SINET: Ethiop. J. Sci., 35(2):95–106, 2012
 ISSN: 0379–2897

SPAWNING MIGRATION OF *LABEOBARBUS* SPP. (PISCES: CYPRINIDAE) OF LAKE TANA TO ARNO-GARNO RIVER, LAKE TANA SUB-BASIN, ETHIOPIA

Shewit Gebremedhin [1], Minwyelet Mingist [1], Abebe Getahun [2] and Wassie Anteneh [3]

[1]Department of Fisheries, Wetlands and Wildlife Management, Bahir Dar University, PO Box 79, Bahir Dar, Ethiopia; E-mail: shewitlove@gmail.com
[2]Department of Zoological Sciences, Addis Ababa University, PO Box 1176, Addis Ababa, Ethiopia
[3]Department of Biology, Bahir Dar University, PO Box 79, Bahir Dar, Ethiopia

ABSTRACT: The spawning migration of *Labeobarbus* species of Lake Tana to Arno-Garno River was studied from July to December 2010. Five sampling sites, based on the nature, flow-rate of the river, human interference and suitability for fish spawning were selected by preliminary survey. Fish were sampled monthly in the non-peak spawning season (July, November and December) and bimonthly in the peak spawning season (August to October) using 6, 8, 10, 12 and 14 cm stretched mesh size gillnets. A total of 1077 *Labeobarbus* specimens were collected. *Labeobarbus intermedius*, *L. brevicephalus, L. nedgia* and *L. tsanensis* were the dominant species, contributing 93.03% of the total catch. The monthly gonado-somatic index indicated that the peak spawning season for *Labeobarbus* species was from August to October. *Labeobarbus intermedius* and *L. tsanensis* were the first species to aggregate at the river mouth starting from July and *L. brevicephalus* and *L. nedgia* aggregate starting from September. *Labeobarbus intermedius* was the first to migrate to the upstream sites starting from the end of July followed by *L. tsanensis*. The last migrant species was *L. brevicephalus* starting from the fourth week of August. Pairwise comparison of the *Labeobarbus* spp. showed temporal segregation in all sampling months, except *L. intermedius* and *L. brevicephalus* that did not show temporal segregation with *L. nedgia*. The best management option to protect these species is closed season that should be strictly implemented during the spawning season (from July to October).

Keywords: Arno-Garno, gonado-somatic index, *Labeobarbus*, migration, segregation

INTRODUCTION

Lake Tana, which is the largest lake in Ethiopia, constitutes almost half of the freshwater bodies of the country (Reyntjes *et al*., 1998; de Graaf *et al*., 2004) and contains three commercially important families of fish: Cichlidae, Clariidae and Cyprinidae. Cyprinidae, being the most widespread family, has the highest diversity among all freshwater fish families and even vertebrates (Nelson, 1994). *Labeobarbus* species of Lake Tana, belonging to the family of Cyprinidae, are the only remaining intact species flock in the world (Kornfield and Carpenter, 1984; Nagelkerke *et al*., 1994; Nagelkerke and Sibbing, 2000).

The recent revision by Nagelkerke and Sibbing (2000) revealed 15 biologically distinct *Labeobarbus* species that form a species flock. The common evidences for the species status of *Labeobarbus* of Lake Tana are: their distinct morphometrics (Nagelkerke *et al*., 1994; Nagelkerke, 1997; Nagelkerke and Sibbing, 2000); their segregation in food niches (Nagelkerke *et al*., 1994; Nagelkerke, 1997; Sibbing and Nagelkerke, 2001; de Graaf *et al*., 2008); their spatial distribution patterns (Nagelkerke *et al*., 1994; de Graaf *et al*., 2008); the maximal body size they attain (Nagelkerke and Sibbing, 1996); different immuno-genetics (Dixon *et al*., 1996; Kruiswijk *et al*., 2002); and indications of spawning segregation (Nagelkerke and Sibbing, 1996; de Graaf *et al*., 2003; Palstra *et al*., 2004; de Graaf *et al.,* 2005; Wassie Anteneh *et al*., 2008).

Cyprinids are riverine in their origin and have adapted to live in lakes or lacustrine environments. However, most of these species still migrate upstream to spawn in tributary rivers (Tomasson *et al*., 1984; Skelton *et al*., 1991) which indicates that they are not still fully adapted to the lake environment. Different studies conducted in some tributary rivers of Lake Tana such as Gelgel Abay, Gelda and Gumara Rivers (Nagelkerke and Sibbing, 1996; Palstra *et al*., 2004; de Graaf *et al*., 2005) and Ribb, Dirma and

Megech Rivers (Wassie Anteneh *et al.*, 2008; Abebe Getahun *et al*., 2008) showed the upstream spawning migration of some lacustrine *Labeobarbus* species. From previous studies, at least eight *Labeobarbus* species (*L. acutirostris*, *L. brevicephalus*, *L. intermedius*, *L. macrophtalmus*, *L. megastoma*, *L. platydorsus*, *L. truttiformis* and *L. tsanensis*) are reported as riverine spawners. The remaining seven 'missing' *Labeobarbus* species (*L. dainellii*, *L. surkis*, *L. gorgorensis*, *L. crassibarbis*, *L. gorguari*, *L. nedgia* and *L. longissimus*) have been assumed either migrating to spawn in Arno-Garno River, the perennial tributary of Lake Tana and other temporary tributaries of Lake Tana such as Enfraz River, or they might be lacustrine spawners (Nagelkerke and Sibbing, 1996; Palstra *et al*., 2004; de Graaf *et al*., 2005; Wassie Anteneh *et al*., 2008).

Most of the large African cyprinids are vulnerable to fishing activities as a result of their aggregation at the river mouths (Ogutu-Ohwayo, 1990; de Graaf *et al*., 2004; de Graaf *et al*., 2006). Usually gillnets are set near the river mouths to effectively block upstream spawning migrations. The most plausible explanation for the dramatic decline (>75% in number) of the riverine spawning *Labeobarbus* species in Lake Tana is thought to be recruitment over fishing by the commercial gillnet fishery (de Graaf *et al*., 2004) and poisoning of the spawning stock in rivers using the crushed seeds of *Birbira* (Abebe Amha, 2004). In addition to this, alteration of breeding and juvenile nursery grounds can also be the cause for the decline of *Labeobarbus* stock in Lake Tana.

Arno-Garno is one of the unstudied permanent rivers flowing into Lake Tana. Therefore, it was found necessary to carry out detailed investigation of the *Labeobarbus* species migrating into this river for the rational exploitation and conservation of this unique species flock. Thus, the aim of this study was to investigate whether or not the *Labeobarbus* species of Lake Tana migrate to spawn in Arno-Garno River. In this study, the presence or absence of spatial and temporal spawning segregations among the species were assessed which is helpful in unravelling lacustrine and migratory assumption dilemmas about the seven missing *Labeobarbu*s species.

MATERIALS AND METHODS

Description of the study area

Seven big perennial rivers (Gelgel Abay, Gumara, Dirma, Gelda, Ribb, Megech and Arno-Garno) flow into Lake Tana. The only out flowing river from Lake Tana is Abay (Blue Nile). Arno-Garno River is located in the north-eastern part of Lake Tana and originates from the north Gonder highlands (Mikael Debir) (Fig. 1). During the rainy season, Arno-Garno River is, on average, about 5–10 m wide in the upstream sampling sites. Boulders, pebbles and gravel beds characterize the bottom of the main channel of the river. Before 20 years, the river used to join the lake about 1.5 km north of the current river mouth (pers. comm. with local people). Two temporary rivers, Gramtit and Dobit, join Garno River at about 6 and 8 kms west of the main Bahir Dar–Gonder asphalt road, respectively. One temporary river (Wombha) joins the Arno River near the main asphalt road. The Arno-Garno River is completely disconnected from the lake during the dry season (starting from February up to June) due to high sand mining activities and water diversion by the local farmers for irrigation purposes. So, these activities are serious problems for both Arno and Garno Rivers and their tributaries. However, during the spawning season both rivers recover in volume due to the heavy rains in the area.

Field sampling

Five sampling sites based on, suitability for fish spawning and gillnet setting, accessibility, slow flow-rate of the river and, less human interference were selected by preliminary assessment/survey, and sampling sites were fixed using GPS (Table 1). At all sampling sites, water temperature (°C), pH, total dissolved solids (TDS) (ppm), and conductivity (µS cm^{-1}) were measured using multi conductivity meter, Oxygen (mgl^{-1}) and water transparency (Secchi-depth; cm) were measured using oxyguard portable probe and secchi disc, respectively. Fish specimens were collected monthly in July, November and December 2010. However, samples were collected twice per month from August to October 2010 at all selected sites of Arno-Garno River. Gillnets of 6, 8, 10, 12 and 14 cm stretched bar mesh, having a length of 25 m and depth of 1.5 m were used to sample fish.

Gillnets were set at the river mouth at a depth of about 2.5-3.5 m overnight. But in the upstream sites fish were sampled during day time since it is difficult to set gillnets overnight due to the heavy rainfall, consequently high flow in the area, especially in the afternoon. Gonado-Somatic Index (GSI) is the ratio of fish gonad weight to body weight and it was determined using the following formula (Bagenal, 1978).

$$GSI\ (\%) = \frac{Gonad\ weight\ (g)}{Body\ weight\ (g)} \times 100$$

Fish were identified to species level using keys developed by Nagelkerke and Sibbing (2000). Gonad maturity of each fish specimen was identified using a seven-point maturity scale (Nagelkerke, 1997).

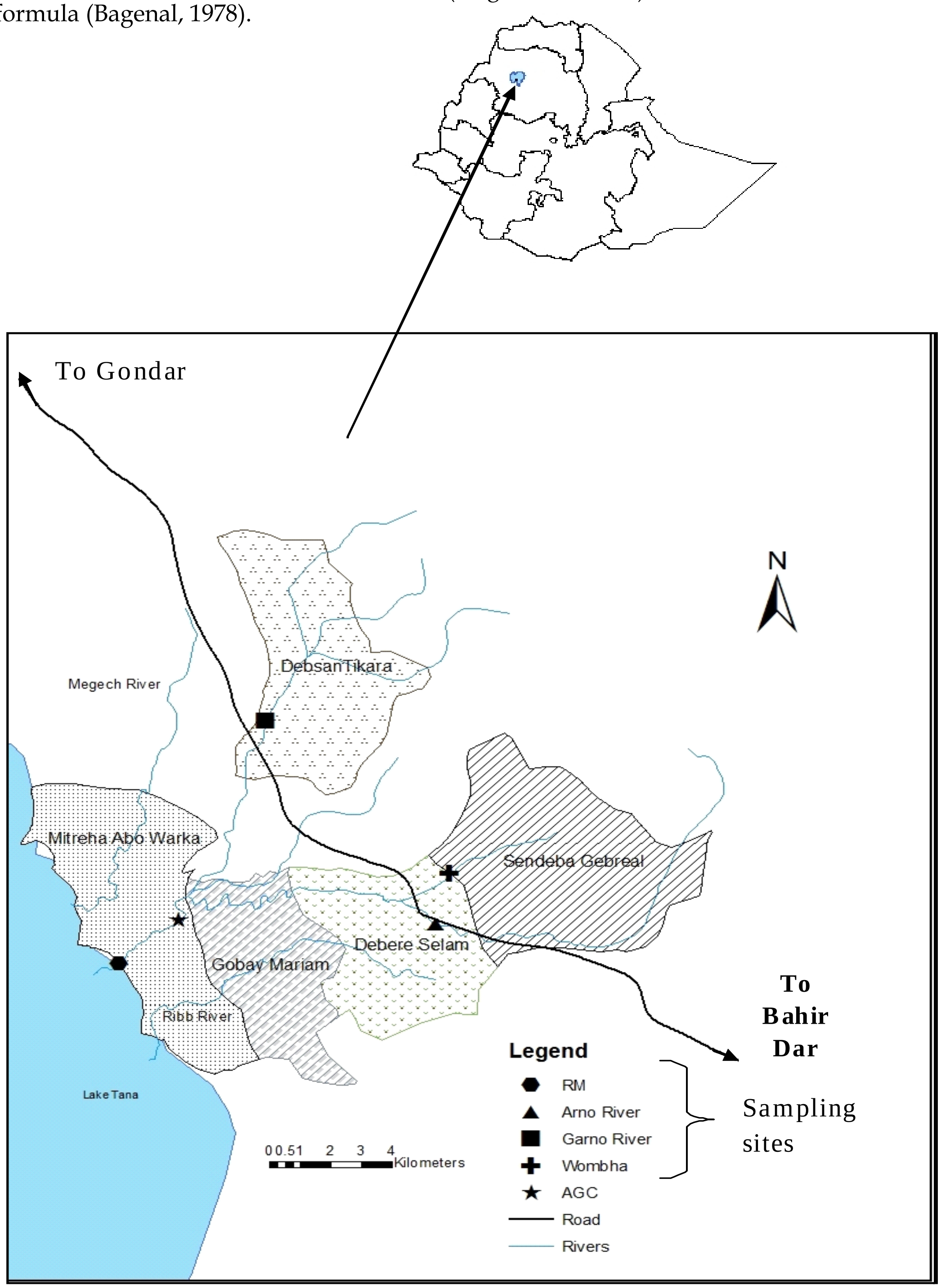

Fig. 1. Map of Lake Tana and the sampling sites in Arno-Garno River (RM is river mouth and AGC is Arno-Garno Confluence).

Table 1. Sampling sites, estimated distances from the mouth of the Arno-Garno River and geographic coordinates.

Site	Code	Distance from RM	Coordinate (GPS)
River mouth	RM	---	12°09′29.6″N; 037°34′31.8″E
Arno-Garno confluence	AGC	2 km	12°11′07.6″N; 037°36′30.5″E
Arno	Arno	30 km	12°10′13.7″N; 037°43′03.8″E
Garno	Garno	24 km	12°14′09.7″N; 037°37′38.7″E
Wombha	Wombha	28 km	12°09′29.6″N; 037°40′22.3″E

Data analysis

SPSS version 16 software was used for statistical data analysis. One-way ANOVA was used to analyze spatial and temporal segregation and Mann-Whitney U test to analyze abiotic parameters.

RESULTS

Physico-chemical parameters

The DO, temperature, pH, TDS and conductivity are shown in Table 2. The measured physic-chemical parameters did not show significant difference among the sampling sites (Mann-Whitney U test, P>0.05). However, water transparency (secchi depth) showed significant variations between most of the sampling sites (Table 3; P<0.05).

Species composition at the river mouth and upstream areas

A total of 1077 *Labeobarbus* specimens were collected from July to December, 2010, from all sampling sites. Four species (*L. intermedius*, *L. brevicephalus*, *L. nedgia* and *L. tsanensis*) were the most dominant species and contributed about 93% of the total *Labeobarbus* catches in the Arno-Garno River. *Labeobarbus platydorsus*, *L. truttiformis*, *L. surkis, L. megastoma, L. crassibarbis,* and *L. gorgorensis* were caught rarely over the sampling months. No specimens of *L. dainellii*, *L. gorguari*, *L. macrophtalmus*, and *L. longissimus* were caught over the sampling months.

Gonado-Somatic Index (GSI)

The gonad proportion of mature *Labeobarbus* species (gonad stage IV, V), running (gonad stage VI), and spent (gonad stage VII) together was higher (about 86.4%) than the immature gonads (gonad stages I-III) in the samples collected during the sampling period (July to December) (Fig. 2). The calculated maximum monthly mean of GSI for *L. intermedius*, *L. bervicephalus*, *L. tsanensis* and *L. nedgia* were 6.51, 8.03, 4.18 and 2.73, respectively (Fig. 3). During this study, 16 females of *Labeobarbus* specimens (3 at the river mouth and 13 from the upstream sites) were caught with spent gonads and generally they were more numerous at the end of October. From the total catch of specimens with spent gonads *L. intermedius* and *L. brevicephalus* were represented by 8 specimens each, 2 and 1 at the river mouth and 6 and 7 in the upstream sites, respectively.

Table 2. Abiotic parameters at the river mouth and upstream areas with their Mean ± Standard Error (SE).

Site	Dissolved Oxygen (mgl^{-1})	Temperature (°C)	pH	TDS (ppm)	Conductivity ($\mu S\ cm^{-1}$)	Secchi depth (cm)
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
RM	6.71 ± 1.07	22.82 ± 0.75	6.69 ± 0.33	82.48±11.32	160.34 ± 23.33	17.44 ± 6.33
AGC	7.01 ± 0.50	22.57 ± 0.66	7.04 ± 0.15	94.44 ± 6.85	189.33 ± 13.55	49.00 ±15.02
Garno	7.46 ± 0.69	20.48 ± 1.04	7.48 ± 0.17	86.41 ± 6.08	173.47 ± 12.23	82.56 ± 20.01
Wombha	5.53 ± 1.77	20.13 ± 2.58	6.47 ± 0.84	86.58± 1.69	167.76 ± 21.95	98.48 ±18.12
Arno	7.53 ± 0.62	21.96 ± 0.75	7.38 0.23	97.24 ± 3.11	195.72 ± 4.43	100.13 ± 22.43
Average	7.78 ± 0.44	21.59 ± 0.61	7.01 ± 0.19	89.43 ± 3.70	177.33 ± 7.36	69.52 ± 8.81

Table 3. Pairwise comparison of water transparency (secchi depth in cm) at all sampling site.

Sampling sites	RM	AGC	Arno	Garno	Wombha
RM	X				
AGC	ns	X			
Arno	**	ns	X		
Garno	*	ns	ns	x	
Wombha	**	*	ns	ns	x

** (P<0.01), * (P<0.05), not significant (ns) (P>0.05)

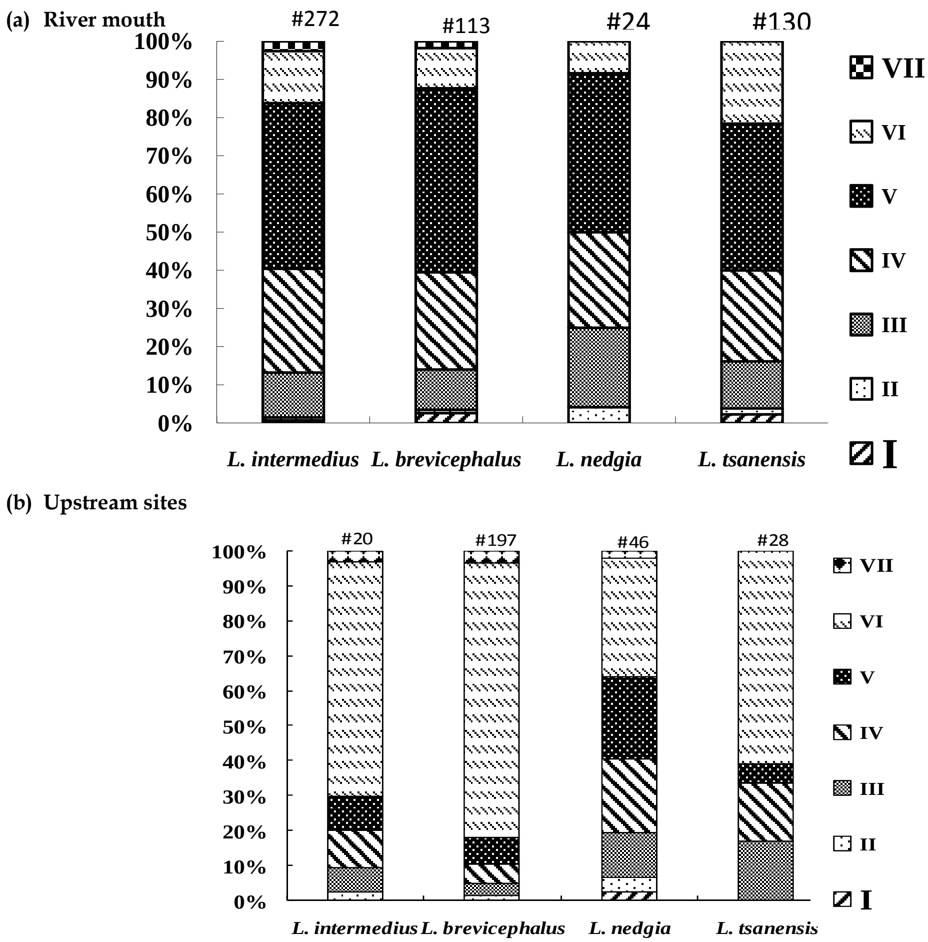

Fig. 2. Proportion of gonad maturity stages (I to VII) of the most dominant *Labeobarbus* species during spawning season (July to December) (a)at the river mouth and (b)upstream areas in the Arno-Garno River.

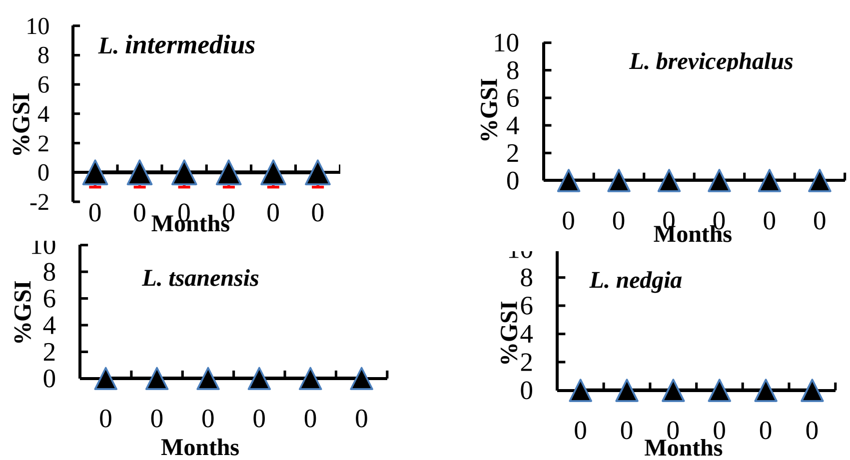

Fig. 3. Monthly calculated percentage of gonado-somatic index of the dominant *Labeobarbus* species in Arno-Garno River.

Segregation of Labeobarbus spp. in Arno-Garno River

There was no significant variation in the distribution patterns of the four most abundant species of *Labeobarbus* spatially over the five sampling sites in the Arno-Garno River (one-way ANOVA, P >0.05). However, there was significant temporal segregation of the dominant *Labeobarbus* species during the sampling period (July to December; one-way ANOVA, P <0.05) (Fig. 4).

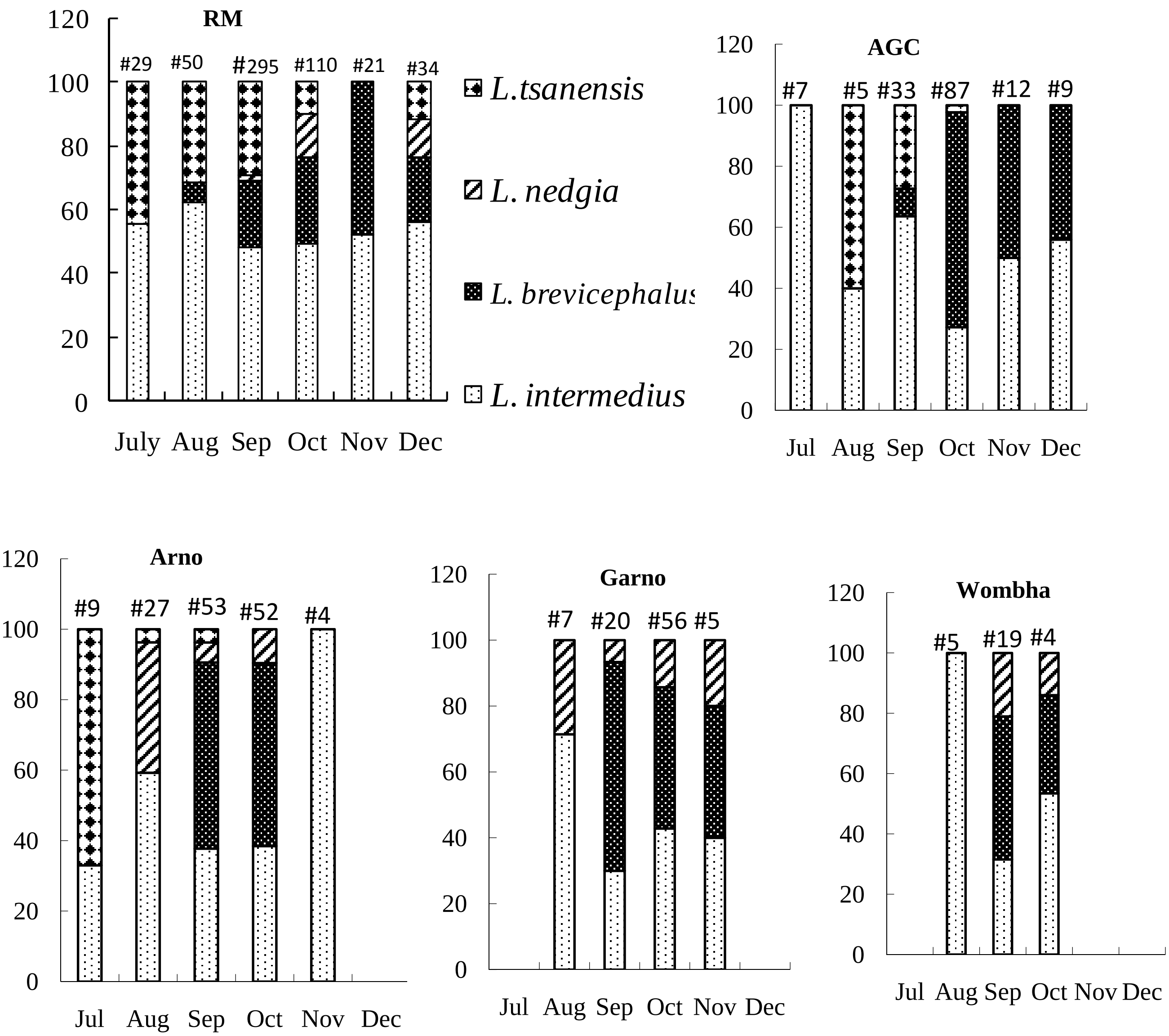

Fig. 4. Proportions (in number) of *Labeobarbus* species collected during the spawning season from RM, AGC, Arno, Garno and Wombha sites.

The aggregation patterns of the *Labeobarbus* species at the river mouth varied during the spawning months (July to December). The aggregation patterns at the river mouth and migration patterns in the upstream sites on monthly basis for the non-peak spawning months and bimonthly basis for the peak spawning months are given in Figures 5a and 5b. *Labeobarbus intermedius* and *L. tsanensis* were the first species to aggregate at the river mouth starting from July and reached their peak in the third week of September (Fig. 5a). L*abeobarbus brevicephalus* started to aggregate at the river mouth in the third week of August and reached its peak in the third week of September. *Labeobarbus nedgia* was the last species to aggregate starting from the first week of September and reached its peak in the first week of October (Fig. 5a). All *Labeobarbus* species showed a declining pattern in catch from October to December (Fig. 5b). The first species to ascend to upstream sites was *L. intermedius,* which started to migrate at the end of July, but its catch was higher in August both in Arno and Garno sites (Fig. 5b). *Labeobarbus tsanensis* was the second migrant species, which started migrating in the second week of August. The last migrant was *L. brevicephalus* that started migrating from the fourth week of August. Catch of *L. brevicephalus* and *L. tsanensis* reached its peak in October and September, respectively. Pairwise comparison of the four dominant *Labeobarbus* species in Arno-Garno River showed significant variations in temporal segregation (P<0.001), except between *L. intermedius* and *L. nedgia* and *L. brevicephalus* and *L. nedgia* (Table 4).

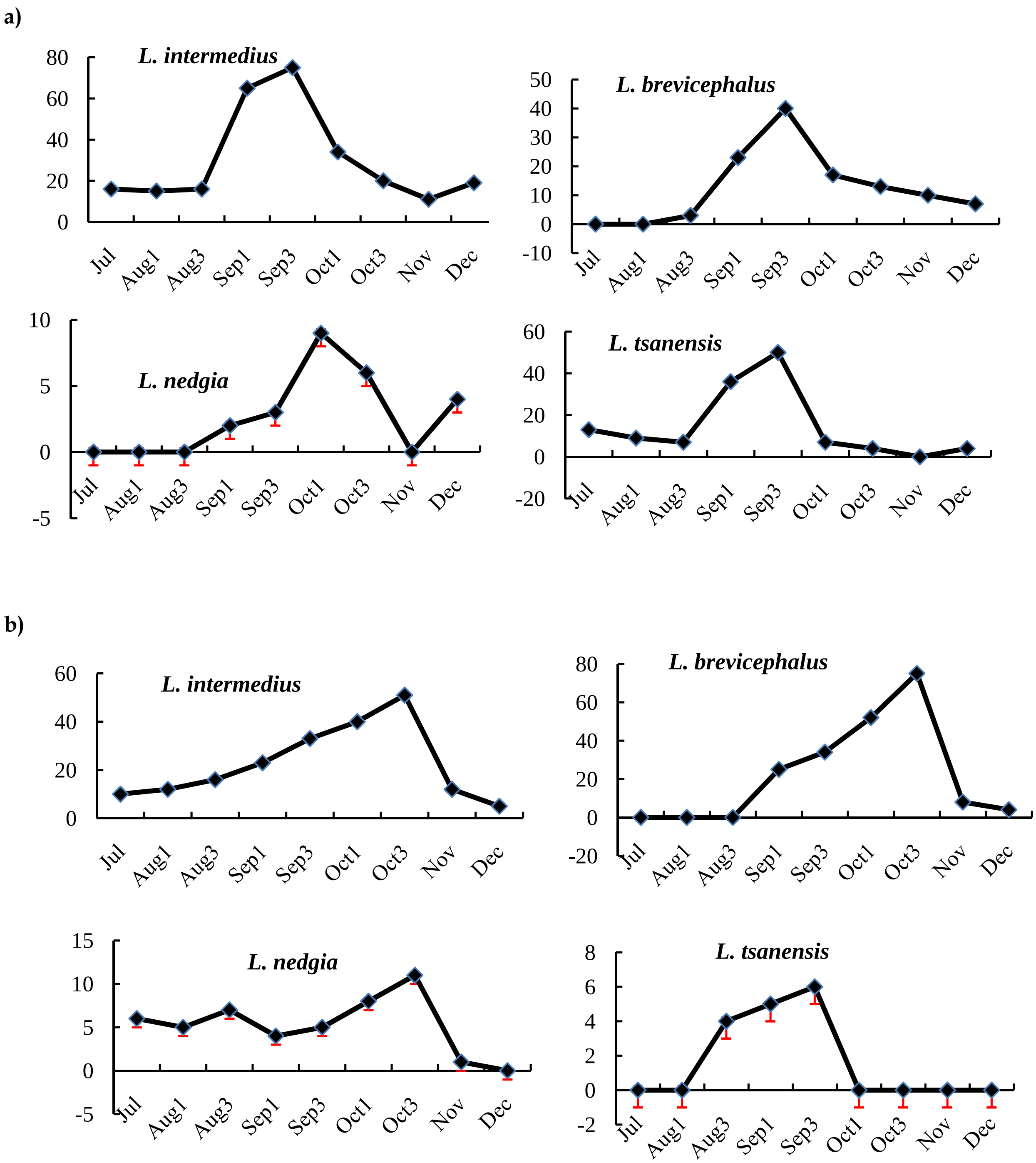

Fig. 5. Temporal variation in abundance of *Labeobarbus* species during the breeding season (July to December) (a) at the river mouth and (b) upstream sites.

Table 4. Pairwise comparison of temporal segregation of *labeobarbus* species during the peak spawning season (August to October) in all upstream sites.

Temporal	*L. intermedius*	*L. brevicephalus*	*L. nedgia*	*L. tsanensis*
L. intermedius	X			
L. brevicephalus	***	X		
L. nedgia	ns	ns	X	
L. tsanensis	***	***	***	X

***** (P<0.001), ns (not significant; P>0.05)**

DISCUSSION

Abiotic factors

Abiotic factors are the controlling factors for aquatic life, since they shape most of the biological functions of aquatic life (Murdoch and Martha, 1999). Arno-Garno River serves as one of the best spawning areas for *Labeobarbus* species since it has fast flowing, clear and highly oxygenated water, gravel beds, which are spawning ground requirements for these species. Moreover, there is no major waterfall on Arno-Garno River that could deter the migration of these species. The abiotic parameters taken from all sampling sites were analyzed using Mann-Whitney U test and there was no significant difference (P>0.05) except in secchi depth measurements at all sampling sites. Water transparency (secchi depth) showed significant variation (P<0.05) between the river mouth and the upstream sites. This might be due to the fact that the river mouth gets more turbid due to sediment deposition from various sources. Adequate concentration of dissolved oxygen (DO) is a critical factor for the survival of fish species, because DO can influence growth and development of the different life stages of fishes, for larval survival and for swimming activity of adults when they migrate (Washington State Department of Ecology, 2002). Even if the requirement of DO varies according to species and life stage, DO levels below 3 mgl^{-1} are stressful to most aquatic organisms and DO levels 5 to 6 mgl^{-1} are usually required to perform their biological functions (Campbell and Wildberger, 1992). The mean DO level of the Arno-Garno River was 7.78 mgl^{-1}, that is greater than the minimum required DO level (6 mgl^{-1}) for fish to perform their biological functions (USEPA, 1986). The pH value of the river was almost neutral at all sampling sites. A similar observation was made by Wassie Anteneh *et al*. (2008) in Megech and Dirma Rivers, which are thought to be ideal breeding grounds for the *Labeobarbus* species of Lake Tana.

Gonado-Somatic Index

The mean GSI of a stock tends to increase as the species approaches spawning. From the four dominant *Labeobarbus* species migrating to Arno-Garno River, *L. brevicephalus* had the highest percentage of GSI (8.03%) which was measured in August. Thus, as the monthly calculated GSI indicated that, the peak spawning months of the migratory *Labeobarbus* species to Arno-Garno River were August to October, although there were some specimens of the *Labeobarbus* species, which started to reproduce in early July. Similar findings were also reported by de Graaf *et al*. (2005). Both the appearance of large number of spent females in October and low abundances in the catch may indicate the end of spawning season for those species.

Spawning aggregation and segregation

Migration of the tropical freshwater fish to breeding grounds is mainly triggered by rainfall patterns and water level variations (Lowe-McConnell, 1975). The *Labeobarbus* species in Lake Tana also aggregate at river mouths to spawn in the rainy season (Nagelkerke and Sibbing, 1996; Dgebuadze *et al*., 1999; Palstra *et al*., 2004; de Graaf *et al*., 2005). In this study, four *Labeobarbus* species (*L. intermedius, L. brevicephalus, L. nedgia* and *L. tsanensis)* aggregated at the river mouth of Arno-Garno River starting from mid July to the end of October. Those *Labeobarbus* species aggregating at the river mouth were caught with gonad stages IV and V but gonad stage VI was very rare. However, most of the *Labeobarbus* species in the upstream areas were caught with gonad stage VI. This implies that *Labeobarbus* species may not spawn at the river mouth but migrate to the upstream areas. *Labeobarbus acutisrostris, L. macrophtalmus, L. megastoma, L. tsanensis* and *L. truttiformis* were riverine spawners in Gumara River and its tributaries but *L. intermedius* was absent (Dgebuadze *et al*., 1999; Palstra *et al*., 2004). In contrast to this, *L. intermedius* was the dominant species in Arno-Garno River. Wassie Anteneh *et al*. (2008) also reported a similar result from Megech and Dirma Rivers. In agreement with de Graaf *et al*. (2005) in Gelda, Gelgel Abay, Gumara and Rib Rivers *L. surkis* did not aggregate at the river mouth of Arno-Garno River. However, it aggregated in Megech and Dirma Rivers (Wassie Anteneh *et al*., 2008).

Labeobarbus megastoma and *L. truttiformis* which were riverine spawners in Gumara, Megech and Dirma Rivers (Palstra *et al*., 2004; Wassie Anteneh *et al*., 2008), were found rarely in Arno-Garno River. The possible explanation for this might be the size-dependent removal of those species by fishermen who set gill nets near the river mouth. Local fishermen's catches are constituted of a large number of specimens of *L. megastoma* starting from July to end of September and that of *L. truttiformis* starting from September to end of August. This evidence strengthens the reason why these species are rarely found in the river. Moreover, *L. macrophtalmus* was found to migrate to Gumara River (Palstra *et al*., 2004) but was not found in Arno-Garno River. This is similar to what has been reported by Wassie Anteneh *et al*. (2008) for Megech and Dirma Rivers. This might be due to the river specific spawning behaviour of the species. *Labeobarbus nedgia,* that was not found in Gelda, Gelgel Abay, Gumara and Rib Rivers (Palstra *et al*., 2004; de Graaf *et al*., 2005), was found in Arno-Garno River. *Labeobarbus nedgia* was found in all of the upstream areas with running gonad stage of both females and males. Its catch also showed a declining pattern starting from the end of October like other *Labeobarbus* species, which probably indicates the end of spawning period. Thus, *L. nedgia* was one of the migratory *Labeobarbus* species of Lake Tana to Arno-Garno River.

There was no significant difference in the distribution patterns of the four most abundant species of *Labeobarbus* (one-way ANOVA, $P > 0.05$) over the five sampling sites in Arno-Garno River. The results of this study do not support the presence of micro-spatial spawning segregation among riverine spawning species of *Labeobarbus* claimed by Palstra *et al*. (2004). The pair-wise comparison of the four dominant *Labeobarbus* species in Arno-Garno River showed significant variations in temporal segregation ($P<0.001$), except *L. intermedius* with *L. nedgia* and *L. brevicephalus* with *L. nedgia*. The monthly and bi-monthly basis distribution patterns of *Labeobarbus* species during the non-peak and peak spawning months showed that thespecies aggregated at the river mouth. *Labeobarbus intermedius* and *L. tsanensis* were the first to aggregate at the river mouth starting from July and reached their peak in the third week of September, whereas *L. brevicephalus* and *L. nedgia* aggregated on the third week of August and first week of September and peaked in the third week of September and third week of October, respectively.

All the four dominant *Labeobarbus* species showed a declining pattern in catch from October to November, which is the indication of the end of spawning period. Different studies conducted in other tributaries of Lake Tana also revealed temporal segregation in *Labeobarbus* species. Palstra *et al*. (2004), de Graaf *et al*. (2005) and Wassie Anteneh *et al*. (2008) reported the aggregation of *Labeobarbus* species at different times during the spawning season in Gumara, Gelgel Abay, Gelda, Ribb, Megech and Dirma River mouths. Similar results were obtained by de Graaf *et al*. (2005) for *L. tsanensis* and *L. brevicephalus*, which were the first and the last species to aggregate in Gelgel Abay, Gelda, Gumara, and Ribb River mouths, respectively. However, *L. megastoma* was the first to aggregate in Megech and Dirma River mouths (Wassie Anteneh *et al*., 2008). The possible reason for this difference might be the heavy exploitation of this species by fishermen before aggregating at the river mouth because of its large size. The first and last species to migrate to the upstream sites were *L. intermedius* and *L. brevicephalus* starting from the end of July and first week of September, respectively, with highest running species in the third week of October.

Missing species

From previous studies on spawning migration of *Labeobarbus* species of Lake Tana, seven species (*L. dainellii*, *L. nedgia*, *L. surkis*, *L. gorgorensis*, *L. gorguari*, *L. crassibarbis*, and *L. longissimus*) were reported as missing species from both river mouths and upstream areas of Gumara, Gelda, Ribb, Megech and Dirma Rivers (Nagelkerke and

Sibbing, 1996; Dgebuaze *et al*., 1999; Palstra *et al*., 2004; de Graaf *et al*., 2005; Wassie Anteneh *et al*., 2008), although *L. surkis* was found to aggregate at the river mouths of Megech and Dirma Rivers (Wassie Anteneh *et al*., 2008). Two possible explanations were given in the previous studies in the other rivers entering Lake Tana (*i.e.*, the missing species either migrate and spawn in Arno-Garno River or they might be lacustrine spawners). In this study, out of the seven species reported as missing, *L. nedgia* was the only one found to be migrating in Arno-Garno River.

Therefore, the missing *Labeobarbus* species most probably breed in the lake and adjacent floodplains and deposit their eggs on sand or rocks, near roots of plants or on aquatic or flooded terrestrial vegetation as is common in many other cyprinid genera (Mills, 1991).

For example, the spawning grounds of *Barbus sharpeyi* are confined to the lakes and marshes in the alluvial plain and, to a lesser extent, to the lower reaches of the Tigris and Euphrates Rivers (Al-Hamed, 1972 cited in de Graaf *et al*., 2005). This species deposit eggs on submerged parts of aquatic vegetation or other objects, from the surface down to a depth of 1 m. Similarly, Elias Dadebo *et al*. (2003) suggested that *Labeo horie* spawns in the shallow, littoral zone of Lake Chamo.

Therefore, like the large African *Labeobarbus* species mentioned above and reasons probably given for missing *Labeobarbus* species which is common in other cyprinid genera, these missing *Labeobarbus* species of Lake Tana may also spawn in the lake itself or migrate and spawn in the other smaller temporary tributaries (like Enfraz River).

Implications for fisheries management

Most of the large African cyprinids are vulnerable to fishing activities due to their reproductive strategy (Skelton *et al*., 1991). The decline of the African *Labeobarbus* stocks was attributed primarily to increased fishing pressure after the introduction of more efficient gillnets compared to artisanal fishing gear, targeting ripe females during breeding migration (Ogutu-Ohwayo, 1990; Skelton *et al*., 1991; Ochumba and Manyala, 1992). The migratory *Labeobarbus* species of Lake Tana are also facing the same problem and showed dramatic reduction (75%) in abundance (both in number and biomass) of adults and (90%) of the juveniles within ten years (1991–2001) (de Graaf *et al*., 2004). The most important explanation for this is recruitment over fishing. Recruitment over fishing is the exploitation of aggregating species for spawning using unregulated materials that brings a serious reduction of next year recruits (Gabriel *et al*., 1989; Craig, 1992).

The fishing activity in the northern part of Lake Tana, particularly in the shore areas of Arno-Garno River is traditional (using reed boats) and there are about 320 fishermen on average with 5 nylon gillnets having 50 m length each on average (pers. comm. with fishermen). Due to the lack of motorized boats, the local fishermen (mostly the Negedie ethnic group) target their fishing activity at the river mouth (pers. observation). *Labeobarbus* species is the preferred fish during the rainy season (July to September) because its price is relatively good (6.00-8.50 Ethiopian Birr/kg for fresh fish) (pers. comm. with the fishermen). Therefore, except *L. brevicephalus* that has smaller size, all the three aggregating species at the river mouth and the two species (*L. megastoma* and *L. truttiformis*) which are found rarely at the river mouth are highly vulnerable to reed boat fishing in this river.

The migratory *Labeobarbus* species of Lake Tana may be endangered like the large African cyprinids in other lakes unless the gillnet fishery in the river, at least during the peak spawning months (July to October), is prohibited and the river degrading activities such as sand mining and water diversion are reduced reasonably to the extent of having less impact on migratory fishes. Sand mining was a common activity at Arno-Garno River. This activity was common in upstream areas during the rainy season and in the river mouth, it was common during the dry season. Gravel bed of the river channel is known to be very important for *Labeobarbus* species but due to this activity, it was strongly affected, as a result, the species were seriously suffering from reaching important breeding ground. On the other hand, there were farmers, who diverted part of the river channel to draw water for irrigation, sometimes they blocked the whole river and diverted it to their farming land for irrigation purpose. So as the river was diverted the juveniles moved to the farmland when they returned to the lake and died on it. The full participation of the various stakeholders is very important for any policy to be effective. Hence, the executive bodies at the federal level generally and at the regional level (Amhara Region for this case) particularly should create awareness in places where destructive fishing activities are practiced and they should take into consideration the recommendations given by researchers. Therefore, closing fishing activity during spawning seasons (from June to October) and regulating diversion of the river and sand mining, which have serious impacts on the habitat, are important measures that need to be implemented by concerned bodies. Moreover, assessing the number of fishermen around the shore areas, monitoring commercial catch continuously, and conducting regular exploratory sampling programs are important to evaluate the outcomes of implemented regulations.

ACKNOWLEDGEMENTS

The kind collaboration of the staff members of Bahir Dar Fish and Other Aquatic Life Research Centre in providing materials needed for the study is very much appreciated. We also like to thank fishermen and field assistants for their unreserved field and laboratory assistance. This study was funded by Rufford Foundation, UK and Bahir Dar University, Ethiopia.

REFERENCES

1. Abebe Ameha (2004). The effect of birbira, *Milletia ferruginea* (Hochst.) Baker on some *Barbus* spp. (Cyprinidae, Teleostei) in Gumara River (Lake Tana), Ethiopia. MSc Thesis, Addis Ababa University.
2. Abebe Getahun, Eshete Dejen and Wassie Anteneh (2008). Fishery studies of Ribb River, Lake Tana Basin, Ethiopia. Ethiopian Nile Irrigation and Drainage Project Coordination Office, Ministry of Water Resources, Final report E1573, Vol.2, Addis Ababa, Ethiopia.
3. Bagenal, T.B. (1978). Aspects of fish fecundity. **In**: *Ecology of Freshwater Fish Production*, pp. 75–102, (Gerking, S., ed.) Black-well, Oxford.
4. Campbell, G. and Wildberger, S. (1992). T*he Monitor's Handbook.* LaMotte Company, Chestertown, MD, 71 pp.
5. Craig, F.J. (1992). Human-induced changes in the composition of fish communities in the African Great Lakes. *Reviews in Fish Biology and Fisheries* **2**:93–124.
6. de Graaf, M., Machiels, M.A.M., Tesfaye Wudneh and Sibbing, F.A. (2003). Length at maturity and gillnet selectivity of Lake Tana's *Barbus* species (Ethiopia): implications for management and conservation. Aquatic Ecosystem *Health and Management* **6**(3)**:**325–336.
7. de Graaf, M., Machiels, M.A.M., Tesfaye Wudneh and Sibbing, F.A. (2004). Declining stocks of Lake Tana's endemic *Barbus* species flock (Pisces; Cyprinidae): natural variation or human impact? *Biological Conservation* **116**:277–287.
8. de Graaf, M., Nentwich, E.D., Osse, J.W.M. and Sibbing, F.A. (2005). Lacustrine spawning, a new reproductive strategy among 'large'African cyprinid fishes? *Journal of Fish Biology.* **66**:1214–1236.
9. de Graaf, M., van Zwieten, P.A.M., Marcel, MA.M., Endale Lemma, Tesfaye Wudneh, Eshete Dejen, Ferdinand, A. and Sibbing, F.A. (2006). Vulnerability to a small-scale commercial fishery of Lake Tana's (Ethiopia) endemic *Labeobarbus* compared with African catfish and Nile tilapia: An example of recruitment-over fishing. *Fisheries Research***82:**304–318.
10. de Graaf, M., Eshete Dejen, Osse, J.W.M., Sibbing, F.A., (2008). Adaptive radiation of Lake Tana's *Labeobarbus* species flock (Pisces, Cyprinidae). *Mar. Fresh Res.* **59**:391–407.
11. Dgebuadze, Yu. Mina, M.V., Alekseyev, S.S. and Golubtsov, A.S. (1999). Observations on reproduction of the Lake Tana barbs. *Journal of Fish Biology* **54:**417–423.
12. Dixon, B., Nagelkerke, L.A.J., Sibbing, F.A., Egberts, E. and Stet, R.J.M. (1996). Evolution of MHC class II chain-encoding genes in the Lake Tana barbell species flock (*Barbus intermedius* complex). *Immunogenetics* **44**:419–431.
13. Elias Dadebo, Ahlgren, G. and Ahlgren, I. (2003). Aspects of reproductive biology of *Labeo horie* Heckel (Pisces: Cyprinidae) in Lake Chamo, Ethiopia. *African Journal of Ecology* **41**:31–38.
14. Gabriel, W.L., Sissenwine, M.P. and Overholtz, W.J. (1989). Analysis of spawning stock biomass-per-recruit: an example for Georges Bank haddock. *North American Journal of Fisheries Management* **9**:383–391.
15. Kornfield, I. and Carpenter, K.E. (1984). Cyprinids of Lake Lanao, Philippines: taxonomic validity, evolutionary rates and speciation scenarios. In: *Evolution of Fish Species Flocks*, pp. 69–83, (Echelle, A.A. and Kornfield, I., eds), Orono Press, Maine.
16. Kruiswijk, C.P., Hermsen, T., van Heerwaarden, J., Dixon, B., Savelkoul, H.F.J. and Stet, R.J.M. (2002). Different modes of major histocompatibility class Ia and class IIb evolution in the Lake Tana African ''large''

barb species flock. **In**: *Evolution of Major Histocompatibility Genes in Cyprinid Fish, Molecular Analyses and Phylogenies*, pp. 77–116. (PhD thesis, Kruiswijk, C.P), Wageningen: Cell Biology and Immunology Group, University of Wageningen.

17. Lowe-McConnell, R. (1975). *Fish Communities in Tropical Freshwaters: their Distribution, Ecology, and Evolution.* Longman, London, 337 pp.

18. Mills, C.A. (1991). Reproduction and life history. **In**: *Cyprinid Fishes, Systematics, Biology and Exploitation*, pp. 483–529, (Winfield, I.J. and Nelson, J.S., eds), Chapman and Hall, London.

19. Murdoch, T. and Martha, C. (1999). *The Stream Keeper's Field Guide: Watershed Inventory and Stream Monitoring Methods. A Product of the Adopt-A-stream Foundation*. Everett, WA, 296 pp.

20. Nagelkerke, L.A.J. (1997). The barbs of Lake Tana, Ethiopia: morphological diversity and its implications for taxonomy, trophic resource partitioning and fisheries. PhD thesis, Agricultural University Wageningen, The Netherlands.

21. Nagelkerke, L.A.J. and Sibbing, F.A. (1996). Reproductive segregation among the large barbs (*Barbus intermedius* complex) of Lake Tana, Ethiopia. An example of intralacustrine speciation? *J. Fish. Biol.* **49**:1244–1266.

22. Nagelkerke, L.A.J. and Sibbing, F.A. (2000). The large barbs (*Barbus* spp., Cyprinidae Teleostei) of Lake Tana (Ethiopia), with a description of a new species, *Barbus ossensis*. *Neth J. Zool*. **2**:179–214.

23. Nagelkerke, L.A.J., Sibbing, F.A., Boogaart, J.G.M. vanden, Lammens, E.H.R.R. and Osse, J.W.M. (1994). The barbs (*Barbus* spp.) of Lake Tana: a forgotten species flock? *Environ. Biol. Fish.* **39**:1-22.

24. Nelson, J.S. (1994). *Fishes of the World*. Wiley: NewYork, 234 pp.

25. Ochumba, P.B.O. and Manyala, J.O. (1992). Distribution of fishes along the Sondu-Miriu River of Lake Victoria, Kenya with special reference to upstream migration, biology and yield. *Aquac. Fish. Manag.*, **23**:701–719.

26. Ogutu-Ohwayo, R. (1990). The decline of the native fishes of Lakes Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile Perch, *Lates niloticus* and the Nile tilapia, *Oreochromis niloticus*. *Envi. Biol. Fish* **27**:81–96.

27. Palstra, A.P., de Graaf, M. and Sibbing, F.A. (2004). Riverine spawning in a lacustrine cyprinid species flock, facilitated by homing? *Animal Biology* **54**:393–415.

28. Reyntjes, D., Tesfaye Mengistu, Tesfaye Wudneh, and Palin, C. (1998). Fisheries development in Ethiopia–which way now? *European Union Bulletin* **11**(1):20–22.

29. Sibbing, F.A. and Nagelkerke, L.A.J. (2001). Resource partitioning by Lake Tana barbs predicted from fish morphometrics and prey characteristics. *Rev. Fish Biol. Fish.* **10**:393-437.

30. Skelton, P.H., Tweddle, D. and Jackson, P. (1991). Cyprinids of Africa. **In**: *Cyprinid Fishes, Systematics, Biology and Exploitation*, pp. 211–233. (Winfield, I.J. and Nelson, J.S., eds), Chapman and Hall, London.

31. Tomasson, T., Cambray, J.A. and Jackson, P.B.N. (1984). Reproductive biology of four large riverine fishes (Cyprinidae) in a man-made lake, Orange River, South Africa. *Hydrobiologia* **112**:179–195.

32. USEPA (1986). Ambient Water Quality Criteria for Dissolved Oxygen. Office of Water. United State Environmental Protection Agency (USEPA). EPA 440/5-86-003, 46 pp.

33. Washington State Department of Ecology (2002). Evaluating criteria for the protection of freshwater aquatic life in Washington's surface water quality standards: dissolved oxygen. Draft discussion paper and literature summary. publication number 00-10-071.

34. Wassie Anteneh, Abebe Getahun and Eshete Dejen (2008). The lacustrine species of *Labeobarbus* of Lake Tana (Ethiopia) spawning at Megech and Dirma tributary rivers. *SINET: Ethiop. J. Sci*. **31(1):**21–28.