	23.59	24.34	24.87	24.05	24.52	24.55
	Aug. 2014 (shore)	22.32	22.52	23.06	21.88	26.04	23.46
	Aug. 2014 (open)	22.25	22.67	22.68	24.20	25.33	23.20
Electrical conductivity, mS/cm^3	Nov. 2013	0.146	0.147	0.146	0.153	0.155	0.145
	March 2014	0.163	0.163	0.158	0.166	0.164	0.153
	Aug. 2014 (shore)	0.118	0.111	0.103	0.110	0.118	0.102
	Aug. 2014 (open)	0.110	0.114	0.102	0.100	0.108	0.102
Specific conductance [K25], mS/cm^3	Nov. 2013	0.140	0.142	0.141	0.148	0.152	0.141
	March 2014	0.159	0.160	0.157	0.163	0.163	0.152
	Aug. 2014 (shore)	0.112	0.105	0.100	0.104	0.120	0.099
	Aug. 2014 (open)	0.104	0.109	0.098	0.098	0.108	0.098
Dissolved oxygen [DO], mg/L	Nov. 2013	5.84	6.38	6.80	6.95	6.28	6.81
	March 2014	5.58	5.48	5.24	5.38	4.98	5.56
	Aug. 2014 (shore)	7.02	6.85	7.49	7.08	5.30	6.62
	Aug. 2014 (open)	7.20	7.02	6.79	6.08	6.30	7.08
% of saturation [%DO]	Nov.2013	68.0	74.9	77.3	80.5	74.4	80.4
	March 2014	65.7	65.9	63.2	64.9	59.8	66.2
	Aug. 2014 (shore)	79.4	79.2	87.6	80.6	65.4	77.8
	Aug. 2014 (open)	82.7	81.6	78.2	72.2	72.6	82.9
Total dissolved	Nov.2013	0.095	0.095	0.095	0.100	0.101	0.094

		Sampling site					
Name		**"Resort"**	**"St. George"**	**"Shum-Abo"**	**"Infranz"**	**"Hospital"**	**"Gerima"**
solids [TDS], g/L	March 2014	0.106	0.106	0.103	0.108	0.107	0.010
	Aug. 2014 (shore)	0.770	0.072	0.670	0.072	0.077	0.066
	Aug. 2014 (open)	0.710	0.740	0.066	0.065	0.070	0.066
Salinity, g/L	Nov. 2013	0.07	0.07	0.07	0.07	0.07	0.07
	March 2014	0.08	0.08	0.07	0.08	0.08	0.07
	Aug. 2014 (shore)	0.05	0.05	0.05	0.05	0.05	0.05
	Aug. 2014 (open)	0.05	0.05	0.05	0.05	0.05	0.05
pH	Nov. 2013	7.90	8.30	8.49	8.21	7.48	8.69
	March 2014	7.78	7.93	7.91	7.82	7.87	7.61
	Aug. 2014 (shore)	7.38	7.88	8.04	7.11	7.93	8.34
	Aug. 2014 (open)	7.84	7.81	8.06	7.09	7.52	8.31
PO_4, mg/L	Nov. 2013	0.12	0.14	0.28	0.34	0.10	0.10
	March 2014	0.22	0.20	0.14	0.26	0.30	0.18
	Aug. 2014 (shore)	0.51	0.20	0.14	0.78	0.20	0.24
	Aug. 2014 (open)	0.24	0.67	1.42	0.22	0.30	0.22
NO_3, mg/L	Nov. 2013	2.42	1.89	3.30	3.08	1.10	2.55
	March 2014	1.06	2.20	2.07	1.67	1.67	1.36
	Aug. 2014 (shore)	1.85	2.40	3.30	4.84	2.55	2.20
	Aug. 2014 (open)	1.45	3.70	2.30	5.28	4.60	3.50
NO_2, mg/L	March 2014	0.0033	0.0132	0.0033	0.0198	0.0033	0.0099
	Aug. 2014 (shore)	0.0100	0.0200	0.0360	0.0033	0.0200	0.0130
	Aug. 2014 (open)	0.0033	0.0230	0.0230	0.0100	0.0130	0.0033
NH_3, mg/L	Nov. 2013	0	0	0	0	0	0
	March 2014	0	0	0.012	0	0	0.072
	Aug. 2014 (shore)	0	0	0	0	0	0
	Aug. 2014 (open)	0	0	0	0	0	0
H_2S, mg/L	Aug. 2014 (shore)	0.0210	0.0318	0.0318	0.0318	0.0420	0.0318

Table 2. Macrozoobenthos taxa of Bahir Dar Gulf of Lake Tana in Nov. 2013-Aug. 2014 (sh = shore/littoral; o = open/pelagic).

TAXA	**"Shum-Abo"**		**"St. George"**		**"Resort"**		**"Gerima"**		**"Hospital"**		**"Infranz"**	
	sh	**o**	**Sh**	**O**	**sh**	**o**	**sh**	**o**	**Sh**	**o**	**sh**	**o**
OLIGOCHAETA												
Branchiura sowerbyi Beddard, 1892	+	+	+	–	+	–	+	–	–	+	+	+
Limnodrilus udekemianus Claparede, 1862	–	–	–	–	–	–	–	–	–	–	–	+
Tubifex tubifex (Müller, 1774)	–	+	+	–	–	+	–	+	–	–	–	–
HIRUDINIDA												
Glossiphonidae sp.	–	–	–	–	–	–	–	–	–	–	+	–
BIVALVIA												
Afropisidium sp.	–	–	–	–	–	–	–	–	–	–	–	+
GASTROPODA												
Bellamyia unicolor abyssinica Bacci, 1951	–	–	–	–	–	–	+	–	–	–	–	–
ODONATA												
Erythromma sp.	–	–	–	–	–	–	–	–	–	–	+	–
TRICHOPTERA												
Dipseudopsis sp.	–	–	–	–	–	–	+	–	–	–	+	+
CERATOPOGONIDAE												
Nilobezzia sp.	+	–	–	–	–	–	–	–	–	+	–	–
CHAOBORIDAE												
Chaoborus anomalus Edwards, 1930	+	+	–	–	–	–	–	–	–	–	–	+
CHIRONOMIDAE												
Clinotanypus claripennis Kieffer, 1918	–	–	–	–	–	+	–	+	–	–	–	–
Procladius (*Holotanypus*) sp.	–	+	–	–	–	–	–	–	–	–	+	–
Tanypus sp.	+	–	–	–	–	–	–	–	–	+	–	–
Cryptotendipes sp.	–	+	–	–	–	–	–	–	–	–	–	+
Cryptochironomus sp.	–	+	–	–	–	–	+	–	–	–	+	+
Stictochironomus sp.	–	+	–	–	–	–	–	–	–	–	–	–
Polypedilum aff. deletum Goetghebuer, 1836	–	–	–	–	–	–	–	–	–	–	+	–
Polypedilum aff. bipustulatum Freeman, 1958	–	–	–	–	–	–	–	+	–	–	–	+
Chironomus aff. formosipennis Kieffer, 1908	+	+	+	–	–	+	+	–	–	+	+	+
Chironomus (*s.str.*) sp.	–	–	+	–	–	–	–	+	+	–	–	–
Chironomus (*Camptochironomus*) sp.	–	–	–	–	–	–	–	–	–	–	+	+
Total:	5	8	4	0	1	3	5	4	1	4	9	10
	10		4		4		9		5		14	

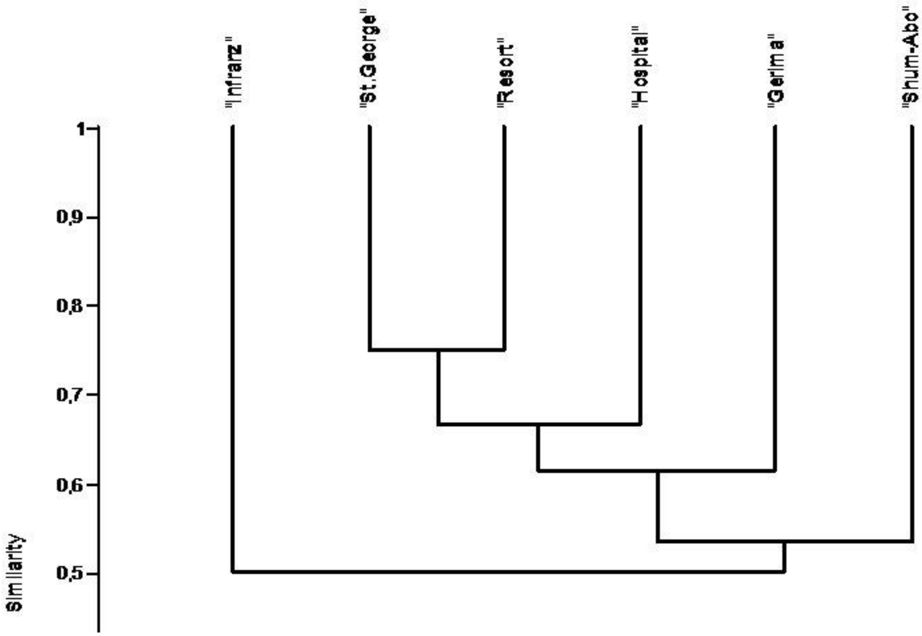

Fig. 4. Dendrogram of macrozoobenthos faunistic similarity in different locations of Bahir Dar Gulf of Lake Tana in Nov.2013-Aug.2014 according to the Bray-Curtis coefficient.

Maximum species richness (14) was registered near Infranz mouth river, in sites "Shum-Abo" and "Gerima" – 9-10 species, and 4-5 species in others. In most sites, except "Shum-Abo" and "Infranz", species common for the littoral and pelagial zones were absent. Species *Branchiura sowerbyi* Beddard, 1892 (Oligochaeta) and *Chironomus aff. formosipennis* Kieffer, 1908 (Chironomidae) were registered in all sites; *Tubifex tubifex* (Müller, 1774) (Oligochaeta) was found in 4 sites, and other species only from one to three sites.

Faunal similarity of macrozoobenthos at all sites was extremely high, usually more than 50% (Fig. 4), thus indicating that most studied sites do not differ in macrozoobenthos composition and the term “community” can be applied for the studied animal assemblages of each site with a high degree of assumption. Among the study sites, “Infranz” was separated from other sampling sites with its maximum species richness (Table 2).

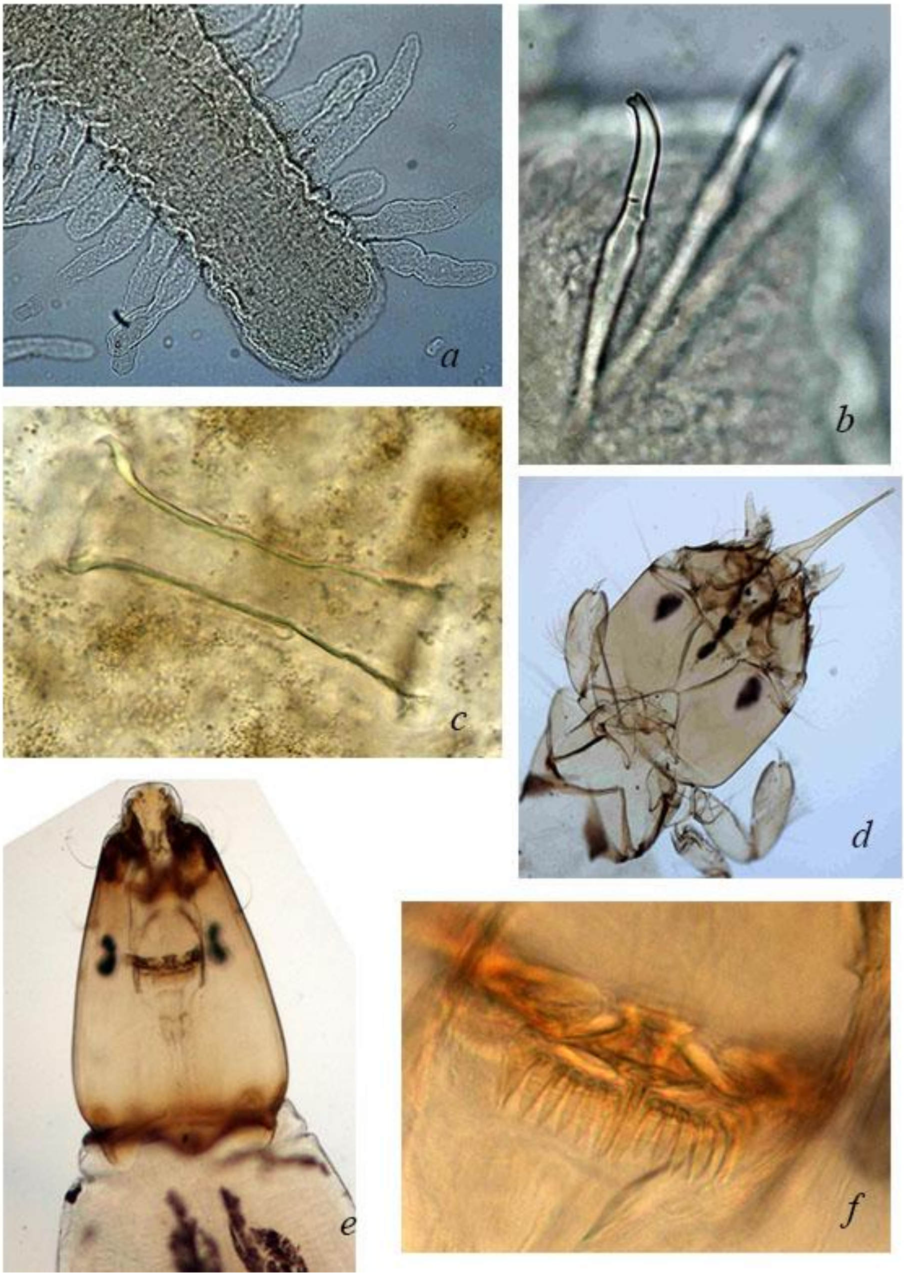

Fig. 5. Representatives of Oligochaeta and larvae of Dipseudopsidae (Trichoptera) and Ceratopogonidae (Diptera): a,b – *Branchiura sowerbyi* Beddard, 1892 (a – rear end of the body; b – bristles); c – penial bristle of *Limnodrilus udekemianus* Claparede, 1862; d – *Dipseudopsis* sp., head, pro- and mesonotum with legs; e, f – *Nilobezzia* sp. (e – head and pronotum, f – epipharynx).

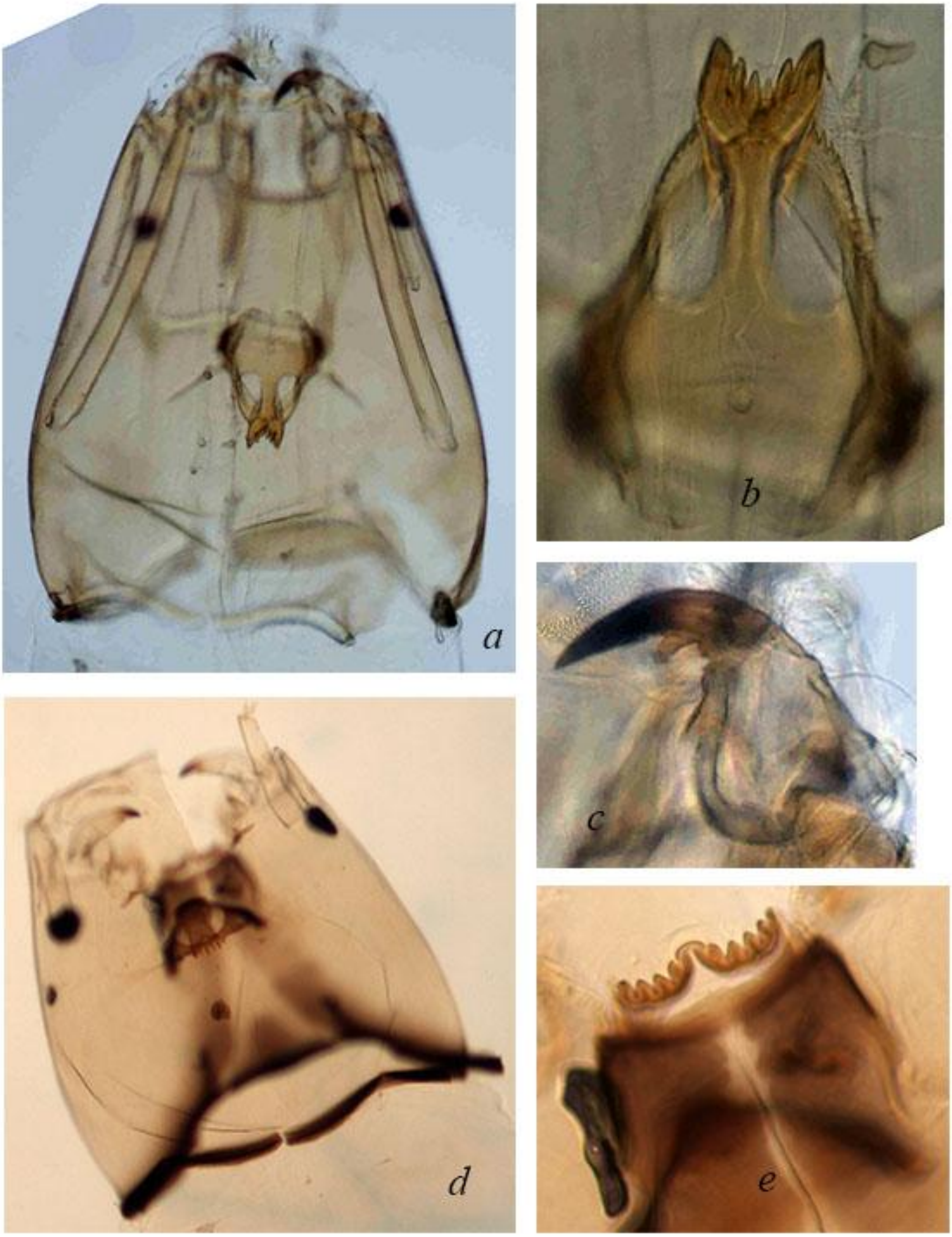

Fig. 6. Representatives of Tanypodinae (Chironomidae) larvae: a,b,c – *Clinotanypus claripennis* Kieffer, 1918 (a – head, b – ligula, c – mandible); d, e, – *Tanypus* sp. (d – head, e – ligula, paraligula and mentum).

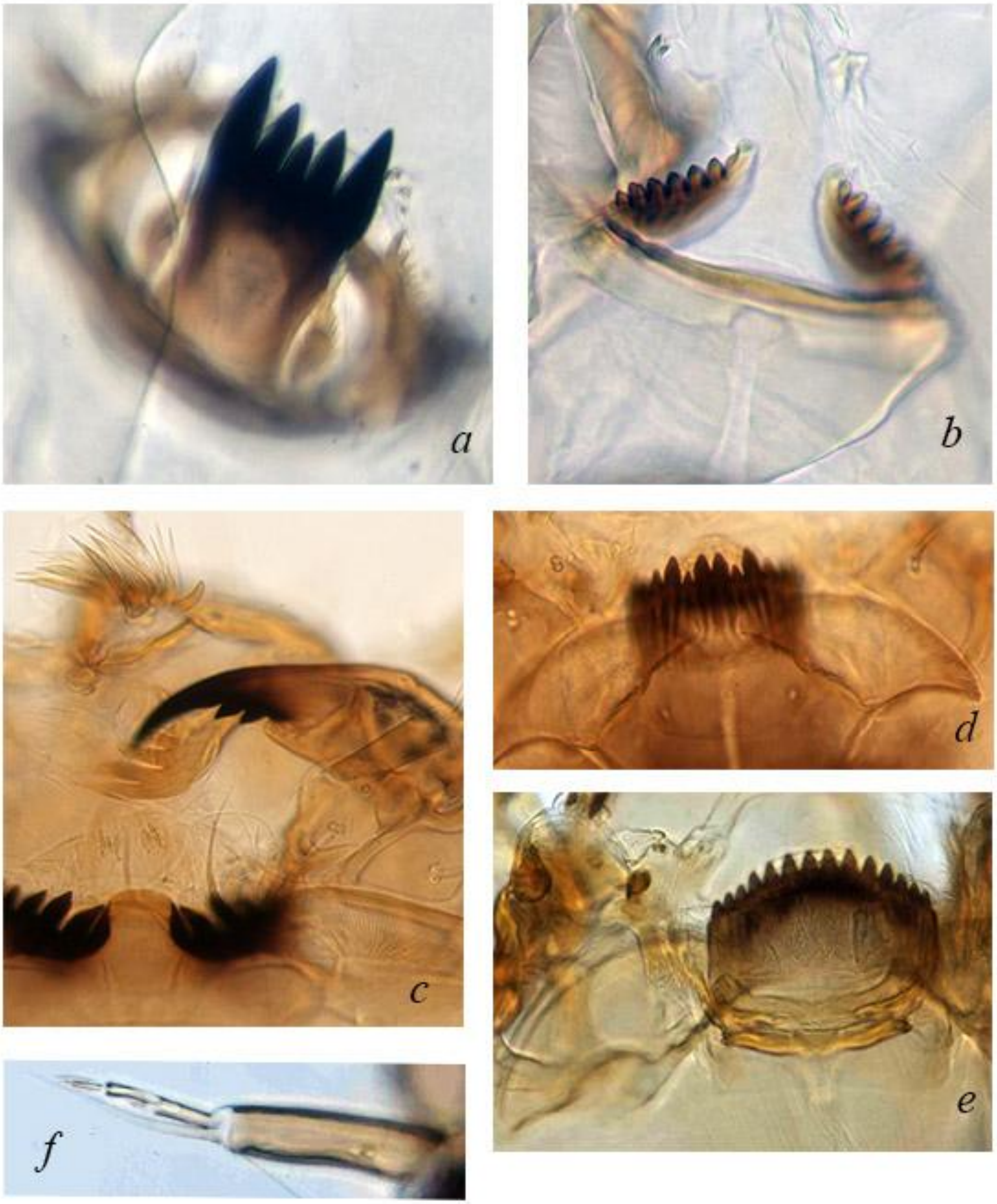

Fig. 7. Representatives of Tanypodinae and Chironominae (Chironomidae) larvae: a,b – *Procladius* (*Holotanypus*) sp. (a – ligula, b – mentum); c – *Cryptochironomus* sp., mentum, mandible and labral premandible; d – *Polypedilum* aff. *deletum* Goetghebuer, 1836, mentum and ventromental plates; e,f – *Polypedilum* aff. *bipustulatum* Freeman, 1958 (e – mentum and ventromental plate, f – antenna).

Fig. 8. Representatives of Chironominae (Chironomidae) larvae: a-c – *Cryptotendipes* sp. (a – mentum and ventromental plate, b – antenna, c – head dorsaly), d – *Chironomus* (*s. str*.) sp., head; e,f – *Stictochironomus* sp. (e – mentum, f – antenna).

Fig. 9. Representatives of Chironominae (Chironomidae) larvae: a,b – *Chironomus* (*Camptochironomus*) sp. (a – head, b – epipharynx and labrum); c,d – *Chironomus* aff. *formosipennis* Kieffer, 1908 (c – head, d – epipharynx and labrum).

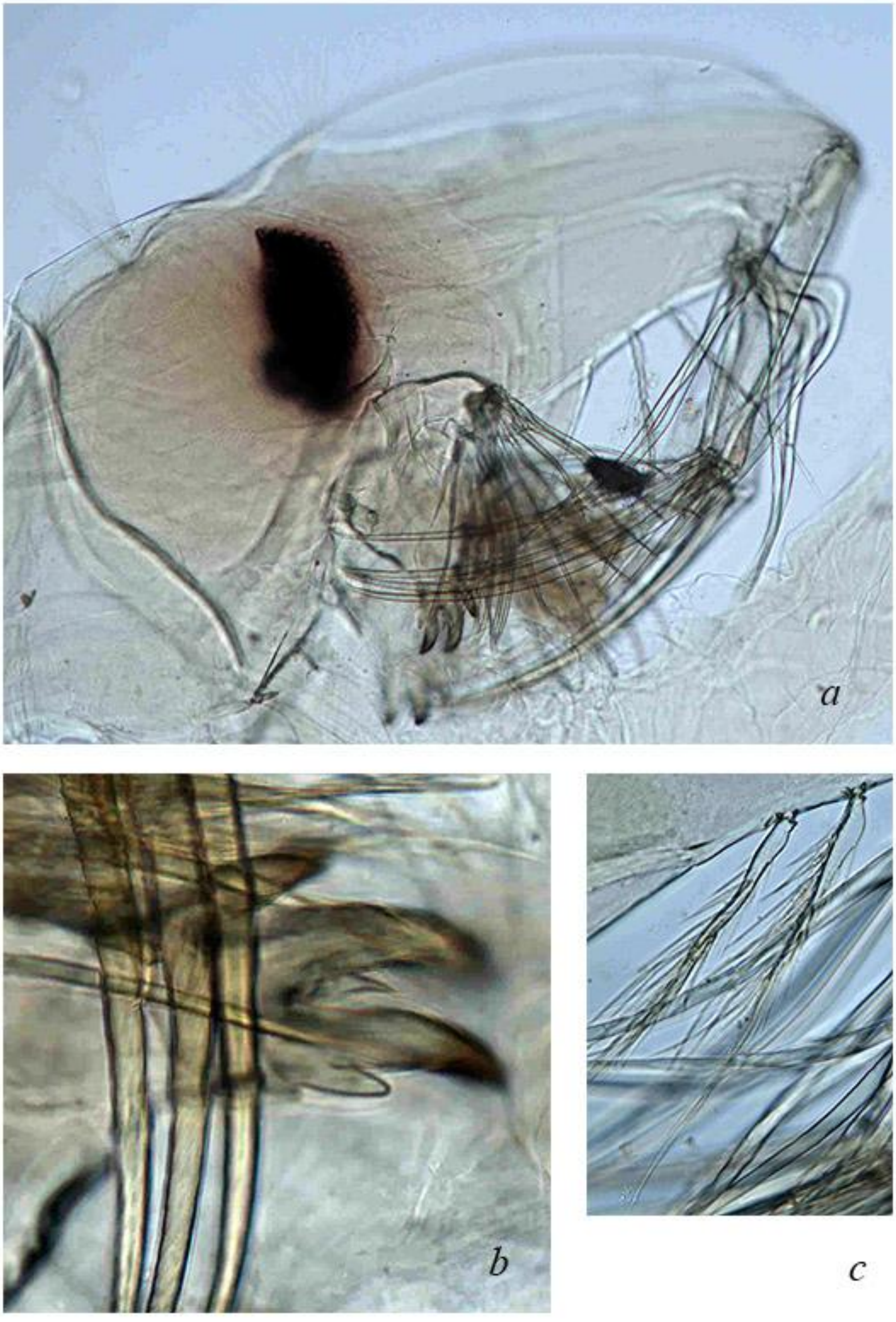

Fig. 10. Larva of *Chaoborus anomalus* Edwards, 1930 (Diptera, Chaoboridae): a – head, b – mandible, c – prelabral appendages.

In most sampling sites total abundance and biomass decreased from the dry to the wet season; typically, the abundance was higher in littoral zone as compared with open water, except the "Hospital" and Infranz mouth (Table 3), when water transparency was higher in the pelagic zone (Wondie Zelalem and Prokin, 2016).

Table 3. Total numbers, ind./m^2 (above the bar) and biomass, g/m^2 (under the bar) of macrozoobenthos in Bahir Dar Gulf of Lake Tana.

Sampling site		**Season**			
		November 2013	**March 2014**	**August 2014**	**Average**
"Shum-Abo"	Shore	1062.50 / 12.87	500.00 / 12.35	187.50 / 2.59	583.33 / 9.27
	Open	281.25 / 6.12	375.00 / 6.44	187.50 / 0.31	281.25 / 4.29
"St. George"	Shore	312.50 / 2.72	0	750.00 / 1.88	354.17 / 1.53
	Open	0	0	0	0
"Resort"	Shore	0	0	281.25 / 2.81	93.75 / 0.94
	Open	62.50 / 0.75	0	93.75 / 0.28	52.08 / 0.34
"Gerima”	Shore	781.25 / 9.28	125.00 / 3.62	125.00 / 2.16	62.50 / 5.02
	Open	62.50 / 0.09	0	62.50 / 0.06	41.67 / 0.05
“Hospital"	Shore	0	62.50 / 0.13	31.25 / 0.16	31.25 / 0.10
	Open	125.00 / 0.47	825.00 / 12.69	0	333.33 / 4.37
"Infranz"	Shore	218.75 / 1.22	1812.50 / 1.25	156.25 / 0.84	729.17 / 1.10
	Open	1531.25 / 20.84	2625.00 / 22.82	593.75 / 5.41	1583.33 / 16.36

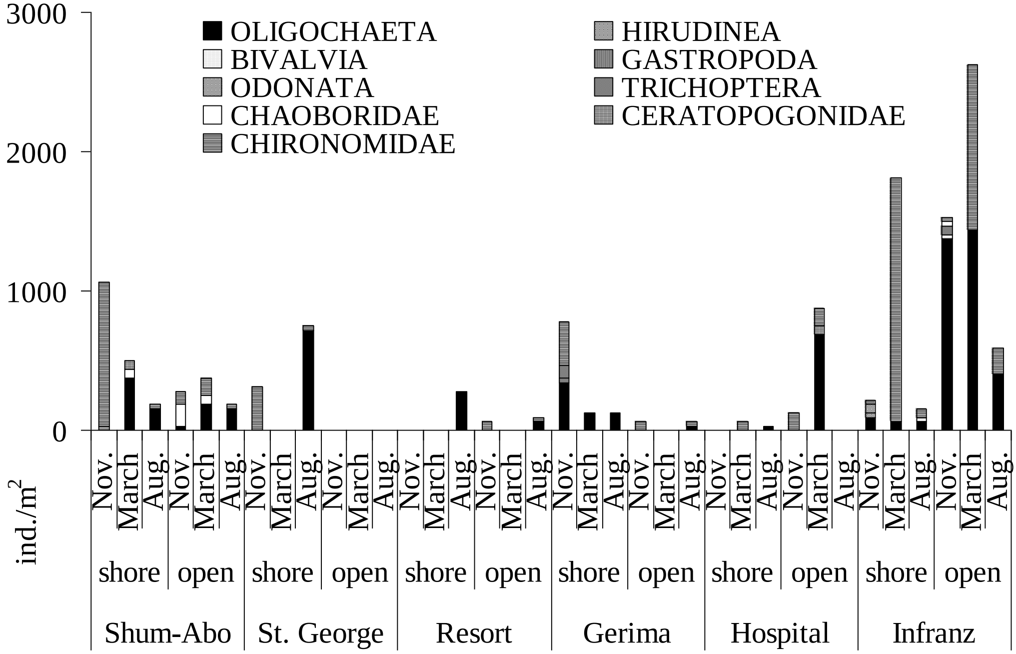

Fig. 11. Seasonal dynamics of macrozoobenthos taxonomic groups total number in Bahir Dar Gulf of Lake Tana.

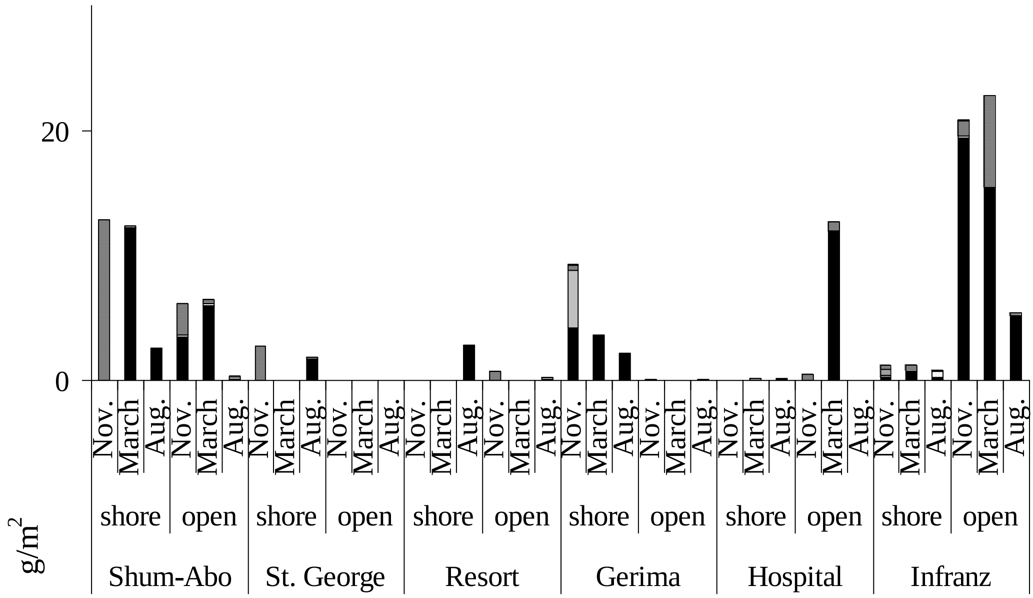

Fig. 12. Seasonal dynamics of biomass of macrozoobenthos taxonomic groups in Bahir Dar Gulf of Lake Tana.

Among other taxa Oligochaeta and Chironomidae showed seasonal variability in their total number and biomass (Fig. 11, 12).

In "Shum-Abo" total number of Chironomidae decreased during the studied period, while Oligochaeta increased. In the littoral zone of "St. George" Chironomidae was a dominant group in November while Oligochaeta prevailed in August. In the littoral zone of "Resort" macrozoobenthos was recorded only in August, when it was represented only by Oligochaeta; and in pelagic zone in March it was represented only by Chironomids. In August both Oligochaeta and Chironomidae were recorded in the site.

In the littoral area of "Gerima" Oligochaeta, Gastropoda, Trichoptera and Chironomidae were recorded in November, but only Oligochaeta in subsequent periods. In open water zone in November only few Chironomidae were found, in March they were completely absent and in August – represented by few Oligochaeta and Chironomidae. In littoral zone of "Hospital" in March only few Chirononids and in August – Oligochaeta were recorded. Only Chironomidae were recorded in the open water zone during November. In March both Ceratopogonidae and abundant Oligochaeta were recorded in the site. The most diverse macrozoobenthos of

"Infranz" was characterized by maximum biomass in March, due to numerous Chironomidae and Oligochaeta in the pelagic zone (Fig. 11).

Seasonal dynamics of biomass was characterized by the same features with a slightly higher share of Oligochaeta (Fig. 12), with large and heavy specimens of *Branchiura sowerbyi*. Only once Gastropoda (juveniles of *Bellamyia unicolor*) accounted for more than 49% of biomass ("Gerima", November).

DISCUSSION

Water near the mouth of Infranz River was colder than in other areas due to the inflow of the river water, so that the August temperature maximum in the pelagic zone indicates dilution of river water by warmer precipitation water. Similar situation in the "Hospital" is perhaps explained by lower mixing due to the overgrown shelter bay or local outputs of groundwater. The much higher altitude of Lake Tana compared with that of Lake Chad located on the same latitude, explains the lower values of water temperature (Beadle, 1981).Our data indicates the active entry of the dissolved solids with unorganized storm- water from residential neighborhoods. Different degree of littoral plants' overgrowth and their floristic composition is likely to determine their various "buffer capacity" in relation to the incoming dissolved solids.

Water in the investigated sites of the lake can be characterized as a weakly alkaline pH which varied from 7.09 ("Infranz", August in the pelagic zone) to 8.69 ("Gerima", November). Except the littoral zone in "Hospital", where its maximum was recorded in August, the maximum pH values at most sites were recorded in November associated with minimum dilution with rain (Table 1). This is probably due to the impact of mineral soils of shallow, floods during this period.

Presumably, the nitrates get into the lake from the catchment in most cases, particularly intensively during the wet period. They are rapidly accumulated by littoral macrophytes (unlike phosphates), which leads to greater concentration in the pelagic zone. This was especially noticeable in the Infranz river mouth, which accumulated the runoff to lake from fields, containing mineral and organic fertilizers. In "Resort", located within the boundaries of modern urban buildings, runoff is well-organized and flow of nitrates from the catchment area was limited, leading to their maximum concentration in the period of low water levels in November. In "Shum-Abo", adjacent to the slums and gardens, nitrate intake occurred constantly, but developed macrophyte beds were effectively absorbing them.

The presence of Ammonia in March at “Shum-Abo” was probably due to the inflow of sewage from slums and gardens adjacent to this site. Similarly, at “Gerima” high Ammonia is associated with the influence of water and shore birds, for which this site is the main nesting place in the Gulf.

Maximum biomass of macrozoobenthos in Infranz mouth open water zone can be explained by organic pollution due to fertilizers’ runoff from fields: Nitrate levels were up to 5.28 mg/L in August (like "Hospital"). "Shum-Abo" site is located in a densely populated area without installed sewerage services.

This study has identified significant changes in the physico-chemical characteristics of Lake Tana water, in particular, an increase of nitrate (NO_3, mg/L) content by nearly four times compared with data of Ayalew Wondie (2010). Conductivity decreased by nearly two times and dissolved oxygen concentration by 1.5 times compared with data of Ayalew Wondie *et al*. (2007), as well as local sites of nutrient pollution, in which oligochaete worms *Branchiura sowerbyi* were the dominant species in macrozoobentos community.

Relatively high macrozoobenthos biomass was recorded in this study. The high macrozoobenthos biomass here can be explained by PO_4 contamination which had high levels of up to 1.42 mg/L. Relatively high total biomass near "Gerima" is probably due to the existence of birds’ colonies: NH_3 was up to 0.072 mg/L – the highest level for the lake (Table 1). In all these cases, *Brachyura sowerbyi* was the dominant species in the macrozoobenthos.

The most widely distributed and abundant species in this study, *B. sowerbyi* is known to be widespread in N. America, Europe, Asia, S. America, Africa, Mauritius and Australia (Brihkhurst and Jamieson, 1971). It is an indicator of β-mesosaprobic conditions (moderately influenced waters) in Europe with Saprobic Index = 2.4 (Hörner *et al*., 2002). *B. sowerbyi* is a conveyor-belt feeder that mixes benthic sediments, bringing deeper sediments to the surface (Matisoff *et al*., 1999) and can transport large quantities of sediment particles from deep zones. Due to its large size, *B. sowerbyi* can homogenize layers to a greater depth than some other oligochaetes that are abundant in parts of the Great Lakes, including *Limnodrilus hoffmeisteri* and *Tubifex tubifex* (Matisoff *et al*., 1999), the same taxa as in Lake Tana.

B. sowerbyi, with other oligochaetes, has been documented as a host of myxosporean parasites which cause fish pathologies such as swim-bladder disease and haemorrhagic thelohanellosis (*Thelohanellus hovorkai)* in Asia and Europe, and its presence has been correlated with high levels of infection in fish (Liyanage *et al*., 2003). Consequently, it is necessary to undertake a special parasitological study to clarify its role in Lake Tana and the influence on fish population.

The second dominant species is close to *Chironomus formosipennis,* which is widely distributed in East Africa. It was described from Lake Chad, then recorded from the Rift Valley lakes in Ethiopia, lakes Kivu, Edward, Albert, Naivasha and others (Eggermont and Verschuren, 2004). Despite wide distribution in East Africa, its saprobic value has not been yet recognized.

Total species richness of Lake Tana cannot be estimated from a single season data, but it seems to be much less than in Ethiopian mountains streams and rivers (Harrison and Hynes, 1988), or Nile River (El-Shabrawy and Fishar, 2009). Total number of macroinvertebrates in Bahir Dar Gulf of Lake Tana, excluding "Infranz" is also smaller, than the case of Aswan Reservoir and Lake Nasser, where it is usually more than 1000 ind./m^2 (El-Shabrawy and Fishar, 2009).

The most diverse and abundant macrozoobenthos community, most different from the other sampling sites, was formed in the Infranz river mouth. Perhaps the reason for this is the mixing of river and lake waters and settling of additional organic matter, imported to this area from river catchment, as well as additional microhabitats formed because of diverse vegetation development.

In general, it should be noted that macrophyte beds are a very important component in the formation of physico-chemical regime and hydrobiological characteristics of Lake Tana. They buffer nutrients' runoff and affect the quality of water along with formation of bottom substrates and create good habitat conditions for macroinvertebrate communities.

ACKNOWLEDGEMENTS

We are grateful to Dr. Fedor N. Shkil (A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia), for his help in fieldwork, and Dr. Andrey A. Darkov, for coordination of the work from the Joint Ethio-Russian Biological Expedition (JERBE), which organized and financially supported our research. A.P.'s studies were financed by the grant of the Russian Science Foundation No 15-14-10020.

REFERENCES

Ayalew Wondie, Seyoum Mengistou, Vijverberg, J. and Eshetie Dejen (2007). Seasonal variation in primary production of a large high altitude tropical lake (Lake Tana, Ethiopia): effects of nutrient availability and water transparency. *Aquat. Ecol*. **41**: 195–207.

Ayalew Wondie (2010). Current land use practices and possible management strategies in shore area wetland ecosystem of Lake Tana: towards improving livelihoods, productivity and biodiversity conservation. Management of shallow water bodies for improved productivity and people' livelihoods in Ethiopia. In: Proceedings of the Second National Conference of the Ethiopian Fisheries and Aquatic Science Association (EFASA), pp. 9–16, 20-21 Feb., Bahir Dar.

Beadle, L.C. (1981). **The Inland Waters of Tropical Africa. An Introduction to Tropical Limnology**. Second edition. Longman Group Limited, London-New York.

Berhanu Teshale, Lee, R. and Girma Zawdie (2001). Development initiatives and challenges for sustainable resource management and livelihood in the Lake Tana region of Northern Ethiopia. In: Proceedings of the Wetland Awareness Creation and Activity Identification Workshop in Amhara National Regional State, pp. 33–43, Bahir Dar.

Berhanu Teshale (2003). Influence of sediment on physico-chemical properties of Lake Tana. A Workshop "Fish and Fisheries of Lake Tana: Management and Conservation", 6-8 October, Bahir Dar.

Brihkhurst, R.O. and Jamieson, B.G.M. (1971). **Aquatic Oligochaeta of the World**. Oliver & Boyd, Edinburg.

Dereje Tewabe, Said Muhammed and Belay Abdissa (2005). Distribution and abundance of macro-benthic and weed-based faunas in the northern part of Lake Tana. Internal Report, ARARI, Bahir Dar.

Eggermont, H. and Verschuren, D. (2004). Sub-fossil Chironomidae from East Africa. 2. Chironominae (Chironomini and Tanytarsini). *J. Paleolimnol.* **32**: 413–455.

El-Shabrawy, G.M. and Fishar, M.R. (2009). The Nile Benthos. In: **The Nile: Origin, Environments, Limnology and Human Use,** pp. 563–583 (Dumont, H.J., ed.). Springer Science + Business Media B.V.

Harrison, A.D. and Hynes, H.B.N. (1988). Benthic fauna of Ethiopian mountain streams and rivers. *Arch. Hydrobiol.* Suppl.-Bd. **81**: 1–36.

Hörner, K., Moog, O. and Sporka, F. (2002). Oligochaeta (oligochaete worms) including Aeolosomatidae. Part III, 18 pp. In: **Fauna Aquatica Austriaca,** (Moog, O., ed.). 2002. Wasserwirtshaftskataser, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft. Wien.

Hutsemékers, V., Szövény, P., Shaw, A.J., González-Mancebo, J-M., Muñoz, J. and Vanderpoorten, A. (2011). Oceanic islands are not sinks of biodiversity in spore-producing plants. *Proc. Nat. Acad. Sci. USA*. **108**: 18989–18994.

Liyanage, Y.S., Yokoyama, H. and Wakabayashi, H. (2003). Evaluation of a vector-control strategy of haemorrhagic thelohanellosis in carp, caused by *Thelohanellus hovorkai* (Myxozoa). *Dis. Aquat. Organ.* **55**(1): 31–35.

Matisoff, G., Wang, X. and McCal, P.L. (1999). Biological redistribution of lake sediments by tubificid oligochaetes: *Branchiura sowerbyi* and *Limnodrilus hoffmeisteri*/*Tubifex tubifex*. *J. Great Lakes Res*. **25**(1): 205–219.

Starobogatov, Y.I. (1970). Fauna of molluscs and zoogeographic division of continental waterbodies of the globe. Leningrad: Nauka, 372 pp. [in Russian].

Vijverberg, J., Sibbing, F.A. and Eshetie Dejen (2009). Lake Tana: Source of the Blue Nile. In: **The Nile: Origin, Environments, Limnology and Human Use**, pp. 163–192 (Dumont, H.J., ed.). Springer Science + Business Media B.V.

Wondie Zelalem and Prokin A. (2016). Macrozoobenthos diversity and abundance of the Bahir Dar Gulf of Lake Tana, Ethiopia. In: Lake ecosystems: Biological processes, antropogenic transformation, water quality: Materials of the V International Scientific Conference, pp. 200–201, September 12-17, 2016, Minsk-Naroch. Minsk: “Publishing center BSU”.