SPAWNING MIGRATION AND REPRODUCTIVE BIOLOGY OF *LABEOBARBUS* (CYPRINIDAE: TELEOSTEI) OF LAKE TANA TO DIRMA AND MEGECH RIVERS, ETHIOPIA

A thesis presented to the School of Graduate Studies,
Addis Ababa University

In partial fulfillment of the requirement for the degree of
Master of Science in Biology

WASSIE ANTENEH

JUNE 2005

ACKNOWLEDGEMENT

I am so grateful to Drs. Abebe Getahun and Eshete Dejen, my research advisors, for their unreserved scientific advice, guidance and consistent support in the accomplishment of this study. Their critical constructive comments in the field, in the writing and supply of related literature enormously facilitated the smooth completion of this study.

Indeed, it is quite difficult to me to express my internal feelings with the languages I know so far to acknowledge Dr. Eshete's contribution to the realization of this study. He was seriously committed right from the beginning by suggesting the research area. He was many times in the field work and supplied me the necessary field and laboratory logistics in time. He was also highly influential in securing additional fund for the study. He is so friendly and has helpful attitude, which I consider it as an important quality. Generally, this acknowledgment of indebtedness to him I feel is inadequate.

I am grateful to the staff members of the Gorgora Fish and Other Aquatic Life Research Sub Center for their warm support and hospitality in my four months stay there. Especially Belay Abdissa was almost equally engaged in the tedious laboratory works with me. Bazezew Getahun and Biniyam Hailu also deserve due thanks for their courage in fishing in the spate rivers in the rainy season. Other field assistances Endalk and Melkie were also helpful. Boat drivers Asratu and Alemayehu are highly appreciated. Car drivers Sisay and Muluken cooperated in driving from Bahir Dar to Gorgora and then to upstream sampling times. Dereje and his wife (Kidist), Birhan and Yiftusira, besides their help in the lab, they were enthusiastic. The" Maize campfires" in the evenings during October were unforgettable circumstances.

I am grateful to my friends and colleagues Ayalew Wonde, Amy Collick, Sewmehon Demssie, Bizuayehu Kerisew, Delele Worku, Dr. Mulugeta Kibret and Eyayu Molla for their unfailed encouragement. Especially Ayalew and Sewmehon were indebted for material support and stimulating discussions related to my study area. Amy Collick (Coordinator of Bahir Dar-Cornell Universities ALO partnership) was so honest and skillful in the utilization of various computer programs. Most part of the thesis was typed by her.

I am especially thankful to Dr. Nand Sibbing (Wageningen University, The Netherlands) for his critical comments of most part of the thesis. In the field, while we were in Gorgora, I received good lessons from his long research experiences on Lake Tana's *Labaeobarbus*.

My due thanks goes to my family, especially my elder sisters Yeshi Anteneh and Firnus Anteneh for their sympathy and sensitive follow up while I was in the field work. My heartfelt thanks also goes to my younger sister, Meskerem Anteneh, for passing her college vacation with me in Gorgora. My best friends Yibeltal Mersha and Asamnew Alemayehu need also due thanks for settling my personal matters. I would like to thank also all my friends in Fishery and Aquatic Science stream, especially Gashaw Beyene, Getachew Beneberu and Tadesse Fetahi for the fruitful interactions we had for the past three years.

Financial expenses for this study were secured from Bahir Dar- Cornell Universities ALO partnership project and School of Graduate Studies, Addis Ababa University.

“I proposed it, My Lord gave me the courage to dispose it’’

TABLE OF CONTENTS

LIST OF TABLES

PAGE

LIST IGURES

LIST OF APPENDICES

ABSTRACT

The reproductive biology of the endemic ‘large’ *Barbus* (renamed *Labeobarbus*) species was studied from December 2003 to November 2004 in Dirma and Megech affluent rivers of Lake Tana. Fish and other environmental parameters were sampled monthly from November to June, bimonthly in July and weekly from August to October at the river mouths. Similarly, the spawning migration to upstream reaches of these rivers was monitored weekly in the peak breeding season (August to October) using 6, 8, 10, 12 stretched mesh size multi-filament and multi-mesh monofilament gillnets, fykes, local basket traps and hook-and-line fishing gears. Samples of fish caught were identified, measured, weighed, dissected and sexed. Changes in mean gonado-somatic index, Fulton’s condition factor and relative abundance of each particular *Labeobarbus* species were analyzed seasonally. Peak spawning generally occurred from August to October. Six species (*L. brevicephalus*, *L. intermedius*, *L. megastoma*, *L. tsanensis*, *L. truttiformis* and *L. surkis*) formed aggregation in the river mouths. The first species to congregate was *L. megastoma*, followed by *L. tsanensis* and *L. truttiformis* and the final were *L. brevicephalus* and *L. surkis*. Macro-spatial segregation among these species between the two river mouths did not occur, however, except *L. intermedius*, temporal segregation was apparent in the river mouths in the spawning season. All these species, except *L. surkis*, that congregate in the river mouths ascend to upstream reaches of the rivers. This spawning run showed sequential patterns of segregation among the migrating *Labeobarbus* species. *L. truttiformis* and *L. tsanensis* were the first to migrate up rivers and *L. megastoma* just run next to them, however, *L. brevicephalus* was the last in the sequence of migration. Excluding the running (egg shedding) individuals, mean absolute fecundity and egg diameter of *L. truttiformis*, 4563 eggs and 1.99 mm, respectively, were higher than *L. brevicephalus* (2421 eggs and 1.97 mm) but their relative fecundity remained the same. The relationships of absolute fecundity with fork length, body weight, and gonad weight were curvilinear. Length-weight relationships were curvilinear and in agreement with the cube law. Based on the results obtained in this study and previous investigations in other affluent rivers, the Lake Tana *Labeobarbus* spawning strategies are hypothetically categorized into three: (1) obligate riverine spawners (*L. brevicephalus*, *L. tsanensis*, *L.truttiformis*), (2) generalists (spawning in the rivers and in Lake Tana) (*L. acutirostris*, *L. intermedius*, *L. macrophtalmus*, *L. megastoma*, and *L. platydorsus*), and (3) lacustrine spawners (*L. crassibarbis*, *L. dainellii*, *L. gorgorensis*, *L. gorguari*, *L. longissimus*, *L. nedgia*, and *L. surkis*). Generalists and lacustrine spawners most probably spawn in the littoral and adjacent floodplains of Fogera and Dembea; however, their actual breeding ground should be investigated to implement sound management options. To sustain the riverine *Labeobarbus* spawners, closing the gillnet fishery from August to October in the rivers and river mouths is believed to be necessary.

Keywords: endemic, fecundity, *Labeobarbus*, Lake Tana, reproduction, spawning migration

Bini (1940) identified 10 species and 23 subspecies; Banister (1973) lumped all the *Barbus* of Lake Tana into one subspecies: *Barbus intermedius intermedius* Rüppell, 1936 (Nagelkerke *et al*., 1994, ref. therein). Mina *et al*., (1996a) and Dgebuadze *et al.* (1999) have suggested that the Lake Tana *Labeobarbus* constitutes a combination of some distinct species and several phenotypically plastic species. The latest taxonomic revision was done by Nagelkerke (1997) and Nagelkerke and Sibbing (2000), which revealed 15, biologically distinct, *Labeobarbus* species that form a species flock.

A species flock is a group of closely related fish species all circumscribed in the same ecosystem. In a strict sense, the species must have monophyletic origin (Greenwood, 1984). The clear reflection is that a species flock evolved within the ecosystem from a single ancestral species by repeated speciation events. For an assemblage to be a species flock, theoretically it should be possible to have one or more synapomorphs (shared derived characters) in all the flock members of the fish but not in relatives outside the flock.

The cumulative evidence for the species status of Lake Tana *Labeobarbus* include: morphology (Nagelkerke *et al*., 1994; Nagelkerke *et al*., 1995a; Mina *et al*., 1996a,b, Nagelkerke and Sibbing, 1998), ecology (Nagelkerke, 1997; de Graaf, 2003; Sibbing and Nagelkerke, 2001), reproductive characteristics (Nagelkerke and Sibbing, 1996; Alekseyev *et al*., 1996; Dgebuadze *et al*., 1999; Abebe Amha and Alemu Assefa, 2002; Palstra *et al*., 2004; de Graaf *et al*., 2005), and genetics (Golubtsov and Krysanov, 1993; Dixon *et al*., 1996; Berrebi and Valiushok, 1998). The *Labeobarbus* species flock most likely radiated sympatrically from the ancestral riverine barbs resembling *Labeobarbus intermedius*, which still is common in the tributary rivers and shore areas of Lake Tana (Nagelkerke *et al.,* 1994; Sibbing *et al*., 1998).

The radiation of the Lake Tana's *Labeobarbus* species is hypothesized to be driven by trophic resource partitioning (Nagelkerke, 1997; Sibbing *et al*. 1998). Diversification is achieved by evolving unique anatomical features particularly in their head and mouth structures. Sibbing and Nagelkerke (2001) distinguished five trophic groups based on gut content analyses and morphological predictions: zooplanktivore-insectivore (*L. brevicephalus),* molluscivore *(L. gorgorensis),* macrophytivore *(L. surkis),* four benthivore*s (L. crassibarbis, L. nedgia, L. tsanensis, L. intermedius),* and eight piscivores *(L. macrophthalmus, L. acutirostris, L. megastoma, L. longissimus, L. platydorsus, L. gorguari, L. dainellii, L. truttiformis*).

One of the most unusual aspects of the Lake Tana *Labeobarbus* species flock is the evolution of a large number (eight) of piscivorous species (de Graaf *et al*., 2000). It seems that cyprinids are not well designed for piscivory as they lack teeth in the oral jaws, stomach and low pH necessary to digest large prey. The reason why piscivores are common in Lake Tana is most probably the absence of other common African specialist piscivores (like Perciform fishes) as competitors. This absence allows the *Labeobarbus* of Lake Tana to use their potential for trophic diversification to the fullest (de Graaf *et al*., 2000; de Graaf, 2003). *Labeobarbus* species differ not only in their resource partitioning (feeding) but also in their reproductive strategies (de Graaf *et al*., 2005).

A fish at some time in its life must begin to allocate resources to reproduction if it needs to be represented in the next generation (Stearns, 1992). Every fish has its own suite of reproductive traits, which are determined by its genotype (Wootton, 1990). Genetic and environmental factors are important in shaping the reproductive ecology of fishes. The most important environmental factors probably include the harshness and variability of the abiotic factors, the availability of food for the parental fish and their offspring, the presence of predators on the parental fish and on the offspring and the level of dissolved oxygen (Lowe-McConnell, 1987; Wootton, 1990). The most favorable areas for fish feeding are not necessarily best for reproduction (Northcote, 1984). Hence, migration enables a fish to utilize different habitats.

According to Rodriguez-Ruiz and Granado-Lorencio (1992), migration of fish refers to a displacement between two or more habitats, commonly between feeding and reproduction habitats, with a regular periodicity (sometimes annually) and involving a large fraction of a population. Migration could also be a response to environmental adversity (Northcote, 1975; Thorpe, 1988). Control of the timing of migration to rivers depends on interaction between the internal physiological state of the fish and external triggering factors in the environment (Northcot*e et al.,* 1970). The external triggering factors include mostly moon phase, photoperiod, river flow, water temperature, turbidity, and water volume.

Gonad maturation is endogenously regulated but environmentally synchronized, in the temperate region, most probably by the rate of photoperiod change (Thorpe, 1988). However, most tropical freshwater fishes spawn seasonally during the rainy period (Lowe-McConnell, 1975; Payne, 1986). This certainly applies to tropical cyprinids, which lack parental care, viviparity and adaptations for aestivation. Exceptions, however, do occur and a species may spawn throughout the year (*B. magdalenae*: Welcomme, 1969; *B. lorenzi*: Loiselle and Welcomme, 1971) or even be confined to the dry season (*B. melanampyx*: Harikumar *et al*., 1994).

In general many cyprinids are riverine fishes in their origin, which have secondarily adapted to lakes. Nevertheless, most of these species still migrate upstream to spawn in tributary rivers (Skelton *et al*., 1991). This is the best indication that they are not fully adapted to the lake environment. From the studies conducted in four tributary rivers (Gelgel Abbay, Gelda, Gumara, and Rib), this ancestral (riverine) reproductive strategy is found to be a characteristic for at least seven *(L. acutirostris, L. brevicephalus, L. macrophthalmus, L. megastoma, L. platydorsus, L.*

truttiformis, and *L. tsanensis*) of the 15 *Labeobarbus* species of Lake Tana. The remaining eight 'missing' *Labeobarbus* spp. (*L. dainelli, L. surkis, L. gorgorensis, L. crassibarbis, L. gorguari, L. nedgia, L. longissimus, L. intermedius*) might possibly migrate and spawn in other inflowing rivers (Dirma, Megech, and Arno-Garno), or maybe even within the lake itself (lacustrine spawning) (Nagelkerke and Sibbing, 1996; Palstra *et al*., 2004; de Graaf *et al.,* 2005).

The riverine spawners of *Labeobarbus* species ascend 30 to 40 km upstream Gumara River from August to October. They spawn in fast flowing, shallow, and well-oxygenated gravel beds of small tributaries of the river, and possibly in the main channel (Palstra *et al*., 2004). The migration pattern of Lake Tana's riverine spawners *Labeobarbus* species is partitioned into three major phases:

(1) migrating from the foraging area of the lake to affluent river mouths;
(2) migrating upstream in the rivers' main channels; and
(3) entering a tributary for spawning after sunset.

Heavy rainfall usually starts in May and peaks in July and August in the Lake Tana area (Tesfaye Wudneh, 1998; Eshete Dejen, 2003; Fig. 3.2). During this time the tributary rivers increase in volume and cause massive soil erosion (Birhanu Teshale *et al*., 2002). As a result of the inflow of sediment and dissolved organic compounds, turbidity, increased water level, or a combination of both is hypothesized to serve as environmental cues to trigger spawning migration of *Labeobarbus* species to river mouths (Sibbing *et al*., 1998).

Unlike other cyprinids that spawn at different times of the day, *Labeobarbus* are nocturnal spawners (Alekseyev *et al*., 1996; de Graaf *et al*, 2005). This is most probably due to: (1) the late afternoon rains causing a rapid rise in tributaries' water level and (2) the low risk of predation in shallow waters at night (Dgebuadze *et al.,* 1999).

Most large cyprinids of Africa spawn by making a single annual breeding migration to upstream areas of rivers (Lowe-McConnell, 1975; Tômasson *et al.,* 1984). Most cyprinids occur primarily in rivers, however, some large *Barbus* and *Labeobarbus* species are adapted to the lacustrine environment (Skelton *et al*., 1991). These lake-adapted cyprinids congregate in the river mouths during spawning. This makes them highly vulnerable for modern fisheries (Ogutu-Ohwayo, 1990). Unregulated modern fishing has proven to have severe impact on the stocks of lake-dwelling riverine spawning cyprinids. Gill nets are set near river mouths and effectively block upstream migrations.

Until the end of the 1980s, fishing on Lake Tana was subsistence reed boat fishery. In 1986 motorized boats and nylon gill nets were introduced as part of the Lake Tana Fisheries Resource Development Programme (LTFRDP), which was initiated by the Ethiopian Ministry of Agriculture, the Ethiopian Orthodox Church, and two Dutch NGOs (ISE-URK and ICCO-Zeist (Tesfaye Wudneh, 1998). This opened 'good' opportunities for the fishermen, extending their fishing areas to offshore waters and distant river mouths.

The total annual catches increased from 39 MT in 1987 to 360 MT in 1997 (Tesfaye Wudneh, 1998). The catches roughly consisted of one third *Labeobarbus* spp., one third *O. niloticus* and one-third *C. gariepinus* (LFDP, 1995). The commercial gillnet fishery on *Labeobarbus* is, however, highly seasonal as more than 50% of the annual catch is obtained in the river mouths during August and September (Tesfaye Wudneh, 1998; Nagelkerke *et al.*, 1995b). Catch per unit effort (CpUE) of the *Labeobarbus* species from the commercial gill net fishery drastically dropped down from 63 kg/trip in 1991 to 28 kg/trip in 2001 (de Graaf *et al.,* 2004). De Graaf *et al.*(2004) has reported about 75% decline (in biomass) and 80% (in number) of *L. acutirostris, L.*

macrophtalmus, L. platydorsus, L. brevicephalus, L. tsanensis, L. intermedius in the southern gulf of Lake Tana. This calls for an urgent measure to be taken to conserve this endemic *Labeobarbus* species flock.

The most plausible explanation for the decline of the stock is not natural environmental destruction but recruitment overfishing by the commercial gill net fishery (de Graaf *et al.,* 2004) and poisoning of the spawning stock in rivers using the crushed seeds of birbira (*Milletia ferruginea*) (Nagelkerke *et al*., 1996; Abebe Amha, 2004). The most simple, effective, easily controlled management measure to protect the spawning stock of *Labeobarbus* populations and to ensure future recruitment is the restriction of fishing efforts on the spawning stock (Reyntjes *et al.,* 1998; de Graaf *et al*., 2004). Therefore, the spawning place and time (season) of each *Labeobarbus* species should be investigated in detail in order to conserve the endemic species flock.

Generally, studies on Lake Tana are highly polarized to the southern gulf of the lake. The northern part of the lake is, however, highly marginalized due to environmental and logistic problems. Such local circumstances prevented extensive sampling in time and space important in studying reproductive segregation of fishes in the field. Scientific data on the biology of fishes on this larger part of the lake is extremely important to the sustainable utilization of the lake's fishery resources. Particularly lack of information on the spawning migration of *Labeobarbus* species to tributary rivers, Dirma and Megech, hinders the rational exploitation of this unique species flock.

2. Objectives

2.1 General Objective

The general objective of the present study was to collect baseline reproductive data important for rational utilization and management of the fishery of Lake Tana.

2.2 specific objectives

i) To identify which species of *Labeobarbus* spawn in Megech and/or Dirma Rivers.

ii) To investigate the patterns of spatial and/or temporal segregations of *Labeobarbus* species of Lake Tana in their spawning migration to Megech and Dirma tributary rivers.

iii) To assess the spawning season (s) of each *Labeobarbus* species of Lake Tana that migrates to Megech and Dirma Rivers.

iv) To study length-weight relationship, length at first maturity and Fulton's condition factor for some *Labeobarbus* species from Lake Tana.

v) To estimate fecundities of *L. brevicephalus* and *L. truttiformis*.

3. Materials and Methods

3.1 Study Area

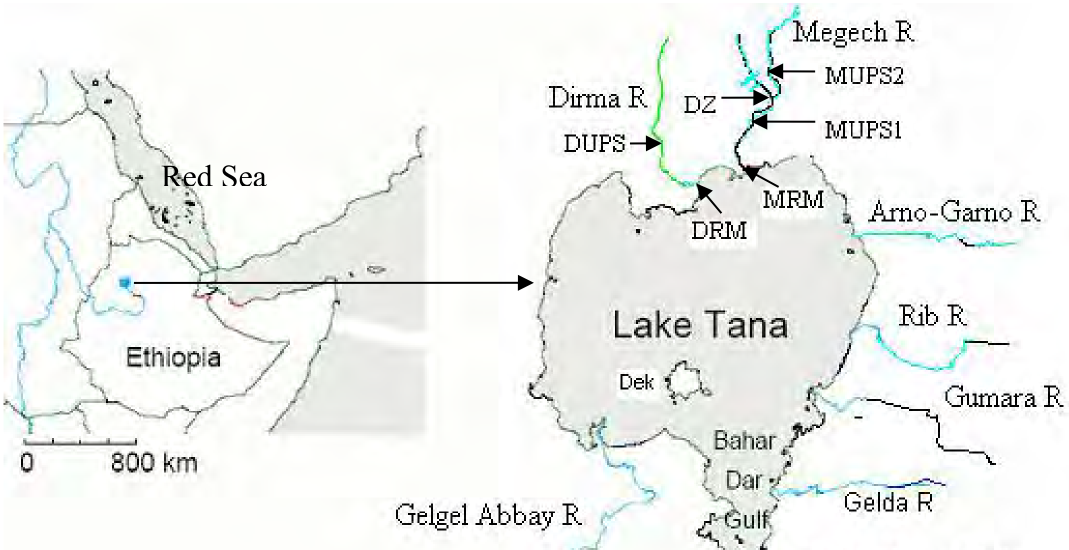
3.1.1 Description of the Lake and its catchments area

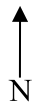
Lake Tana, the headwater of the Blue Nile River, is located in the northwestern highlands of Ethiopia (at an elevation of 1830 m). The lake has an area of about 3200 km^2 and it is the largest water body in the country. It is an oligo-mesotrophic shallow lake with an average depth of 8 m and maximum depth of 14 m. The lake is turbid, well-mixed and has no thermocline (Eshete Dejen *et al*., 2004). Fogera (on the east) and Dembea (on the north) plains border major parts of Lake Tana, and they are considered to be the buffering zones of the lake (Nagelkerke, 1997). The lake is believed to have originated two million years ago by volcanic blocking of the Blue Nile River (Mohr, 1962). It assumed its present shape through blocking of a 50 km long quaternary basalt flow, which filled the exit channel of the Blue Nile River (Chorowicz *et al*., 1998). However, there are strong evidences that Lake Tana had dried up between 16000 and 50000 years ago (Lamb *et al*., 2004).

Ta ble 3.1 Physical and chemical features of Lake Tana**.**

Physical or chemical feature	**Value**	**Reference**
Max. length	78 km	Rzoska, 1976

Max. width	67 km	Rzoska, 1976
Volume	28 km^3	Wood and Talling, 1988
Shoreline	385 km	Rzoska, 1976
Catchment area	16500 km^2	Rzoska, 1976
Temperature	20.2-26.9 ^{0}c	Eshete Dejen *et al*., 2004
TDS	163.6 mgl^{-1}	Eshete Dejen *et al*., 2004
pH	6.8-8.3	Eshete Dejen *et al*., 2004
Conductivity	132.8 µS.cm^{-1}	Eshete Dejen *et al*., 2004
Turbidity (NTU)	23.2	Eshete Dejen *et al*., 2004
Chlorophyll a	6.4 µgl^{-1}	Eshete Dejen *et al*., 2004
Alkalinity (meq l^{-1})	1.70	Wood and Talling, 1988
Salinity (g l^{-1})	0.143	Wood and Talling, 1988





KEYS FOR SAMPLING SITES

DRM = Dirma River Mouth
DUPS = Dirma Upstream
DZ = Dimaza River
MRM = Megech RM
MUPS1 = Megech Upstream1
MUPS2 = Megech Upstream2

Figure 3.1 Lake Tana and the sampling stations (reproduced from Palstra *et al*., 2004).

The area around Lake Tana is characterized by a tropical highland climate type which has a moderate temperature due to its altitude (Nagelkerke, 1997). Climatic conditions, however, are strongly pulsed (de Graaf *et al.,* 2004; Nagelkerke, 1997) and dominated by the dry season (November to May), and a rainy season (June to October) with heavy rains (Fig. 3.2). Sometimes, however, there is a minor rain during February and March (Eshete Dejen *et al*., 2004). During 2004 monthly rainfall data ranged from 1.4-378.6 mm and it was maximum in July (Fig. 3.2) in the northern part of Lake Tana area. The maximum mean monthly air temperature in the study period ranged from 31.3 (March) to 23.2^{o}C (July) (Fig. 3.2). The lake's water level regularly increases with such heavy rains, up to 1.44 m (de Graaf *et al*., 2004). Besides increasing the water level, the heavy rainfall also causes excessive siltation (Birhanu Teshale *et al*., 2002). The silt introduction increases the turbidity of the lake water (Eshete Dejen *et al*., 2004). Most of the silt is introduced through perennial and ephemeral rivers of the lake.

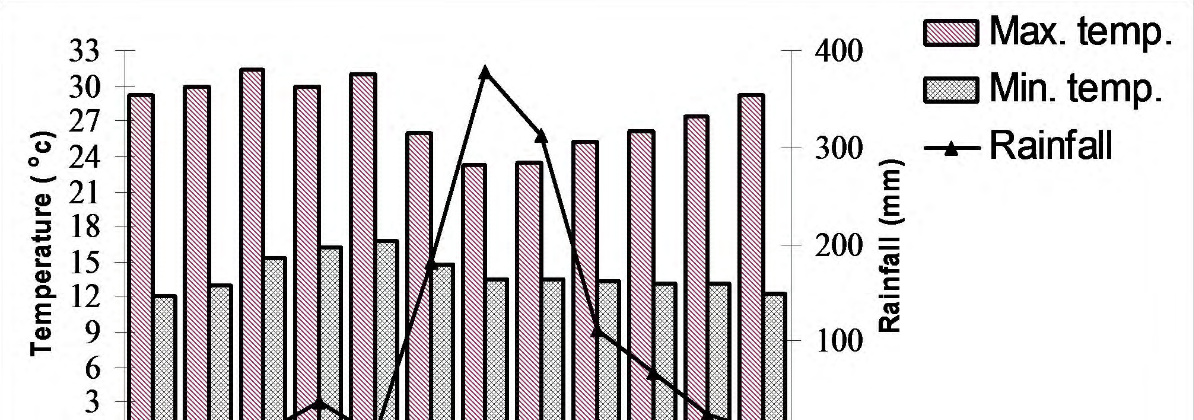


Figure 3.2 Mean monthly maximum and minimum temperature and total rainfall per month in North Gondar during 2003 December to 2004 November (data, North Gondar station, from National Meteorology office, Addis Ababa).

The catchment area of Lake Tana (16,500 km^2) has a dendritic type of drainage network (Tekalign *et al*., 1993 in Eshete Dejen, 2003). Seven big perennial rivers flow into Lake Tana: Gelgel Abbay, Gelda, Gumara, Rib, Arno-Garno, Megech and Dirma (Fig. 3.1). However, the only outflowing river from Lake Tana is the Blue Nile. Although the lake is the source of the Blue Nile, the lake's ichthyofauna is completely isolated from the lower Nile basin by 40 m high waterfalls, down 30 km from the Blue Nile outflow (Fig. 3.1).

Megech and Dirma Rivers are located in the northern part of the lake. Megech originates near the Semien Mountains National Park at an altitude of about 3500 to 4000 m.a.s.l. and it has a length of about 80 to 90 km. During the rainy season, Megech is on average about 10-15 m wide and 1.5-2.50 m deep in our upstream sampling reaches. The bed of the main channel of the river in the lotic habitat is characterized by bedrock, boulders, pebbles and gravel beds. However, about 30 km the river flows through the alluvial and lacustrine Dembea plain deposits until it joins Lake Tana which has muddy mouth. The local inhabitants tell that 15 years ago the river used to join the lake about 5 km west of the current river mouth (pers. com). About 3 km upstream from the bridge (main asphalt road to Gondar town), a small temporary river, Dimaza, joins Megech (Fig. 3.1). Dimaza River, starting from its mouth to Azezo town and upper, flows over of pebble and gravel beds. It is the first tributary of Megech with gravel beds as the other streams in the Dembea plain are muddy. The stream has clear waterfalls (3 m high) about 2 km upstream, which completely blocks *Labeobarbus* migration further upstream. Another seasonal tributary river, Keha flows through Gondar town and joins Megech about 10 km upper Dimaza's river mouth.

Dirma, smaller than Megech River, originates at about an altitude between 2500 and 3000 m and has a length of approximately 60-65 km. In the rainy season the river has a width of about 8-10 m and a depth of about 0.5-1.5 m at our sampling sites (Fig. 3.1). Starting from the bridge at Kola Diba, the river's upstream substratum, like Megech, is covered with boulders, pebbles and gravel beds. However, downstream from Kola Diba town, the river runs slowly through the alluvial Dembea plain until it joins Lake Tana. Aynekura, about 6 km upper from our sampling site, is the only seasonal tributary to Dirma with a gravel bed.

During the dry season (from last February to the first week of June 2004), both rivers completely dried at their mouths due to excess water extraction for irrigation by the local farmers. Nearly all stretches of the river banks of both rivers were subjected to crop farming. This problem is particularly severe in the Dirma River, as it was almost completely dry or reduced to pools for extended periods of time. During the spawning season, both rivers recovered in volume due to the heavy rains in the area.

3.1.2 Flora and Fauna

The most dominant phytoplankton in Lake Tana are the genera: *Melosira, Surirella* and *Synedra* (Wood and Talling, 1988). *Microcystis* and *Anabaena* species are also abundant blue-green algae. The green algae (Chlorophyta) are less abundant, however, *Pediastrum*, *Staurastrum*, and *Volvox* are common (Gasse, 1987 in Nagelkerke, 1997). In the rainy season both Dirma and Megech River mouths were covered by dense macrophytes such as *Typha, Phragmites* and many grasses (Fig. 3.3). *Cyperus papyrus*, which is common in Gumara and Gelda River mouths (Nagelkerke and Sibbing, 1996) was absent in Dirma and Megech River mouths. The upper regions of the rivers have patches of shrubs and a few big indigenous and the introduced Eucalyptus trees. The catchment areas of most of the lower parts of both rivers (in the Dembea plain) that are usually inundated by floods during the rainy season are swampy and covered by grasses.

The zooplankton community of Lake Tana contains 13 species (Eshete Dejen *et al*., 2004). Copepods and Cladocerans have nearly equal contribution in their relative abundance (Table 3.2). The calanoid copepod subspecies *Thermodiaptomus galebi lacustris*, the dominant zooplankton in the lake, is endemic to Lake Tana (Tesfaye Wudneh, 1998; Eshete Dejen *et al*., 2004, Ayalew Wondie, unpublished). Bivalves, midges (e.g. *Chironomidae*), different species of annelids, and various Ephemeroptera, Plecoptera species are also abundant in the river mouths of the lake (Pers. obs.; Dereje Tewabe, unpublished).

Table 3.2 Zooplankton species found in Lake Tana with their mean relative abundance (n, %) (N = 124; three habitats, four seasons) (Source: Eshete Dejen *et al.*, 2004).

Species	Relative Abundance (%)
Copepoda	
Mesocyclops aequatorialis similis	4.2
Microcyclops varicans	<0.1
Thermocyclops ethiopiensis	15.2
Thermodiaptomus galebi lacustris	31.2
Cladocera	
Bosmina logirostris	13.9
Ceriodaphnia cornuta	0.3
Ceriodaphnia dubia	1.4
Chydorus sphaericus	<0.1
Daphnia hyalina	9.1
Daphnia lumholtzi	8.1
Diaphanosoma excisum	3.3
Diaphanosoma sarsi	10.8
Moina micrura	2.5

The Nile monitor (*Varanus niloticus*) is the most frequently encountered and largest reptile in the lake. Crocodiles are absent in the rivers and in the lake we sampled. However, the most common vertebrates at the river mouths are various species of birds. The piscivorous birds include: the great white pelican (*Pelecanus onocrotalus*), great and long-tailed cormorants (*Phalacrocorax carbo* and *P. africanus*), Hammerkop (*Scopus umbretta*) and the African fish eagle (*Haliacetus vocifer*). The non-piscivorous birds are: Egyptian goose (*Alopochen aegytiaca*), pygmy goose (*Nettapus auritus*), and spur-winged goose (*Plectropterus gambensis*) (Nagelkerke, 1997; pers.

obs.). The only mammal we observed in the lake is the common hippopotamus (*Hippopotamus amphibious*).

As described by Greenwood (1976) Lake Tana has a truncated fish community. In 1938, during the Italian colonialist occupation, two species of fish were introduced, *Esox lucius*, for lake stocking, and *Gambusia holbrooki*, for mosquito control. However, this introduction was not successful as these species of fish are apparently absent in the lake (Nagelkerke, 1997). The other obscured species in Lake Tana is *Nemacheilus abyssinicus* (Balitoridae). A single specimen of 40 mm was recorded in the lake (Beadle, 1981), but in 1993 it was caught in small streams close to Lake Tana (Dgebuadze *et al*., 1994). Only one specimen was caught by Nagelkerke (1997) at a depth of 14 m in Lake Tana. Two families, Cichlidae and Claridae, are represented by a single species each: *Oreochromis niloticus* and *Clarias gariepinus*, respectively. The family *Cyprinidae* is the largest in the lake and represented by four genera: *Barbus*, *Garra*, *Labeobarbus* and *Varicorhinus* (Nagelkerke and Sibbing, 2000). The genus *Varicorhinus* has only one species in the lake, *V. beso*. Although the taxonomic position of *Garra* spp. is still unclear, recently, Abebe Getahun (2000) described four species: *G. tana, G. microstoma, G. dembecha* and *G. dembensis* from the lake. The genus *Barbus* in Lake Tana is currently valid for three diploid small barb species: *B. humilis, B. pleurogramma,* and *B. tanapelagius* (Eshete Dejen, 2003). The genus *Labeobarbus*, previously classified as 'large' *Barbus*, now comprises 15 endemic species (Nagelkerke and Sibbing, 2000). These *Labeobarbus* species in Lake Tana, as far as available evidence is concerned, form the only intact species flock of large cyprinids. The other cyprinid species flock in Lake Lanao, Philippines, has already disappeared due to destructive anthropogenic activities (Kornfield and Carpenter, 1984).

3.2 Sampling sites, gear and fish collection

Fish were sampled monthly during the dry months (December 2003 to June 2004 and November 2004) from the river mouths of Dirma and Megech. In July 2004 samples were taken twice from each river mouth to check whether or not the *Labeobarbus* species start to aggregate.

Figure 3.3 Dirma River mouth with its dense macrophytes during the rainy season.

During the rainy season (August to October 2004), the frequency of sampling was increased and samples were taken every week at both river mouths. Polyfilament gill nets (6, 8, 10, and 12 cm stretched mesh size) with a panel length of 100 m and depth of 3 m were used in every sampling. During the spawning season (August to October) multi-mesh monofilament gill nets (type Norden from Lundgrens, Stockholm; 5, 6.25, 8, 10, 12.5, 15, 19.5, 24, 29, 35, 43, and 55 mm stretched mesh) with each mesh panel size of length 3 m and depth of 1.5 m, besides the polyfilament gill nets, were also used. These monofilament gill nets provide assurance that juvenile *Labeobarbus* could be captured; hence a reliable estimate of the minimum size of maturity could be calculated. Gill nets were set, within 400-600 m distance from the river mouths and at a depth of 3-4 m, overnight usually at 5:30 PM. Catches were collected in the following morning at about 7:00 AM.

Table 3.3 Sampling sites estimated distance from the mouth, gears used and Coordinates. Here onwards, DUPS, MUPS1 and MUPS2 refer to the sampling site codes in Figure 3.1 unless stated otherwise**.**

Site	Code	Distance	Gear Used	Coordinate (GPS)
Dirma river mouth	DRM	__	Gill nets	12^{0}15’40.8’’N; 37^{0} 15’ 43.9’’E
Megech river mouth	MRM	__	Gill nets	12^{0} 16’ 03.2’’N; 37^{0} 24’ 03.9’’E
Dirma upstream	DUPS	25km	Traps, Fyke, Gill net	12^{0} 26’ 26.1’’N; 37^{0} 20’ 13.9’’E
Megech upstream	MUPS1	28km	Traps, Fyke, Gill net, Hook and line	12^{0} 29’ 11.4’’N; 37^{0} 26’ 49.9’’E
	MUPS2	32km	Traps, Fyke, Gill net	12^{0} 29’ 48.3’’N; 37^{0} 27’ 19.3’’E
Dimaza	DZ	30km	Traps, Fyke, Gill net	12^{0} 29’ 24’’N; 37^{0} 26’ 53.3’’E

In order to see what fish species are available in the upstream river sampling sites during the dry and beginning of rainy seasons, fish samples were taken monthly from April to July 2004 in Megech River (MUPS2) by setting 6, 8, 10, and 12 cm stretched mesh size gillnets. It was impossible to sample fish in Dirma River during the dry season as it was nearly dry due to irrigation activities by local farmers. However, in the spawning season (August to October 2004), fish samples were taken every week at upstream sampling sites of both rivers and at one seasonal tributary, called Dimaza, of Megech River (Fig. 3.1). In the upstream sampling areas various fishing gears were employed for an overnight sampling: two fykes (polyfilament twine, bar mesh 5 mm, length 4 m, 8 compartments) and two locally-made basket traps (‘keffo’) of average bar mesh of 30 mm (Fig. 3.4) were used throughout the spawning months. Starting from the middle of September, in addition to fykes and local basket traps, a 25 m long and 1.5 m deep gill net with 6 cm stretched mesh sizes was set in all upstream sites. At the same time a 25 m long and 1.5 m deep gill net of 10 cm stretched mesh size was used at MUPS1 and DUPS (Fig. 3.1) to check the availability of big sized *Labeobarbus* species. To improve the sample size, fish were also purchased from local fishermen who used hook and line to capture fish.

(a) Fyke (b) Local basket trap ('keffo')

Figure 3.4 The two most commonly used (in our sampling) fishing gears in the rivers upstream reaches of Dirma and Megech.

Fish collected in the river mouths were transported fresh to the laboratory of Gorgora Fish and other Aquatic Life Research Sub Center (GFALRSC), whereas catches from upstream sites were preserved in jars of 4% formalin solution and transported to GFALRSC. Fish were classified to species level with the help of identification key developed by Nagelkerke *et al*. (1994) and experienced fish technical assistants at Bahir Dar and Gorgora Research Centers. In the laboratory fork length (0.1 cm), total weight (0.1 g), and gonad weight (0.01 g) of each specimen of *Labeobarbus* spp. were measured. Each fish was dissected, the gonads were examined visually and sexed. The gonad maturity stage of each *Labeobarbus* was determined according to Pet *et al.* (1996), modified from De Silva *et al*. (1985) (Table 3.4). Samples of eggs from some ripe females were taken for fecundity studies.

Table 3.4 Gonad maturity stages and descriptions for cyprinids by Pet *et al*. (1996), modified from De Silva *et al*. (1985) (Source: Nagelkerke, 1997).

Gonad stages	Male	Female
I	*Immature, impossible to distinguish females from males. Gonads are a pair of transparent strings running along the body cavity.*	*Immature, impossible to distinguish females from males. Gonads are a pair of transparent strings running along the body cavity.*
II	*Unambiguously male, very small testes, white-reddish, not lobed, tube-shaped strings*	*Unambiguously female, very small ovaries, tube shaped and reddish, eggs not visible.*
III	*Larger testes, white-reddish, some what lobed starting to flatten sideways*	*Ovary somewhat larger and starting to flatten sideways, eggs visible, but very small*
IV	*Large testes, white-reddish, lobed, flattened sideways*	*Larger ovary, flattened sideways and almost covering body cavity wall, eggs yellowish*
V	*Large, white testes, some sperm runs out when testis is cut*	*Larger and full ovary, completely covering body cavity wall, yellowish eggs run out when ovary is cut*
VI	*Large white testes, running, large amount of sperm runs out when testis is cut*	*Running, yellow eggs can be extruded by putting pressure on the abdomen*
VII	*Spent, empty testes, reddish and wrinkled*	*Spent, wrinkled ovary, reddish, containing a few yellow eggs*

3.3 Fecundity

Fecundity estimation for *L. brevicephalus* and *L. truttiformis* was carried out using the gravimetric method (MacGregor, 1957) by weighing all the eggs from each of the ovaries of gravid fish species (gonad maturity stage V ovaries). Females at running conditions (gonad maturation stage VI), distinguished by slightly pressing their abdomens to check for the release of eggs, were excluded from the fecundity estimation.

Samples of eggs were taken from different size classes of fish species on various ovary areas. These eggs were preserved using 4% formalin solution. To count the eggs and to measure ova diameter, the ovarian membranes were first removed mechanically using tap water from the preserved ovaries. After vigorous shaking, three sub samples of 1 g of eggs per ovary were counted and the total number of eggs per ovary was estimated by extrapolation. For random measurement of ova diameter, every 1g of eggs counted was poured into a Petri dish, calibrated by a grid every 5 mm. The water from the Petri dish was carefully but completely removed without disturbing the eggs distribution in the dish. Only those eggs which touched the grid lines, having a diameter of ≥1.25 mm, were measured to the nearest 0.05 mm using an ocular micrometer in a dissecting microscope. Because some few ova were not circular, average ovum diameter was taken by measuring the largest and smallest dimensions (Heins and Rabito, 1986).

3.4 Abiotic factors

In every sampling time and site, the oxygen content (mgl^{-1}), water temperature (^{o}C) (using Oxyguard portable probe), water transparency (Secchi-depth) (cm) (using Secchi disc) and pH (using pH meter) were measured. At the beginning of the spawning season measurements of conductivity (using a conductivity meter) and total dissolved solutes (TDS) (using a TDS meter) was tried. Unfortunately, after 3 or 4 samplings both instruments failed to function and the measurements were terminated.

3.5 Data Analyses

3.5.1 Size at Maturity

The average length at fist maturity ($FL_{50\%}$) can be defined as the mean length at which 50% of all individuals of a fish species become sexually mature (Willoughby and Tweddle, 1978). In practice, large samples of fish should be collected during the spawning season to correctly estimate the proportion of sexually mature individuals in different length classes (King, 1995). $FL_{50\%}$ of some *Labeobarbus* of Lake Tana was calculated using the gonad maturity stage information. Females and males with gonad development stage IV and higher were considered as sexually mature. Fish collected during the spawning season (August to October 2004) were used for FL_{50} analysis. The percentage of mature fish per length class with class width 2 cm was calculated and FL_{50} was estimated according to King (1995).

$$p_i = \frac{e^{(a+bFL_i)}}{(1+e^{(a+bFL_i)})}$$

Where Pi = estimated proportion of mature fish, FL = fork length (cm), a and b = coefficients of the regression. This equation can be transformed into logarithmic form:

$$\frac{\ln Pi}{(1-Pi)} = \text{a + bFLi}$$

To estimate the values of the constants (a and b), linear regression was performed in which $\frac{\ln pi}{(1-pi)}$ was taken as the dependent variable and FL as the independent variable.

According to the sigmoid curve ($FL_{50\%}$) can be estimated by:

$$FL_{50\%} = \frac{a}{-b}$$

3.5.2 Gonado-Somatic Index (GSI)

Gonado-somatic index is defined as the weight of the gonad expressed as a percentage of the somatic body weight. The graphs of the mean monthly GSI against months has been used to determine the period and frequency of spawning of the species during the year (Bagenal, 1978). The percentage of GSI was calculated from the gonad weight (g) and body weight (g) using the following formula:

$$GSI(\%) = \frac{gonad \quad weight}{total\ weight - gonad\ weight} x100$$

Mean monthly GSI for mature fish ($FL_{50\%}$ and higher, for a species whose $FL_{50\%}$ is determined otherwise FLmin) was used for calculation as immature fish are not expected to show temporal variation in their monthly GSI.

3.5.3 Abundance of fish in the river mouths

First the species of *Labeobarbus* aggregated in the river mouths, during the peak breeding season (assessed mainly based on GSI calculated values), was determined. Those *Labeobarbus* species that were rare in both river mouths (pooled) were left out of analysis of spatial and temporal spawning segregations. To see the statistically significance difference in abundance during the peak breeding season (three months) and non-breeding season (nine months), Mann-Whitney U test was employed. Presence or absence of Spatial and temporal segregation patterns of *Labeobarbus* species in Dirma and Megech River mouths during the spawning period and significant differences in absolute fecundities as well as ova diameters between *L. brevicephalus* and *L. truttiformis* were tested by one-way ANOVA (Sokal and Rohlf, 1981). Comparison of temporal and spatial differences in the frequency of occurrence among *Labeobarbus* species in the upstream sites of the rivers were made using x^2 r X c contingency tables. Specimens from hook and line and 10 cm stretched mesh size multifilament gillnet (set at DUPS and MUPS1) were excluded in the determination of relative abundance, spatial and temporal segregation analyses. Statistically significant differences ($p<0.05$) indicate segregation in area or time. Sex ratios were determined by using chi-square (x^2).

3. 5. 4 Length-weight relationship and Fulton's condition factor

Length-weight relationship of *Labeobarbus* species of Lake Tana was computed using least square regression analysis of $TW = aFL^b$ (Bagenal and Tesch, 1978), where, TW = total weight (g), FL = fork length, a is the intercept, and b is the slope of the regression line. Fulton's condition factor (K) for each species was calculated as total weight in percent of fork length cube ($K = \frac{TW100}{FL^3}$) (Bagenal and Tesch, 1978). Mann-Whitney U test was used to test FCF significance differences between Peak and non-peak spawning seasons for each species. For statistical data analysis SPSS for windows software (Version 10) was used. Index of relative importance (by biomass and number) was determined by Pasgear software (Version 2000).

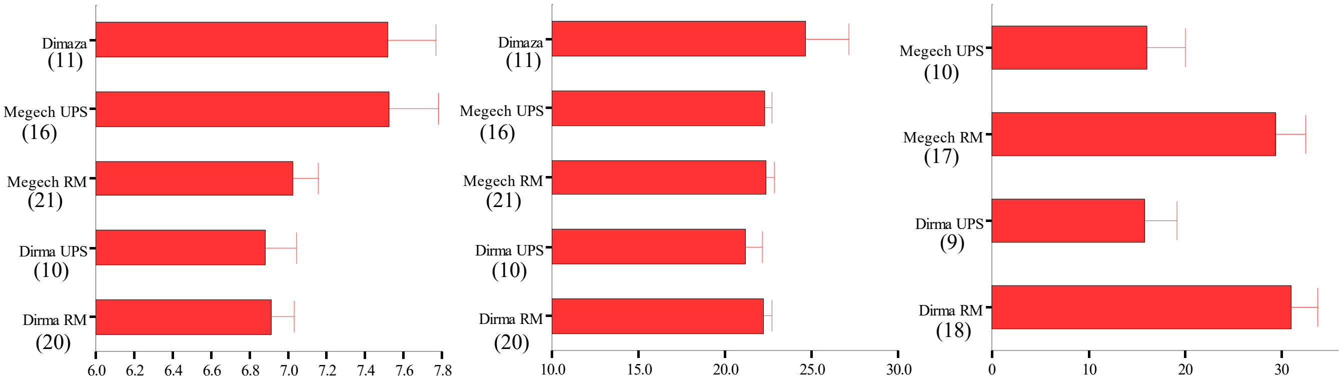
4. Result

4.1. Physical (abiotic) parameters

Environmental factors such as dissolved oxygen, temperature, vertical transparency (Secchi depth) were compared among sampling sites (Table 4.2). There was no significant difference ($P>0.05$) in all of these factors between the two river mouths (Dirma and Megech). In upstream river sites, these factors didn't show significant variation ($P>0.05$) except oxygen (Table 4.2, Fig. 4.1). Nevertheless, dissolved oxygen at Megech and Dimaza (7.52 ± 0.73 SE, 7.51 ± 0.44 SE, respectively) was higher and statistically different ($P<0.05$) from other sampling sites. Mean temperature was highest at Dimaza (24.63 ± 2.5 SE) as it had smaller volume of water during the sampling period. Vertical transparency (Secchi depth) didn't show significant variation ($P>0.05$) between the two river mouths, however, it was very low in the upstream areas and showed significant variation ($P<0.05$) when compared with the river mouths (Table 4.2). Secchi depth in the rivers was measured during the rainy season and measurement at Dimaza was impossible as it was too shallow. The pH of the rivers and the river mouths was similar ($P>0.05$) although the upstream river sites seem slightly alkaline.

Table 4.1 Abiotic parameters in the river mouths and upstream areas with their means ± SE, and months of minimum (min) and maximum (max) values.

Site	**Oxygen (mgl^{-1})**			**Temperature (^{0}C)**			**Secchi depth (cm)**			**pH**		
	Mean ± SE	**Month**		Mean ± SE	**Month**		Mean ± SE	**Month**		Mean ± SE	**Month**	
		Min	Max		Min	Max		Min	Max		Min	Max
Dirma RM	6.90 ± 0.42	Jul	Feb	22.20 ± 0.5	Oct	May	30.42 ± 3.0	Jul	Mar	7.75 ± 0.2	Sep	Jan
Megech RM	6.92 ± 0.52	Jul	Feb	22.32 ± 0.5	Jan	Apr	29.46 ± 3.0	Jul	Apr	7.61 ± 0.1	Aug	Mar
Dirma	6.87 ± 0.40	Jul	Dec	21.18 ± 0.9	Dec	Jun	15.75 ± 3.3	Jul	Sep	7.82 ± 0.2	Jul	Dec
Megech	7.52 ± 0.73	May	Dec	22.29 ± 0.4	Apr	Jun	16 ± 4.01	Jul	May	7.87 ± 0.3	Jul	Dec
Dimaza	7.51 ± 0.44			24.63 ± 2.5						7.65 ± 0.2		



(a) Oxygen (mgl^{-1}) **(b)** Temperature (^{0}C) **(c)** Secchi Depth (cm)

Figure 4.1 (a) Average monthly oxygen (mgl^{-1}), **(b)** Temperature (^{0}C) and **(c)** Secchi depth (cm) in the sampling sites. Numbers in brackets indicate number of measurements taken.

Table 4.2 Pairwise comparison of abiotic parameters (Oxygen, Temperature, pH and Secchi depth) between sampling sites using Mann-Whitney U test at 0.05 degree of significance. O = Oxygen, T = Temperature, S = Secchi depth.

	Dirma RM	**Megech RM**	**Megech ups**	**Dirma ups**	**Dimaza**
Dirma RM	**X**				
Megech RM	O = 0.734 T = 0.707 S = 0.644 pH =0.73	**X**			
Megech ups	O = 0.028 (*) T = 0.699 S = 0.023(*) pH = 0.54	O = 0.043(*) T = 0.877 S = 0.048 (*) pH = 0.29	**X**		
Dirma ups	O = 0.888 T = 0.281 S = 0.021(*) pH = 0.57	O = 0.840 T = 349 S = 0.049 (*) pH = 0.39	O = 0.033 (*) T = 0.301 S = 0.806 pH = 0.89	**X**	
Dimaza	O = 0.041(*) T = 0.386 pH = 0.89	O = 0.049(*) T = 0.248 pH = 0.99	O = 0.683 T = 0.413 pH = 0.54	O = 0.037 (*) T = 0.302 pH = 0.61	**X**

(*) Significant difference ($P<0.05$)

4.2 Species composition in the river mouths and upstream areas

A total of 7056 fish specimens were collected over one year period (December 2003 to November 2004) from all sampling sites. The 14 species of the genus *Labeobarbus* captured in the samples contributed 70.6% of the total catch in number. However, during the peak-spawning season (determined mainly from GSI calculated, Fig. 4.4), August to October, its catch was increased to 83%. Six species of *Labeobarbus* (Table 4.3) contributed more than 95% of the total catch of the genus in the river mouths during the spawning season. From the overall gillnet labeobarbs catch over the year in the river mouths, *L. intermedius* constituted about 42 % by number. In the peak spawning season *L. brevicephalus* was the second most abundant species in the catch. Except *L. megastoma*, all the six labeobarbs species, which aggregated in the river mouths, showed significant variation ($P<0.05$) in their mean abundance in their peak and non-peak breeding seasons (Table 4.3). Other species which were rare in the river mouths include: *L. acutirostris* (1.1 ± 0.6 SE), *L. crassibarbis* (1.25 ± 0.76 SE), *L. gorgorensis* (0.50 ± 0.46 SE), *L. longissimus* (0.6 ± 1.01 SE), *L. macrophtalmus* (0.42 ± 0.3 SE), *L. nedgia* (0.30 ± 0.3 SE) *and L. platydorsus* (0.8 ± 0.88 SE). Only two specimens of *L. dainellii* and no specimen of *L. gorguari* were caught over the year round samples. The other fish species captured in our samples include: *O. niloticus* (14.9%), *C. gariepinus* (13.8%), *V. beso* (0.8%) and *Garra* species (0.7%).

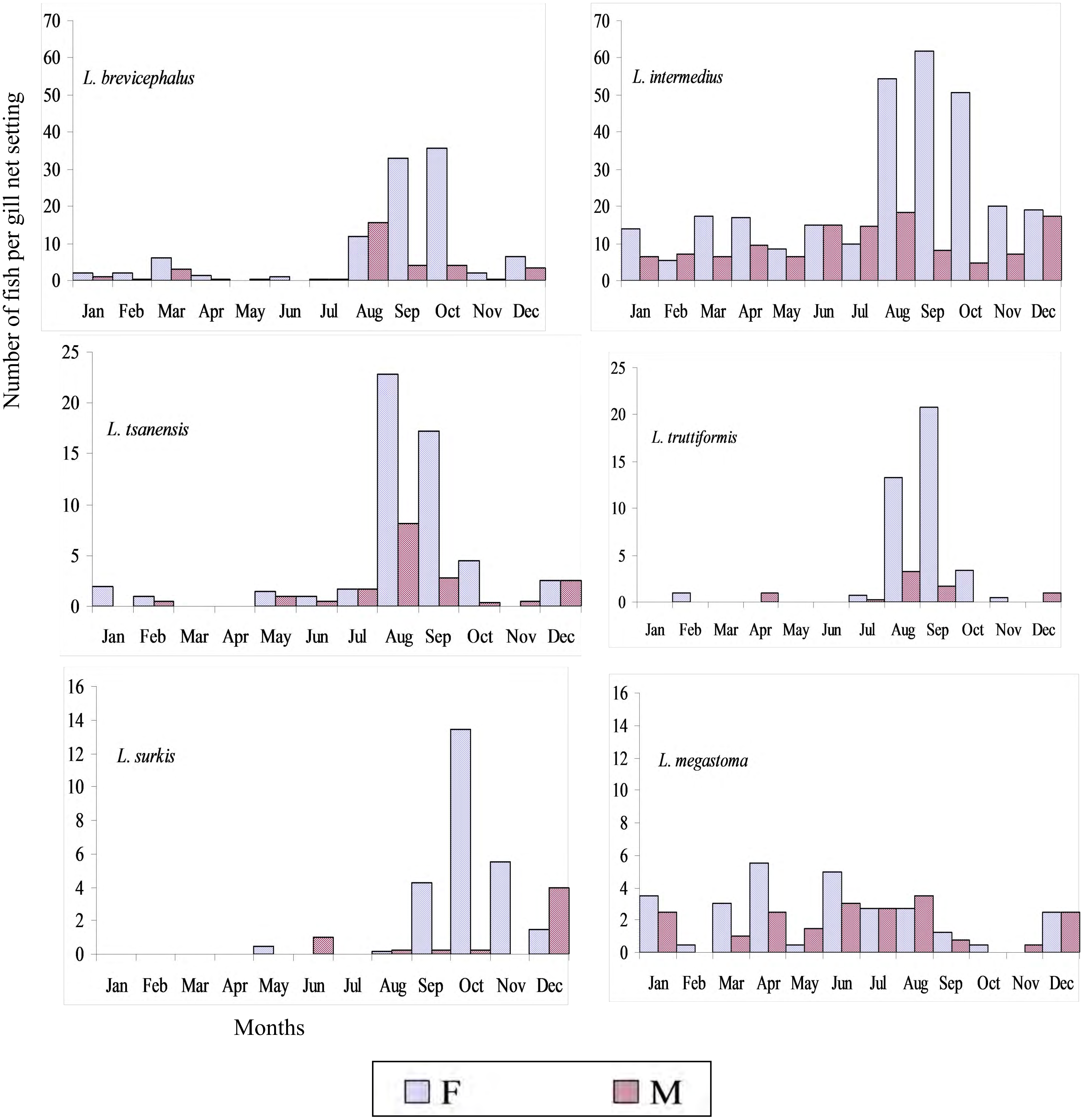


Figure 4.2 Abundance of *Labeobarbus* species (number of fish per sampling night) in Dirma and Megech River mouths (monthly catch in the river mouths pooled) over the year. Number of overnight gillnet settings, November-June, n = 16; July, n = 4; August-October, n = 24. Note the different Y-scales.

A total of 703 fish specimens of *Labeobarbus* were collected in the upstream areas (Appendix F). Most *Labeobarbus* species that were abundant in the river mouths were also numerous in the river upstream areas. The only difference was, instead of *L. surkis*, *L. nedgia* was more abundant in the upstream areas. In May 2004 samples, an immature *L. nedgia* was caught at Megech river upstream pools while it was dry at the mouth and totally disconnected from the lake. These six species (Table 4.4) contributed about 98.5% of the total *Labeobarbus* catch. The rest *Labeobarbus* species collected in the rivers include: *L. crassibarbis* (0.43%), *L. longissimus* (0.58%), *L. surkis* (0.7%) and *L. macrophtalmus* (0.01%). Five species (*L. acutirostris, L. dainellii, L. gorgorensis, L. gorguari, L. platydorsus*) were totally absent in the upstream areas (Table 5.1). Those *Labeobarbus* species which were rare in the spawning season were not included in spatial and temporal analyses. The similarities and differences in the species composition of *Labeobarbus* in the river mouths and upstream reaches is shown in Tables 4.3 and 4.4.

Table 4.3 Comparison of abundance (number of fish per overnight gillnet setting) during peak breeding and non-peak breeding season in the river mouths using Mann-Whitney U test. n = number of specimens, mean = number of fish per gillnet setting, N = number of overnight gillnet settings, p = significance level.

		Peak spawning season				**Non-peak spawning season**			
Species	**n**	**Months**	**Mean ± SE**	**N**	**n**	**Month**	**Mean ± SE**	**N**	**P**
L. brevicephalus	736	Aug-Oct	30.6 ± 4.38	24	116	Nov-Jul	5.8 ± 2.1	20	0.021^(*)^
L. intermedius	1585	Aug-Oct	65.9 ± 8.2	24	476	Nov-Jul	23.6 ± 3.8	20	0.013^(*)^
L. megastoma	70	Aug-Oct	2.9 ± 1.1	24	87	Nov-Jul	4.4 ± 1.2	20	0.576^(ns)^
L. surkis	156	Sep-Nov	8.67 ± 1.7	18	15	Dec-Aug	0.58 ± 0.61	26	0.003^(**)^
L. truttiformis	339	Aug-Oct	14.13 ± 3.4	24	10	Nov-Jul	0.5 ± 0.2	20	0.01^(*)^
L. tsanensis	446	Aug-Oct	18.58 ± 4.8	24	41	Nov-Jul	2.05 ± 0.4	20	0.02^(*)^

(*) significant, (**) very significant, (ns) not significant

Table 4.4 Composition of the most abundant *Labeobarbus* species (temporally and spatially) in the upstream of Megech and Dirma Rivers. Data represents absolute numbers of specimens.

	Temporal variation			**Spatial variation**			
Species	**Aug**	**Sep**	**Oct**	**DUPS**	**MUPS1**	**MUPS2**	**DZ**
L. brevicephalus	33	45	65	28	26	49	40
L. intermedius	58	78	108	71	37	110	26
L. megastoma	2	12	0	6	3	5	0
L. nedgia	2	3	20	0	6	14	6
L. truttiformis	74	54	2	10	33	23	64
L. tsanensis	50	58	5	9	32	13	59

4.3 sex ratio

From the total of 4983 *Labeobarbus* annual catch, 1139 (22.8%) were males and 3809 (76.5%) were females. Thirty five specimens (0.7%) were unsexed. In general females were more numerous than males. Except, *L. acutirostris, L. megastoma and L. nedgia*, the sex proportions of all labeobarbs species were significantly different (x^2, $p< 0.05$) from the theoretical 1:1 ratio (Table 4.5). During the peak spawning season (August to October) females outnumbered males and the variation in proportion was wider than the depicted ratios in Table 4.5. the highest skewness in sex ratios was observed in *L. surkis* (nearly 1:13).

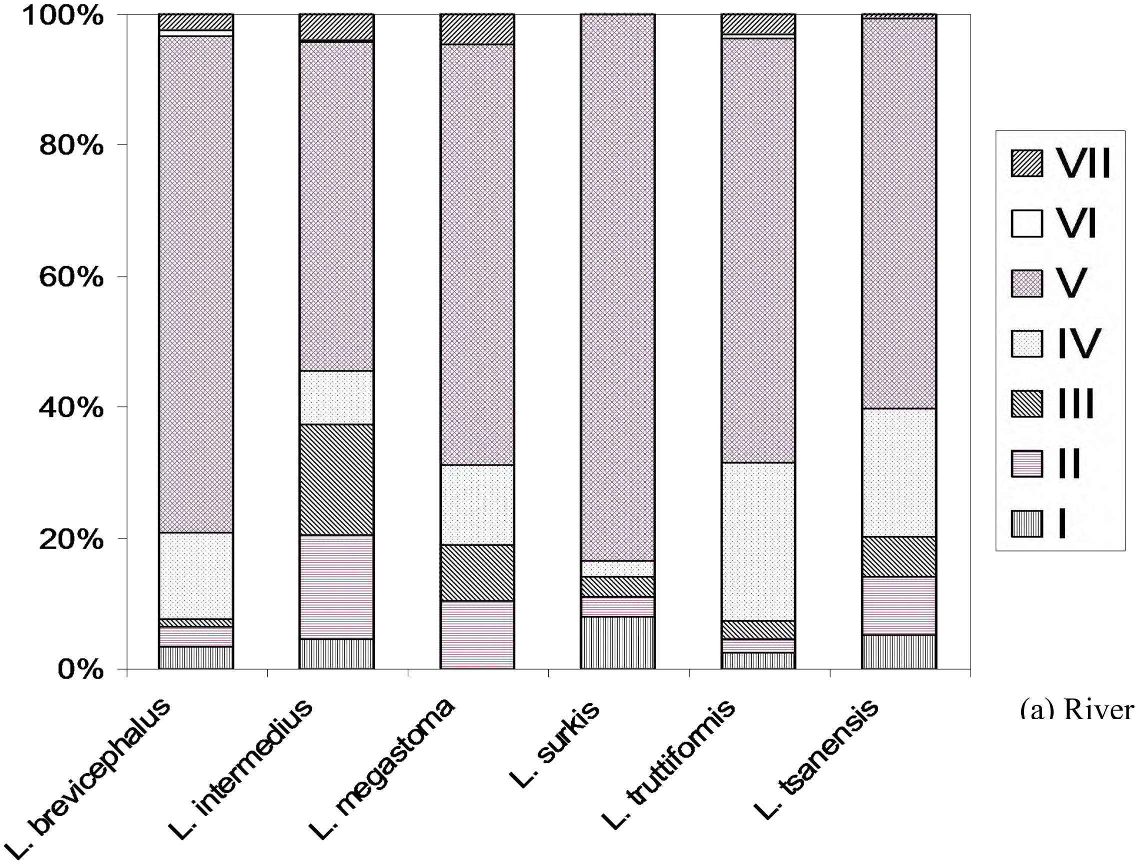
Table 4.5 Number of males, females and the corresponding sex ratios in *Labeobarbus* species (pooled data from all sites) from Lake Tana.

Labeobarbus Species	Males	Females	Sex ratio (Male: Female)	X^2	p
L. acutirostris	20	27	1:1.35	1.04	0.307 $^{(ns)}$
L. brevicephalus	162	827	1:5.11	447.14	0.000 $^{(**)}$
L. crassibarbis	11	38	1:3.45	14.88	0.000 $^{(**)}$
L. gorgorensis	5	16	1:3.20	5.76	0.016 $^{(*)}$
L. intermedius	576	1731	1:3.01	2015	0.000 $^{(**)}$
L. longissimus	10	21	1:2.10	3.90	0.048 $^{(*)}$
L. macrophtalmus	7	10	1:1.43	0.53	0.467 $^{(*)}$
L. megastoma	79	90	1:1.14	0.72	0.397 $^{(ns)}$
L. nedgia	15	20	1:1.33	0.71	0.398 $^{(ns)}$
L. platydorsus	10	21	1:2.10	3.90	0.048 $^{(*)}$
L. surkis	13	162	1:12.46	126.86	0.000 $^{(**)}$
L. truttiformis	81	396	1:4.89	208.02	0.000 $^{(**)}$
L. tsanensis	149	450	1:3.02	151.25	0.000 $^{(**)}$
L. dainellii	0	2	-	-	-

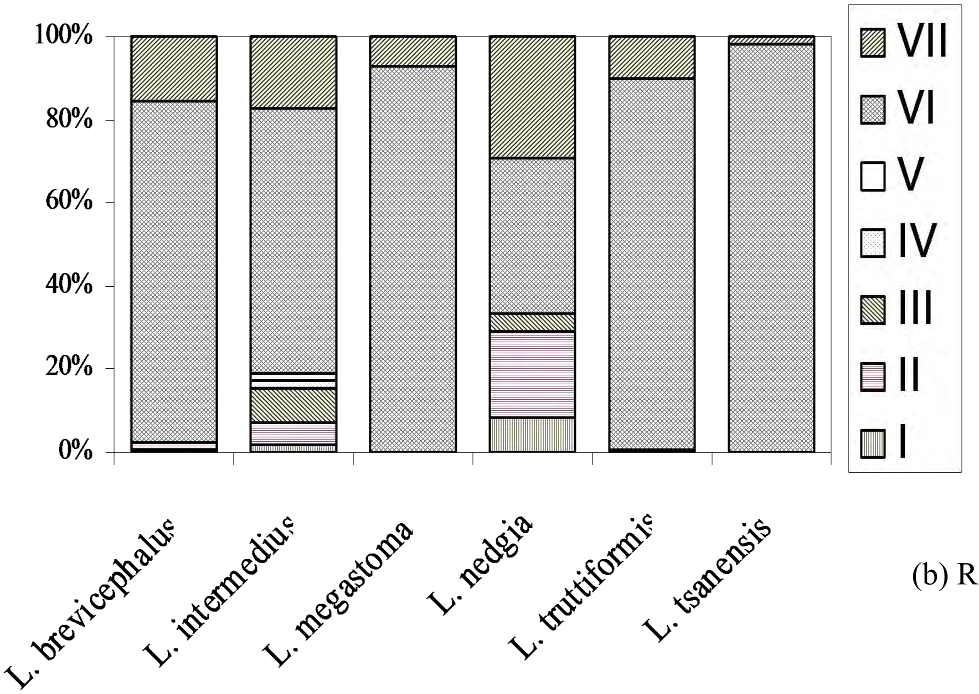
$^{(**)}$ (P<0.001), $^{(*)}$ (P<0.05), $^{(ns)}$ not significant (P>0.05)

4.4 Gonado-Somatic Index (GSI)

For most *Labeobarbus* species the gonad proportion of mature (gonad stages IV, V), running (gonad stage VI), and spent (gonad stage VII) together was higher (about 90%) than the immature gonads (gonad stages I-III) in the samples collected from August to October (Fig. 4.3). Gonad stage V was most abundant in the river mouths in all the species but immature gonads (I, II, III) were relatively more in *L. intermedius* as compared to others (Fig. 4.3). A total of about 152 (60 in the river mouths and 92 in the upstream areas) *Labeobarbus* specimens with spent gonads were caught. For most species spent fish were relatively numerous at the end of October (Table 4.7). *L. tsanensis* has the highest individual GSI (32.53 %), measured in September, whereas the maximum mean monthly GSI was highest for *L. surkis* females (11.37 %) in October (Table 4.6). Maximum individual and mean monthly GSI (%), as well as the months of such measurements taken for each species of *Labeobarbus* is given in Table 4.6.



(a) River mouth



(b) River upstream

Figure 4.3 Proportion of different gonad maturity stages (I to VII) of *Labeobarbus* species during peak breeding season (August to October) in the river mouths (a) and upstream reaches (b).

Mean monthly GSI was low during the dry season (December to May) (< 2 for males and < 3 for females). It starts to increase in the pre-rainy season (May-June) for most species and reaches its peak in August, September and October. Then it starts again to decline in the post rainy season (end of October and beginning of November) (Fig. 4.4).

Table 4.6 Species of female *Labeobarbus* with max. mean monthly GSI (%) calculated and individual fish with max.GSI (%) measured. N refers to the number of specimens used for calculating max. mean GSI (%).

Species	**Max. mean monthly GSI (%)**	**Month Max.mean GSI calculated**	**N**	**Max. individual GSI (%)**	**Month Max. individual GSI observed**	**FL (cm) of individual fish with the max. GSI**	**Site of fish with max. GSI caught**
L. acutirostris	4.37	August	2	8.33	August	28.30	Megech RM
L. brevicephalus	11.08	October	322	19.35	September	19.10	Dirma RM
L. crassibarbis	8.49	July	2	14.24	September	23.00	Dirma RM
L. gorgorensis	2.91	August	5	5.83	August	46.00	Megech RM
L. intermedius	8.05	November	40	30.78	September	21.20	Dirma RM
L. longissimus	7.38	August	8	12.78	August	21.10	Megech RM
L macrophtalmus	11.19	September	4	12.56	September	23.30	Dirma RM
L. megastoma	5.48	September	12	21.36	September	31.70	Megech RM
L. nedgia	3.04	September	4	12.36	October	12.50	MUPS2
L. platydorsus	4.94	September	10	9.44	September	31.00	Megech RM
L. surkis	11.37	October	108	22.69	October	27.80	Dirma RM
L. truttiformis	10.28	September	200	21.94	August	20.90	Megech RM
L. tsanensis	8.40	September	180	32.53	September	24.80	Megech RM

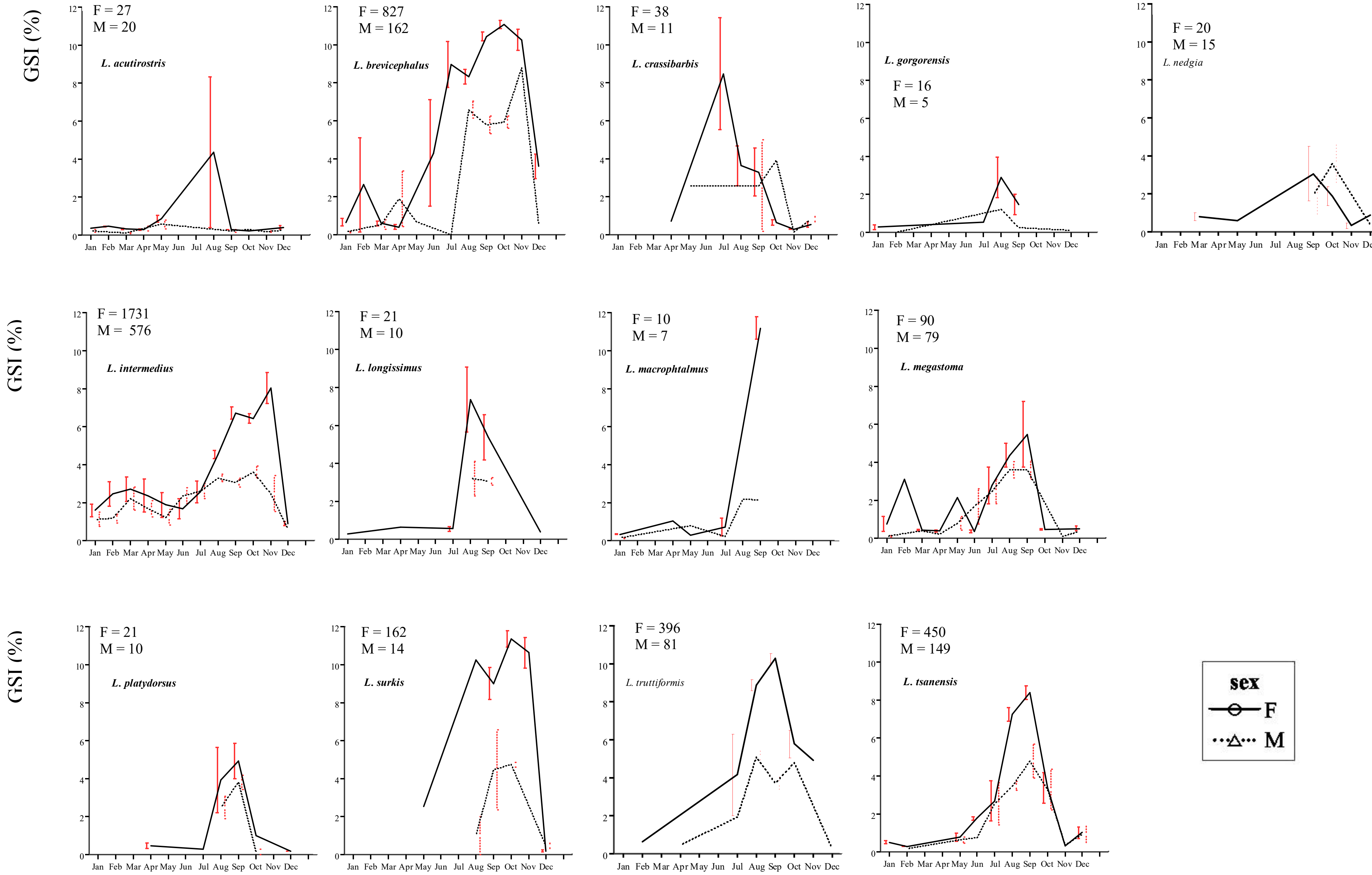


Figure 4.4 Year round female and male GSIs (mean ± SE) of *Labeobarbus* species in Lake Tana. Note the absence of *L. dainellii* and *L. gorguari*.

Table 4.7 Number of *Labeobarbus* species caught with spent gonads in the river mouths and upriver areas and month (s) of maximum number of individuals captured with such gonads. Numbers in brackets refer to the number of fish caught in the specified month.

Species	**Number of spent fish**			**Site of capture**		**Month (max. number caught)**
	♀	♂	**total**	**RM**	**Upstream**	
L. brevicephalus	24	2	26	4	22	October (15)
L. intermedius	71	13	84	39	45	October (32)
L. megastoma	4	1	5	4	1	September (3)
L. nedgia	8	1	9	2	7	October (6)
L. truttiformis	10	4	14	1	13	September (12)
L. tsanensis	8	1	7	5	2	October (2)
L. gorgorensis	2	0	2	2	0	September (2)
L. acutirostiris	0	2	2	2	0	October & November (1 each)
L. crassibarbis	2	0	2	1	1	October (2)
L. platydorsus	1	0	1	0	1	October (1)

* No spent gonads were caught for other *Labeobarbus* species

4.5 Size at maturity ($FL_{50\%}$)

The median size at first maturity; the fork length at which 50% of the males and females mature, described by the logistic curve is shown in Figure 4.5. The female and male maturity data were complete over the whole size range for only *L. truttiformis* and *L. tsanensis* (Table 4.8). Hence, for most species and some males it was impossible to estimate a reliable maturity curve most probably due to small overall catch and absence of small size immature males in the sample. In all species of *Labeobarbus* investigated, males mature at a smaller length than females and $FL_{50\%}$

is larger than FL_{min} (Table 4.8). *L. brevicephalus* has the smallest $FL_{50\%}$ and FL_{min}, while the largest FL_{min} was recorded for *L. crassibarbis* female (30.5 cm).

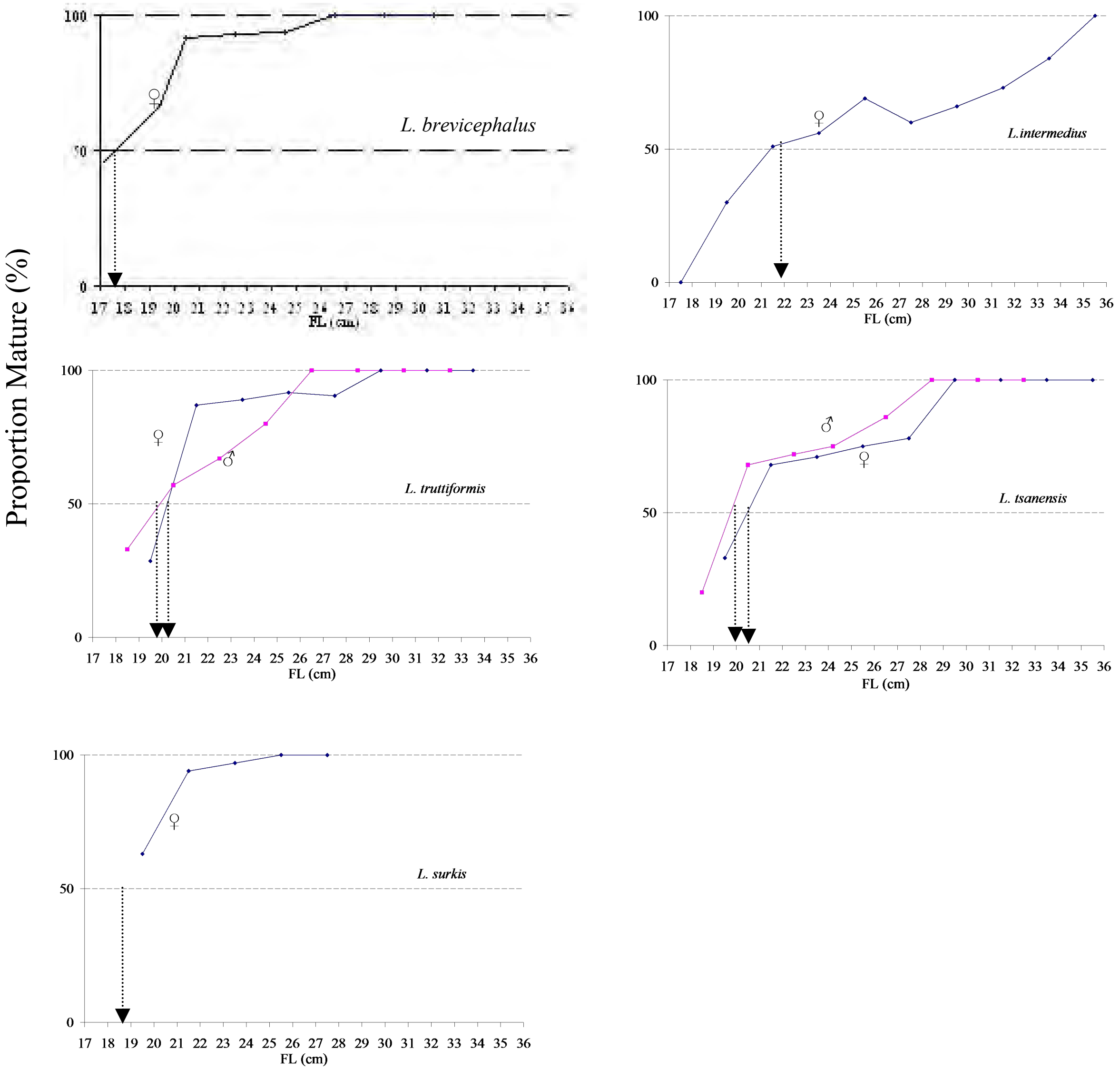


Figure 4.5 Median length at first maturity ($FL_{50\%}$) curves for some species of *Labeobarbus* from Lake Tana.

Table 4.8 Mean length at first maturity ($FL_{50\%} = \frac{a}{-b}$, estimated according to King, 1995) for labeobarb species of Lake Tana. (n) Number of specimens; (a, b) coefficients of the regression, R^2 = coefficient of determination, FL_{min} = fork length of the smallest ripe specimen caught.

Species	sex	n	a	b	R^2	Data points	$FL_{50\%}$ (cm)	FL_{min} (cm)
L. acutirostris	♀	5	—	—	—	—	—	27.30
	♂	5	—	—	—	—	—	23.90
L. brevicephalus	♀	639	7.89	-0.45	0.69	7	17.53	13.50
	♂	84	—	—	—	—	—	11.10
L. crassibarbis	♀	32	—	—	—	—	—	30.50
	♂	5	—	—	—	—	—	27.40
L. gorgorensis	♀	10	—	—	—	—	—	35.10
	♂	2	—	—	—	—	—	28.40
L. intermedius	♀	1303	3.16	-0.14	0.85	9	22.57	12.10
	♂	434	—	—	—	—	—	11.80
L. longissimus	♀	19	—	—	—	—	—	21.10
	♂	10	—	—	—	—	—	19.00
L. macrophtalmus	♀	6	—	—	—	—	—	22.50
	♂	3	—	—	—	—	—	21.70
L. megastoma	♀	49	—	—	—	—	—	20.00
	♂	57	—	—	—	—	—	23.30
L. nedgia	♀	16	—	—	—	—	—	22.50
	♂	14	—	—	—	—	—	12.50
L. platydorsus	♀	17	—	—	—	—	—	20.60
	♂	10	—	—	—	—	—	19.90
L. surkis	♀	152	13.61	-0.74	0.93	5	18.39	17.45
	♂	6	—	—	—	—	—	13.90
L. truttiformis	♀	325	15.15	-0.75	0.80	8	20.20	18.60
	♂	74	7.48	-0.37	0.89	8	19.68	15.30
L. tsanensis	♀	349	7.10	-0.34	0.79	9	20.88	18.00
	♂	90	4.40	-0.21	0.74	8	20.43	15.20
L. dainellii	♀	—		—		—	—	—
	♂	1		—		—	—	25.80

4.6 Segregations in the spawning months

4.6.1 Spatial segregation

The mean abundance differences among the aggregating *Labeobarbus* species in Megech and Dirma river mouths during the breeding season were tested using one-way ANOVA. *L. intermedius*, *L. megastoma, L. truttiformis* and *L. tsanensis*, showed significant variation ($P<0.05$) but the other two (*L. brevicephalus*, and *L. surkis*) didn’t show significant difference ($P>0.05$) in their mean abundance in between the two river mouths (Table 4.9). Hence, the latter labeobarb species have similar densities at both river mouths (Appendix F). In the upstream areas strong spatial segregation patterns were observed (x^2, $p<0.001$) among the six *Labeobarbus* and pairwise comparison of these species also revealed significant variation, except *L. tsanensis* and *L. truttiformis* (Appendix B).

The relative contribution of each *Labeobarbus* within the sampling sites is depicted in Figure 4.6. Two species of labeobarbs (*L. truttiformis,* and *L. tsanensis*) were almost equally abundant at Dimaza stream (Fig. 4.6b) but rare at Megech River, upper Dimaza mouth (MUPS2). *L. intermedius* was most abundant at Dirma upstream and Megech River upper Dimaza’s mouth, whereas it was rare (2.6%) at Dimaza stream. *L. brevicephalus* was available in all upstream sites with almost equal density (Fig. 4.6b).

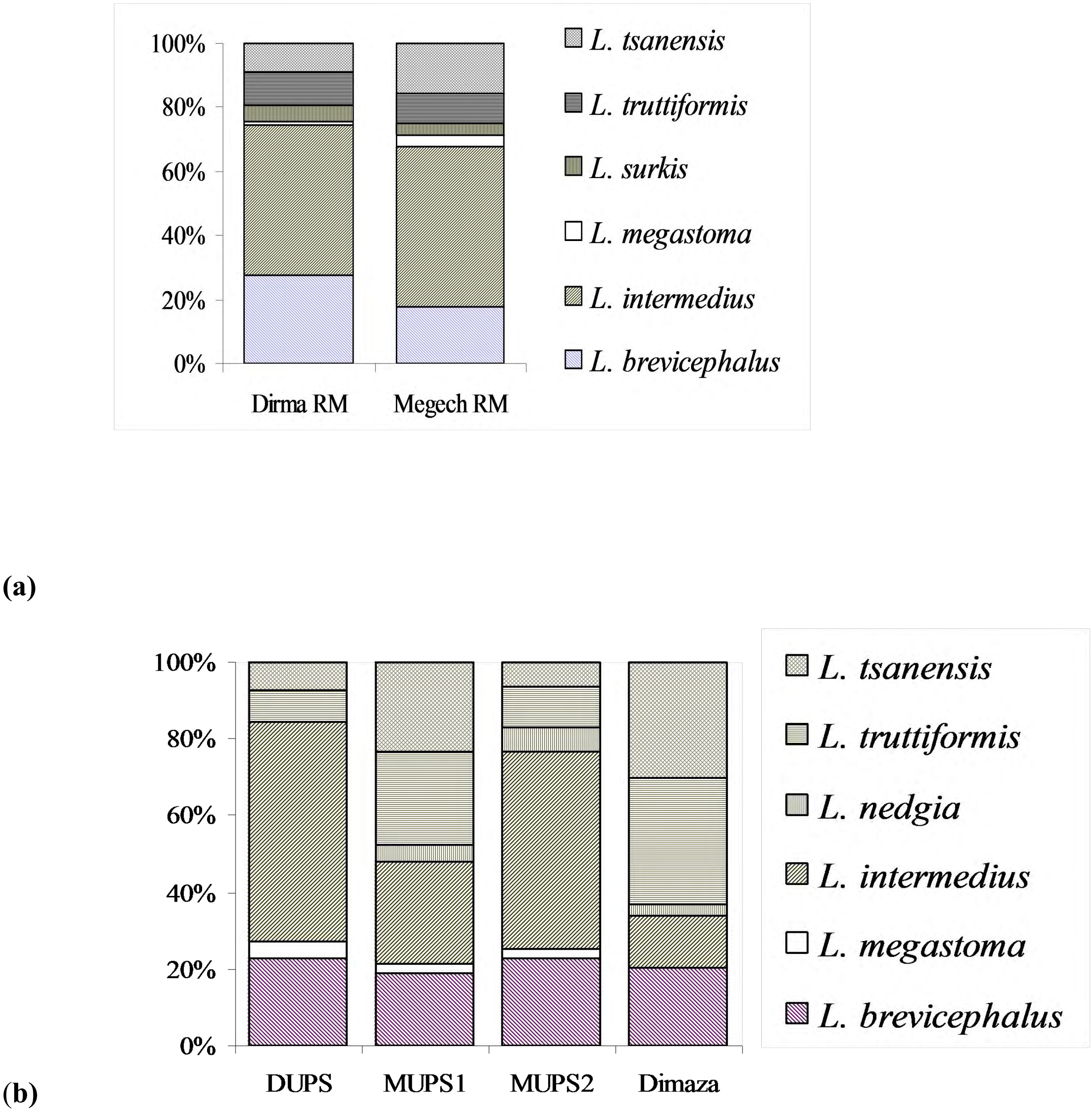


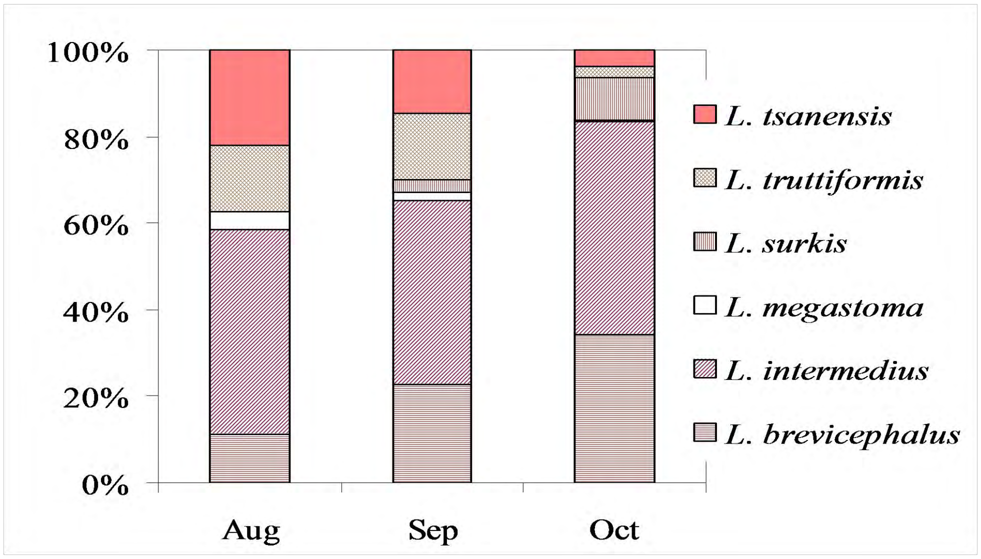
Figure 4.6 Relative contribution of labeobarbs at different sampling sites in the river mouth during peak spawning season (pooled data from both river mouths) (a) and in upstream sites (pooled data) (b).

4.6.2 Temporal segregation

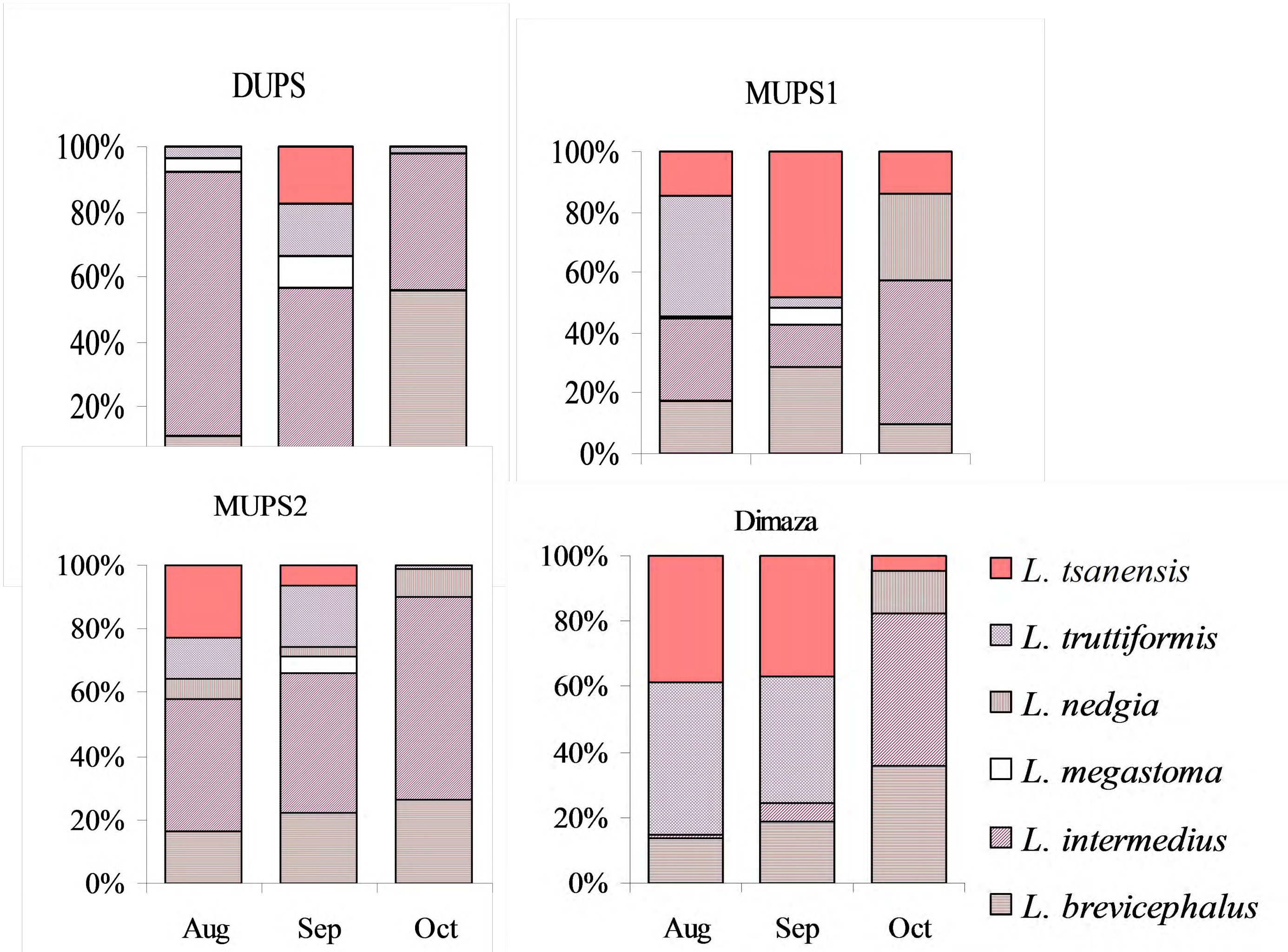
The aggregation patterns of *Labeobarbus* species in the river mouths differ over the spawning months (July to November). *L. megastoma* was the first labeobarb species to aggregate in the river mouths starting in the first week of July and reaching peak in the last week of this month and beginning of August (Fig. 4.8). *L. truttiformis* and *L. tsanensis* have similar aggregation period in the river mouths making their peaks in catch at the end of August and beginning of September. As depicted in Figure 4.8, *L. brevicephalus* and *L. surkis* start to aggregate in September and their peak was in the third week of October. Three species (*L. tsanensis, L. truttiformis*, and *L. megastoma*) showed a declining pattern of catch from August to October (Fig. 4.7a) but it was the reverse in the case of *L. brevicephalus* and *L. surkis*.

L. intermedius didn't show significant variation (x^2, $P<0.05$) in its temporal segregation pattern during the breeding months in the river mouths (Table 4.9). It was always available with mature and immature gonads in the river mouths and upstream areas even when the rivers were totally disconnected from the lake.

Aggregation patterns in the river mouths and migration patterns in the upstream areas on weekly basis are given in Figure 4.8. The first migrants to upstream were *L. tsanensis* and *L. truttiformis*. They started to ascend at the middle of August, but caught in mass at the end of August and beginning of September in Megech (MUPS1) and Dimaza stream (Fig. 4.7b). Catches of *L. nedgia* and *L. brevicephalus* reached their peak at the end of October (Fig. 4.8).



(a) River Mouths



(b) Upstream Areas

Figure 4.7 Relative proportions of *Labeobarbus* species (pooled data from both river mouths) during the peak-spawning months in the river mouths (a) and upstream riverine sites (b) as a function of time

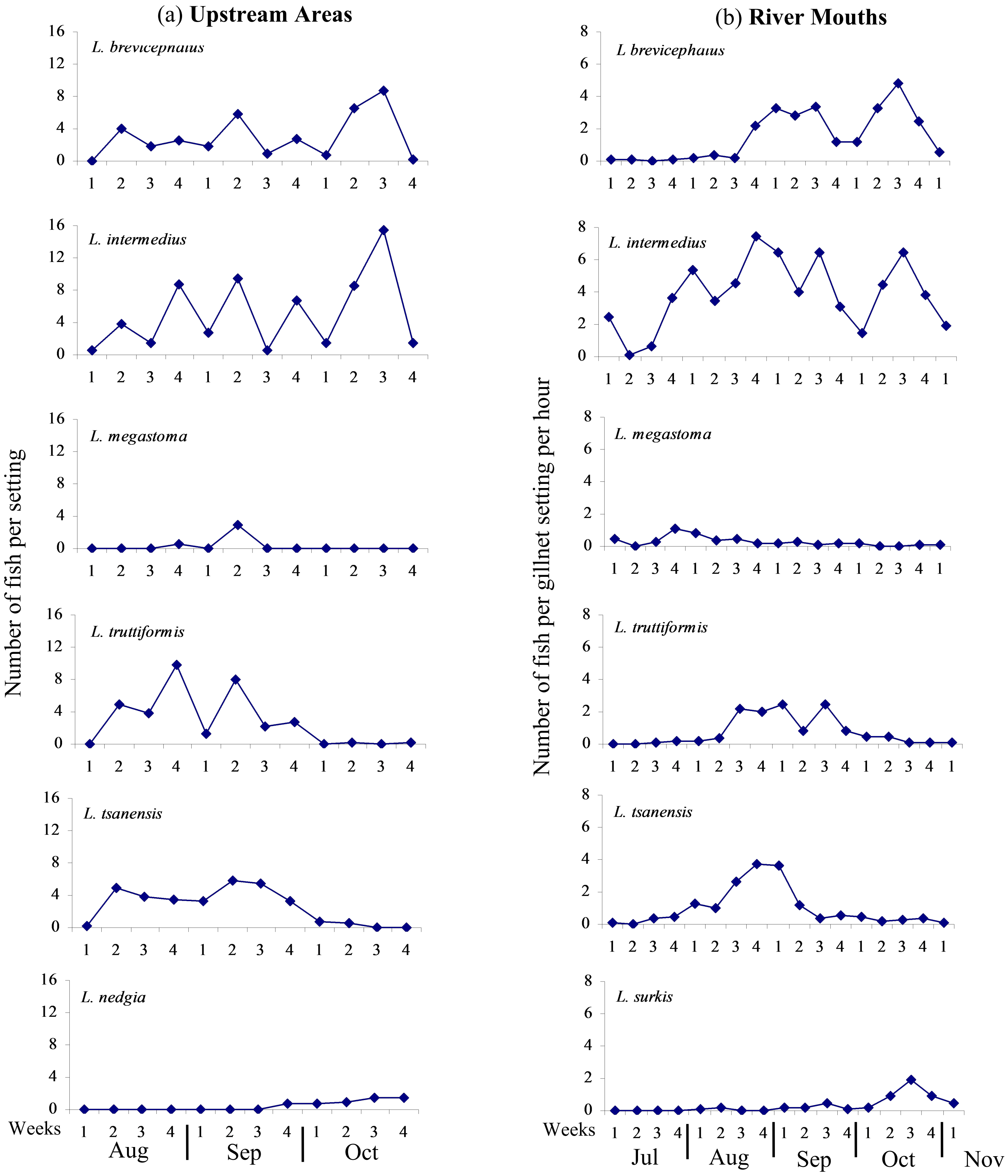


Figure 4.8 Temporal variation in abundance (pooled data of all upstream sites) of labeobarbs in the breeding season in upstream (August to October) (a) and river mouths (pooled data from both river mouths) (July to November) (b)

Table 4.9 Comparison of mean monthly abundances of *Labeobarbus* by month and river mouth during the spawning season (July to November) using one-way ANOVA. ms = mean squares, df =degree of freedom.

	Species								
	L. brevicephalus			*L. intermedius*			*L. megastoma*		
source of variation	**df**	**ms**	***P***	**df**	**ms**	***P***	**df**	**ms**	***P***
Month	4	7.57	0.001(**)	4	7.74	0.23(ns)	4	4.65	0.04(*)
River mouth	1	0.21	0.96(ns)	1	8.99	0.024(*)	1	5.23	0.006(**)

	L. surkis			*L. truttiformis*			*L. tsanensis*		
	df	**ms**	***P***	**df**	**ms**	***P***	**df**	**ms**	***P***
Month	4	5.41	0.001(**)	4	6.39	0.02(*)	4	6.28	0.01(**)
River mouth	1	0.49	0.88(ns)	1	5.55	0.03(*)	1	4.98	0.02(*)

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

4.7 Fecundity

Mean absolute (total) and relative fecundities (number of eggs per FL) at different fork length classes of *L. brevicephalus* and *L. truttiformis* are given in Table 4.11. Thirty specimens of the former species (180-260 cm FL) and 24 specimens of the latter (210-330 cm FL) were used for fecundity estimation. The mean absolute fecundity for *L. brevicephalus* was 2421 and ranged from 1284 to 4563 eggs whereas *L. truttiformis* had 3948 mean absolute fecundity with the range of 1732 to 8134 eggs. Absolute fecundity of the two species was statistically different ($P<0.001$) but relative fecundity wasn’t ($P>0.05$). Absolute fecundity increased with an increase in FL in both species (Fig. 4.10). Mean relative fecundity remained more or less constant in *L. brevicephalus* but in *L. truttiformis* it seemed to be slightly increasing below 270 cm FL but then declined above this FL (Table 4.11). In general, absolute fecundities (AF) of both species were explained by exponential regression with fork length (FL) and quadratic regression with total body weight (BW) and gonad weight (GW) and the lines of best fit to the relationships respectively, were:

$AF = 0.0353\ FL^{3.64}$, ($R^2 = 0.64$)

$AF = 1.2406\ GW^2 + 165.43\ GW + 275.8$, ($R^2 = 0.89$)

$AF = 0.0124\ BW^2 + 19.172BW – 169.35$, ($R^2 = 0.58$) for *L. brevicephalus*, and

$AF = 0.6107\ FL^{2.72}$, ($R^2 = 0.6147$)

$AF = -3.157\ GW^2 + 340.29\ GW – 1028$, ($R^2 = 0.84$)

$AF = -0.0463\ BW^2 + 42.545\ BW – 2319.7$, ($R^2 = 0.69$) for *L. truttiformis*.

The egg diameter of these species showed significant variation ($P<0.05$) although the mean difference is about 0.02 mm (Table 4.10). The size frequency distribution of eggs showed one modal diameter (2 mm) in *L. brevicephalus* whereas *L. truttiformis* had almost four equal modes of egg diameters, from 1.90 mm to 2.05 mm (Fig. 4.9).

Table 4.10 Mean, minimum and maximum ova diameter for the two *Labeobarbus* species from Lake Tana.

Species	**N**	**Minimum (mm)**	**Maximum (mm)**	**Mean ± STD (mm)**
L. brevicephalus	977	1.65	2.25	1.97 ± 0.11
L. truttiformis	721	1.65	2.30	1.99 ± 0.11

Table 4.11 Mean relative and absolute (total) fecundities of *L. brevicephalus* and *L. truttiformis* in relation to their lengths. N= number of specimens in the particular fork length class.

Species	Size class (cm)	N	Mean body weight (g)	Mean absolute fecundity	Mean relative fecundity
L. brevicephalus	18-19.9	9	99	2024	21
	20-21.9	16	120	2432	21
	22-23.9	3	141	2666	19
	24-25.9	2	180	4042	22
L. truttiformis	21-22.9	10	136	2433	18
	23-24.9	8	186	4220	23
	25-26.9	2	218	5495	25
	27-28.9	-	-	-	-
	29-30.9	2	341	5651	17
	31-32.9	2	563	7186	14

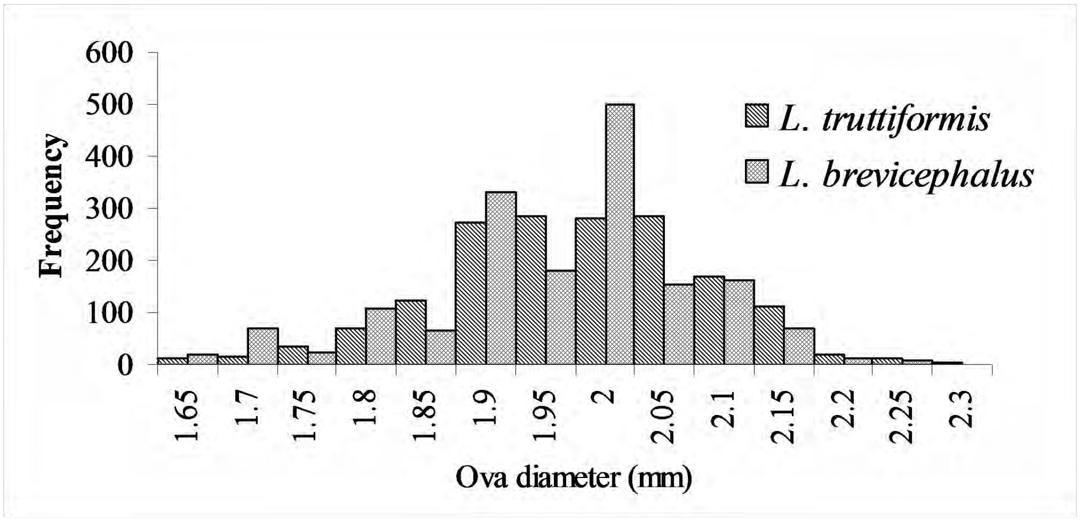
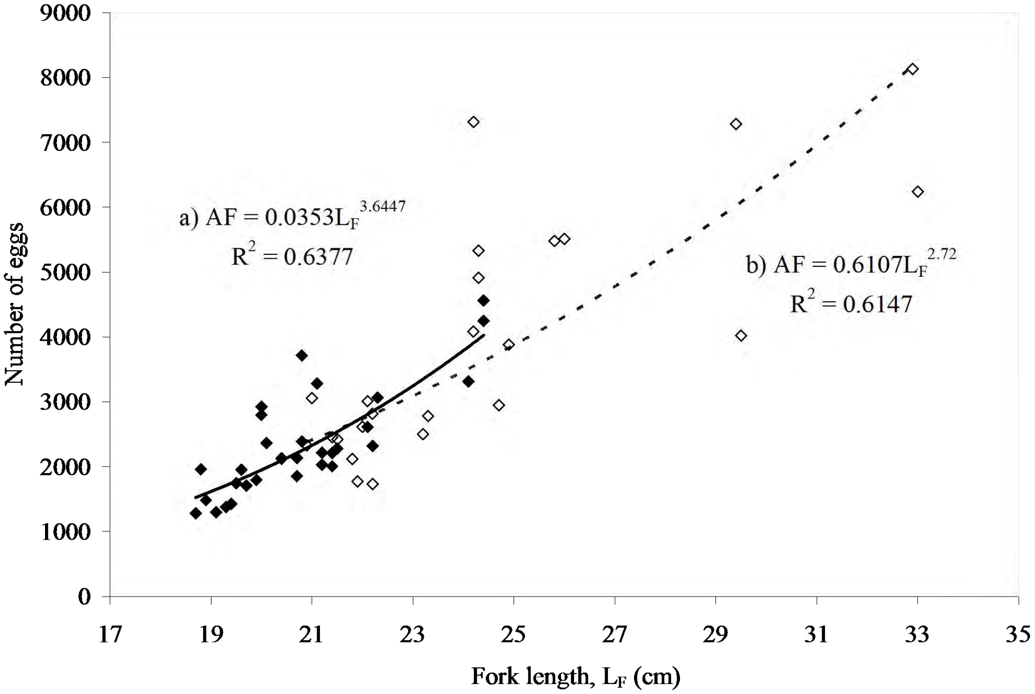
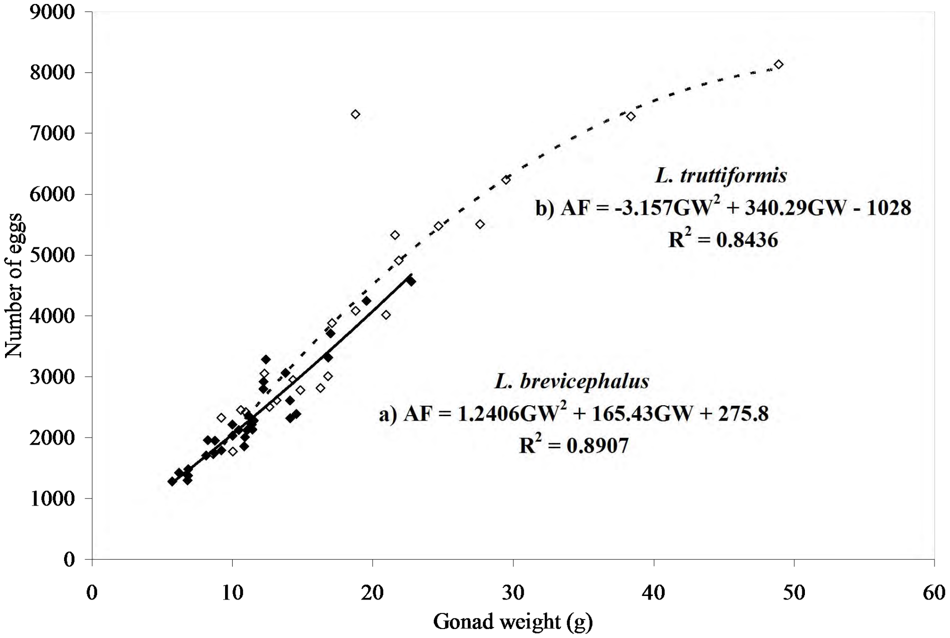


Figure 4.9 Ova diameter frequency distribution histogram.



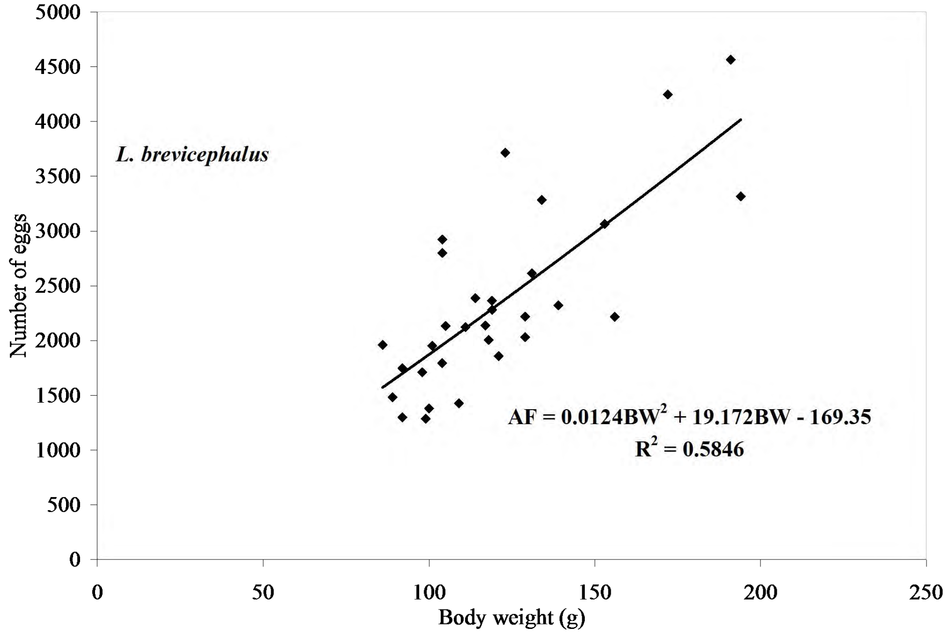
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Number of eggs
17
19
21
23
25
27
29
31
33
35
Fork length, L_F (cm)
a) $AF = 0.0353L_F^{3.6447}$
$R^2 = 0.6377$
b) $AF = 0.6107L_F^{2.72}$
$R^2 = 0.6147$

(A)

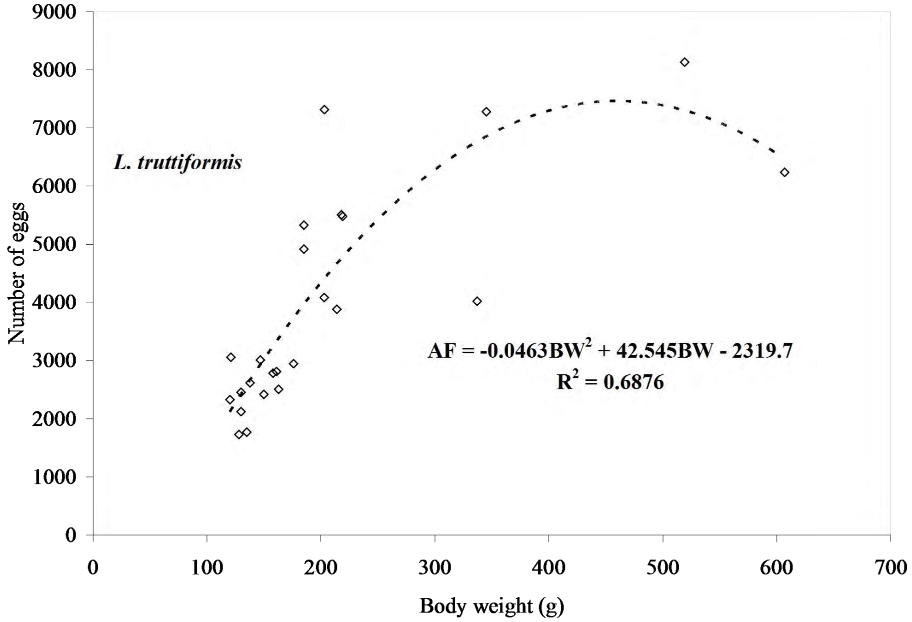


9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Number of eggs
0
10
20
30
40
50
60
Gonad weight (g)
L. truttiformis
b) $AF = -3.157GW^2 + 340.29GW - 1028$
$R^2 = 0.8436$
L. brevicephalus
a) $AF = 1.2406GW^2 + 165.43GW + 275.8$
$R^2 = 0.8907$

(B)



(C)



(D)

Figure 4.10 Absolute fecundity (AF) of a) *L. brevicephalus* (black diamonds and solid line) and b) *L. truttiformis* (open diamonds and dashed line) as a function of: fork length (L_F) (A), gonad weight (B), and body weight (C, D).

4.8 Length-weight relationship and Fulton's condition factor

Total weight (TW) of each *Labeobarbus* species of Lake Tana was curvilinearly related with fork length (FL) (Appendix D) and was statistically significant ($P<0.001$). The line fitted to the data was described by the following regression equations for each species.

Table 4.12 The length-weight regression equations and the correlation coefficient (R^2) of *Labeobarbus* species from Lake Tana.

Species	Regression equation	R^2
L. brevicephalus	$TW = 0.0229FL^{2.97}$	0.87
L. intermedius	$TW = 0.0092FL^{3.02}$	0.92
L. megastoma	$TW = 0.0149FL^{2.94}$	0.92
L. surkis	$TW = 0.0117FL^{3.03}$	0.96
L. truttiformis	$TW = 0.011FL^{3.05}$	0.88
L. tsanensis	$TW = 0.0073FL^{3.18}$	0.92

Fulton's condition factor generally was lower for females than males (Appendix E). During the peak spawning season (August to October) the value of the condition factor was significantly ($P<0.05$) lower than the non-peak spawning season (November to July) (Table 4.13).

Table 4.13 Mean Fulton's condition factor (FCF) and condition factor by sex and by season. SD is standard error and n is sample size. P = significant difference (Mann-Whitney U test) between seasons.

Species	n	FCF ± SD	sex	**season**		**P**
				Non peak spawning season	Peak spawning season	
L. brevicephalus	983	1. 28 ± 0.11	♂	1.35 ± 0.19	1.26 ± 0.16	**
			♀	1.30 ± 0.22	1.23 ± 0.11	
L. intermedius	2311	1.37 ± 0.23	♂	1.41 ± 0.16	1.34 ± 0.17	***
			♀	1.38 ± 0.14	1.31 ± 0.16	
L. megastoma	168	1.43 ± 0.32	♂	1.45 ± 0.13	1.25 ± 0.16	***
			♀	1.24 ± 0.09	1.13 ± 0.15	
L. surkis	175	1.34 ± 0.17	♂	1.73 ± 0.54	1.56 ± 0.26	**
			♀	1.46 ± 0.01	1.31 ± 0.10	
L. truttiformis	472	1.30 ± 0.12	♂	1.36 ± 0.04	1.22 ± 0.13	**
			♀	-	1.29 ± 0.11	
L. tsanensis	594	1.41 ± 0.17	♂	1.56 ± 0.13	1.43 ± 0.15	**
			♀	1.48 ± 0.34	1.39 ± 0.19	

** = P<0.01, *** = P<0.001

5. Discussion

5.1 Spawning grounds

In spite of the fact that tropical cyprinids in general lack parental care and other adaptations like viviparity or aestivation (Harikumar *et al*., 1994), they have certain requirements in choosing their spawning places. Fast flowing, clear, highly oxygenated water, and gravel-bed streams or rivers are preferred places for *Labeobarbus* (Rodriguez-Ruiz and Granado-Lurencio, 1992). These conditions are important for the growth of larvae (Tómasson *et al*., 1984). Deposition of eggs in the gravel or pebble beds protects them from being washed away by riffle, and clear water will not prevent diffusion of oxygen (Lowe-McConnell, 1987). Previous studies (Alekseyev *et al*., 1996; Nagelkerke and Sibbing, 1996; Dgebuadze *et al*., 1999; Palstra *et al*., 2004) on spawning migrations of Lake Tana's *Labeobarbus* were focused on Gumara River as it was considered as ideal breeding ground. On the other hand, Rib, the other affluent river, was not found to be good breeding ground since neither of the above conditions was available. No labeobarb species was migrating to the upstream reaches of this river (Palstra *et al*., 2004) even though some species aggregate in the river mouth (de Graaf *et al*., 2005). However, the breeding ground of these aggregating species in Rib River mouth is still unclear.

Although Dirma and Megech tributary rivers (Fig. 3.1) flow about 25 to 30 km in the muddy Dembea plain (lentic habitat); the upper stretches (lotic habitat) of both rivers fulfill the conditions stated above for the best spawning ground for labeobarbs. Some variations in their physical conditions were observed between the two rivers. Megech River has higher oxygen (Table 4.1), water volume and many tributary streams, such as Dimaza, Keha, and Angereb, which have gravel beds at their mouths. This could be the most probable reason for the relatively more abundant specimens of labeobarbs available in Megech

River as compared to Dirma. Megech and its tributary Dimaza stream have rapids and small waterfalls, which can be attributed for their significantly higher oxygenation (Table 4.2). The higher abundance of specimens of a particular labeobarb species in Dimaza stream, like the small seasonal tributaries of Gumara (Kizen, Dukolit, Wanzuma) (Palstra *et al.*, 2004), indicates that the riverine spawners of *Labeobarbus* of Lake Tana prefer side streams to the main channels of the rivers for spawning. In Dimaza the breeding stretch is short as fish migration is blocked by about 3 m waterfalls around two kilometers from its mouth. The rivers were highly turbid in the rainy season, due to high sediment load introduction from the surrounding intensively cultivated farm land; consequently, Secchi depth was too low and minimum during July in these rivers (Table 4.1, Fig. 4.1).

Mean temperature was highest in Dimaza Stream as it had smaller volume of water in the sampling periods; however, there was no statistically significant difference among the sites (Table 4.2). The pH was neutral to slightly alkaline (Table 4.1) in all sites where samplings were carried out.

Megech and Dirma Rivers provide ideal breeding grounds for the *Labeobarbus* of Lake Tana in the northern part of the lake, as does Gumara River in the south. Megech River has higher dissolved oxygen (7.52 mgl^{-1}) (Table 4.1) than Gumara (7.2 mgl^{-1}) (Palstra *et al.*, 2004). Therefore, as deduced from running fish, after brief pre-spawning aggregation in the river mouths, final maturation and spawning occur in the tributaries of Megech and Dirma or possibly at gravel reaches in the main channel.

5.2 Sex ratio and spawning season

For most of *Labeobarbus* species of Lake Tana, females were most numerous than males (Table 4.5). The ratio was even wider when only the catches of the spawning months are considered. The imbalance was most probably related to spawning habits. Females may stay longer time in the breeding areas than males. Al-Kholy (1972) observed a similar result, a cyprinid *Puntius barberinus* females in Lake Lanao live longer time in the spawning areas than males. Segregation by sex during spawning was also observed in weakfish (Alheit *et al*., 1984). Increased vulnerability of females by some gears due to increased ovarian development, as suggested by Tayler and Villoso (1994), can also be the cause for the deviation from 1:1 sex ratio. A combination of the above factors can also happen (i.e. spawning stocks in Megech and Dirma River mouths may be dominated by females in the spawning months and these females may be restricted to certain depths, consequently differing in their vulnerability to different fishing gears).

The mean GSI of a stock tends to increase as female and male gonads reach maturity, just prior to spawning. The GSI has been employed mostly to determine spawning season of fish stocks (Bagenal, 1978; De Silva *et al*., 1985) and thought to be reliable criterion, especially when supported by other evidences. Looking at the year-round gonadal development, it appears that except *L. intermedius*, all the Lake Tana's *Labeobarbus* go into a quiescent phase in their reproductive cycle from November/December to May (Fig. 4.4). During this period both sexes have lower gonad weights, and almost no ripe fish was captured. All the species have relatively higher FCF values in these months (Table 4.13). Reproductively active specimens started to appear in June/July, and peak (intensive) spawning activity was from August to October (Fig. 4.4, Table 4.6). In this season FCF was significantly lower. Although *L. intermedius* reproduces year round, peak spawning was from August to

October, similar to other labeobarbs species. The downward trend in GSI at the end of October and beginning of November (Fig. 4.4), combined with the appearance of high percentage of spent females (Table 4.7) and low over all abundance in the catch (Fig. 4.2), indicates the end of the spawning period. The result obtained in this study about the spawning season of Lake Tana's *Labeobarbus* follows a similar cycle of many tropical fish, which is closely related to the rainfalls (Lowe-McConnell, 1975). De Graff *et al*. (2005) reported that peak spawning for *L. surkis* was from November to January; however, this exception did not happen in our study.

5.3 Spawning aggregation and Segregation

Gonad development precedes spawning migration in most fish species and it is under endocrine control from the pituitary gland and this gland requires a triggering factor (Payne, 1986). In the temperate zone, variation in day length is a major triggering factor for gonad maturation, but in the tropics, most probably the variation is insufficient to be considered as a major factor (Wootton, 1990). However, like spawning period, the timing of gonad maturation must generally coincide with the time of reasonable food supply, which means the fish must lay down so much fat over the feeding phase. For its survival and gonad development (Payne, 1986; Wootton, 1990), migration to the breeding area, for tropical freshwater fishes, seems mainly triggered by rainfall patterns and water level variations (Lowe-McConnell, 1975). All fish species in Lake Tana also follow this pattern. *C. gariepinus* flocks to the flooded areas of Fogera and Dembea from June to July (Tesfaye Wudneh, 1998) and *O niloticus* peak breeding occurs in June and July (Zenebe Tadesse, 1997). The small barbs: *B. humilis* and *B. tanapelagius*, breed from March to September (Eshete Dejen *et al*., 2003). *V. beso* and *Garra* species also breed in the rainy season (unpublished data). The Lake Tana *Labeobarbus* species are found to aggregate in the river mouths for spawning in the rainy season (Nagelkerke and Sibbing, 1996; Dgebuadze *et al*., 1999; Palstra *et al*., 2004; de Graaf *et al*., 2005).

This study revealed that six species of *Labeobarbus* (*L. brevicephalus*, *L. intermedius*, *L. megastoma*, *L. surkis*, *L. truttiformis*, and *L. tsanensis*) aggregated at Dirma and Megech river mouths starting from the last week of July to the end of October (Fig. 4.8). These six species contributed more than 90% of the overall labeobarbs catch over the year in the river mouths (Appendix F). These fish species were significantly abundant in the peak spawning months (August to October) than in other months (Table 4.3), except *L. megastoma*. Absence of significant variation in its mean abundance during the peak and non-peak spawning months of *L. megastoma* leads to wonder about its spawning aggregations in the river mouths during these months. However, the appearance of more than 80% ripe specimens of (Fig. 4.3), *L. megastoma* in the river mouths and upstream reaches indicates spawning aggregation. The remaining nine species of *Labeobarbus* (*L. acutirostris*, *L. dainellii*, *L. crassibarbis*, *L. gorgorensis*, *L. gorguari*, *L. longissimus*, *L. macrophtalmus*, *L. nedgia*, *L. platydorsus*) were incidentally captured and were very rare in the river mouths of Dirma and Megech catches (Table 5.1). From the studies carried out in Gelgel Abbay, Gelda, Gumara, and Rib river mouths (de Graaf *et al*., 2005), unlike the results obtained in Megech and Dirma river mouths, *L. surkis* was not an aggregating species but *L. macrophtalmus*, *L. acutirostris*, and *L. platydorsus* were found to aggregate in these river mouths (Table 5.1).

Nearly all the aggregating fish in Megech and Dirma river mouths were ripe (gonad stage IV or V) or spent (gonad stage VII) but not running i.e. shedding eggs and sperm (gonad stage VI) (Fig. 4.3). This shows that the river mouths are not terminal spawning places rather these fish species migrate to upstream areas of Megech and Dirma Rivers.

In the upstream river reaches a total of 996 specimens were collected. The genus *Labeobarbus* contributed 703 (70.6%) specimens. Other species captured were: C. *gariepinus* 248 specimens (24.9%), *O. niloticus* 9 specimens (0.9%) and *V. beso* 36 (3.6%). Most *Labeobarbus* species which were aggregating in the river mouths (Table 4.3) were also numerous in upstream reaches. The only exceptions were the absence of *L. surkis*, which was abundant in the river mouths, and the numerous appearance of *L. nedgia* in the rivers which was apparently found not to aggregate in the river mouths (Table 4.3). More than 90% of the specimens in each particular species in the upstream area, except *L. intermedius*, were either running or spent, the remaining were immature. No *Labeobarbus* fish with gonad stages IV or V was caught (Fig. 4.3b). Four species (*L. crassibarbis*, *L. longissimus*, *L. macrophtalmus*, and *L. surkis*) were incidentally caught in the upstream reaches of Dirma and Megech Rivers whereas five species (*L. dainellii*, *L. acutirostris*, *L. gorguari*, *L. gorgorensis L. platydorsus*) were totally absent (Table 5.1). Previous studies on the spawning migration of this genus focused on upstream areas of the Gumara River. Dgebuadze *et al*. (1999) and Palstra *et al*. (2004) in Gumara River reported that *L. acutisrostris*, *L. brevicephalus*, *L. macrophtalmus*, *L. megastoma*, *L. tsanensis* and *L. truttiformis* were riverine spawners (Table 5.1).

L. nedgia was totally absent in the upstream areas of Dirma and Gumara Rivers but found only in Megech and its tributary, Dimaza. Besides that, this species did not aggregate in all of the tributary river mouths studied so far (Table 5.1). The most probable explanation is that *L. nedgia* may be dwelling in Megech River basin. In May 2004 samples, an immature *L. nedgia* was captured in upstream pools of

Megech River when it was completely dry at its mouth and totally disconnected from the lake. About 30 % of the catch was immature in the upstream of this river during the spawning season (Fig. 4.3). Individual female with maximum GSI was caught in MUPS2 (Table 4.6). These evidences strengthen that this species is dwelling in Megech River and the lake's population never migrate to the rivers as it didn't form aggregation in the river mouths. However, whether this riverine *L. nedgia* is different from the Lake's population of L. nedgia needs detail biological investigation. The other species which was very common in our upstream samples but absent in Gumara (Table 5.1) was *L. intermedius*.

The highest proportion of the catch in the upstream reaches of Dirma and Megech was contributed by *L. intermedius*, particularly the "cole fish" type (Pers. Obs.; Sibbing, pers. com.). Fish with mature and immature gonads of this species was common even when the rivers were dry in their mouths. This implies that like *L. nedgia*, population of this species is also partly river dwelling, but unlike *L. nedgia*, it migrated to rivers. Its migration is deduced from the aggregation in the river mouths. It was exceedingly high in its relative abundance during the spawning season (Table 5.1) in the upstream river reaches of Dirma and Megech rivers. But, why the species was absent totally from Gumara River was not explained. It is suspected that this species might be lumped with *L. tsanensis* due to identification problem. Moreover it was commonly caught in Gumara River by Bahir Dar Fish and other Aquatic Life Research Center (unpublished data). Abebe Amha (2004) had also caught 44 specimens of this species in Gumara River upstream areas. Another important difference was that *L. surkis* which was not found to aggregate in Gelgel Abbay, Gelda, Gumara and Rib Rivers (de Graaf *et al*., 2005) was found to aggregate in the river mouths of Dirma and Megech. On the other hand *L. macrophtalmus* and *L. acutirostris* were found to migrate in Gumara River (Palstra *et al*., 2004) but not in Dirma and Megech. One possible explanation can be, this species might have river specific spawning behavior.

As indicated in the result, six species (*L. brevicephalus*, *L. megastoma*, *L. intermedius*, *L. tsanensis*, *L. truttiformis*, and *L. surkis*) formed spawning aggregations in the river mouths of Dirma and Megech Rivers. When the relative mean abundance of each species in the two river mouths is analyzed, four species (*L. intermedius*, *L. megastoma*, *L. tsanensis, L. truttiformis*) showed higher densities in Megech river mouths (Table 5.9; Appendix F). This suggests that even though these four species aggregate in both river mouths, Megech provides better breeding conditions than Dirma. This river has more tributaries, such as Dimaza, Keha, and Angereb, with gravel beds as compared to Dirma which has only one tributary, Aynekura, with gravel beds. Megech and its tributary Dimaza have higher oxygen content (Table 4.1), which is one of the critical demands by these spawning fish. This variation could also be associated with the greater discharge of water and availability of long stretch river channels with pebble and gravel beds in upstream reaches of the Megech River. Although it needs further investigation, the quantity of food available for juveniles could also be greater in Megech than in Dirma.

Spawning aggregations in both river mouths of all the above six species indicates absence of macro-spatial segregation i.e. it did not happen that a particular species utilizes one river mouth but not the other. Lack of macro-spatial segregation was also reported in the study conducted by de Graaf *et al.*(2005) in the southern tributary rivers of Lake Tana (Gelgel Abbay, Gelda, Gumara, and Rib). Seven species (*L. acutisrostris*, *L. brevicephalus*, *L. macrophtalmus*, *L. megastoma*, *L. platydorsus*, *L. tsanensis*, and *L. truttiformis*) were found to aggregate in the above four river mouths almost evenly.

Three species, *L. acutisrostris*, *L. macrophtalmus and L. platydorsus*, did form spawning aggregations (Table 5.1) in the tributaries of southern gulf of Lake Tana but not in Megech and Dirma Rivers. It is unlikely that in such a relatively widely dispersed stock to migrate from the northern part of the lake to the southern tributaries, as all the important conditions for spawning are also available in Dirma and Megech Rivers. The absence of these three and other species in those rivers needs another explanation (section 5.4). The occurrence of the above six species in the river mouths of the Dirma and Megech Rivers does not necessarily indicate absence of spatial segregation in their real breeding grounds.

The comparison of abundance of running species in the four upstream sites showed very significant spawning segregation (x^2, $p < 0.001$) among the six species (Table 4.4). Pairwise comparison of these species also indicated variation in spatial utilization for breeding in all the pairs (Appendix B), except for *L. truttiformis* and *L. tsanensis*. Three species, *L. brevicephalus*, *L. tsanensis* and *L. truttiformis*, were most abundant at Dimaza stream (Fig. 4.6b). Rare abundance of the latter two species at Megech River, above Dimaza's mouth (MUPS2) can also be used as strengthening evidence that these species utilize mostly Dimaza Stream as their major spawning ground. The few specimens ascending in Megech upstream above the mouth of the Dimaza (Fig. 4.6b: MUPS2) may spawn either in other tributaries, such as Keha, or in the gravel beds in the main channel. A few specimens of these two species caught in DUPS (Table 4.4) may spawn in Aynekura. Running fish of *L. intermedius* and *L. megastoma* were remarkably abundant in Dirma and Megech River upper Dimaza's mouth, but rare and absent, respectively, in Dimaza. This implies that these species most probably spawn in the main channels of the rivers or other upper tributaries. *L. brevicephalus* was almost equally abundant in Dimaza and MUPS2, indicating that it may spawn in other upper tributaries of the river. A similar result was obtained for this species in Gumara, it was equally abundant in all the tributary streams (Kizen, Dukolit or Wanzuma) but didn't spawn in the main channel (Palstra *et al*., 2004).

In summary, the results in this study clearly showed that macro spatial segregation, i.e. each species choosing its own river for spawning, was not evident in *Labeobarbus* aggregating in Megech and Dirma river mouths. However, in the breeding grounds (upstream reaches), except the two species (*L. tsanensis* and *L. truttiformis*), micro spatial segregation patterns occur among the species. The co-occurrences of two or more species in a breeding ground, for instance, *L. tsanensis*, *L. truttiformis*, *L. brevicephalus* in Dimaza stream do not necessarily indicate absence of reproductive segregation. These species could spawn at different times in the given stream.

The distribution patterns of the six river mouth aggregating species (Table 4.3) over the spawning months is significantly different (x^2, $p<0.05$ (Table 4.9) except for *L. intermedius*. This means that the relative abundance of a particular *Labeobarbus* species in Megech and Dirma river mouths varies from month to month in the spawning season. The pairwise comparison also showed that no two species aggregate in these river mouths with the same abundance in the spawning season (Appendix B). The weekly distribution patterns of aggregation in the river mouths given in Figure 4.8b indicates that *L. megastoma* was the first to aggregate (in the last week of July and the first week of August) followed by *L. tsanensis* and *L. truttiformis* (last week of August).The last species to aggregate were *L. brevicephalus* and *L. surkis* (peaked in the 3rd week of October). Temporal aggregation patterns in the river mouths on a monthly basis (Fig. 4.7a) indicate that three species (*L. megastoma*, *L. truttiformis*, and *L. tsanensis*) were declining in their abundance from August to October; however, this trend was reversed for *L. brevicephalus* and *L. surkis*. *L. intermedius* was equally abundant in all the three months. This shows that no temporal segregation was evident for this species. Studies conducted in other tributary rivers of Lake Tana also revealed temporal spawning segregation in *Labeobarbus*.

De Graaf *et al*. (2005) reported the appearance of different labeobarb species at different times during the spawning season in Gelgel Abbay, Gelda, Gumara, and Rib River mouths. However, the sequence of occurrence of species is slightly different from the results obtained in Dirma and Megech. In the above four river mouths *L. tsanensis* was the first to aggregate followed by *L. truttiformis* and lastly *L. brevicephalus* and *L. macrophtalmus*. This difference is most probably due to limited sampling frequency (twice a month in the spawning season) as compared to the weekly sampling done in Dirma and Megech. As the gap between consecutive samplings is wider, the possibility to miss some peaks of aggregations will be higher since these species do not spend long time (Fig. 4.8) in the river mouths to migrate upstream, i.e. in most cases, a species is simultaneously abundant in the river mouths and upstream areas at a given instant.

Temporal variation in upstream migration in Dirma and Megech Rivers was also evident among the six (Table 4.2) most abundant species. Pairwise comparison among these species indicated that no two species migrate together except *L. tsanensis* and *L. truttiformis* (Appendix B). These two species were segregated neither spatially nor temporally; therefore, there must be another mechanism for their assortative mating. The sequence of the migration pattern to the upstream reaches of Dirma and Megech Rivers was determined based on weekly catches on the four upstream sampling sites (pooled). The first species to run in the rivers were *L. truttiformis* and *L. tsanensis*, starting from the second week of August, with most running fish in the last week of August and the first half of September (Fig. 4.8a). The second river spawner was *L. megastoma*, the highest number of running specimens were seen in the second week of September. This species, although it was the first to aggregate in the river mouths, was not found to be the first to ascend. *L. megastoma* was also the first to migrate in Gumara upstream (Palstra *et al.,* 2004). Most probably this species may spawn in the flood plains or lower stretches of our sampling sites in Dirma and Megech Rivers. Its limited catch (14 specimens) in the upstream sites corroborates this assumption. The last spawners were *L. brevicephalus* and *L. nedgia*, with the highest running fish observed in the third week of October. In Gumara River, the second species to migrate up were *L. acutirostris* and *L. tsanensis*, *L. truttiformis* followed them, and then *L. brevicephalus* comes next to it. The last river spawner in this river was *L. macrophtalmus*.

If we compare and contrast this study with the results obtained in Gumara upstream (Palstra *et al*., 2004), four species (*L. brevicephalus, L. megastoma, L. tsanensis*, and *L. truttiformis*) were common. However, *L. intermedius* was absent in Gumara but abundant in the results obtained in Dirma and Megech. *L. macrophtalmus* and *L. acutirostris* were found to migrate in Gumara River but not in Dirma and Megech Rivers. The remaining eight species of *Labeobarbus* were absent in the upstream reaches of the three rivers.

5.4 Missing Species

In the previous studies of spawning migration of Lake Tana's *Labeobarbus* (Nagelkerke and Sibbing, 1996; Dgebuaze *et al*., 1999; Palstra *et al*., 2004; de Graaf *et al*., 2005), seven species (*L. crassibarbis*, *L. dainellii*, *L. gorgorensis*, *L. gorguari*, *L. longissimus*, *L. nedgia*, and *L. surkis*) did not form aggregation in Gelgel Abbay, Gelda, Gumara, and Rib River mouths and upstream areas. Despite quite extensive and systematically designed fishing efforts throughout the year in Megech and Dirma tributary rivers, out of the seven missing species reported above, *L. surkis* was found to form aggregation in these two river mouths. But it was absent in the upstream sites of the two rivers. Three species (*L. acutirostris, L. macrophtalmus, L. platydorsus*) which formed spawning aggregations in the above mentioned four rivers were absent in Dirma and Megech River mouths. However, these species are common in the fishermen's catch in the northern part of the lake (Pers. obs.).

In general, two hypotheses can be pointed out for all the eight missing species (*L. crassibarbis*, *L. dainellii*, *L. gorgorensis*, *L. gorguari*, *L. longissimus*, *L. nedgia*, *L. platydorsus*, and *L. surkis*) in the upstream reaches of all rivers studied so far and additional two species, *L. acutirostris* and L. *macrophtalmus*, (in Dirma and Megech) and *L. intermedius*, (in Gumara) upstream areas (Palstra *et al*., 2004):

1. They may spawn in a smaller perennial river Arno-Garno (Fig. 3.1), one of the seven perennial rivers discharging to Lake Tana. This possibility is very remote in such a wide lake for all the missing species to aggregate to this river only. From the information obtained from Gorgora fishery experts, from the interviews of local fishermen, and observations that we made on the catches of the fishermen in September and October 2004 at Enfranze town (the main fish market outlet in the area) none of these species were migrating to this river.
2. These fish species may spawn in the lake (lacustrine spawning). Lacustrine spawning, a novel derived reproductive strategy in cyprinids, seems to be evolved in these missing *Labeobarbus* species of Lake Tana. These species probably complete their whole life history, including reproduction, in the lake. It is even too difficult to confidently conclude that *L. megastoma* spawns only in the upstream reaches of rivers. The catches of this species in all the upstream areas were all very low (Table 5.1) as compared to the stock abundance in the lake.

By taking into consideration the following main criteria:

- the absence of a particular *Labeobarbus* species in the river mouths and/or upstream reaches,
- occurrence of a species in one affluent river mouth and/or upstream reaches but not in another,
- observations of running females within the lake but away from any tributaries,

- comparisons of relative abundance of a particular species in the lake and spawning area,
- frequent appearance of hybrids between two species,
- comparison of relative abundance in the spawning and non-spawning season in the river mouths and upstream reaches, the Lake Tana's 15 species of *Labeobarbus* can be classified into three categories of reproduction:

1. Obligatory riverine spawners
2. Generalists (spawning in the lake and tributary rivers)
3. Lacustrine spawners.

L. brevicephalus, *L. tsanensis* and *L. truttiformis* can be considered as obligatory riverine spawners. This is due to the fact that they are abundant in the river mouths and upstream reaches during the spawning season (Table 5.1) and no running specimens of these species were observed in any part of the lake away from the river mouths. This is the most common reproductive strategy in most African *Labeobarbus* (Skelton, 2001).

Five species (*L. acutirostris, L. intermedius*, *L. macrophtalmus*, *L. megastoma*, and *L. platydorsus*) can be classified as generalist spawners. It seems that these species are under transition (incipient) from riverine (ancestral) spawning to lacustrine (derived) spawning. *L. acutirostris, L. macrophtalmus,* and *L. platydorsus* were smaller in their catch in Gumara upstream (Palstra *et al*., 2004) and absent in Dirma and Megech (Table 5.1). the catch of *L. megastoma* was too small (Table 4.4) in Dirma and Megech Rivers, but it is one of the most abundant species in the lake (Nagelkerke, 1997). This species showed no significant difference in abundance in the spawning and non-spawning season (Table 4.3). Hybrids of

L. acutirostris and *L. platydorsus* and *L. acutirostris* and *megastoma* were common in the catches (Pers. obs.; Sibbing, Pers. com.) which most probably indicates the utilization of the same breeding ground. *L. intermedius* was apparently 'absent' in Gumara upstream (Palstra *et al*., 2004) but running individuals were abundant in the upstream sites of Dirma and Megech Rivers. A few hundred running male and female specimens of this species were caught close to the papyrus fields to the west of Bahir Dar (de Graaf *et al*., 2003). This was also extremely abundant in the river mouths as compared to upstream sites, which indicates that some part of the population may be spawning in the littoral region adjacent to the river mouths. This reproductive strategy is also observed in other species. Al-Hamed (1972) reported that *B. sharpeyi* mostly spawns in the lake as well as in marshes on the alluvial plain depositing its eggs under submerged parts of plants or other objects, but to some extent in the lower reaches of Tigris and Euphrates Rivers. *B. anoplus* is another example in Lake LeRoux. It migrates upstream but also spawns near the shore (Cambray and Bruton, 1984).

The remaining seven species (*L. crassibarbis*, *L. dainellii*, *L. gorgorensis*, *L. gorguari*, *L. longissimus*, *L. nedgia*, and *L. surkis*) are considered as lacustrine spawners. They were almost totally absent in the upstream reaches of the rivers (Table 5.1). Except *L. surkis*, all do not aggregate in the river mouths. *L. surkis*, although it aggregated in the river mouths, was absent in the upstream areas of Dirma and Megech Rivers. Running specimens of this species were caught near 'Mendaba', west of Gorgora, where there is no river around this monastery (GFALRSC, unpublished data). Running individuals of this species were also observed far away Gelda river mouth and floodplains covered by dense macrophytes (Nagelkerke and Sibbing, 1996). Running *L. dainellii* specimens were observed in the littoral areas of Lake Tana (Nagelkerke and Sibbing, 1996). Most probably these species breed in the lake and/or adjacent Fogera and Dembea Floodplains and deposit their eggs on sand or rocks, near roots of plants on shore or under flooded terrestrial vegetation, as it is common in other cyprinids (Mills, 1991). Although marginal vegetation spawning sites are more likely to suffer oxygen depletion (Mills, 1991), it shields juveniles and larvae from predators.

The evolution of lacustrine spawning in cyprinids is a novel adaptation and very few reports are available among *Barbus* and *Labeo* species. *B. longiceps* (Fishelson *et al*., 1995) in the Middle East and *Labeo horie* in Lake Chamo (Elias Dabebo *et al*., 2003) were confined in the littoral zones of the lakes for spawning, but no migration was observed to tributary rivers.

Most lacustrine spawners in Lake Tana are ecologically restricted in the littoral zone. Particularly *L. dainellii*, *L. gorguari*, *L. longissimus*, and *L. nedgia* are associated with rocky substrates and have patchy and limited distribution patterns, occupying less than 2% of the lake area (Nagelkerke and Sibbing, 2000). Spawning of these fish species in such rocky habitats or adjacent flood plains rather than remote and degrading rivers renders their offspring to live under optimal trophic conditions. On the other hand, obligate riverine spawners and generalists, smaller in body size, are widely distributed throughout the littoral and offshore waters (de Graaf, 2003). This implies that like their ecological segregation, macro-spatial spawning segregation among the three categories does occur. Whether the lacustrine spawners are spatially and/or temporally segregated should be investigated. The presence of considerable overlapping of two or more species temporally and spatially during spawning such as *L. tsanensis* and *L. truttiformis* or, if encountered in the species of lacustrine spawners, does not guarantee absence of reproductive segregation. Reproductive isolation between these species could be achieved through size-assortative mating; this is common in cichlids (Schliewen *et al*., 2001).

Table 5.1 *Labeobarbus* species composition in river mouths and upstream tributary rivers spawning areas.

	River Mouths			**Upstream Rivers**			
Source	This study	De Graaf (2003)	Nagelkerke and Sibbing (1996)	This study	Palstra *et al.*, 2004	Dgebuadze et al. (1999)	Nagelkerke and Sibbing (1996)
Sampling period	Dec 2003 –Nov 2004	Jul-Oct 1999 Jul-Oct 2000	Sep-Oct 1993 Sep-Oct 1994	Aug-Oct	Sep-Oct 1999	Sep-Nov 1994 Aug-Oct 2000	Sep 1994
Sampling frequency	Monthly (Nov-Jun), bimonthly (Jul), weekly (Aug-Oct)	Twice per month	3 times Sep 4 times Oct	weekly	Twice per week	Few times	Once
Sampling area	Dirma and Megech	Gumara, Gelda, Rib, and Gelgel Abbay	Gumara	1tributary and 2 sites in Megech main channel & 1 main channel in Dirma	3 tributaries and 4 locations in main channel of Gumara	1 tributary and 1 location in main channel of Gumara	1 location in main channel of Gumara
Sample size	4280	8147	1530	703	4897	540	70
Species composition	%	%	%	%	%	%	%
L. tsanensis	11.4	15.6	18	16.1	52	33[a]	42
L. brevicephalus	19.9	14.5	46	20.3	29	36[b]	27
L. truttiformis	8.2	2.5	1	18.6	5.6	0.5	19
L. megastoma	3.7	2.4	3	2.0	5.0	2	8
L. macrophtalmus	0.4	4.7	23	0.01	4.9	19	0
L. acutirostris	1.1	7.7	5.5	0	3.0	8	0
L. platydorsus	0.7	4.0	1	0	0.7	2	2
L. gorgorensis	0.5	0.7	0.5	0	0.2	0.2	2
L. crassibarbis	1.1	0.4	0.5	0.4	0.1	0.3	0
L. dainellii	0.05	0.1	0	0	0	0	0
L. gorguari	0	0.9	0.3	0	0	0	0
L. surkis	4.0	0.5	0.5	0.7	0	0	0
L. nedgia	0.3	0.9	0.5	3.7	0	0	0
L. longissimus	0.6	0.5	0	0.6	0	0	0
L. intermedius	42.8	44.7	0	37.4	0	0	0

[a] Referred to as morphotype ''normal intermedius'' in Dgebuadze *et al*. (1996) but named as *L. tsanensis* according to Nagelkerke and Sibbing (2000).

[b] Referred to as ''precocious intermedius'' in Dgebuadze *et al*. (1996) but named as *L. brevicephalus* according to Nagelkerke and Sibbing (2000).

5.5 Length-weight relationship, condition factor and Length at Maturity

There was curvilinear relationship between total weight and fork length in the *Labeobarbus* species of Lake Tana. The regression coefficients obtained for each species were near the cube value (b = 3). The findings obtained are in agreement with the "theoretical" cube law (Allen 1938 cited in Demeke Admassu, 1990), which means growth in these fish species is isometric (weight increases at a rate of about a cube of increase in length). A similar result was obtained for these species by Naglekerke *et al*. (1994) in Lake Tana. The result was also in agreement with the findings obtained by Demeke Admassu and Elias Dadebo (1997) for *L. intermedius* from Lake Awassa.

The mean Fulton's condition factor (FCF) of the *Labeobarbus* species in Lake Tana showed seasonal variation (Mann-Whitney U test, $P < 0.05$) (Appendix E). It was lower during the peak spawning season (August and September) in both sexes (Table 4.13). The reduction was higher in the case of females than males. This is probably because the energy expenditure for eggs is costly for females than males (Fryer and Iles, 1972). The condition of the fish can be affected by various factors such as environment, food quantity and quality, rate of feeding, disease and reproductive activity (Bowen, 1979; Getachew Teferra, 1987; Paye, 1986). During the breeding season the spawning stocks mobilize and transfer body reserves to the gonads. In addition to energy transfer, feeding is minimized during spawning as the feeding and breeding grounds mostly do not coincide. However the FCF computed for *L. intermedius* in Lake Awassa was (0.95 ± 0.13 SE) in the dry season and 0.85 ± 0.18 in the wet season (Demeke Admassu and Elias Dadebo, 1997). The relatively higher value of FCF in Lake Tana as compared to Lake Awassa for *L. intermedius* may be genetic difference (as they are virtually different species) or may be the size difference of the two lakes. In Lake Tana, being the largest lake, this fish will have minimized competition of feeding and breeding grounds.

The determination of length at maturity (FL_M) is an important factor not only to predict size-assortative mating but more importantly to implement management measures, such as mesh size restrictions, in order to prevent the over exploitation of the reproductive portion of the *Labeobarbus* population. Unfortunately, it was impossible to estimate length at maturity for some species in this study due to the small overall sample size (*L. acutirostris*, *L. crassibarbis*, *L. dainellii*, *L. gorgorensis*, *L. gorguari*, *L. longissimus*, *L. macrophtalmus*, *L. megastoma*, *L. nedgia*, and *L. platydorsus*) and lack of small-sized immature male specimens (*L. brevicephalus*, *L. intermedius*, and *L. surkis*). Fortunately, recently various authors in the previous studies estimated length at maturity of the Lake Tana *Labeobarbus* species (Table 5.2).

The result of FL_M obtained in this study is in agreement with Tesfaye Wudneh *et al*. (1999) for *L. tsanensis* and de Graaf *et al*. (2003) for *L. brevicephalus*. However, for the remaining species the FL_M estimated by Nagelkerke and Sibbing (1996) and de Graaf *et al*. (2003) were higher than the results of this study. In fact, it is very difficult to pin point the exact reason for the variation within this very short period of time (~ two years). In most cases, fishing pressure is considered as the major factor to induce the reduction in length at maturity (Cowx, 1990). However, this could not be the reason in our case since fishing is subsistence traditional reed boat fishery. Another equally important factor is change in environmental conditions. Most probably the 2003 drastic lake level reduction (about 3 m) could have resulted in differential growth of successive annual cohorts of labeobarbs when facing such environmental conditions. This can be substantiated by the large difference in size at maturity of *L. surkis*. This species feed on macrophytes, which are the most immediately affected entities due to extreme reduction of water level. Inter-annual rapid change in length at maturity due to changes in environmental conditions was reported in the cyprinids of the Guadiana Basin (Portugal) (Pires *et al*., 2000).

In general, most fish species are characterized by high plasticity in some of their reproductive traits (Stearns, 1992; Alheit, 1989). The spawning tactics are to adjust with the prevailing conditions. This is based on the ability of the fish to change rapidly one or more of the characteristics, such as age or length at maturity, spawning frequency, and fecundity whenever environmental conditions require or permit it.

Table 5.2 Length at maturity (FL$_{50\%}$) of *Labeobarbus* species from Lake Tana as determined by different authors at different times.

		FL$_{50\%}$ (cm)			
Species	Sex	This study	Nagelkerke and Sibbing (1996)	Tesfaye Wudneh *et al.* (1999)	De Graaf *et al.* (2003)
L. acutirostris	♀	-	28.3	A*	33
	♂	-	26.6		25.5
L. brevicephalus	♀	17.53	22.5	-	18.2
	♂	-	-	-	-
L. crassibarbis	♀	-	-	-	44.1
	♂	-	-	-	28
L. gorgorensis	♀	-	-	-	46
	♂	-	-	-	-
L. intermedius	♀	22.57	-	-	26
	♂	-	-	20.5	-
L. longissimus	♀	-	28	-	37.8
	♂	-	-	-	-
L. macrophtalmus	♀	-	-	A*	27
	♂	-	-	-	19.6
L. megastoma	♀	-	-	-	36.1
	♂	-	-	-	26.5
L. nedgia	♀	-	-	-	29.7
	♂	-	-	-	19.8
L. platydorsus	♀	-	-	A*	37
	♂	-	-	-	24.4
			-		
L. surkis	♀	18.39	-	-	32.9
	♂	-	-	-	-
L. truttiformis	♀	20.20	-	-	26.6
	♂	19.68	-	-	21.8
L. tsanensis	♀	20.88	24	-	26
	♂	20.43	22.1	20.4	17.7
L. dainellii	♀	-	-	-	24.8
	♂	-	-	-	22.1
L. gorguari	♀	-	-	A*	34.3
	♂	-	-	-	-

A* referred as gross estimation of FL$_{50\%}$ ranging from 23.4-24.5 cm.

5.6 Fecundity

The information about fecundity of pelagic fish species in African lakes is scarce (Marshall, 1995). This problem is severe in the case of the endemic *Labeobarbus* species of Lake Tana. As there is still no clear fecundity data for any of the 15 species, in this study an attempt was made to include the fecundity estimation of two species of *Labeobarbus*. The eggs of *L. brevicephalus* and *L. truttiformis* were similar in their color (whitish-yellow) and eggs are adhesive. Within a mature ovary all the eggs are almost similar in size. This indicates that the eggs are shed once; there is no multiple or fractional spawning. Absolute fecundity in both species is curvilinearly related with fork length, gonad weight, and total body weight (Fig. 4.10). *L. truttiformis* lays more eggs than *L. brevicephalus*, but their relative fecundity is almost similar (Table 4.11). The higher absolute fecundity of *L. truttiformis* is related to its bigger body size compared to *L. brevicephalus*; consequently, this results in larger ovary with more eggs. When the size effect of the fishes is ruled out (relative fecundity), their fecundity remained the same.

Fecundity of *Labeobarbus* in other African lakes is moderately high (Skelton *et al*., 1991). Other *Labeobarbus* like *Labeobarbus aeneus* and *L. kimberleyensis* in Vaal-Orange River drainage system fecundity estimated is as many as 60, 000 eggs (Gaigher, 1976; Skelton, 2001) for larger females on average. This is far higher than the two species of Lake Tana (Table 4.11). The main cause for such variation, at the genus level, may be due to the unstability of the Orange River as fast growth, early maturity and high fecundity are characteristics of such environments (Oliva-Paterna *et al*., 2002).

5.7 Fisheries Management

The single annual upstream migration reproductive strategy of African *Labeobarbus, Barbus*, and *Labeo* species make them highly vulnerable as fishermen target the spawning aggregations (Skelton *et al*., 1991). Dramatic reduction (75%) in total abundance, both in number and biomass of *Labeobarbus* adults and (90%) in the number of juveniles was observed in Lake Tana species within ten years (1991 – 2001) (de Graaf *et al*., 2004). The most likely explanation for such drastic reduction is recruitment overfishing. This overfishing occurs due to severe and unregulated over exploitation of spawning aggregations, resulting in radical decrease of recruits (Craig, 1992; Gabriel *et al*., 1989).

Modernization of Lake Tana's fishery did not appear until the end of the 1980s. It was purely traditional subsistence reed boat fishery. The fishermen were restricted in the shore areas and used locally-made fish traps, hook-and-line, and small gillnets (15 – 20 m). However, in 1986, motorized boats and modern fishing gears (nylon gillnets) were introduced as part of Lake Fisheries Development Project (LFDP), which was initiated by the Ethiopian Ministry of Agriculture, the Ethiopian Orthodox Church, and two Dutch NGOs (ISE-Urk and ICCO-Zeist). This created an opportunity for local fishermen to extend their fishing areas even to distant river mouths, and the total annual catch increased from 39 MT in 1987 to 360 MT in 1997 (Tesfaye Wudneh, 1998). But, this modern fishery (especially the use of motorized boats) has been restricted to Bahir Dar area (in the southern part of the lake).

Although the current fishing activity in the northern part of Lake Tana (Enfranz, Gorgora, and Delgi areas) still uses reed boats, the number of fishermen (about 185 with 4 nylon gillnets each on average) is growing in the area (Unpublished data). Due to lack of motorized boats, the local fishermen (mostly the Woito ethnic group) living around the shore areas target the fishes at the mouths of Dirma and Megech Rivers in the Gorgora area (Pers. obs.). The most preferred fish by the local inhabitants are the *Labeobarbus* species; hence they are the most targeted fish by fishermen as they fetch more money. Therefore, except *L. brevicephalus* (due to its smaller size), the five river aggregating species of *Labeobarbus* are highly vulnerable for fisheries.

Figure 5.1 Farming activities in Megech River banks near Lake Tana (Photo taken 14 February 2004).

In the upstream spawning areas of labeobarbs in Dirma and Megech Rivers, fishing activity currently is quite limited. Only a few people accustomed to fish most often use hook-and-line fishing gears for subsistence purposes. Nevertheless, the potential problem is the degradation of the spawning rivers. Diversion of the rivers for irrigation by local farmers (Fig. 5.1) and sand extraction for construction (Gondar town) in Megech River has altered the rivers' natural flows. Juvenile fish are usually stranded in the irrigated farmlands when the rivers are completely diverted (pers. comm. with farmers). At some stretches of Dimaza and Megech, the rivers' natural channels are changed due to intensive digging for sand (Pers. Obs.). Unless the gill net fishery in the river mouths during the spawning season stops and the rivers' degradation problem is at least curved, Lake Tana's *Labeobarbus* species, which aggregate in the river mouths, will follow the same path of collapse like other cyprinids in other lakes.

Fishing activities on spawning aggregations in the affluent river mouths had severely impacted some cyprinids in Africa (Ogutu-Ohwayo, 1990; Ochumba and Manyala, 1992). For instance, *Labeo altivelis* populations were highly deteriorated due to overfishing during the spawning runs up the Luapula River from Lake Mueru (Zambia). A similar situation was also observed in Lake Victoria, *L. victorianus* and *B. altianalis* has reduced populations due to overfishing of spawning aggregations. *Labeo horie* is also facing the same problem in Lake Chamo (Elias Dadebo *et al*., 2003). Therefore, these conditions necessitate urgent management measures to be taken to conserve this endemic cyprinid species flock.

For any policy to be effective the full participation of the various stakeholders, from its commencement to implementation, is invaluable. The executive bodies of the Amhara Regional fishery legislation should create awareness in places where active fishery activities are in operation, such as the northern part of Lake Tana. Such executive bodies should also consider the recommendations given by researchers.

From arrays of fishery management options, as recommended for Gumara River (de Graaf *et al*., 2004), closing gillnet fishery during spawning months (from July to October), in Dirma and Megech river mouths, surrounding flood plains, and upstream spawning areas is thought to be an appropriate management measure. This management option is simple to put in practice, cheap to implement, enforce and control. Another advantage is that all the *Labeobarbus* species can be lumped and treated as 'one' since all species generally spawn from August to October. This option is also advantageous for the fishermen as it will not create a total loss of income or food, since they can still fish in the non-spawning areas during the spawning months.

Besides implementing the management measures, continuous monitoring of commercial catches, and doing regular exploratory sampling programs, is of paramount importance to evaluate the outcomes of implemented management regulations.

6. Conclusions and recommendations

6.1 Conclusions

After year round intensive data collection on the spawning migration of the endemic Lake Tana's *Labeobarbus* species to Dirma and Megech tributary rivers, the following main features were concluded:

- The spawning season generally for all labeobarb species was from August to October. One exception was *L. intermedius*, which spawns throughout the year, but its peak spawning is from August to October like the rest of *Labeobarbus* species.
- Six species (*L. brevicephalus*, *L. intermedius*, *L. megastoma, L. surkis*, *L. tsanensis* and *L. truttiformis*) formed spawning aggregations in Dirma and Megech River mouths. However, *L. surkis* never migrated to upstream reaches of these rivers, rather *L. nedgia*, which was rare in the river mouths was abundant in Megech River.
- No macro-spatial segregation (each species choosing its own tributary river for spawning) was observed among the aggregating species. Nevertheless, they apparently showed spatial segregation at micro level in the upstream reaches of rivers, except *L. tsanensis* and *L. truttiformis*.
- The aggregating species show temporal segregation patterns in their aggregation in the river mouths, except *L. intermedius*. *L. megastoma* was the first to aggregate followed by *L. tsanensis* and *L. truttiformis*. *L. brevicephalus* and *L. surkis* were the last to aggregate. However, the first river spawners were *L. truttiformis* and *L. tsanensis* and *L. megastoma* follows them. *L. brevicephalus* was the last to ascend to river upstream reaches.
- Based on the results obtained in this and previous studies, the Lake Tana's *Labeobarbus* spawning strategies can be classified into three: (1) three species are obligate riverine spawners (*L. brevicephalus L. truttiformis* and *L. tsanensis*), (2) five are considered as

generalists (spawning in the river and in the lake) (*L. intermedius, L. acutirostris, L. megastoma, L. macrophtalmus, L. platydorsus*) and (3) the remaining seven are considered as lacustrine spawners (*L. crassibarbis, L. dainellii, L. gorgorensis, L. gorguari, L. nedgia, L. surkis,* and *L. longissimus*).

- *L. truttiformis* has more eggs and ova have larger diameter than *L. brevicephalus*. Absolute fecundity was curvilinearly related with FL, body weight, and gonad weight in both species.
- Length-weight relationships were curvilinear for the six species of *Labeobarbus* from Lake Tana.
- FCF was significantly lower in the peak spawning season (August to October) as compared to the non-peak spawning months.
- This study, in general, will possibly indicate some evolutionary evidences on the reproductive isolation of *Labeobarbus* species of Lake Tana through assortative mating. It will also provide useful information for other researchers to study fish migration in Lake Tana or in other lakes and rivers.

6.2 Recommendations

⇒ The actual breeding ground of lacustrine spawning *Labeobarbus* species of Lake Tana has to be investigated urgently, to put in place sound management decisions.

⇒ The nursery ground of the juveniles of *Labeobarbus* must be determined to assure future recruitment as the breeding rivers are under degradation.

⇒ Arno-Garno, the other perennial tributary river should be studied as to which species of *Labeobarbus* spawns there.

⇒ Fecundity studies for the remaining 13 species of labeobarbs are required.

⇒ The detailed biology of *L. nedgia* in Megech River needs to be investigated in order to compare and contrast with the Lake Tana's population.

⇒ Almost no management measure is in place in the northern part of Lake Tana. At least closure, for fishery purposes, of Dirma and Megech River mouths during the spawning months (July to October) needs to be implemented to minimize recruitment overfishing.

⇒ Establishment of catch and effort data recording system must be the first priority in the northern part of Lake Tana, as fishing is newly developing activity in the area.

⇒ Excess sand and water extraction from the spawning rivers must be minimized.

⇒ Distance of migration of *Labeobarbus* needs to be studied further using more accurate methods such as telemetry.

7. References

Abebe Amha. (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.

Abebe Amha, Alemu Assefa. (2002) The fate of the barbs of Gumara River, Ethiopia. SINET: Ethiop J Sci 259(1):1-18.

Abebe Getahun. (2000) Systematic studies of the African species of the genus *Garra* (Pisces: Cyprinidae). PhD thesis, City University of New York.

Alekseyev SS, Dgebuadze YY, Mina MV, Mironovsky AN. (1996) Small 'large barbs' spawning in tributaries of Lake Tana: What are they? Fol Zool 45 (suppl.1): 85-96.

Al-Hamed MI. (1972) On the reproduction of three Cyprinid fishes of Iraq. Fresh Biol 2: 65-76.

Alheit J, Alarcon VH, Macewicz BJ. (1984) Spawning frequency and sex ratio in the Peruvian anchovy, *Engraulis ringens*. California Cooperative Fisheries Investigation Report 25: 43-52.

Alheit J. (1989) Comparative spawning biology of anchovies, sardines and sprats. Con Int Explor Mer 191: 7-14.

Al-Kholy AA. (1972) Aquatic resource of Arab countries. Alesco Science Monograph Series, pp. 451.

Bagenal TB. (1978) Aspects of fish fecundity. In: ecology of freshwater fish production, S.Gerking (ed), Oxford, Black-well, pp.75-102.

Bagenal TB, Tesch FW. (1978) Age and growth. In**:** Methods for assessment of fish production in Fresh waters, Bagenal TB (ed), IBP Hand book No.3, Oxford, Blackwell, pp.101-136

Beadle LC. (1981) Lake Tsana. In: The inland waters of tropical Africa: an introduction to tropical liminology, Beadle LC (ed), London, Longman, pp. 191-193.

Berrebi P, Tsigenopoulos CS. (2003) Phylogenetic organization of the genus *Barbus* sensu stricto. In: The freshwater fishes of Europe Cyprinidae 2, Banarescu PM, Bogutskaya NG (eds), Part II, AULA- Verlag, Wiebelsheim, Germany, pp. 11-22.

Berrebi P, Valiushok D. (1998) Genetic divergence among morphotypes of Lake Tana (Ethiopia) barbs. Biol J Linn Soc, 64: 369-384.

Birhanu Teshale, Eshete Dejen, Mohammed Akmel.(2002) Sedimentation and its impact on aquatic community in a large shallow tropical lake: the case of Lake Tana (Ethiopia). 5th sediment quality assessment symposium, Chicago, USA.

Bowen SH. (1979) A nutritional constraint in detritivory by fishes: the stunted growth population of *Sarotherodon mossambicus* in Lake Sibaya, South Africa. Ecol. Monogr. 49: 17-31.

Cambray JA, Bruton MN. (1984) The reproductive strategy of a barb, *Barbus anoplus* (Pisces: cyprinidae), colonizing a man-made lake in South Africa. J. Zool Lond 204: 143-168.

Chorowicz J, Collet B, Bonavia FF, Mohr P, Parrot JF, Korme T. (1998) The Tana basin, Ethiopia: intra-plateau uplift, rifting and subsidence. Technophysics 295: 351-367.

Cowx IG. (1990) The reproductive tactics of roach, *Rutilus rutilus* (L.) and dace, *Leuciscus leuciscus* (L.) populations in the rivers Exe and Culm, England. *Polsk Arch Hydrobiol,* 37: 193-208.

Craig FJ. (1992) Human-induced changes in the composition of fish communities in the African Great Lakes. Rev Fish Biol Fisheries 41: 369-402.

De Graaf M, Eshete Dejen, Sibbing FA, Osse JWM. (2000). *Barbus tanapelagius*, a new species from Lake Tana (Ethiopia): its morphology and Ecology. Envi Biol Fish 59: 1-9.

De Graaf M, Machiels M, Tesfaye Wudneh, Sibbing FA. (2003) Length at maturity and gillnet selectivity of lake Tana's *Barbus* species (Ethiopia): implications for management and conservation. Aquatic Ecosystem Health & Management 6(3): 325-336.

De Graaf M, Marcel, AM, Machiels M, Tesfaye Wudneh, Sibbing FA. (2004) Declining stocks of Lake Tana's endemic *Barbus* species flock (Pisces: Cyprinidae): natural variation or human impact? Biol cons 116: 277-287.

De Graaf M. (2003) Lake Tana's piscivorous *Barbus* (Cyprinidae, Ethiopia) Ecology. Evolution. Explitation. PhD thesis, Wageningen Agricultural University, The Netherlands.

De Graaf M, Nentwich D, Osse JWM, Sibbing FA. (2005) Lacustrine spawning: is this a new reproductive strategy among 'Large' African Cyprinid fishes? J Fish Biol 66: 1214-1236.

De Silva SS, Schu J, Kortmulder K. (1985) Reproductive biology of six *Barbus* species indigenous to Sri Lanka. Envi Biol Fishes 12(3): 201- 218.

Demeke Admassu. (1990) Some morphometric relationship and the condition factor of *Oreochromis niloticus* (Pisces: *Cichlidae*) in Lake Awassa, Ethiopia. SINET: Ethiop J Sci 13(2): 83-96.

Demeke Admassu and Elias Dadebo. (1997) Diet composition, Length-weight relationship and condition factor of *Barbus* species Rüippell,1836 (Pisces: Cyprinidae) in Lake Awassa, Ethiopia. SINET: Ethiop J Sci 20 (1):13-30.

Dgebuadze YY, Golubtsov AS, Mikheev VN, Mina, MV. (1994) Four fish species new to the Omo-Turkana basin, with comments on the distribution of *Nemacheilus abyssinicus* (Cypriniformes: Balitoridae) in Ethiopia. Hydrobiologia 286: 125-128.

Dgebuadze YY, Mina MV, Alekseyev SS, Golubtsov AS. (1999) Observations on reproduction of the Lake Tana barbs. J Fish Biol 54: 417-423.

Dixon B, Nagekerke LAJ, Sibbing FA, Egberts E, Stet RJ M. (1996) Evolution of the MHC class II b chain-encoding genes in the Lake Tana barbel species flock (*Barbus intermedius* complex). Immunogenetics 44: 419-432.

Elias Dadebo, Ahlgren G, Ahlgren I. (2003) Aspects of reproductive biology of *Labeo horie* Heckel (Pisces: Cyprinidae) in Lake Chamo, Ethiopia. Afri J Ecol 41: 31-38.

Eshete Dejen. (2003) Ecology and Potential for Fishery of the small barbs (Cyprinidae, Teleostei) of Lake Tana, Ethiopia. PhD thesis, Wageningen Agricultural University, The Netherlands.

Eshete Dejen, Osse JWM, Sibbing FA. (2003) Ecological position of 'small barbs' and their potential for fisheries: An option to reduce fishing pressure on 'large barbs' of Lake Tana (Ethiopia)? Aquat Ecos Health & Manag 6(3): 337-342.

Eshete Dejen, Vijverberg J, Nagekerke, LAJ, Sibbing FA. (2004) Temporal and spatial distribution of microcrustacean zooplankton in relation to turbidity and other environmental factors in large tropical lake (L. Tana, Ethiopia). Hydrobiologia, 513: 39-49.

Fishelson L, Gorn M., Van Vuren J, Manelis, R. (1995) Some aspects of the reproductive biology of *Barbus* spp., *Capeota damascina* and their hybrids (Cyprinidae, Teleostei) in Israel. Hydrobiologia 317: 79-88.

Fryer G, Iles TD. (1972*)* The cichlid Fishes of the Great Lakes of Africa: Their Biology and Evolution. Oliver and Boyd, Edinburgh, pp. 66-72.

Gabriel WL, Sissenwine MP, Overholtz WJ. (1989) Analysis of spawning stock biomass per recruite: an example for Georges Bank haddock, North Amer J Fish Manag 9: 383-391.

Gaigher IG. (1976) The reproduction of *Barbus kimberleyensis* (Pisces: Cyprinidae) in the Hardap Dam, South West Africa. Zool Afr 11(1):97-110.

Getachew Teferra. (1987) Food, nutrition and digestive efficiency in *Oreochromis niloticus* Linn. (Pisces:Cichlidae) in Lake Awassa, Ethiopia. PhD thesis, University of Waterloo, Ontario.

Golubtsov AS, Krysanov EY. (1993) Karyological study of some cyprinid species from Ethiopia. The ploidy difference between large and small *Barbus* of Africa. J Fish Biol. 42: 445-455.

Greenwood PH. (1976) Fish fauna of the Nile. In: The Nile, biology of an ancient river, Rzóska J (ed), Dr. W. Junk Publishers, The Hague, pp. 127-141.

Greenwood PH. (1984) What is a species flock? In: Evolution of fish species flocks, Echelle, AA, Kornfield I (eds), University of Maine Press, Orono, pp. 13-19.

Harikumar S, Padmanabhan KG, John PA, Kortmulder K. (1994) Dry-season spawning in cyprinids fish of South India. Envi Biol Fishes 39: 129-136.

Heins DC, Rabito FG. (1986) Spawning performance in North American Minnows: direct evidence of multiple clutches in the genus *Notropis*. J Fish Biol 28: 343-357.

King M.(1995) Fisheries Biology, Assessment and management. Fishing news Books Blackwell Science ltd. pp. 341.

Kornfield I, Carpenter KE. (1984) Cyprinids of Lake Lanao, Philippines: taxonomic validity, evolutionary rates and speciation scenarios. In**:** Evolution of fish species flocks, Echelle AA, Kornfield I (eds), Orono press, Maine, pp. 69-83.

Lamp H, Mohammed Umer, Bates R, Davies S, Eshete Dejen, Coombes p, Marshall M, Zelalem Kubesse, Kebede Seifu. (2004) Discovering the history of the Tana basin, a joint project of the Universities of Wales, Addis Ababa, and St Andrews, (Scotland), and ARARI, Bahir Dar. http://www.aber.ac.uk/quaternary/tana/

LFDP (Lake Fisheries Development Project).(1995) Fisheries statistical Bulletin, Number Two. Working number three, MOA. 28pp.

Loiselle PV, Welcomme RL. (1971) Two new species of *Barbus* (Pisces; Cyprinidae) from Southeastern Dahomey. Rev Zool Bot Afr 83: 1-15.

Lowe-McConnell R. (1975) Fish communities in tropical freshwaters: their distribution, ecology, and evolution, London, Longman, pp. 337.

MacGregor JS. (1957) Fecundity of the Pacific sardine (*Sardinops caerulea*). Fish Bull Fish Wildl Serv U.S 121: 427-449.

Marshal BE. (1995) Why is *Limnothrissa miodon* such a successful introduced species and is there anywhere else we should put it? In: The impact of species changes in African lakes, Pitcher TJ, Hart PJB (ed), Chapman and Hall, London.

Mills CA. (1991) Reproduction and life history. In: Cyprinid fishes, systematics, biology and exploitation, Winfield IJ, Nelson JS (eds), Chapman & Hall, London, pp. 483-529.

Mina MV, Moronovsky AN, Dgebuadze YY. (1996a) Lake Tana large barbs: phenetics, growth and diversification. J Fish Biol 48: 383-404.

Mina MV, Moronovsky AN, Dgebuadze YY. (1996b) morphometry of barbel of Lake Tana, Ethiopia: multivariate ontogenetic channels. Folia Zoologica 45 (Suppl. 1): 109-116.

Mohr PA. (1962) The geology of Ethiopia. University college of Addis Ababa press, Addis Ababa, Ethiopia.

Nagelkerke LAJ.(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.

Nagekerke LA J, Sibbing FA. (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.

Nagekerke LAJ, Sibbing FA. (1998) The Barbus intermedius species flock of Lake Tana (Ethiopia): I- The ecological and evolutionary significance of morphological diversity. Ital J Zool 65 (supp. l.): 3-7.

Nagekerke LAJ, Sibbing FA. (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.

Nagekerke LAJ, Sibbing FA Osse JW M. (1995a) Morphological divergence during growth in the large barbs (*Barbus* spp.) of Lake Tana, Ethiopia. Neth J Zool (3-4): 431-454.

Nagekerke LAJ, Sibbing FA, van den Boogaart JGM, Lammens EHRR, Osse JWM. (1994) The barbs (B*arbus* spp.) of Lake Tana: a forgotten species flock? Envir Biol Fishes 39: 1-22.

Nagelkerke LA J, Mina MV, Tesfaye Wudneh, Osse JWM. (1995b) In Lake Tana, a unique fish fauna needs protection. Bioscience 45: 772-775.

Northcote TG. (1975) Migratory strategies and production in freshwater fishes. In: Ecology of freshwater fish production (Gerking SD (ed), Oxfored: Blakwell Scientific Publications, pp. 326-329.

Northcote TG. (1984) Mechanism of fish migration in rivers. In*:* Mechanism of migration in fishes, McCleave JD, Arnold GP, Dodson JJ, Neill WH (ed), New York, Plenum press, pp. 317-355.

Northcote TG, Williscroft SN, Tsuyuki H. (1970) Meristic and lactate dehydrogenase genotype differences in a stream populations of rainbow trout below and above a waterfall. J Fish Res Board Canada 27: 1987-1995.

Ochumba PBO, Manyala JO. (1992) Distribution of fishes along the Sondu-Miriu River of Lake Victoria, Kenya with special reference to upstream migration, biology and yield. Aquacul Fisher Manage 23: 701-719.

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

Oliva-Paterna FJ, Torralva MM, Fernandez-Delago C. (2002). Age, growth and reproduction of *Cobitis paludica* in a seasonal stream. J. Fish Biol 60(2): 389-404.

Palstra A, de Graaf M, Sibbing FA. (2004) Riverine Spawning and reproductive segregation in lacustrine cyprinid species flock, facilitated by homing? Anim Biol, 54(4): 393-415.

Payne A I. (1986) Ecology of tropical lakes and rivers. John Wiley & Sons, Chichester, pp. 301.

Pires IM, Cowx IG Coelho MM. (2000) Life history strategy of *Leuciscus pyrenaicus* (Cyprinidae) in intermittent streams of the Guadiana Basin (Portugal). Cybium 24(3): 287-297.

Reyntjiens D, Tarekegn Mengistu, Tesfaye Wudneh, Paulin C. (1998) Fisheries Development in Ethiopia – Which way now? BIODATA. Bulletin Vol. 11, No. 1.

Rodriguez-Ruiz A, Granado-Lorencio C. (1992) Spawning period and migration of three species of cyprinids in a stream with Mediterranean regime (SW Spain). J Fish Biol 41: 545-556.

Rsoska J. (1976) Lake Tana, head water of the Blue Nile. In: The Nile, biology of an ancient river, Rsoska J (ed), Dr Junk Publishers, The Hague, pp. 223-232.

Schliewen U, Rassman k, Markmann M, Markert J, KochersT, Tautz D. (2001) Genetic and ecological divergence of a monophyletic cichlid species pair under fully sympatric conditions in Lake Ejagham, Cameroon. Mol. Ecol 10: 1471-1488.

Shibru Tedla. (1973) Fresh-water Fishes of Ethiopia. Haile Selassie I University Dept. of Biology, Addis Ababa, Ethiopia, pp. 101.

Sibbing FA, Nagekerke LAJ. (2001) Resource partitioning by Lake Tana barbs predicted from fish morphometrics and prey characteristics. Rev Fish Biol Fisher. 10: 393-437.

Sibbing F A, Nagekerke LAJ, Stet RJM Osse JWM. (1998) Speciation of endemic Lake Tana barbs (Cyprinidae, Ethiopia) driven by trophic resource partitioning; a molecular and ecomorphological approach. Aquat Ecol 32: 217-227.

Skelton PH, Tweddle D, Jackson P. (1991) Cyprinids of Africa. In: Cyprinid fishes, systematics, biology and exploitation, Winfield IJ, Nelson JS (eds),Chapman & Hall, London, pp. 211-233.

Skelton PH. (2001) A complete guide to the freshwater fishes of southern Africa, 2nd edition, Southern Book Publishers, South Africa, pp. 388.

Skelton PH. (2002) Changes to the scientific and common names of Southern African freshwater fishes. *Afr J Aquat Sci* 27: 171-174.

Snoeks J. (2004) The non-cichlid fishes of the Lake Malawi system. In:The cichlid diversity of the lake Malawi: identification, distribution, and taxonomy, Snoeks, J(ed), Cichlid pres, El paso, Texas, pp. 20-26.

Sokal RR, Rohlf FJ. (1981) Biometry, 2nd edition. New York, W. H. Freeman and Company, pp. 1-859.

Stearns SC. (1992) The evolution of life histories. Oxford University Press, New York, pp. 249.

Taylor MH, Villoso EP. (1994) Daily ovarian and spawning cycles in weakfish. Trans Amer Fisher Soc 123: 9-14.

Tesfaye Wudneh. (1998) Biology and Management of fish stocks in Bahir Dar Gulf, Lake Tana, Ethiopia. PhD thesis, Wageningen Agricultural University, The Netherlands.

Tesfaye Wudneh, Machies MMM, Van Densen WLT. (1999) The selective impact of a developing fishery on the fish community of Lake Tana. In: Fish and fisheries of Lakes and reservoirs in Southeast Asia and Africa, Van Densen WLT, Morris MJ (eds), Westbury Academic & Scientific Publishing, pp. 259-280.

Thorpe JE. (1988) Salmon migration. Sci Progr Oxford 72: 345-370.

Tomasson T, Cambray JA, Jackson PBN. (1984) Reproductive biology of four large riverine fishes (*Cyprinidae*) in a man-made lake, Orange River, South Africa. Hydrobiologia 112:179-195.

Welcomme RL. (1969) The biology and ecology of the fishes of a small tropical stream. J Zool Lond 158: 485-529.

Welcomme, RL. (1985) River Fisheries. FAO Fisheries technical paper, (262), Rome, pp. 330.

Willoughby NG, Tweddle D. (1978) The ecology of the catfish *Clarias gariepinus* and *C. ngamensis* in the Shire Valley, Malawi. J Zool 186: 507-534.

Wood R, Talling J.(1988) Chemical and algal relationships in a salinity series of Ethiopian waters. Hydrobiologia 158: 29-67.

Wootton RJ. (1990) Ecology of Teleost fishes. Fish and Fisheries Series 1, Chapman and Hall, London, pp. 404.

Zenebe Taddesse. (1997) Breeding season, fecundity, length-weight relationship and condition factor of *Oreochromis niloticus* L. (Pisces: Cichlidae) in Lake Tana, Ethiopia. SINET: Ethiop J Sci 20(1): 31-47.

8. Appendices

Appendix A. Pairwise comparison of relative abundance of *Labeobarbus* species using x^2rxc contingency tables with 4df (degrees of freedom) over the five months (Jul-Nov) in the river mouths. Statistically significant differences ($p<0.05$) are indicated by asterisks. Numbers in bracket indicate chi- square values.

	L. brevicephalus	*L. intermedius*	*L. megastoma*	*L. surkis*	*L. tsanensis*	*L. truttiformis*
L. brevicephalus	x					
L. intermedius	* (198.66)	x				
L. megastoma	* (302.61)	* (312.64)	x			
L. surkis	* (64.74)	* (95.21)	* (176.16)	x		
L. tsanensis	* (465.44)	* (101.02)	* (73.06)	* (309.68)	x	
L. truttiformis	* (313.8)	* (96.25)	* (100.58)	* (268.5)	$^{\text{ns}}$ (25.35)	x

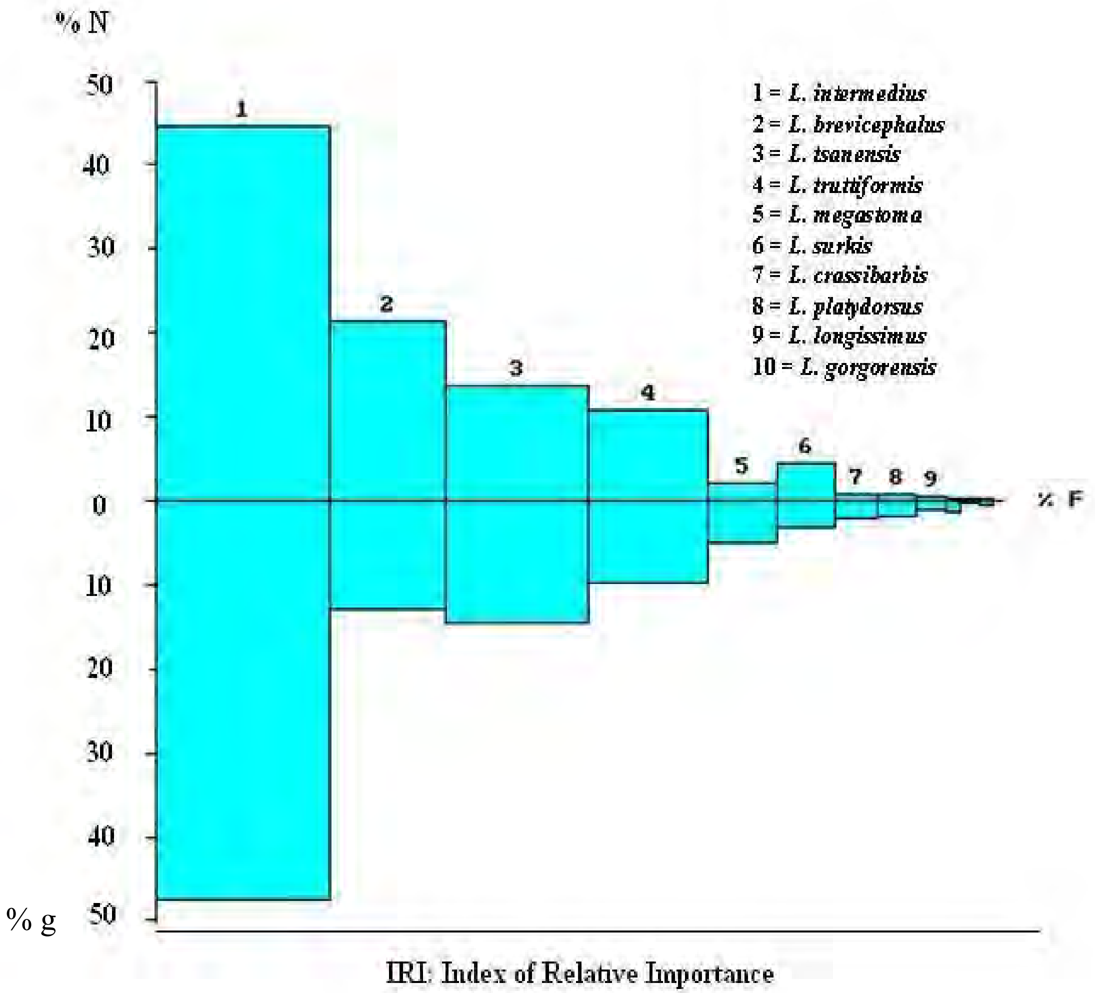
* = $p<0.05$, ns = not significant ($P>0.05$)

Appendix B. Pairwise comparison of temporal and spatial segregation (gray background in the table) of *Labeobarbus* species using x^2 rxc contingency tables with 2 and 3 df (degrees of freedom) respectively over the three months (Aug-Oct) in the river upstream reaches. Numbers in bracket indicate x^2 values.

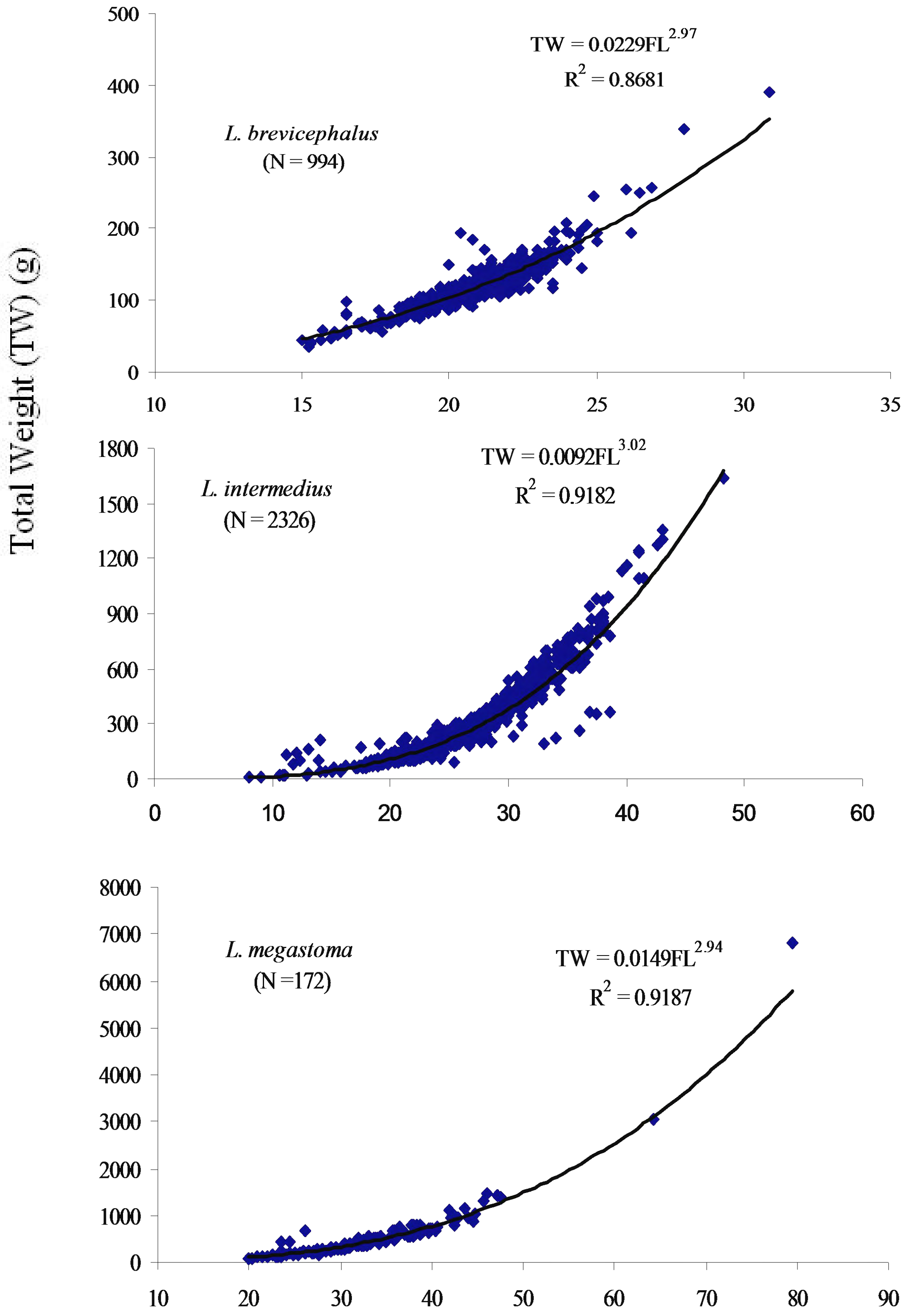
	L.brevicephalus	*L. intermedius*	*L. megastoma*	*L. nedgia*	*L. tsanensis*	*L. truttiformis*
L. brevicephalus	**x**	ns (0.05)	*** (17.14)	* (10.17)	*** (53.77)	*** (75.32)
L. intermedius	*** (22.11)	x	*** (17.67)	* (11.62)	*** (57.03)	*** (81.25)
L. megastoma	* (7.19)	* (12.93)	x	*** (24.23)	* (6.02).	* (9.95)
L. nedgia	* (7.83)	* (11.93)	* (15.01)	x	*** (78.84)	*** (106.16)
L. tsanensis	*** (31.85)	*** (103.60)	*** (25.52)	*** (25.63)	x	ns (4.91)
L. truttiformis	*** (23.71)	*** (93.01)	*** (23.15)	*** (21.29)	ns (1.83)	x

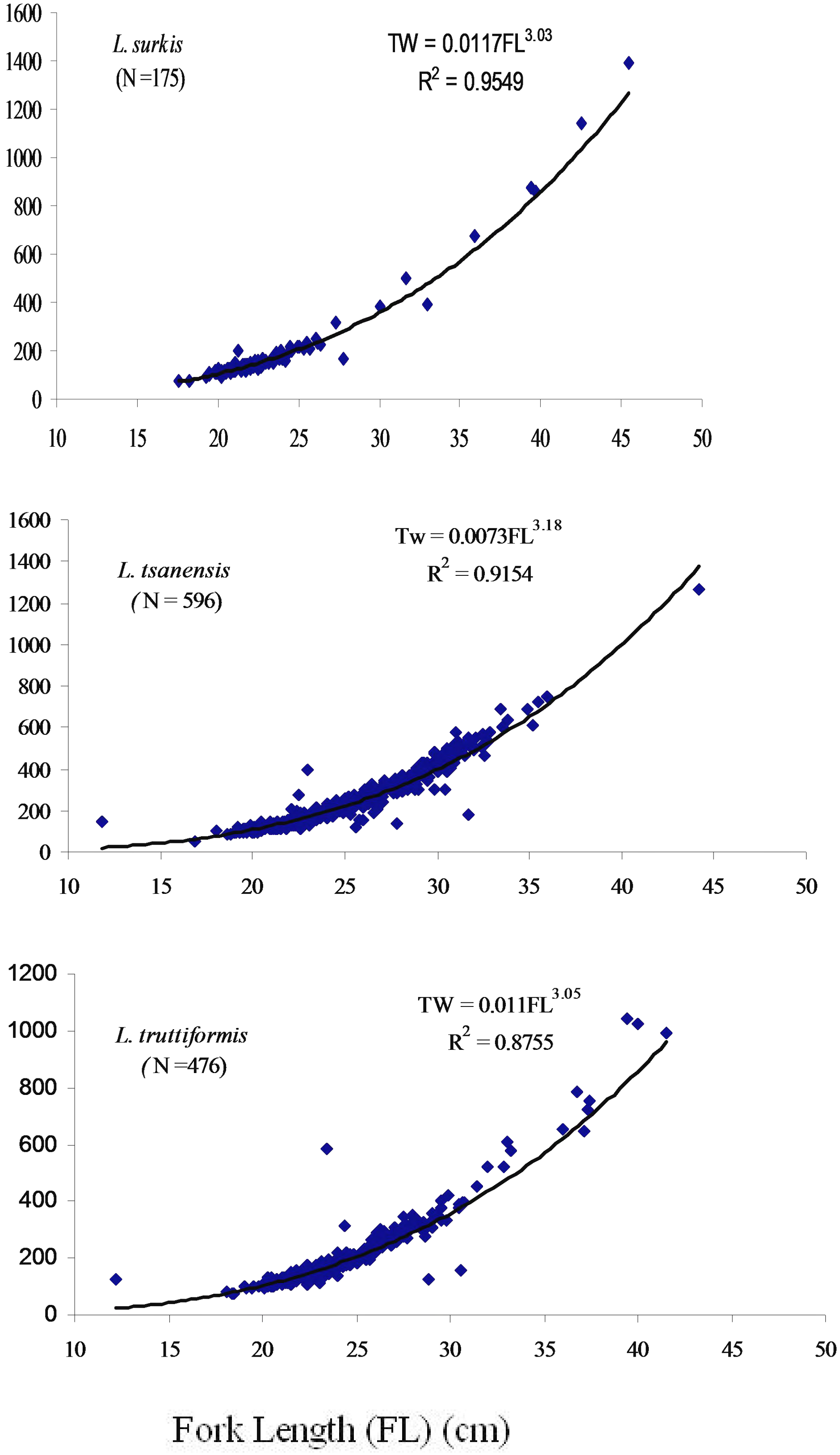
* = P<0.05, *** = P<0.01, ns = not signifiant (P>0.05)

Appendix C. The IRI of abundance of species in number (%N) (the upper part) and in biomass (% g) (the lower half) in the year round samples in all sites (pooled).

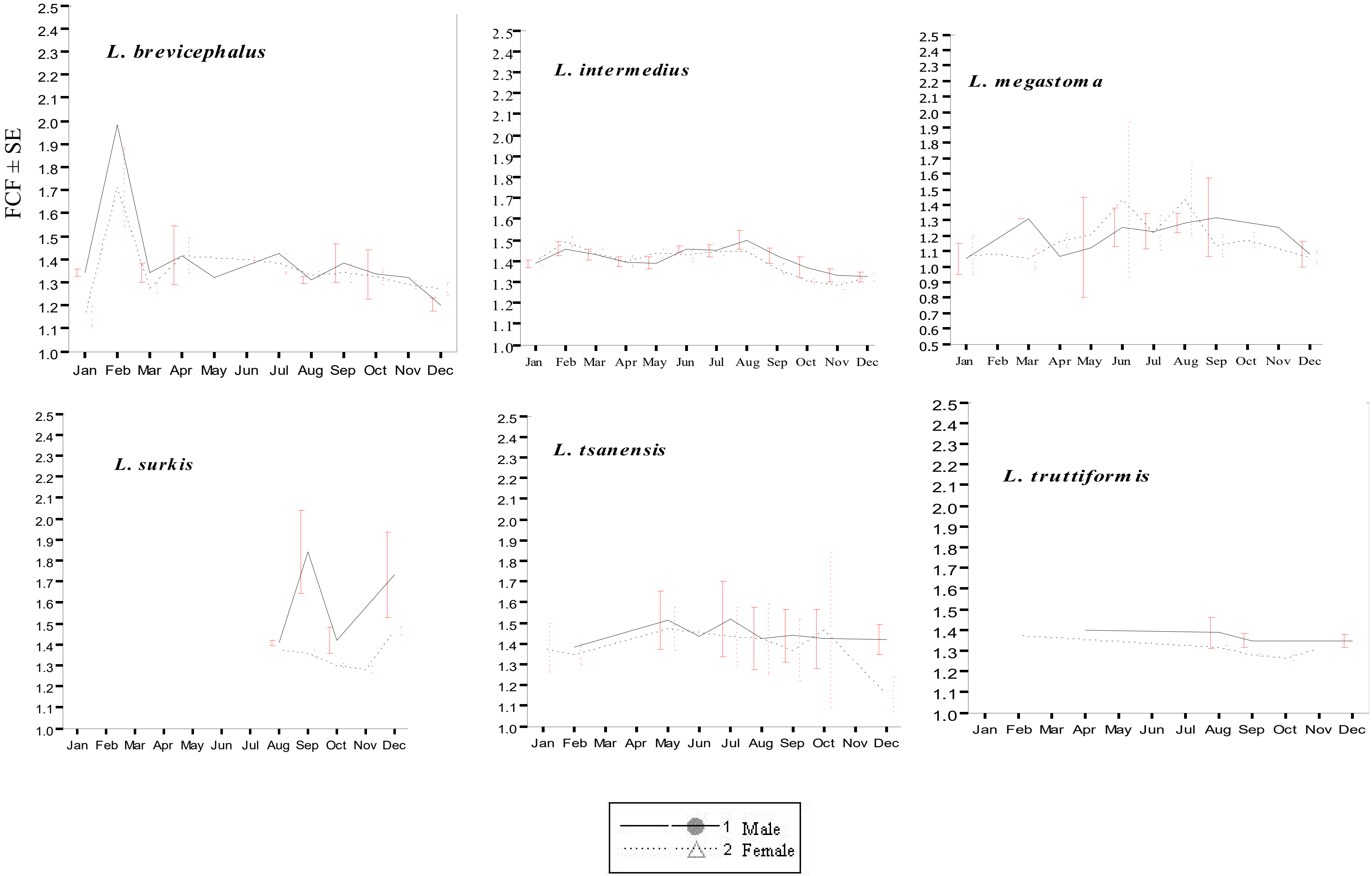


Appendix D. Length-weight relationships of the six *Labeobarbus* species from Lake Tana.




L. surkis
(N =175)
TW = 0.0117FL^3.03
R^2 = 0.9549
1600
1400
1200
1000
800
600
400
200
0
10
15
20
25
30
35
40
45
50
L. tsanensis
(N = 596)
Tw = 0.0073FL^3.18
R^2 = 0.9154
1600
1400
1200
1000
800
600
400
200
0
10
15
20
25
30
35
40
45
50
L. truttiformis
(N =476)
TW = 0.011FL^3.05
R^2 = 0.8755
1200
1000
800
600
400
200
0
10
15
20
25
30
35
40
45
50
Fork Length (FL) (cm)

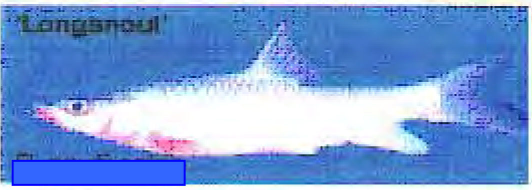
Appendix E. Mean monthly Fulton's condition factor (FCF) ± SE for male and female *Labeobarbus* species from Lake Tana.



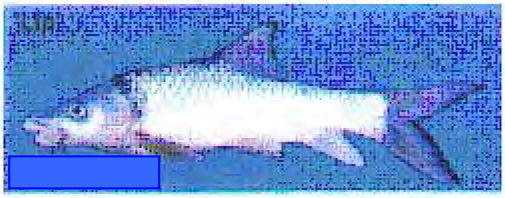
Appendix F. Labeobarbus caught in each sampling site over the year (December 2003 to October 2004).

Species	**Sampling sites** Dirma RM	Megech RM	DUPS	MUPS1	Dimaza	MUPS2	Total
L. acutirostris	26	21	-	-	-	-	47
L. brevicephalus	416	436	28	26	40	49	995
L. crassibarbis	12	34	1	2	-	-	49
L. dainellii	1	1	-	-	-	-	2
L. gorgorensis	3	18	-	-	-	-	21
L. intermedius	712	1348	71	37	26	130	2324
L. longissimus	3	24	1	3	-	-	31
L. macrophtalmus	6	10	-	-	-	1	17
L. megastoma	21	136	6	3	5	-	171
L. nedgia	2	10	-	6	6	14	38
L. platydorsus	13	18	-	-	1	-	32
L. surkis	72	99	1	4	-	-	176
L. truttiformis	134	215	10	33	64	23	479
L. tsanensis	135	353	9	32	59	13	601
L. gorgorensis	-	-	-	-	-	-	-
					Grand Total		**4983**

Appendix G. *Labeobarbus* species of Lake Tana.



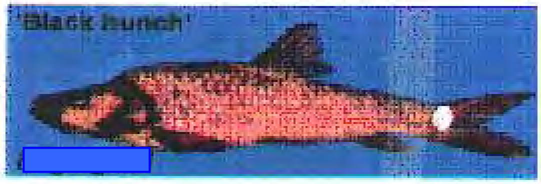
L. acutirosris



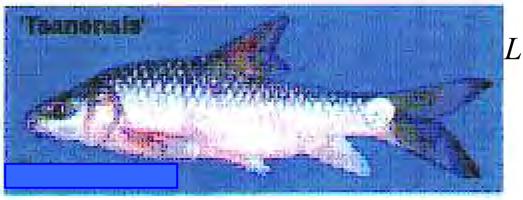
L. nedgia

L. megastoma

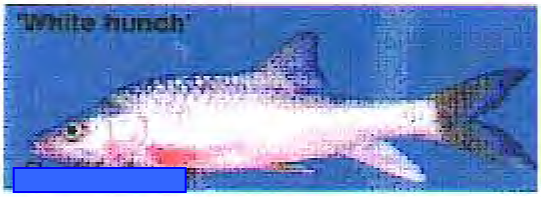
L. gorgorensis



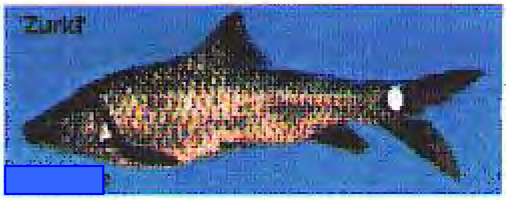
L. gorguari



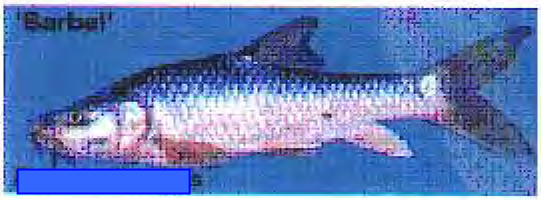
L. tsanensis



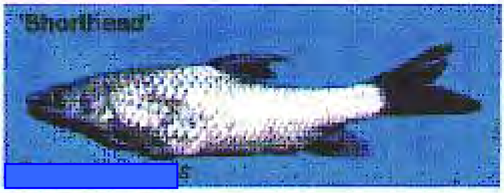
L. platydorsus



L. surkis

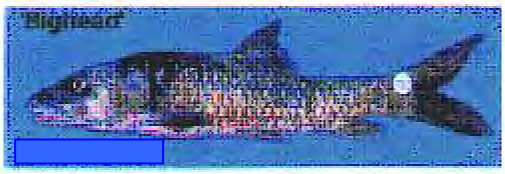


L. crassibarbis

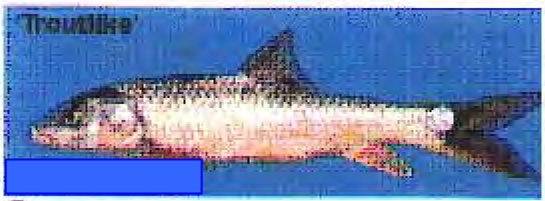


L. brevicephalus

L. longissimus



L. dainellii



L. truttiformis

L. macrophtalmus

Highly variable in color and shape

L. intermdius