Sustainable systems

Spatial and temporal segregation of *Labeobarbus* species migrating to Arno-Garno River

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https://doi.org/10.59411/1ks94919

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How to Cite:

Gebremedhin, S., Mingist, M., Getahun, A., & Anteneh, W. (2023). Spatial and temporal segregation of Labeobarbus species migrating to Arno-Garno River. *Sustainable Systems*, *4*(1). https://doi.org/10.59411/1ks94919

ABSTRACT

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

Keywords: Arno-Garno, *Labeobarbus*, fish migration, segregation

1. Introduction

Lake Tana, the largest lake in the country, encompasses nearly half of Ethiopia's freshwater bodies and is home to three commercially significant fish families: Cichlidae, Clariidae, and Cyprinidae (Reyntjes et al., 1998; de Graaf et al., 2004). The Cyprinidae family, with over 2000 species, is globally the most diverse among freshwater fish families and vertebrates (Nelson, 1994). Lake Tana hosts the last intact species flock of large cyprinid fishes, particularly the Labeobarbus species, following the disappearance of a similar flock in Lake Lanao, Philippines, due to human activities (Kornfield and Carpenter, 1984).

The taxonomy of Labeobarbus species in Lake Tana has been a subject of debate, but recent revisions identified 15 biologically distinct Labeobarbus species constituting a species flock (Nagelkerke and Sibbing, 2000). These species exhibit unique morphometrics, food niche segregation, spatial distribution patterns, maximal body size, immuno-genetics, and indications of spawning segregation (Nagelkerke et al., 1994, 1997; Nagelkerke and Sibbing, 2000; Dixon et al., 1996; Palstra et al., 2004).

While cyprinids typically have a riverine origin and often migrate upstream for spawning, studies in Lake Tana's tributary rivers revealed upstream spawning migrations of lacustrine Labeobarbus species (Nagelkerke and Sibbing, 1996; Palstra et al., 2004; Wassie Anteneh et al., 2008; Abebe Getahun et al., 2008). However, the spawning behavior of seven Labeobarbus species remains uncertain, with assumptions ranging from migration to spawn in Arno-Garno River or other temporary tributaries to lacustrine spawning (Nagelkerke and Sibbing, 1996; Palstra et al., 2004; de Graaf et al., 2005; Wassie Anteneh et al., 2008).

Fishing activities, particularly recruitment overfishing and poisoning of spawning stocks, have led to a significant decline in riverine spawning Labeobarbus species in Lake Tana (de Graaf et al., 2004; Abebe Amha, 2004). This study focuses on Arno-Garno River, one of the unstudied perennial rivers flowing into Lake Tana, to investigate the spawning migration patterns of Labeobarbus species, aiming for informed conservation and exploitation of this unique species flock.

2. Materials and Methods

2.1. Description of the Study Area Arno-Garno River, located in the northeastern part of Lake Tana, originates from the north Gonder highlands and is one of the seven perennial rivers flowing into Lake Tana (Gelgel Abay, Gumara, Dirma, Gelda, Ribb, Megech, and Arno-Garno) (Fig. 1). The river, disconnected from the lake during the dry season, faces challenges such as sand mining and water diversion by local farmers for irrigation. Despite these challenges, Arno-Garno River experiences increased water volume during the spawning season due to heavy rains.

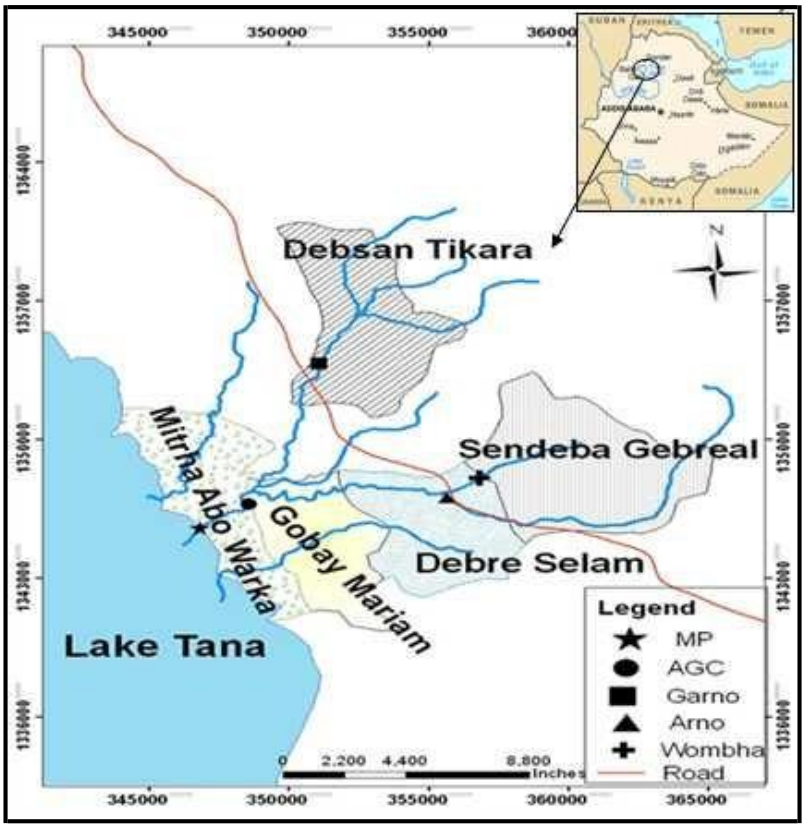

Fig. 1. Map of Lake Tana and the sampling sites at River Arno-Garno, Lake Tana Watershed

2.2. Field Sampling

To ensure effective fish spawning and gillnet setting, accessibility, and minimal human interference, five sampling sites were selected through a preliminary assessment and survey. GPS coordinates and estimated distances from the river

mouth were recorded for each site (Table 1). Monthly fish specimen collections were conducted from July to December 2010, with twice-monthly collections from August to October. Gill nets with varying mesh sizes (6, 8, 10, 12, and 14 cm stretched bar mesh), measuring 25 m in length and 1.5 m in depth, were set at the river mouth at a depth of approximately 2.5-3.5 m overnight. In upstream sites, due to heavy rainfall and increased flow, daytime sampling was preferred over overnight. Fish specimens were identified to the species level using keys developed by Nagelkerke and Sibbing (2000), and gonad maturity was assessed using a seven-point maturity scale (Nagelkerke, 1997).

Table 1. Sampling Sites, Estimated Distance from the Mouth, and GPS Coordinates at River Arno-Garno

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

2.3. Data Analysis

Statistical analysis was performed using SPSS version 16 software. One-way ANOVA was utilized to analyze spatial and temporal segregation.

3. Results

3.1. Species Composition at the River Mouth and Upstream Areas

A total of 1077 Labeobarbus specimens were collected between July and December 2010 from all sampling sites. Four dominant species (L. intermedius, L. brevicephalus, L. nedgia, and L. tsanensis) constituted approximately 93% of the total Labeobarbus catches in Arno-Garno River. Other species such as L. platydorsus, L. truttiformis, L. surkis, L. megastoma, L. crassibarbis, and L. gorgorensis were caught infrequently, while no specimens of L. dainellii, L. gorguari, L. macrophtalmus, and L. longissimus were observed over the sampling months.

3.2. Gonado-Somatic Index (GSI)

During the peak spawning season (August to October), the gonad proportion of mature Labeobarbus species (gonad stages IV, V), running (gonad stage VI), and spent (gonad stage VII) combined was higher (approximately 86.4%) than immature gonads (gonad stages I-III) in the collected samples. In this period, 16 specimens with spent gonads were identified, with higher numbers observed at the end of October. Among these, L. intermedius and L. brevicephalus were the most represented species.

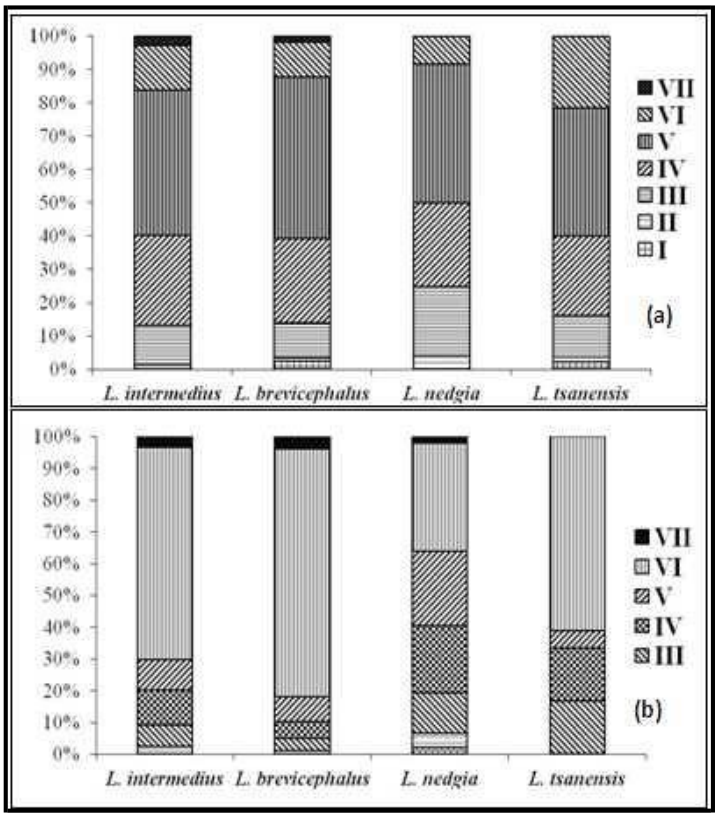

Fig. 2. Proportion of gonad maturity stages (I to VII) of the most dominant *Labeobarbus* species during peak spawning season (August to October) (a) at the River mouth and (b) at upstream areas of River Arno-Garno

3.3. Segregation of Labeobarbus spp. in Arno-Garno River

3.3.1. Spatial and Temporal Segregation

The distribution patterns of the four predominant Labeobarbus species exhibited no significant variation spatially across the five sampling sites in Arno-Garno River (Fig. 3) (one-way ANOVA, $P > 0.05$). However, there were notable changes in aggregation patterns at the river mouth and migration dynamics in the upstream sites on a monthly basis during non-peak spawning months and a bimonthly basis during peak spawning months (Fig. 4).

Labeobarbus intermedius and *L. tsanensis* were the first species to aggregate at the river mouth, initiating in July and peaking in the third week of September (Fig. 4a). *Labeobarbus brevicephalus* began aggregating in the third week of August, reaching its peak around the same time as *L. intermedius* in September. *Labeobarbus nedgia* was the last species to aggregate, commencing in the first week of September and peaking in the first week of October (Fig. 3a). All Labeobarbus species exhibited a declining catch pattern from October to November (Fig. 4b).

The upstream migration pattern showed that *L. intermedius* was the first species to ascend, commencing migration at the end of July, with a higher catch in August in both Arno and Garno sites (Fig. 4b). *Labeobarbus tsanensis* was the second migrant species, initiating migration in the second week of August. The last to migrate was *L. brevicephalus*, starting in the fourth week of August. The catch of *L. brevicephalus* and *L. tsanensis* peaked in October and September, respectively. Pairwise comparisons of the four dominant Labeobarbus species in Arno-Garno River indicated significant variations in temporal segregation ($P < 0.001$), except between *L. intermedius* and *L. nedgia*, and *L. brevicephalus* and *L. nedgia* (Table 2).

Table 2. Pairwise Comparisons of Temporal Segregation of Labeobarbus Species During the Peak Spawning Season (August to October) in All Upstream Sites.

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

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

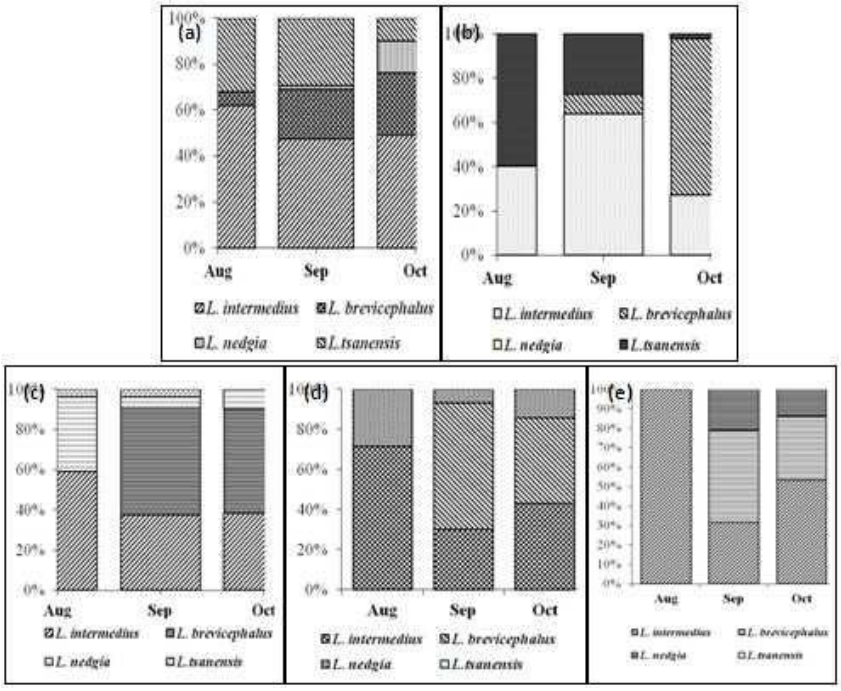

Fig. 3. Proportions (in number) of *Labeobarbus* species collected during the peak spawning season from (a) RM, (b) AGC, (c) Arno and (d) Garno sites and (e) Wombha

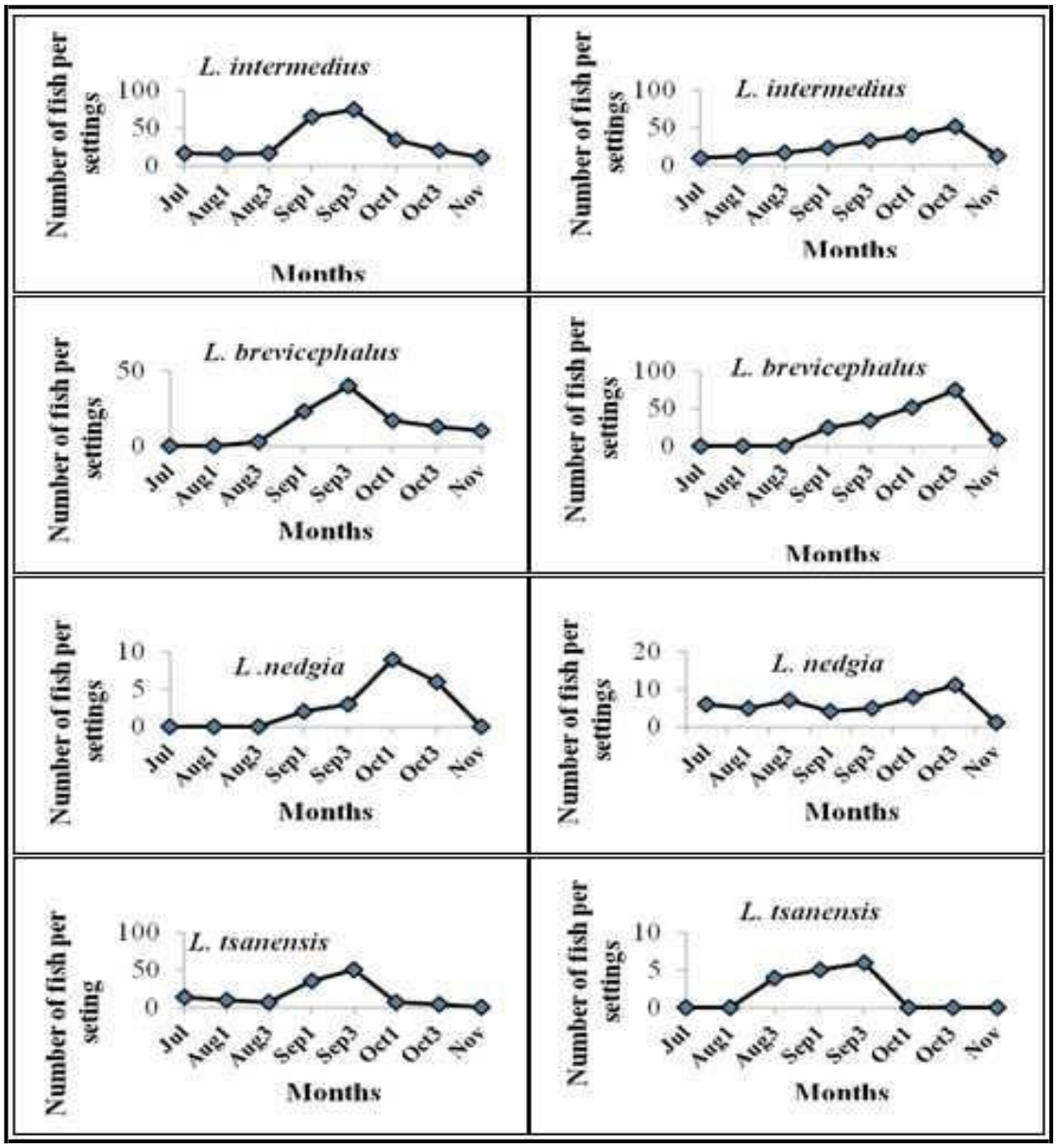

Fig. 4. Temporal variation in abundance of *Labeobarbus* species in the breeding season (July to November) (a) at the river mouth (left column figures) and (b) upstream sites (right column figures)

4. Discussion

4.1. Gonado-Somatic Index

The mean Gonado-Somatic Index (GSI) of the Labeobarbus species in Arno-Garno River exhibited an increasing trend as the species approached spawning. While some specimens began reproductive activities in July, the peak spawning period occurred from August to October. *Labeobarbus megastoma* showed the highest individual GSI (39%) in September, while the highest mean monthly GSI was recorded for *L. tsanensis* (32.52%) in Megech and Dirma Rivers. The appearance of a high number of spent females in October, coupled with a decline in catch, suggests the end of the spawning season. The peak spawning season for Labeobarbus species migrating to Arno-Garno River aligned with findings reported by de Graaf et al. (2005).

4.2. Spawning Aggregation and Segregation

The migration of tropical freshwater fish to breeding grounds is typically influenced by rainfall patterns and water level variations (Lowe-McConnell, 1975). In Lake Tana, Labeobarbus species aggregate at river mouths for spawning during the rainy season (Nagelkerke and Sibbing, 1996; Dgebuadze et al., 1999; Palstra et al., 2004; de Graaf et al., 2005). In the Arno-Garno River, four dominant Labeobarbus species (*L. intermedius, L. brevicephalus, L. nedgia, and L. tsanensis*) exhibited aggregation at the river mouth from mid-July to late October. While these species aggregated with gonad stages IV and V at the river mouth, gonad stage VI was rare. In contrast, most Labeobarbus species in upstream areas were found with gonad stage VI, suggesting that these species may not spawn at the river mouth but migrate to upstream areas.

Comparisons with other studies in tributaries of Lake Tana, such as Gumara, Gelgel Abay, Gelda, Ribb, Megech, and Dirma Rivers, revealed temporal segregation in Labeobarbus species (Palstra et al., 2004; de Graaf et al., 2005; Wassie Anteneh et al., 2008). The temporal distribution patterns indicated aggregation at the river mouth during both non-peak and peak spawning months, with declining catches from October to November, signaling the end of the spawning period.

The study did not find significant differences in the distribution patterns of the four most abundant Labeobarbus species across the five sampling sites in Arno-Garno River, contradicting claims of micro-spatial spawning segregation among riverine spawning species by Palstra et al. (2004). However, pairwise comparisons revealed significant variations in temporal segregation ($P < 0.001$), except between *L. intermedius* with *L. nedgia* and *L. brevicephalus* with *L. nedgia*. The findings align with previous studies reporting temporal segregation in Labeobarbus species in various river mouths (Palstra et al., 2004; de Graaf et al., 2005; Wassie Anteneh et al., 2008).

Acknowledgements

The authors express their gratitude to the Bahir Dar Fish and Other Aquatic Life Research Center staff for their collaboration and provision of materials. Special thanks are extended to fishermen and field assistants for their invaluable field and laboratory support. The study received funding from the Rufford Foundation, UK, and Bahir Dar University, Ethiopia.

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