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The composition of fish communities of four Tekeze sub-basin rivers of Tigray, northern Ethiopia

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(ID NO: CNCS /PR009/11)

A thesis submitted to the Department of Biology in the partial fulfillment of the requirements for the Degree of Master of Science in Biology (Aquatic ecology and Fishery Sciences)

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Declaration

I, the undersigned, declare that this thesis entitled "The composition of fish communities of four Tekeze sub-basin rivers of Tigray, Northern Ethipia" is my original work and has not been presented for any other award, and that all sources of materials used in this thesis are duly acknowledged. This thesis was carried out under the supervision of my Advisor MekonenTeferi (PhD) Department of Biology, College of Natural and Computational Sciences, Mekelle University.

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This thesis has been submitted for examination with my approval as University **advisor/co-advisor**.

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Signature of the Advisor with date: ________________________

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Abbreviations and Acronyms

APHA	American Public Health Association
APHA	American Public Health Association
CCA	Canonical Correspondence Analysis
CPUE	Catch per unit effort
DO	Dissolved Oxygen
FAO	Food and Agriculture Organization of the United Nations
LFDP	Lake Fisheries Development Project
NTU	Nephelometric Turbidity Units
pH	Power of Hydrogen / for measurement of Acidity, Neutrality or basicity /
SFCC	Scottish Fisheries Co-ordination Centre

Abstract

Freshwater fish communities are structured by a combination of abiotic and biotic factors, with habitat heterogeneity playing a key role in shaping their composition, distribution, and assemblage structure. This study aimed to investigate the fish community composition and the environmental factors influencing them in four rivers of the Tekeze sub-basin in Tigray, Northern Ethiopia: Atsela, Mesgi, Geba, and Worie. Water quality parameters were measured using standard probes, and fish sampling was conducted using electrofishing across two seasons (December 2019 and April 2020). A total of 2,917 fish belonging to 14 species, four families, and three orders were recorded. Cyprinidae was the dominant family, accounting for 79% of the species. Only two species, Garra blanfordii and Garra dembecha, were common to all rivers. Chelaethiops bibie and Chiloglanis niloticus were uniquely recorded from Worie and Geba rivers, respectively. Labeobarbus intermedius was the most abundant species in Worie and Geba, while Garra species dominated in all rivers. Water quality parameters varied across rivers, with higher temperatures, conductivity, and turbidity observed in lowland rivers (Geba and Worie) compared to highland rivers (Atsela and Mesgi). Fish species richness and diversity were higher in lowland rivers, with Worie recording the highest richness (11 species) and Mesgi the lowest (2 species). Multivariate analysis (CCA) indicated that altitude, temperature, turbidity, salinity, and chlorophyll-a were key environmental drivers influencing fish community structure. The study highlights the importance of altitude and associated environmental gradients in shaping fish assemblages in the Tekeze sub-basin. The findings underscore the need for sustainable management of riverine habitats, particularly in light of anthropogenic pressures such as water abstraction, sand mining, and riparian degradation. Conservation efforts should focus on maintaining habitat integrity and ecological connectivity to preserve fish diversity and support local fisheries.

Keywords: Fish communities, assemblage structure, environmental variables, Tekeze sub-basin, Ethiopia, river ecology

CHAPTER ONE

1. Introduction

1.1. Background and Justification

It is a common view that freshwater fish live not in random groupings, but in structured communities held together by favorable abiotic and biotic mechanisms. In some cases, a small number of environmental variables seem to exercise a strong influence on community structure, while in others, it is related to a wider range of factors (Robinson & Tonn, 1989; Edds, 1993). In addition, the composition of fish species in stream and river systems can vary greatly within a small range (Gebrekiros, 2016). Migrations and movements between systems occur, feeding habits and diets may differ, and because of this, the stable isotopes of the animals fluctuate (Hobson, 1999).

Habitat heterogeneity in lotic environments generally influences fish community composition, assemblage structure, and distributions. In normal conditions, downstream (river), these parameters should be generally increased as lateral and vertical profiles are enhanced via increased off-channel habitat complexity and water volume (Pinto *et al.,* 2006; Terra *et al.*, 2010). Several environmental variables are preferentially selected by fish species in these ecosystems (Bovee, 1982; Baltz *et al.*, 1987; Yu and Lee, 2002; Vadas & Orth, 2000, 2001). For example, habitat availability affects fish species selection, with most habitat preference models based on individual factors such as depth, velocity, substrate, and cover type (Sheppard and Johnson, 1985; Leonard & Orth, 1988; Arnhold et al., 2019).

Ethiopia could be called a water tower of Eastern Africa in a continent where most part is arid. The inland water body is estimated at 7,400 km^2 of the lake area and about 7,000 km total length of rivers (Wood & Talling, 1988). The lakes represent an excess of 88 billion cubic meters of storage capacity, and Lake Tana comprises 52% of the total surface area or 33% of the total volume. The total annual discharge of rivers was 63 billion cubic meters, of which the Blue Nile accounts for 80% (Aubrey, 1975). There are over 200 species of fish and numerous other aquatic resources in its water bodies (GebreTsadik, 2003). The main drainage basins of the country flow away from the rift system either towards the Nile system in the west or to the Indian Ocean in the southwest (Gebremariam & Dadebo, 1999). Ethiopia has seven drainage basins, which currently consist of 12 large river basins. These are Abay, Awash, Shebelle-Genale, Omo-Gibe, Baro-Akobo, Tekeze, and Rift Valley basins (Woldemariam, 1970; IUCN, 2010), which can be categorized under three main drainage systems. Among these are the Tekeze basin, Angereb, Sanja, and Guang, which are draining the northwestern parts of the western highlands of the country (Tesfaye, 2006). All the rivers drain to Sudan to join the White Nile via the western direction of Ethiopian territory.

The second system is the central drainage system known as the Rift Valley system, which is composed of the Awash sub-drainage system that drains to Lake Abbe, at the Ethio-Djibouti border, and it is a closed basin system. The Omo-Gibe sub-drainage system flows in a south direction to Lake Turkana (Rudolf) at the border with Kenya (LFDP, 1996). The third main drainage basin is the Shebelle-Juba drainage system, which is composed of a sub-drainage system of Rivers Ghenale, Dawa, and Weyb that join the Shebelle River and then drain to the southwestern part of the eastern highlands. The Shebelle River is called Juba after the Ethiopian boundary in Somalia. The major rivers in this drainage system rise from the eastern highlands in the Bale Mountains and flow into the Indian Ocean (Roberts, 1975).

The production potential and fishery development in Ethiopia depend only on inland water to capture fish (Ameha & Assefa, 2002; Janko, 2014). The total potential fish production is estimated at 51,481 tonnes/year (FAO, 2003; FAO, 2012). Of these, only less than 38% of this potential is being exploited annually (Chekol, 2013). Over half of the estimate comes from Lake Tana (Chekol, 2013; Tesfaye & Wolff, 2014). In the last 2 decades, fishery production in Ethiopia has been growing from 2009 to date, particularly from the Tekeze dam. The rivers and streams of the Tekeze sub-basins are home to many species of fish and wildlife with diverse habitat requirements that are defined by hydrology, fluvial geomorphology, water quality, biology, and connectivity (Gebrekiros, 2016; Tesfay et al., 2019).

1.2. Significance of the study

Ethiopian fishery production was mainly limited to lakes and a few rivers. However, this could not balance the current demand and supply for the ever-increasing population and urbanization. So, to support the Ethiopian fishery production, particularly in Tigray, which is limited to Tekeze dam and nominally Lake Hashenge, studying the composition of fish communities of the rivers can scale up our fish production and secure food security, particularly the protein demand.

1.3. Statement of the problem

In the Ethiopian highlands, there are few taxonomic studies of fish on major rivers (Stiassny & Getahun, 2007) and community composition on small reservoirs (Asmelash *et al.*, 2007; Dejenie *et al.*, 2008; Teferi *et al.*, 2013). Although there are few studies in small streams by Tesay et al. (2019; 2024), the diversity and community structure of fish in small rivers in Tigray highlands remain poorly documented. There is also a limited understanding of how the abiotic (physicochemical) and biotic (biological) variables influence fish community structure and assemblage patterns in these systems. This knowledge gap restricts effective fishery development, management and conservation planning in these water bodies. As to our current knowledge, there is no study on the diversity, distribution, and abundance of fish communities on the representative highland and lowland streams or rivers of Tigray.

1.4. Objectives

1.4.1. General objective

- To study and document the diversity, distribution, abundance, and assemblage structures of the fish community in relation to environmental variables of the respective rivers and their specific study sites.

1.4.2. Specific objectives

- ✓ To evaluate the physico-chemical parameters of the Study Rivers
- ✓ To identify the fish species composition of the rivers
- ✓ To estimate the relative abundance of the fish species in the rivers.
- ✓ To examine the relationship between environmental variables and fish assemblage structures

CHAPTER TWO

2. Review of Literature

River fish assemblages are a key component of freshwater biodiversity in river systems, and they are crucial in playing basic roles in ecosystem functions, nutrient cycling, and energy transfer. Apart from their ecological functions, fish assemblages are also a sensitive indicator of the environment, reacting to water chemistry, habitat quality, and hydrological regime. The distribution, diversity, and composition of riverine fishes are shaped by a complex interaction of environmental factors such as hydrology, habitat complexity, and water quality, biological processes including predation, competition, and reproductive strategies, and human impacts such as damming, pollution, and species introductions. Therefore, it is essential to comprehend these processes in order to manage rivers effectively, conserve biodiversity, and harvest fisheries resources in a sustainable manner (Karr, 1981; Deacon, 1997).

2.1. History of Ethiopian Freshwater Ecosystems

Ethiopia, at times referred to as the "water tower of Eastern Africa," has extensive inland water resources in the form of numerous lakes and rivers, which collectively support a typical and diverse aquatic fauna. Lakes of the country cover an estimated area of approximately 7,400 km², with rivers covering approximately 7,000 km in length and forming intricate networks over varying topographies (Wood & Talling, 1988). These new water systems are organized into expansive drainage basins, like the Abay (Blue Nile), Awash, Omo-Gibe, Baro-Akobo, Wabi-Shebelle/Genale, Rift Valley lakes, and the Tekeze/Atbara basin, of which the latter is the focus of this review (Woldemariam, 1970; IUCN, 2010).

The Ethiopian ichthyofauna comprises some 190–200 species, with exceptionally high endemism rates in cyprinids, especially in the *Labeobarbus* genus (GebreTsadik, 2003; Mengesha, 2021). Because of factors like altitude, hydrographic features, and past biogeographic isolation, fish species are dispersed differently throughout drainage basins. Despite this enormous diversity, only about 38% of the country's estimated 51,481 tonnes of annual fishery potential are currently utilized (FAO, 2003; Chekol, 2013). Fisheries operations were traditionally concentrated in large lakes like Lake Tana, but due to growing demand as well as the discovery of unexploited fishery resources, there has been a shift towards river and reservoir systems, especially in under-exploited basins like the Tekeze (Tesfaye & Wolff, 2014).

2.2. Biogeography and Composition of Riverine Fish Communities

Ethiopian rivers support a complex assemblage of fish species that reflects a mixture of Nilo-Sudanic and East African faunal elements, shaped by pronounced highland–lowland gradients and periodic hydrological connectivity with the Nile Basin (Mengesha, 2021). The most commonly represented families include Cyprinidae, Cichlidae, Bagridae/Claroteidae, Clariidae, and Schilbeidae, with cyprinids dominating both ecologically and numerically. Genera such as *Labeobarbus*, *Labeo*, and *Garra* constitute the structural backbone of many riverine assemblages, supporting ecosystem functioning and biodiversity. Other widespread and economically important taxa, including *Oreochromis niloticus*, *Clarias gariepinus*, and *Bagrus docmak*, contribute significantly to local fisheries productivity (Shibabaw et al., 2019).

The genus *Garra* provides a clear example of adaptive radiation in Ethiopian highland rivers. Species within this genus exhibit specialized morphological traits, such as adhesive mental discs and ventrally positioned mouths, which allow them to cling to rocks and feed effectively in fast-flowing, unstable habitats (Stiassny & Getahun, 2007). In contrast, lowland rivers and reservoirs support a higher proportion of lentic-adapted species, reflecting slower water velocities, increased habitat stability, and broader ecological niches along longitudinal gradients. This pattern demonstrates how hydrological and geomorphological variation shapes species composition and the functional structure of fish communities along Ethiopian river systems.

2.3. Determinants of River Fish Community Composition

Fish assemblages in lotic (running water) systems are not opportunistic but are structured by the dynamic and complex interaction of numerous influences. Physical factors such as flow velocity, depth, channel shape, and substrate establish a sequence of microhabitats that encompass species with varied habitat affinities. Chemical constituents, including dissolved oxygen, pH, temperature, and nutrient content, act as filters in the environment, determining which species can live, develop, and propagate under given conditions. Biological processes, including predation, competition, reproductive strategies, and trophic interactions, also impact community structure and dynamics. Together, these abiotic and biotic factors interact across spatial and temporal scales to produce highly heterogeneous assemblages of fish that reflect both local environmental conditions and broad landscape processes (Robinson & Tonn, 1989; Edds, 1993). Some of the determinants are:

2.3.1. Hydrology and Regime of Flow

Seasonal flow variations are among the key drivers of habitat availability, reproduction, and population connectivity in riverine fish assemblages. Peak-flow events overtop adjacent floodplains and lateral habitats, creating new spawning and feeding grounds, larval dispersal, and gene flow among populations. These natural hydrological events are vital for the recruitment of most rheophilic species and maintain population resilience. Dry-season contractions, on the other hand, reduce the amount of water, split habitats, and force fish into solitary pools or refugia, which increases competition, predation, and localized extinctions. These natural seasonal cycles are upset by anthropogenic changes like dam construction, flow regulation, and excessive water withdrawal, which reorganize habitat availability and flow connectivity. These disturbances tend to reduce overall biodiversity and change the structure and function of riverine fish assemblages by favoring generalist or lentic-specialized species at the expense of specialists of dynamic lotic habitats, which become less common (Pusey et al., 2020; Deacon et al., 2003).

2.3.2. Habitat Heterogeneity and Substrate Composition

Structural heterogeneity in river channel morphology—e.g., the presence of riffles, pools, woody debris, submersed vegetation, and heterogeneous substrate types—is a critical determinant of fish community composition. Physical attributes such as these create a mosaic of microhabitats that accommodate species having different ecological requirements for cover, feeding, and spawning. For example, riffles accommodate oxygenated, high-velocity habitats well adapted to rheophilic species, while deeper pools accommodate refugia for juvenile and predatory fishes. Aquatic vegetation and wood debris introduce richness in terms of predator shelter and spawning or feeding areas. Substrate diversity, such as combinations of cobbles, gravel, and sand, also allows benthic and demersal species to establish niches according to foraging and reproduction mechanisms. Conversely, human-induced habitat simplification through channelization, damming, sedimentation, or dredging reduces structural diversity, homogenizes the flow regime, and lowers the number of available ecological niches, typically resulting in reduced species richness and dominance by tolerant or generalist species (Pinto et al., 2006; Terra et al., 2010).

2.3.3. Pollution and Water Quality

Riverine fish communities' abundance, composition, and distribution are greatly impacted by water quality factors such as temperature, dissolved oxygen, pH, and nutrients. While dissolved oxygen determines a species' survival and activity, temperature controls metabolic rate, growth, and reproduction. Changes in community structure can result from stressful environments caused by elevated nutrient loads or pH deviations from ideal levels. By favoring tolerant opportunistic species and discouraging sensitive specialists, eutrophication which is frequently the result of over-enrichment with nitrogen and phosphorus inputs can lower species richness. For instance, fish assemblages in the Upper Colorado River Basin were found to vary significantly with concentration of dissolved solids, water temperature, and sediment load, demonstrating how chemical and physical water quality conditions regulate community composition (Deacon, 1997). Furthermore, urbanization and industrial waste change these parameters, lowering habitat quality and changing the structure of fish assemblages, which typically leads to the overpredominance of generalist species at the expense of ecologically specialized species (Jargal et al., 2024).

2.3.4. Connectivity

Longitudinal upstream–downstream and lateral main channel–floodplain connectivity is one of the major drivers of fish community structure in river systems. Longitudinal connectivity facilitates seasonal migration, disturbance-dependent recolonization of habitat, and maintenance of genetic exchange between populations. By connecting to seasonally flooded feeding, spawning, and nursery areas, lateral connectivity with floodplains improves recruitment and population resistance. Barriers like dams, weirs, or badly maintained irrigation systems that interfere with this natural connection have the potential to isolate subpopulations, fragment populations, obstruct migratory routes, and decrease gene flow. As a result, fish assemblages change, becoming general or sedentary species at the expense of migratory and rheophilic species, which reduces species richness and homogenizes the community (Rahel & Hubert, 1991; Paller, 1994).

2.3.5. Life History Features and Biological Interactions

Predation, competition, and reproductive behavior are examples of biotic interactions that are crucial in forming fish communities and controlling population dynamics. Predation influences the distribution and abundance of prey species, and interspecific competition for spawning grounds, space, and food may be employed to promote niche differentiation and partitioning of resources. Reproductive modes, such as fecundity, spawning schedule, and parental care, also play a role in the success of species in assemblages. A prime example is the trophically diverse Ethiopian riverine *Labeobarbus* complex, where diet and habitat use exhibit fine-scale niche partitioning across species. This specialization promotes community stability and resilience overall, permits multiple species to coexist in a single river reach, and lessens interspecific competition (Gebremedhin et al., 2019). The significance of biotic interactions in preserving the composition and functionality of riverine fish assemblages is intended to be emphasized by these interactions.

2.4. Empirical Evidence from the Tekeze Basin

Compared to the well-studied Abay and Baro-Akobo basins, ecological research in the Tekeze Basin is limited, and many aspects of its riverine fish assemblages remain uninvestigated. Preliminary surveys of Tesfay et al. (unpublished) found more than 14 fish species from different rivers within the Tekeze sub-basins. As a result of these taxa's adaptation to high-gradient environments with swift water flow, Highland rivers were species-poor and dominated by *Garra* spp. On the other hand, more varied assemblages, such as *Labeobarbus intermedius* and *Clarias gariepinus*, were found in lowland rivers. This is in line with the general trend of increasing species richness downstream, where habitats are more variable and environmental harshness is lessened (Mengesha, 2015).

Surveys of Tekeze Reservoir reveal a different community structure, dominated by *Oreochromis niloticus*, *Bagrus docmak*, *Labeo niloticus*, and *Labeobarbus intermedius*, while smaller taxa were found at lower frequencies (Shibabaw et al., 2019). The shift from dominance of rheophilic riverine species to more generalist reservoir species reveals the intense effect of hydrological change, i.e., impoundment, on fish assemblage structure. These changes reflect changes in habitat availability, flow regimes, and ecological connectivity, all of which favor species that are adapted to lentic or altered environments at the expense of specialists that depend on lotic conditions.

2.5. Effects of Human Activity on Riverine Fish Populations

A variety of man-made stressors are gradually altering the composition of riverine fish assemblages in Ethiopia, especially in the Tekeze Basin, threatening aquatic diversity and upsetting natural ecological function (Abdullah et al., 2022). Hydrological change, water abstraction, sedimentation, pollution, overfishing, and species invasions are the most pressing of these pressures (Alemneh et al., 2019; Gebremedhin et al., 2022). These disturbances, both separately and collectively, promote fish assemblage homogenization and the loss of ecological integrity in river systems (Pool et al., 2021).

2.5.1. Hydrological Alteration

Dam, reservoir, and water diversion constructions have profoundly modified natural flow regimes, disrupted habitats, and blocked potamodromous and rheophilic fish species migration. Through conversion of lotic ecosystems to lentic environments, these modifications advantage generalist or lentic-restricted species but disadvantage flow-dependent specialists. Dams in the Tekeze Basin, for instance, have been linked to the loss of rheophilic taxa like *Garra* spp. and an increase in the dominance of *Oreochromis niloticus* and other generalist species (Shibabaw et al., 2019). Community dynamics are further jeopardized by changes in flow patterns, which also alter sediment and nutrient transport, reduce habitat heterogeneity, and interfere with spawning cues.

2.5.2. Irrigation and Water Abstraction

Large-scale abstractions of water for irrigation, hydropower generation, and human consumption reduced downstream flow volumes and alter hydrological connectivity. These decreases limit the supply of habitats significantly affecting feeding, spawning, and juvenile development, particularly during dry seasons. Flow reductions enhance temperature fluctuations and reduce dissolved oxygen concentrations, which impose physiologic stress on aquatic life (Nile Basin Initiative, 2020). Decreased flow regimes in the Tekeze sub-basin led to habitat fragmentation and the disruption of seasonal connectivity, with severely negative effects on flood-pulse-dependent migratory *Labeo barbus* species used for reproduction and dispersal.

2.5.3. Pollution and Sedimentation

Deforestation, increased agricultural production, and urbanization are examples of land use changes that have resulted in an excess of sediment supply and river turbidity, which has deteriorated spawning substrates and decreased light penetration necessary for primary productivity (Allan, 2004). Fertilizers, pesticides, and other agrochemicals are carried by agricultural runoff, which causes eutrophication and adds toxins to aquatic food webs (Dodds & Smith, 2016). Effluents from industry and urban areas also introduce heavy metals and organic pollutants, worsening water quality and impacting the survival of sensitive species (Jargal et al., 2024). These combined effects change the composition of assemblages and the function of ecosystems by favoring opportunistic, tolerant taxa at the expense of stenotopic and specialist species(Townsend et al., 2008).

2.5.4. Overfishing and Uncontrolled Gear Use

Commercially significant species such as *Labeo barbus* spp. and *Clarias gariepinus* have been subject to overexploitation, resulting in the decline of their populations and trophic restructuring in the majority of Ethiopian rivers (Abebe et al., 2023; Tesfaye & Wolff, 2024). Widespread use of uncontrolled or destructive fishing gear; such as fine-mesh nets, small-mesh gillnets, and even dynamite fishing in certain cases, is further adding to recruitment decline and increasing by catch of juveniles and non-target fish (FAO, 2023; Mekonnen et al., 2024). The cumulative effect of these practices diminishes population resilience, promotes dominance by short-lived opportunistic species, and erodes the sustainability of local fisheries (Hicks et al., 2024; Welcomme et al., 2023).

2.5.5. Introduction of Species

The native ichthyofauna is seriously threatened by the introduction and stocking of exotic fishes, in this case *Coptidon ziillii* (Abebe & Tilahun, 2022; Getahun et al., 2023). Exotic species have high growth rates, broad ecological amplitude, and competitive superiority, which enable them to dominate disturbed environments (Britton, 2024). These introductions can lead to competitive displacement, direct predation on indigenous fauna (Canonico et al., 2023; D'Amato et al., 2024), and genetic introgression by hybridization, there by compromising the genetic purity and adaptive potential of indigenous populations (Abebe & Tilahun, 2022).

2.5.6. Effects on the Environment

When combined, these human-induced stressors force community structure to shift toward tolerant, generalist-dominated groups at the expense of the diversity and abundance of specialized taxa that need stable lotic conditions (Hering et al., 2024; Reid et al., 2024). This biological homogenization reduces global biodiversity, modifies trophic relations, and undermines important ecosystem processes such as nutrient cycling and energy transfer (Dudgeon, 2023; Tonkin et al., 2024). Moreover, economically important species decline threatens the productivity of fisheries in the local region and undermines riparian livelihoods based on freshwater habitat (FAO, 2024; Welcomme et al., 2023). The broader ecological implications highlight the need for river basin management practices that are well-balanced and that balance development with aquatic biodiversity conservation.

2.6. Methodological Strategies and New Tools

Traditional methods of assessing river fish assemblages in Ethiopia have tended to rely on overt sampling strategies such as gill nets, seines, electrofishing, and market surveys to measure species composition, relative abundance, and distribution patterns (Teame & Tesfay, 2020). While these methods provide useful baseline data and are reasonably priced, they have some limitations. Particularly, they have the tendency to under-sample low-density, cryptic, or small species, fail to capture nocturnal or elusive taxa, and are lab-intensive and time-consuming. What's more, market surveys are biased towards commercially important species, which discount ecologically important but non-commercial taxa.

Over the past decade or so, molecular approaches such as DNA barcoding and environmental DNA (eDNA) metabarcoding have emerged as robust complementary tools for biodiversity estimation. While eDNA metabarcoding finds genetic material left by organisms in the environment and makes it easier to detect species, including rare, cryptic, or low-abundance taxa, DNA barcoding uses standardized genetic markers to identify specimens at the species level.

High-quality, carefully selected, and validated reference libraries are essential to the success of such molecular tools in order to guarantee precise taxonomic identification (Coble et al., 2019; Yao et al., 2022). The integration of conventional and molecular approaches provides a more comprehensive and accurate description of fish communities, including both obvious and hidden species, and is increasingly recommended for riverine biodiversity evaluation and management in Ethiopia. Integration also allows for long-term ecological monitoring, conservation planning, and enlightened fisheries management by providing finer-scale information on species richness, distribution, and community processes.

2.7. Research Gaps and Future Directions

Despite increasing research effort, major knowledge gaps remain regarding the Tekeze Basin and other Ethiopian river fish communities. Firstly, spatial coverage is not complete, and many tributaries, seasonal streams, and floodplain habitats remain under surveyed, precluding making inferences on the entire range of species distributions and community structure. Second, there is not enough long-term temporal data, as few standardized monitoring schemes have existed, and hence trends, seasonality, or the effect of environmental change on fish populations cannot be identified. Third, taxonomic uncertainty, particularly within morphologically complex genera such as *Labeobarbus*, prevents adequate species identification and reliable estimates of biodiversity. Fourth, molecular methods remain underutilized, and the absence of locally curated reference barcodes limits the full value of tools like DNA barcoding and eDNA metabarcoding for high-throughput detection of species. Lastly, the quality of policy decisions and habitat protection initiatives is diminished by the inadequate integration of ecological and biological data into management and conservation planning.

To bridge these gaps, future research must prioritize seasonally stratified surveys along altitudinal and longitudinal gradients using the classic sampling methods in combination with more advanced molecular tools such as eDNA monitoring. Taxonomic validation will be supported by voucher collections of specimen assemblies and the creation of local reference libraries to enhance species identification and detection of the rare, cryptic species. Alongside that, implementation of environmental flow standards, habitat restoration, and community-based co-management of the fisheries will be necessary in maintaining riverine society as well as freshwater biodiversity. The integrated efforts will provide the scientific foundation necessary for successful conservation and sustainable management of Ethiopian river ecosystems.

2.8. Biotic Interactions

Biotic interactions play a critical role in modulating the structure, function, and stability of river fish assemblages. Predation, competition, and symbiosis modulate species co-occurrence, partitioning of resources, and overall community dynamics, which influence the way fish populations respond to environmental change and human stress.

2.8.1. Species Interactions

Predation is one of the major regulating processes, controlling population levels and controlling prey species' habitat use and activity. Food competition, space, and spawning grounds place pressure on niche specialization to enable species with similar ecological requirements to coexist. Symbiotic relationships, mutualistic or commensal relationships, also influence survival and reproduction. Volcanic perturbations often impede these natural associations by competing with the native taxa for resources, preying on endemic species, or introducing disease, triggering radical alterations in community structure and a loss of indigenous biodiversity (Birk, 2008; Sciencedirect, 2023). Exotic introductions such as *O. niloti*cus in Ethiopian rivers have been linked with competitive displacement of indigenous fishes, altering trophic interactions and community structure.

2.8.2. Trophic Structures

Trophic interactions regulate the routes of energy flow and nutrient cycling in riverine ecosystems. Herbivores, detritivores, omnivores, and predators collectively influence the dynamics of food webs, which leave impacts on both community structure and ecosystem processes. These disturbances, such as overfishing, pollution, or habitat destruction, may alter the density of key functional groups, triggering trophic cascades and reduced ecosystem stability (Karr, 1981; Liu et al., 2025). For example, loss of apex predators or specialized benthic herbivores can increase prey species, which will then overgraze primary producers or detrital subsidies, ultimately affecting nutrient cycling and habitat quality. Knowledge of these biotic interactions is therefore paramount in predicting the response of the community to environmental change and in formulating effective measures of management and conservation.

2.9. Anthropogenic Impacts

Human land use as a consequence of urbanization, agriculture, and industrialization has extreme impacts on riverine ecosystems. The activities bring with them a set of stressors in the guise of chemical pollutants, high sedimentation, and huge habitat disturbance that collectively deteriorate water quality and eliminate natural ecological processes. Agricultural runoff is capable of transferring fertilizers, herbicides, and pesticides into rivers, which can cause eutrophication and poisoning of habitats that harbor sensitive fish populations. Urban and industrial effluents introduce heavy metals, organic pollutants, and thermal pollution, further degrading water quality and reorganizing species. Physical habitat alterations, such as channelization, dredging, and deforestation of riparian zones, reduce habitat complexity, decrease refugia and spawning habitat, and skew flow regimes. Collectively, these stressors reduce species richness, favor tolerant generalist species, and homogenize fish assemblages and lower biodiversity and ecosystem function (Jargal et al., 2024).

2.10. Conservation Implications

Riverine fish community management and conservation depend on an understanding of drivers of environmental, biological, and human origin that influence species structure and community dynamics. Preservation of critical habitats like spawning beds, refugia, and structurally diverse river reaches is essential to population resilience and biodiversity maintenance. Maintenance of water quality by control of pollution, management of nutrient loading, and sediment reduction creates proper conditions for both sensitive and commercially important species. Invasive species management is also critical, as non-native taxa may hybridize with or compete against native fishes, and bring about disruption in trophic interactions and community stability. Additionally, hydrological connectivity between rivers and adjacent floodplains must be maintained because it supports seasonal migration, gene flow, and access to nursery and feeding habitats, thereby promoting stable and diverse fish assemblages (Chang et al., 2025). Integrated conservation practices uniting habitat conservation, water quality management, invasive species control, and ecological connectivity are therefore essential for sustaining freshwater biodiversity and the ecosystem services that local communities depend upon.

CHAPTER THREE

3. Materials and methods

3.1. Description of the study area

The study was conducted in four rivers of the Tigray Tekeze sub-basin (Fig. 1). The rivers are Atsela, Mesgi, Geba, and Worie. All of them flow from east to west. The study rivers represented all ecological conditions (from cold to warm). The average air temperature of the rivers ranges from 11.25-39.6 °C (mean ± SD = 23.7 ± 8.4). Atsela is a large perennial river that passes the town of Adishiho from southeast to northwestern direction at 12^{o}55'54.70''N latitude, 39^{o}30'57.79'' E longitude with an elevation of 2441 m above sea level. It is about 75 km from Mekelle, which is a highland river that finally joins the Tselare, one of the largest and the upper Tekeze Basin. Mesgi is another large river found west of Mainebri town at about 2 km. It is located at an altitude of 1984 m above sea level, 13^{o}08'13.38''N latitude, and 39^{o}29'11.67'' E longitude. Geba, on the other hand, is located at the Geba (Giba: Gereb Giba) sub-basin, which lies between latitudes 13^{o}17'46" and 14^{o}15'00" N and longitudes 38^{o}37'37" and 39^{o}47'47''E. The total drainage area of the Geba up to the junction of the Tekeze River is about 5163 km^2; the length of the main watercourse is 236.4 km. This river has Suluh, Genfel, Agulae, Illala, and Meskilla as its main tributaries. The Geba River is one of the main tributaries of the Tekeze River, located in the northern part of Ethiopia. It joins the Tekeze River 34 km (along the watercourse) downstream of the Tekeze hydropower project at an altitude of about 975 meters above sea level. The Geba River originates at Gasat (Latitude 13^{o}38'50" N, Longitude 39^{o}24'42" E, and Altitude 1762 m a.s.l.), the junction of Suluh and Genfel, and is 143 km long. The Suluh River originates in Keshehat on the Dendera ridge at an elevation of 3323 m. a.s.l. (for the Suluh River) and in Ayfela on the Ayfela ridge at an elevation of more than 2740 m a.s.l. (Abebe, 2014). The current study was located at 1553 m. a.s.l. Lastly Worie River is situated in northern Ethiopia and is a tributary of the Tekeze River. It rises in the Gar'alta and flows to the southwest into the Tekeze River at 13^{o}41'N 38^{o}33'E. The major tributaries of Worie are Teway Ruba, Asem, Kinetal, Tsedia, Ruba Seguh, Yerbay, Gedgeda, Tsalet, Chemit, and Meseuma rivers (Abebe, 2014). Whereas this study was performed at 1357m a.s.l. The Tekeze River is a major river of Ethiopia and forms a section of the westernmost borders of Ethiopia and Eritrea for part of its course. In eastern Sudan, western Ethiopia, and Eritrea, the river is also referred to as the Setit. According to the Ethiopian Central Statistical Agency, the Tekeze River is 608 kilometers long (National Statistics of Ethiopia, 2008). At some point, the canyon it formed reaches a depth of over 2000 meters, making it the deepest in Africa and among the deepest in the world (National Statistics of Ethiopia, 2008; Mulu *et al.*

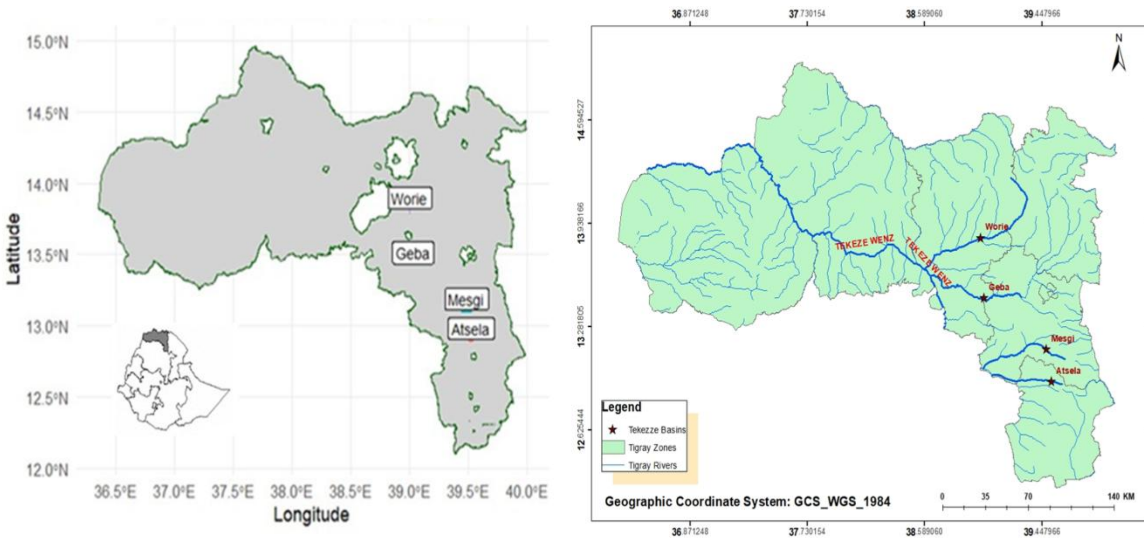


Figure 1: Map of Study Rivers: Location of each river indicated by stars and their corresponding names on map1 prepared by Solomon Tesfay and map 2 prepared by Daniel Girmay).

3.2. Sampling sites selection and data collection

Sampling sites along each stream were selected based on the accessibility and fordability (wadability) of the streams. Sampling sites were selected based on water flow velocity, presence of dry season pools, habitat types in the watershed, water depth, wet width of water, human and other livestock disturbance, and sediment type (Sharma et al., 2011; Gebrekiros, 2016; Tesfay *et al.*, 2019). These diverse characteristics of sampling areas were selected to represent the range of hydrological, physical, and anthropogenic conditions present within each site and the watershed.

Fish specimens were collected in a standardized way using backpack electrofishing (12 V; see Appendix Figure. 1) by depletion sampling technique ("Zippin" method) Scottish Fisheries Co-ordination Centre (SFCC, 2007); Lockwood and Schneider, 2000; Zippin, 1958) from the four study rivers during November and December 2019 (cold dry season) and March and April 2020 (hot dry season). Each river had 4 sampling sites, each having at least two of the microhabitats (Pools, riffles, and runs). Fish samples were collected twice at each site. The length of each sampling site was approximately 50 to 100 meters and depth ≤ one meter. The time taken for each run was 5 minutes, and the time gap between the first and second samplings was 20 minutes. A consistent sampling design for each site in each sampling period was applied to avoid biased results (Jha *et al*., 2005). Samples from the given rivers were taken per the planned time for both the study seasons along an identical trajectory, which included all major river microhabitats (Pools, riffles, and runs) (Jayaratne and Surasinghe, 2010; Jones *et al*., 2003). All samplings were performed from 10:00 to 12:00 A.M for consistency, comparability and water quality parameters sampling instructions.

Collected fish specimens were identified using keys and descriptions (Stiassny & Getahun, 2007) in the field. Specimens of each species were counted, and the total weight was recorded in each run as catch per unit effort (CPUE). Five to ten specimens of unidentified species were preserved in buffered formalin (10%) and transported to Mekelle University Fishery and Aquatic Ecology Laboratory for species validation and confirmation.

At each sampling site, selected physicochemical parameters such as the stream velocity (velocity of flow of water), water depth, river bed width, water temperature, pH, conductivity, and dissolved oxygen were determined using standard techniques (APHA, 1998). Stream velocity was measured using floatation method, by recording the time taken the object to float a specified distance downstream (Gordon *et al.,* 1992). Following this technique, and as Tesfay et al. (2019) also used, surface velocity was measured using a 60 ml vial with ¼ of its volume filled with water. Mean velocity was obtained using a correction factor. $\mathbf{V_{surface} = L/t}$, where '**L**' is travel distance and'**t**' is travel time. Because surface velocities are typically higher than mean or average velocities $\mathbf{V_{mean} = k\,V_{surface}}$, where **k** is a coefficient that generally ranges from 0.8 for rough beds to 0.9 for smooth beds (0.85 is a commonly used value).

Conductivity, pH, oxygen concentration, and water temperature were measured in situ using a conductivity meter (model No: SX713*)*, pH meter (model No*:* pH-013), and oxygen meter (HQ 40d multimeter), respectively. Moreover, other parameters like water transparency were measured using a Snell's tube (diameter 6 cm) (Vande Meutter *et al.,* 2007), and turbidity and chlorophyll-a concentrations (as a proxy of phytoplankton biomass) were measured using a fluorometer (Turner Aquafluor; model No: 8000-001) in the field.

3.3. Data Analysis

To assess for differences in fish species diversity and richness among the four rivers, mean species diversity and richness were calculated for each river. Species diversity for each of the rivers was calculated using the Shannon index of diversity (Shannon and Weaver, 1949; Kwak and Peterson, 2007). The Shannon index of diversity was calculated as $H' = -\Sigma p_i \ln (p_i)$, where $p_i = n_i/N$; n_i is the number of individuals of ‘i’th species and $N = \Sigma n_i$. The indices were used to compare the species distribution, richness, and diversity across the study rivers. The total number of species per site or habitat was used to calculate species richness (Magurran, 1988).

Diversity data among the rivers were compared using PAST-4 software (Hammer et al., 2001). Fish community composition from the catch per unit of effort (CPUE), i.e., individuals/run (King, 1991) for each species and river, was analyzed using abundance data. For temporal (season) differences in fish composition, we used the abundance data and quantitatively described the differences among the rivers.

Multivariate analysis was applied to demonstrate the roles of different variables in the composition of the fish community using CANOCOOv4.5 (Leps and Smilauer, 2003; Legendre and Legendre, 2012). Canonical Correspondence Analysis (CCA) was used to visualize the associations of the variables, like the abundance of different fish species, Chlorophyll a as a proxy of phytoplankton biomass, and abiotic variables (electrical conductivity, dissolved oxygen, pH, temperature, transparency, turbidity, and so on).

CHAPTER FOUR

4. Result

4.1. Physico-chemical and environmental characteristics

Average water temperatures varied between 17.8±2.6 and 31.75±1.8 °C, with the lowest values observed in Atsela (altitude 2431 m), and the highest temperature in Geba (altitude 1553 m). The temperature of Worie (21.54±0.81 °C) and Geba (31.75±1.8 °C) was higher than Atsela (17.8±2.6 °C) and Mesgi (23.74±0.38 °C) rivers. The dissolved oxygen (DO) of all the studied Rivers was within the range of 4.8 and 10.5 mg/L. The pH values of all studied rivers fell above 7 (basic condition), and the electrical conductivity was relatively higher in Worie (0.39±0.01 mS/cm) and Geba (0.40±0.02 mS/cm) rivers (Table 1). The measurements of turbidity and chlorophyll a were also relatively higher in Worie and Geba rivers than in Atsela and Mesgi rivers (Table 1; Figure. 5).

Table 1: Physicochemical and environmental characteristics of the rivers Worie, Geba, Mesgi, and Atsela.

Variables	Worie (Ave. ±SD)	Geba (Ave. ±SD)	Atsela (Ave. ±SD)	Mesgi (Ave. ±SD)
DO(mg/L)	8.36±0.42[a]	**10.03±1.2[a]**	**6.8±2.05[b]**	8.35±0.25[a]
Temp(^{o}c)	21.54±0.81[a]	**31.75±1.8[c]**	**17.8±2.6[b]**	**23.74±0.38[a]**
pH	7.93±0.13 [a]	8.43±0.05 [a]	7.9±0.73 [a]	7.9±0.08 [a]
Cond (mS/cm)	**0.39±0.01 [a]**	**0.40±0.02 [b]**	**0.254±0.01[c]**	**0.329±0.02[c]**
Salinity (ppt)	**0.41±0.01 [a]**	**0.2±0.01 [a]**	**0.13±0.004[b]**	0.16±0.01 [a]
TRB(NTU)	**9.73±2.6 [a]**	8.7±1.2 [a]	**3.13±1.9[b]**	**2.9±0.86 [b]**
CHL(mg/L)	76.92±0.5 [a]	55.5±13.8 [a]	71.18±21.16 [a]	44.36±2.98 [a]
Snell(cm)	28.13±2.17 [a]	30.3±4.6 [a]	32.25±3.3 [a]	35.75±4.18 [a]
Altitude (m)	**1355.5±5.1 [a]**	**1553±265.9 [a]**	**2431.25±9.9 [b]**	1956.5±4.7 [a]
Water depth (cm)	48.4±7.6 [a]	56.9±12.15 [a]	46.88±13.44 [a]	44.02±3.3 [a]
River bed width (m)	**3.13±0.32 [a]**	**4.9±0.85 [a]**	**3.8±0.6 [a]**	**7.31±3.15 [b]**
Velocity (m/s)	0.2±0.08 [a]	0.23±0.11 [a]	0.19±0.06 [a]	0.25±0.09 [a]

The physicochemical and environmental characteristics were taken from the four study sites (rivers); each site with at least 2 different microhabitats (pool, run, and riffle) during the two sampling seasons from the four rivers, and the average value and standard deviation (SD) are presented in Table 1. In addition to the mean ± standard deviation values, different superscript letters within a row indicate significant differences among rivers based on Tukey's HSD post hoc test ($p < 0.05$).

4.2. Fish Composition, abundance, and community structures

A total of 2917 fish representing 14 species belonging to 4 families and 3 orders were recorded from the four study Rivers (Table 3). Two fish species, *Garra blanfordii* and *Garra dembecha*, were present in all four river systems (Table 3). The highest number of fish was collected from the Mesgi river (1250), followed by the Atsela (838), Worie (568), and Geba (261) (Table 3). The majority of the fish species caught from the rivers belonged to the family Cyprinidae (Tables 2 and 3; Figure. 2). The overall relative abundance of the studied rivers was also computed as indicated in Table 3. Accordingly, in the Worie river, *G. blanfordii* (40.9%) showed the highest relative abundance and was followed by *Labeobarbus intermidus* (40.5%). On the contrary, in the Geba river, the fish species with the highest relative abundance was *L. intermidus* (54.4%), followed by *G. blanfordii* (27.2%). In the Mesgi river, *G. dembecha* (68.1%) showed the highest relative abundance, and in Atsela, *G. blanfprdii* (69.1%). There are multiple species with similar lowest relative abundances in the rivers Worie and Geba.

Table 2: List of the species of fish found in the four Study Rivers as well as their categories (classification) during December 2019 and April 2020.

Species (author)	**Genus**	**Family**	**Order**
Garra blanfordii (Boulenger, 1901)	*Garra*	Cyprinidae	Cypriniformes
Garra dembecha (Getahun & Stiassny, 2007)	*Garra*	Cyprinidae	Cypriniformes
Garra ignestii (Gianferrari, 1925)	*Garra*	Cyprinidae	Cypriniformes
Garra dembeensis (Rüppell, 1835)	*Garra*	Cyprinidae	Cypriniformes
Garra geba (Getahun & Stiassny, 2007)	*Garra*	Cyprinidae	Cypriniformes
Labeobarbus intermedius (Rüppell, 1835)	*Labeobarbus*	Cyprinidae	Cypriniformes
Labeo forskalii (Respell, 1835)	*Labeo*	Cyprinidae	Cypriniformes

Varicorhinus beso (Rüppell, 1835)	*Varicorhinus*	Cyprinidae	Cypriniformes
Labeo niloticus (Linnaeus, 1758)	*Labeo*	Cyprinidae	Cypriniformes
Clarias gariepinus (Burchell, 1822)	*Clarias*	Clariidae	Siluriformes
Chiloglanis niloticus (Boulenger, 1900)	*Mochokidae*	Mochokidae	Siluriformes
Chelaethiops bibie (Joannis, 1835)	*Chelaethiops*	Cyprinidae	Cypriniformes
Raiamas senegalensis (Steindachner, 1870)	*Raiamas*	Cyprinidae	Cypriniformes
Oreochromis niloticus (Linnaeus, 1758)	*Oreochromis*	Cichlidae	Perciformes

Among the four fish families encountered in the study, 79% of them were in the family Cyprinidae, and the rest shared 7% each (Fig. 2). In addition, based on the number of individual fish recorded from each river, 99.3% of the Worie and 98.1% of Geba rivers were represented by the family Cyprinidae. The other two (Atsela and Mesgi) rivers had the riverine *Garra* species, which account for 100 % family Cyprinidae (Table 4). In this study, the total fish abundance during April was greater than December (almost twice) in each river. Comparing all the studied rivers, the highest fish abundance was recorded from Mesgi (April) and the lowest in Geba (December) (Table 4; Figure. 3). In addition, the composition of fish in Worie and Geba increased in April. For example, *Chiloglanis niloticus*, *Chelaethiops bibie*, *Raiamas senegalensis,* and *Oreochromis niloticus* were not caught during December. But there were also species caught in December but not in April in Geba (*G. dembeensis* and *G. geba*) (Table 4).

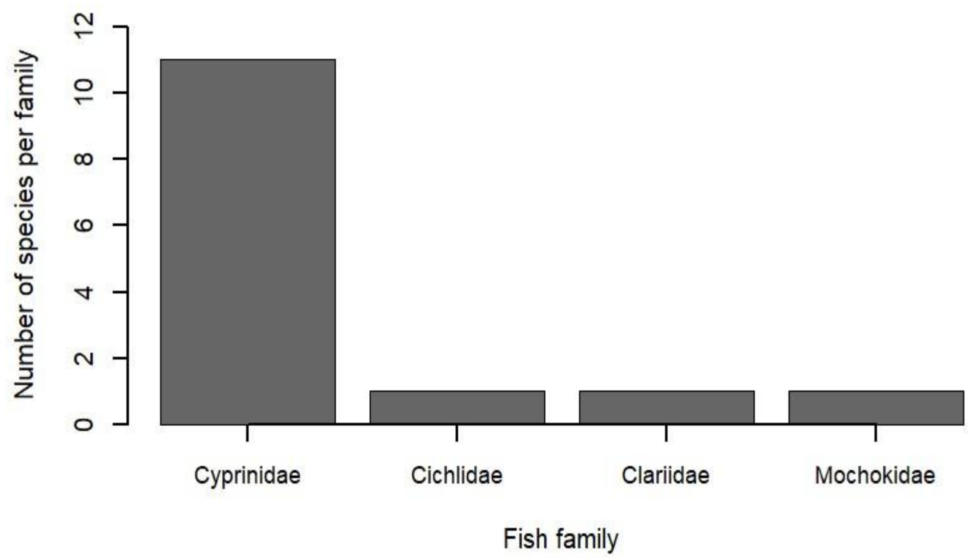


Figure. 2: Relative dominance of fish families based on the number of fish species identified in the four study rivers.

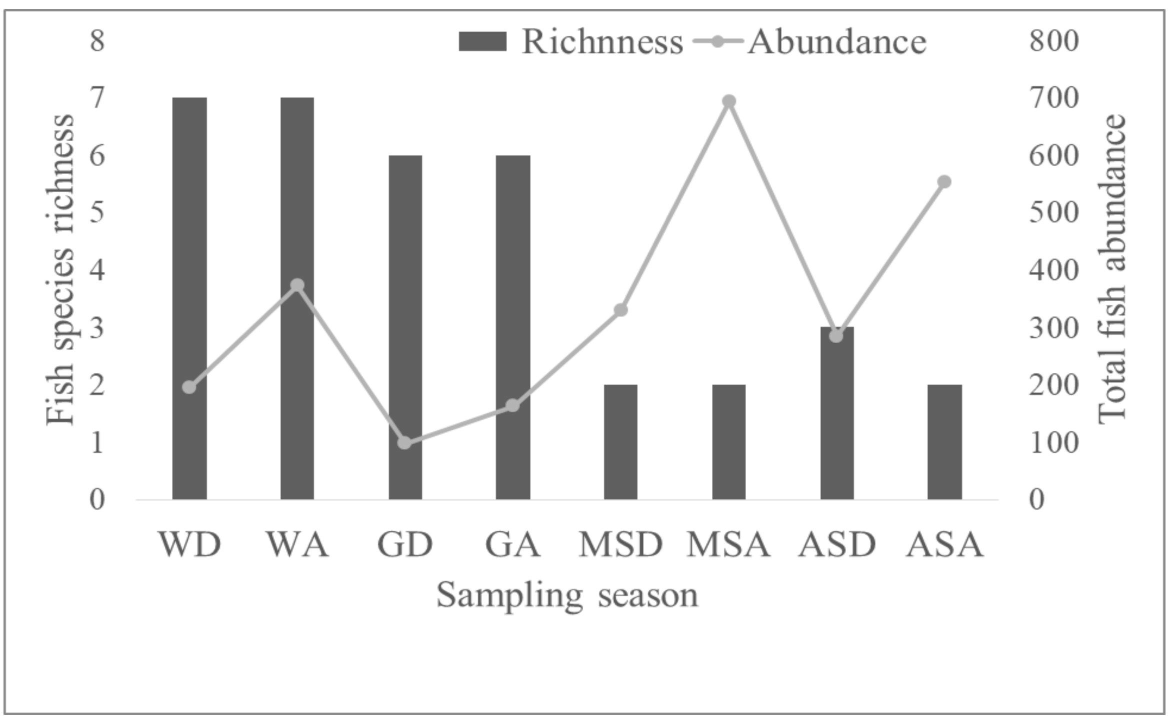


Figure. 3: Fish species richness and total fish abundance during December 2019 and April 2020 (Note: W = Worie, G = Geba, MS = Mesgi, AS = Atsela, D = December, A = April)

Table 3: List of the species of fish found and their number of individuals in the four Study Rivers, as well as their percentage of the total caught during December 2019 and April 2020.

	Worie		Geba		Mesgi		Atsela	
Species	N	%	N	%	N	%	N	%
Garra blanfordii	232	40.9	71	27.2	399	31.9	579	69.1
Garra dembecha	45	7.9	38	14.6	851	68.1	248	29.6
Garra ignestii	2	0.4	0	0	0	0	11	1.3
Garra dembeensis	0	0	2	0.8	0	0	0	0
Garra geba	0	0	1	0.4	0	0	0	0
Labeobarbus intermedius	230	40.5	142	54.4	0	0	0	0
Labeo forskalii	7	1.2	1	0.4	0	0	0	0
Varicorhinus beso	44	7.8	0	0	0	0	0	0
Labeo niloticus	3	0.5	0	0	0	0	0	0
Clarias gariepinus	2	0.4	1	0.4	0	0	0	0
Chiloglanis niloticus	0	0	4	1.5	0	0	0	0
Chelaethiops bibie	1	0.2	0	0	0	0	0	0
Raiamas senegalensis	1	0.2	1	0.4	0	0	0	0
Oreochromis niloticus	1	0.2	0	0	0	0	0	0
Total	568	100	261	100	1250	100	838	100

Table 4: List of fish species recorded their number (N) and the percentage of the total fish caught from the four Study Rivers during December 2019 and April 2020.

	Worie		**Geba**		**Mesgi**		**Atsela**	
	Dec.	**Apr.**	**Dec.**	**Apr.**	**Dec.**	**Apr.**	**Dec.**	**Apr.**
Species	**N (%)**	**N (%)**	**N (%)**	**N (%)**	**N (%)**	**N (%)**	**N (%)**	**N (%)**
Garra Blanfordii	89(45.6)	143(38.3)	24(24.5)	47(28.8)	193(34.65)	206(29.7)	243(85.3)	336(60.8)
Garra dembecha	11(5.6)	34(9.1)	2(2.0)	36(21.1)	364(65.35)	487(70.3)	31(10.9)	217(39.2)
Garra ignestii	2(1)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	11(3.9)	0(0.0)
Garra dembeensis	0(0.0)	0(0.0)	2(2.0)	0(0.0)	0(0.0)	0(0.0)	0(0)	0(0.0)
Garra geba	0(0.0)	0(0.0)	1(1.0)	0(0.0)	0(0.0)	0(0.0)	0(0)	0(0.0)
Labeobarbus intermedius	81(41.5)	149(39.9)	68(69.4)	74(45.4)	0(0.0)	0(0.0)	0(0)	0(0.0)
Labeo forskalii	7(3.6)	0(0.0)	0(0.0)	1(0.6)	0(0.0)	0(0.0)	0(0)	0(0.0)
Varicorhinus beso	0(0.0)	44(11.8)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0)	0(0.0)
Labeo niloticus	3(1.5)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0)	0(0.0)
Clarias gariepinus	2(1.0)	0(0.0)	1(1.0)	0(0.0)	0(0.0)	0(0.0)	0(0)	0(0.0)
Chiloglanis niloticus	0(0.0)	0(0.0)	0(0.0)	4(2.5)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Chelaethiops bibie	0(0.0)	1(0.3)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Raiamas senegalensis	0(0.0)	1(0.3)	0(0.0)	1(0.6)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Oreochromis niloticus	0(0.0)	1(0.3)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Total	**195(100)**	**373(100)**	**98(100)**	**163(100)**	**557(100)**	**693(100)**	**285(100)**	**553(100)**

4.3. Fish species Richness and diversity

Based on our sampling during the two seasons, fish species richness varied from 2-11. The highest species richness was recorded from Worie River, and the lowest was from Mesgi River (Fig. 4). Similarly, the highest and lowest species diversity was observed from Worie and Mesgi rivers, respectively (Fig. 4). Fish species richness between December 2019 and April 2020 within the rivers was almost the same (Fig. 3; Table 4). But when comparing all the rivers, Worie and Geba showed greater species richness than Mesgi and Atsela (Figs. 3 & 4; Table 4).

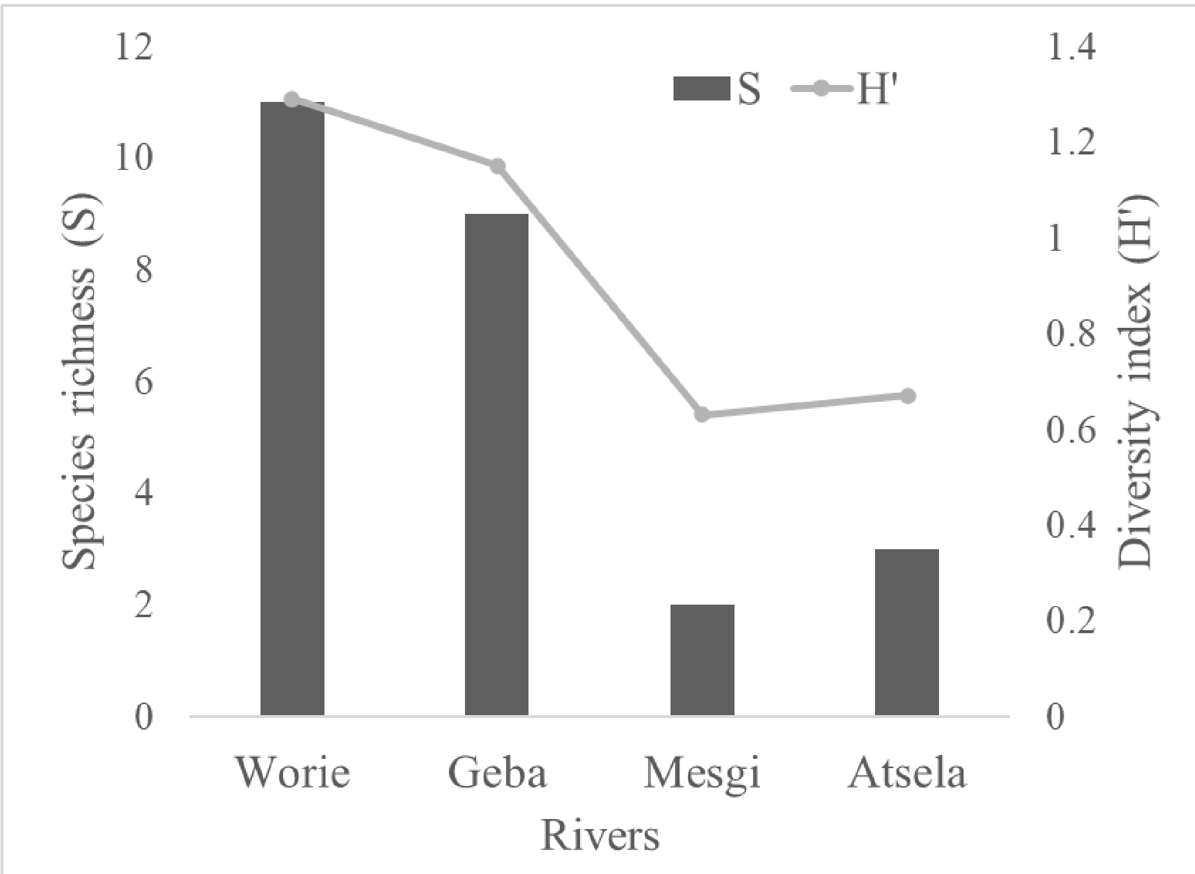


Figure. 4: Fish species richness and Shannon diversity index

4.4. Multivariate analysis: occurrence and characteristics of the fish communities with environmental variables

Fig. 5 represents a triplot CCA for the compositional variation in fish communities, as derived from a CCA of numerical abundance data of December 2019 and April 2020. CCA axes 1 and 2 together represented 65.7% of the variation in the environmental variables and abundance of fish species. Axis 1(Eigenvalue = 50.2%) is mainly represented by turbidity and salinity. Depth, pH, and electrical conductivity were positively associated with this gradient. To a lesser extent, dissolved oxygen and Chl a were positively associated with this gradient. In contrast, altitude, Snell water transparency, velocity of stream water, and wet width of the stream water were strongly negatively associated with Axis 1, indicating that sites with higher values for these variables tend to be positioned on the negative end of this axis. Additionally, the stream's water temperature also showed a negative association with Axis 1, although to a lesser extent. The abundance of fish species *L. intermedius*, *Clarias gariepinus*, *Labeo forskalii*, and *Labeo niloticus* is strongly positively associated with this axis, indicating that higher values along the axis correspond to greater occurrences of these species. As indicated in Figure. 5, most fish species were positively associated with this axis, whereas *G. blanfordii* and *G. dembecha* were strongly negatively associated with axis 1. On the other hand, *G. ignestii* showed an orthogonal (uncorrelated) relationship to axis 1.

Axis 2 (Eigenvalue=15.5%) is mainly represented by the occurrences and abundances of fish. *Garra ignestii* and *G.blanfordii* were strongly positively associated with axis 2. The fish species G. *dembecha*, *C. gariepinus*, *V. beso*, *O. niloticus*, *L. intermedius*, *C. niloticus*, C. *bibie*, *L. niloticus*, *R. senegalensis*, *L. foriskalii*, *G. dembecha*, and *G. dembeensis* were negatively associated with this gradient. The environmental variables, namely, altitude and chlorophyll a, were positively associated with this axis. Whereas velocity, width, temperature, dissolved oxygen, and salinity were negatively associated with this gradient. The environmental variables, such as water depth, velocity, Chlorophyll a, width, transparency, altitude, turbidity, and dissolved oxygen, were negatively associated.

Garra blanfordii was strongly positively correlated with altitude and negatively with the salinity of the stream water. *G. geba*, *G. dembeensis*, *L. forskalii*, *L. niloticus*, *O. niloticus*, *C. gariepinus*, *L. intermedius*, *V. beso*, *C. niloticus*, C. *bibie*, *L. niloticus*, and *R. senegalensis* were positively associated with the depth, turbidity, salinity, pH, and electrical conductivity during December, particularly in *Geba* and *Worie* rivers. To a lesser extent, Chlorophyll a and dissolved oxygen were also positively associated. Those are negatively associated with the water transparency

(Snell reading), altitude, wet width, and temperature of the rivers. Among the fish species, *G. dembecha* was the only fish species negatively associated with both axes.

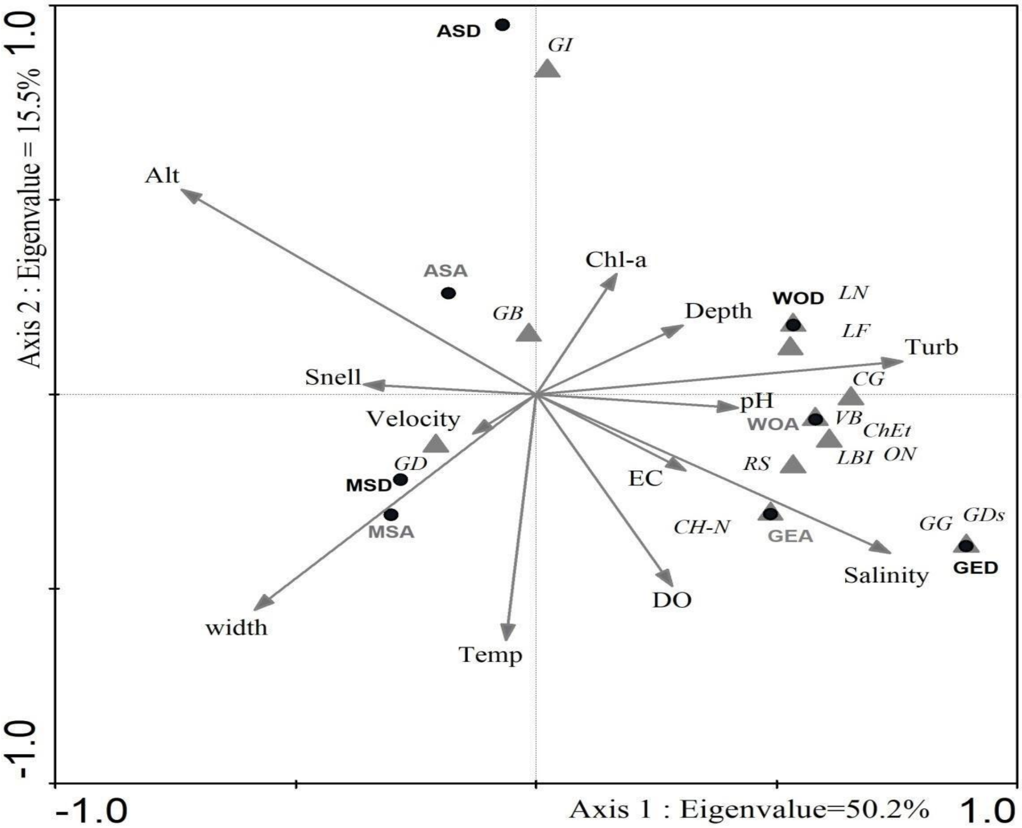


Figure. 5: Triplot CCA for the compositional variation in fish communities. Where the gray arrows indicate environmental or physicochemical variables, dark circle for reservoirs during both seasons, triangles for the different fish species. (Note: WOD = Worie December, WOA = Worie April, GED = Geba December, GEA = Geba April, MSD = Mesgi December, MSA = Mesgi April, ASD = Atsela December, ASA= Atsela April, DO= dissolved oxygen, pH = power of hydrogen, EC = electrical conductivity, Chl-a = chlorophyll a, Temp = temperature, Alt= altitude, Turb = Turbidity, GB= Garra blanfordii, GD = Garra dembecha, GDs = Garra dembeensis, GG = Garra geba, GI = Garra ignestii, LBI= Labeobarbus intermedius, LF=Labeo forskalii, VB = Varicorhinus beso, LN= Labeo niloticus, CG = Clarias gariepinus, CH-N = Chiloglanis niloticus, ChEt = Chelaethiops bibie,RS = Raiamas senegalensis, ON = Oreochromis niloticus).

4.5. Observations

During the river study, the researcher documented several unanticipated environmental conditions. Various forms of plastic waste, including plastic bags, pesticide packaging materials, and discarded plastic water bottles, were observed at multiple sampling sites along the rivers. Additionally, sand mining activities and other forms of anthropogenic disturbance were evident, indicating significant human influence on the riverine environment (Table 5).

Table 5: Observations noted by the researcher during the field sampling

Observation /human interferences	Worie	Geba	Mesgi	Atsela
Sand mining	✓	✓		
Water abstraction for irrigation (pumping)	✓	✓		✓
Water diversion for irrigation		✓		✓
Plastic bag accumulation (water bottles)		✓		✓
Pesticide plastic bags		✓		
Riparian activities /plant cutting /clearing	✓	✓		
Riparian activities /block production				✓
Domestic use / Animal disturbance/ Cattle drinking	✓	✓	✓	✓
Seasonal floods	✓	✓	✓	✓
Car / Bajaj wash		✓		✓
Cloth washing activities with detergents	✓	✓	✓	✓

CHAPTER FIVE

5. Discussion

The overall physicochemical parameters of the rivers studied were found to be within acceptable limits. All parameters were within the permissible limits for fish and any aquatic animal life. In the study of rivers, water temperature is one of the most important determinants of fish composition. While the temperature of the water tends to increase as the elevation of the river decreases, this was not universally true for the rivers studied. For example, the Worei river, although having the lowest altitude of the rivers studied, had a lower temperature than the Geba and Mesgi rivers, as indicated in Table 1. This may indicate that some factors, such as intensity of sun light during sampling, vegetation cover (riparian vegetation), and river flow patterns, may play a more important role in the temperature of the water than the actual elevation of the river. This phenomenon was also noted by previous authors. For example, Coutant (1977) and Deacon (1997) indicated that the temperature of the river was affected by several environmental factors.

The reasons for temperature variability in the rivers could be due to the topographical locations and climatic conditions. Based on the traditional Ethiopian classification of climate based on elevation and temperature (Negash, 1989), Worie and Geba rivers are geographically placed in hot lowlands. Moreover, Worie and Geba rivers showed relatively higher conductivity and turbidity, while chlorophyll-a was highest in Worie, followed by Atsela and Geba. These patterns may be influenced by seasonal floods, domestic animal disturbance, sand mining, and human interference with motor pumping for irrigation (Table 5).

There is no qualitative as well as quantitative information available about the biodiversity of the fish fauna of the surveyed rivers, except for a few reports about Geba. We found evidence that fish assemblages varied among the surveyed rivers and their respective sites, particularly the locations and distribution of the large and commercially important fishes, such as *L. intermedius, V. beso, L. niloticus, C. gariepinus,* and *O. niloticus*. The rivers under study have a variety of fish species, including Nilo-Sudanic (*L. forskalii*) and East African species (*L. intermedius, O. niloticus*, and *Garra* sp.). Among the four families found in the Study Rivers, Cyprinidae was the largest family with greater species richness and ecological diversity. In addition the rivers under study have a variety of fish species, including Nilo-Sudanic (*L. forskalii*) and East African species (*L. intermedius, O. niloticus*, and *Garra* sp.; Table 2; Figure. 3). The distribution of these groups of fish was found to be localized differently based on their habitat preferences (Tesfay *et al.,* 2019) for ample, *L. intermedius* and *V. beso* were mostly found in fast-flowing, rocky or sandy midstream areas of Worie and Geba rivers**.** The Atsela and Mesgi rivers are relatively higher in altitude and relatively cooler areas than the Worie and Geba rivers, which contain only the *Garra* species. Fish abundance differed among stream types and habitats. Habitat types were the most important driving factors behind variation among fish abundances, and pools support the highest fish abundance (Tesfay *et al*., 2019).

The genus *Garra* was found in all the study rivers. Whereas the majority of the large and commercially important fishes listed above (Table 3) were distributed at lower altitudes and higher temperatures, indicating a preference for warmer, lowland aquatic environments. This is in agreement with the reports of Luciana *et al*. (2011), who observed that temperature is one of the major controlling factors in fish community compositions and assemblage structures. Specific areas with selected temperature conditions provide a favorable habitat for selected fish species (Coutant, 1977). In addition, Mengesha (2015) reported in his review that *Garra* fishes are distributed in almost all river basins in Ethiopia. Such extensive distribution and their common high abundance suggest that most of these species are capable of tolerating a wide range of environmental conditions (Pusey *et al.*, 1993).

There might be several reasons for variation in abundance and species richness between the cold, dry, and hot, dry seasons. Possible reasons for variations in fish abundance and richness could be higher water levels during December. This creates a sufficient area of fish distribution and migration. The depth and water velocity are probably the most important requirements of spawning fish, and depth could be the most serious limitation of fish passage during periods of reduced flow (Gebrekiros, 2016; Tesfay *et al.,* 2019). The temperature may also influence the activities of the fish. In April, the water level decreases as a result of the drying season, and in some areas as a result of pumping the water for irrigation, which causes fish to be restricted to pools which making it easier for electrofishing. This is also similar to what have observed and done by my colleagues and supervisors in previous research (Tesfay *et al.,* 2019). In addition, variations in available nutrients and habitats, temperature, fish behavior, size, and life history stages of fishes and others might have contributed to the variation in abundance and richness of the catches. Moreover, water level (Karenge and Kolding, 1995) and turbidity of water may also affect the abundance and species richness (Ambak *et al.,* 2010; Ambak & Zakaria, 2010).

Habitat's physical structure is of greatest importance in determining both the abundance and species composition of stream fishes (Tesfay *et al.,* 2019). The influence of habitat diversity and availability on the composition of riverine fish communities is well known (e.g., Beecher *et al.*, 1988; Pusey *et al.,* 1995; Gebrekiros, 2016), with the greatest species diversity occurring in areas offering the greatest variety of habitats.

The composition of the fish community in a water body was shown to be mostly dependent on latitude, altitude, nutrient concentration, and morphology (Garcia *et al.,* 2006; Mehner *et al.*, 2007; Emmrich *et al*., 2011). Accordingly, we observed that in Geba and Worie, the species composition varied according to altitudinal variability; the species composition of fish increased as we descended to the lowest altitude. Similar results were reported by some authors (e.g. Rahel and Hubert,1991; Paller,1994), and they explained that the progressive increases in habitat availability downstream in many rivers tend to coincide with increases in the number of fish species as well as the formation of biotic zonation patterns in rivers. According to Edds (1993), not only the number of fish species but also the ichthyomass showed a progressive increase, and therefore, a small ichthyomass could be expected in small streams. Habteselassie (2012) also reported that the affinities and patterns of fish distribution varied significantly based on the type of water body and altitudes. The river systems of Ethiopia harbor more fish species than the lakes and reservoirs of the country. The diversity of fish species in major river systems of the country is negatively correlated with the altitude of the river system, i.e., river stretches at lower altitudes have a higher number of fish species than river reaches at higher altitudes.

According to my knowledge and field experiences, among the fish species, the author found in Geba and Worie rivers, *Chiloglanis niloticus* (Appendix Figure. 2) and *Chelaethiops bibie* (Appendix Figure. 3) were not reported in the region before this study. Of course, the region's rivers are hot spots for different fish species, and it has not been fully discovered. So I believe there will be many fish species, including endemic species. For these two specimens, I could not get sufficient information, images, or colored keys from Ethiopia, but the author identified them based on the available literature in the country. *C. niloticus* (Boulenger, 1900), is a species with mouth suckers like papillose circular lip or an upside-down catfish native to the Nile River and Niger River (Daget et al., 1984; Golubtsov *et al.*,1995; Froese and Pauly, 2011). *C. bibie* (Joannis, 1835) is commonly called Lake Turkana sardine. According to Golubtsov *et al.* (1995), it is characterized by the number of branched rays (16-19) in its anal fins. According to Lévêque, (1990) indicated on the Fishbase website, the branched anal soft rays ranged from 17-21. This African Cyprinid family is found distributed in the Nile and Webishebeli rivers in Ethiopia (Golubtsov *et al*., 1995). Besides these Ethiopian rivers, it was also found in the Benoue and Volta basins of Niger (Froese and Pauly, 2017). The environmental (climatic) conditions, pH, and temperature ranges of the fish species are similar to the current study (Lévêque, 1990; Golubtsov *et al.*, 1995).

In addition, I tried to compare the fish species of the four Study Rivers with their basin Tekeze Reservoir. My result from the four Tekeze sub-basin rivers accounts for 14 species, and in comparison with some of the previous reports from the Tekeze reservoir, indicates fewer than this report. For example, Getahun (2007), Goshu *et al.* (2009, EFASA), and Teame *et al.* (2016) reported 10, 12, and 11 species, respectively. However, according to Teferi *et al.* (2014-2017) in their Regional Individual Projects (RIP) project (unpublished document) and Gebru *et al*. (2019), about fifteen fish species were reported. So in comparison with the reservoir lower number of species were recorded from my study rivers. However, there are also species found in the rivers Worie and Geba, but not reported (not observed) in the reservoir, and vice versa. *C. niloticus* (Appendix Figure. 2) from the Geba river, *C. bibe* (Appendix Figure. 3) from the Worie river, and some *Garra* species are not recorded in the reservoir.

Differences in stream and river types, habitat types, and food resources can cause a significant proportion of the variation in the numerical abundance of fish. Fish abundance strongly differed among rivers (Tesfay *et al.*, 2019). In addition, the altitudinal differences among the study streams bring a difference in fish abundance and richness. The highland rivers Mesgi and Atsela were negatively associated with the first axis during both sampling seasons. These rivers were positively associated with altitude and revealed a species richness of 2 and 3, respectively (Table 3). Although they revealed lower species richness, the total fish abundance was 1250 and 838, respectively, which is higher than the other two lowland rivers (Table 3). These are Geba and

Worie rivers which were negatively related to altitude (Fig. 5). The species richness in Geba and Worie rivers consists of 9 and 11 respectively and the fish abundance was 261 and 568 respectively (Tables 2 and 3; Figure. 4). This parameter positively influenced for the abundances of *G. blanfordii*, *G. dembecha*, *G. ignestii* and negatively to the most of the fish species such as *G. dembeensis, G. geba, L. intermedius, L. forskalii, V. beso, L. niloticus, C. gariepinus, C. niloticus, C. bibie*, *R. senegalensis*, and *O. niloticus* collected both or either of the low land rivers Worie and Geba (Tables 2 and 3; Figure. 5). Among the fish species *G. dembecha* and *G. ignestii* were the only fish species negatively associated to both axes (Fig. 5). Altitude was the most important factor determining species distribution (Pusey & Kennard 1996; Súarez and Júnio, 2007). The CCA results showed that altitude is the most important factor determining fish distribution in all the study rivers. The importance of altitude in fish communities can also be seen in the altitudinal species distribution (Fig. 5)

Geba and Worie rivers showed a greater water velocity, depth, turbidity, and salinity than Atsela and Mesgi rivers, especially during December. These characteristics may have a potential role in fish distribution, species richness, and protection from predatory and fishing pressures. The latter two rivers were less turbid with greater wet width. Hence, the CCA analysis revealed that the environmental variables such as altitude, electrical conductivity, dissolved oxygen, pH, water temperature, turbidity, chlorophyll-a, water depth, wet width, and flow substantially influence fish assemblage structuring in the study rivers and their basin. These variables have previously been considered important factors in structuring fish assemblages (Matthews, 1998; Angemeier & Winston, 1999; Marchetti & Moyle, 2001; May & Brown, 2002; Tesfay *et al.*, 2019). In harsh and variable environments such as streams and rivers, abiotic factors are likely to play an important role in determining fish assemblage structure.

CHAPTER SIX

6. Conclusion and recommendations

6.1. Conclusion

The findings confirmed that the composition of fish significantly differed among the rivers due primarily to environmental and physicochemical characteristics such as altitude, water temperature, and water quality. The high-altitude rivers Mesgi and Atsela with low water temperatures were dominated by the fish genus *Garra*, i.e., *G. blanfordii* and *G. dembecha*. The lower-altitude rivers, Worie and Geba, supported more species richness and diversity with over nine species, among them large and valuable commercial species such as *Labeobarbus intermedius*, *Labeo forskalii*, *Varicorhinus beso*, and *Oreochromis niloticus*.

In general, fish species richness and community complexity increasingly rose downstream in parallel to declining altitudes and rising temperatures. These patterns indicate that altitude and temperature may be important factors associated with variations in fish community structure among the sampled river sites, although the limited number of sampling locations does not allow assessment of longitudinal patterns along the rivers. Although comparatively good physicochemical conditions were observed, there were several anthropogenic pressures that were identified (observed; Table 5) as probable threats to the sustainability of these riverine communities. Large-volume water abstractions for irrigation, sand mining, and disturbance of riparian habitats were found to have adverse effects on the natural stream flow regime and habitat integrity with potential implications for fish number declines, spawning success, and feeding behaviour.

The ecological significance of these rivers is again reflected in the altitudinal variations in fish abundance and composition. The presence of numerous economically important species in lowland systems and the predominance of *Garra* species in upland rivers demonstrate the Tekeze sub-basin's high ecological and biological diversity. Moreover, data from previously unrecorded species such as *Chiloglanis niloticus* and *Chelaethiops bibie* also indicate a potential for undiscovered or endemic species in the region.

In conclusion, this research offers the first comprehensive analysis of fish populations in four rivers of the Tekeze sub-basin, showing the uniqueness of the fish assemblages based on factors such as altitude, water quality, and habitats. This research provides important baseline information on the fish fauna and records new species for the region. It emphasizes the importance of integrated management of the rivers, including the riparian zone, water management, and sand mining, to sustain the biodiversity of the fish fauna and the balance of the ecosystem for the benefit of the people of Tigray, Ethiopia.

6.2. Recommendations

Based on the result the following recommendations are put forward to conserve and sustain the fish communities of the studied rivers:

- Intensive activities such as sand mining and clearing riparian habitats on the rivers Geba and Werie should receive immediate attention to enhance habitat stability and ecological integrity. In addition, regular monitoring of water quality is mandatory to detect ecological changes (status).
- Excessive water abstraction for irrigation is seen on the rivers Geba, Werie and Atsela. Encouraging the usage of water-saving and alternative irrigation systems shall be done for the provision of adequate flow regime which is essential to support migration and spawning of the fishes on the rivers.
- Coordination has to be done among the local engaged government agencies, research institutions, and the local communities for a sustainable river management and the fishes for the four Study Rivers.
- Further research is needed on the newly recorded species (*Chiloglanis niloticus* and *Chelaethiops bibe*) and on the ecological roles of the wide spread *Garra* species.
- Promotion of sustainable fishing practices in the low-altitude rivers (Worie and Geba) containing commercially important fish species could create job opportunities for some youths and could improve the surroundings food (protein) security.
- The high biomass small non-commercial *Garra* populations in the four study rivers presents an opportunity for their use as an alternative protein source in poultry feed; therefore, their utilization is recommended following appropriate ecological and nutritional assessments.

References

Abebe, N. 2014. Feasibility Study of Small Hydropower Schemes in Giba and Worie Subbasins of Tekeze River, Ethiopia. *Journal of Energy Technologies and Policy,* **4(8):**8-17.

Abebe, G., and Tilahun, G. 2022. *Threats to freshwater biodiversity in Ethiopia: A national synthesis*. Ethiopian Biodiversity Institute.

Abebe, T., & Tilahun, G. 2022. Impacts of introduced *Oreochromis* species on native fish diversity in Ethiopian freshwater ecosystems. *African Journal of Aquatic Science*, **47**(2): 157–169.

Abebe, T., Getahun, A., & Anteneh, W. 2023. Status of freshwater fish exploitation and management challenges in Ethiopian rivers. *African Journal of Aquatic Science*, **48**(3): 245–258.

Alemneh, T., Ambelu, A., & Zaitchik, B. F. 2019. Multiple stressors shape the structure and function of fish assemblages in the Gilgel Gibe watershed, Ethiopia. *Ecological Indicators*, **107**: 105585.

Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annu. Rev. Ecol. Evol. Syst.*, **35**(1): 257-284.

Ambak MA, Isa MM, Zakaria MZ, & Ghaffar MA. 2010. *Fishes of Malaysia*. Kuala Terengganu: Universiti Malaysia Terengganu.

Ambak, M. A., & Zakaria, M. Z. 2010. Freshwater fish diversity in Sungai Kelantan. *Journal of Sustainability Science and Management*, **5(1)**:13-20.

Ameha, A., & Assefa, A. 2002. The fate of the barbs of Gumara River, Ethiopia. *SINET: Ethiopian Journal of Science*, **25(1)**: 1-18.

Angermeier, P. L., & Winston, M. R. 1999. Characterizing fish community diversity across Virginia landscapes: prerequisite for conservation. *Ecological Applications*, **9(1)**:335-349.

APHA.1998. *Standard method for the examination of water and wasteland. 20th edition*. Am. Public Health Assoc. Washington D.C., 314 pp.

Arnhold, T. R., Penha, J., Peoples, B. K., & Mateus, L. A. 2019. Positive co-occurrence between feeding-associative savannah fishes depends on species and habitat. *Freshwater Biology*, **64(5)**:1029-1039.

Asmelash, T., Dejenie, T., Declerck, S., Nyssen, J., Van der Gucht, K., Risch, S. R. S., ... & Gebrekidan, A. 2007. *Ecological atlas of reservoirs in Tigray, Northern Ethiopia*. Tigray Livelihood Papers No. 4, VLIR-Mekelle University IUC Programme.

Aubrey, R.1975. *The Fisheries of Ethiopia*. An economic study. FAO, Rome.

Baltz, D. M., B. Vondracek, L. R. Brown & P. B. Moyle.1987. Influence of temperature on microhabitat choice by fishes in a California stream. *Transactions of the American Fisheries Society,* **116**: 12-20.

Beecher, H. A., Dott, E. R., & Fernau, R. F. 1988. Fish species richness and stream order in Washington State streams. *Environmental Biology of Fishes*, ***22*(3)**: 193-209.

Birk, S. 2008. *Review of European assessment methods for rivers and streams using Benthic Invertebrates, Aquatic Flora, Fish and Hydromorphology* (Doctoral dissertation, Diplomarbeit, Duisburg, Essen, Universität Duisburg-Essen).

Bovee, K. D. 1982. *A guide to stream habitat analysis using the in-stream flow incremental methodology*. U.S. Fish and Wildlife Service, Instream Flow Information Paper 12, FWS/OBS-82/26.

Britton, J. R. 2024. Ecological impacts of non-native freshwater fishes: Mechanisms, consequences, and management. *Freshwater Biology,* **69**(2): 231–245.

Canonico, G. C., Arthington, A., McCrary, J. K., & Thieme, M. L. 2023. The effects of introduced tilapias on native biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **33**(1): 15–29.

Chang, T., Li, M. and Gao, X. 2025. Dispersal-based processes as drivers of fish communities and species distributions in the Yangtze River–Poyang Lake riverine floodplain of China. *Ecological Processes*, **14(1)**: 1-13.

Chekol, A. A. 2013. *Management and livelihood opportunity of Lake Tana fishery, Ethiopia* (Master's thesis, UiT The Arctic University of Norway).

Coble, A. A., Flinders, C.A., Homyack, J.A., Penaluna, B.E., Cronn, R.C. & Weitemier, K. 2019. eDNA as a tool for identifying freshwater species in sustainable forestry: A critical review and potential future applications. *Science of the Total Environment*, **649**:1157-1170.

Coutant, C. C. 1977. Compilation of temperature preference data. *Journal of the Fisheries Research Board of Canada*, **34(5)**: 739–745.

D'Amato, M. E., Bruton, M. N., & van der Bank, F. H. 2024. Hybridization and genetic introgression in African cichlids: Conservation implications. *Conservation Genetics,* **25**(1):1–14.

Daget, J., Gosse, J.P.& Thys van den Audenaerde, D. F. 1984. *Check-list of the freshwater fishes of Africa, Cloffa*.

Deacon, J. R. 1997. *Effects of water quality and habitat on composition of fish communities in the Upper Colorado River Basin*. US Department of the Interior, US Geological Survey.

Dejenie, T., Asmelash, T., De Meester,L., Mulugeta, A., Gebrekidan, A., Risch,S., pals, A., Van der Gucht, K., Vyverman, W. & Nyssen, J. 2008. Limnological and ecological characteristics of tropical highland reservoirs in Tigray, Northern Ethiopia. *Hydrobiologia*, 610:193-209.

Dodds, W. K., & Smith, V. H. 2016. Nitrogen, phosphorus, and eutrophication in streams. *Inland Waters*, **6**(2): 155-164.

Dudgeon, D. 2023. Multiple threats imperil freshwater biodiversity in the Anthropocene. *Biological Reviews,* **98**(2): 676–697.

Edds, D. R. 1993. Fish assemblage structure and environmental correlates in Nepal's Gandaki River. *Copeia*, **1**: 48-60.

Emmrich M, Brucet S, Ritterbusch D, & Mehner T. 2011. Size spectra of lake fish assemblages: Responses along gradients of general environmental factors and intensity of lake-use. *Freshwater Biology*, **56**: 2316–2333.

FAO. 2003. *Fishery Statistics*. Food and Agriculture Organization of United Nations. 2003; Volume 9 6/1 yearbook, Rome, Italy.

FAO. 2012. *Fishery and Aquaculture Country Profiles*. FAO Fisheries and Aquaculture Department. Rome, Italy. Available from http://www.fao.org/ fishery/country sector.

FAO. 2023. *Inland fisheries in Africa: Status, trends and governance challenges*. Food and Agriculture Organization of the United Nations.

FAO. 2024. *The state of world fisheries and aquaculture 2024: Blue transformation in action*. Food and Agriculture Organization of the United Nations.

Froese, R., & Pauly, D., eds. 2011. "*Chiloglanis niloticus*" in FishBase. December 2011 version.

Froese, R., and Pauly, D., eds. 2017. "*Chelaethiops bibie*". FishBase. Retrieved 21 September 2017.

Garcia, X. F., Diekmann, M., Brämick U, Lemcke, R., & Mehner, T. 2006. Correlations between type-indicator fish species and lake productivity in German lowland lakes. *Journal of Fish Biolology*, **68**: 1144- 1157.

Gebrekiros, S. T. 2016. Factors affecting stream fish community composition and habitat suitability. *Journal of Aquaculture and Marine Biology*, **4(2)**: 00076.

Gebremariam, Z., & Dadebo, E.1999. Limnology in Ethiopia. *In*: Wetzel, R.G. and Gopal, B. (Eds). *Limnology in developing countries*. W.B. Saunders Company, Toronto, Canada. 63-118.

Gebremedhin, S., Bruneel, S., Getahun, A., & Anteneh, W. (2022). The spread of the Nile tilapia (*Oreochromis niloticus*) in Ethiopia: Its potential impacts on endemic fish species. *Fisheries Management and Ecology,* **29**(4): 351-363.

Gebremedhin, S., Bruneel, S., Getahun, A., Anteneh, W. & Goethals, P. 2019. The endemic species flock of Labeobarbus spp. in L. Tana (Ethiopia) threatened by extinction: implications for conservation management. *Water,* 11(12):2560.

Gebremedhin, S., Getahun, A., Anteneh, W., & Bruneel, S. 2021. Human impacts on Ethiopian riverine fisheries: A review. *Aquatic Ecosystem Health & Management,* **24**(1): 27-37.

Gebretsadik, G. 2003. A review on impact of some development activities on the aquatic environment and potential providential solutions for resource base development and management. Proceedings of the wetlands and aquatic resources of Ethiopia: status, challenges and prospects workshop in Faculty of Science, 12-13, February, AAU. *Biological Society of Ethiopia*, 11-15.

Getahun, A., & Stiassny, M. L. 1998. The freshwater biodiversity crisis: the case of the Ethiopian fish fauna. *SINET: Ethiopian Journal of Science*, **21(2)**: 207-230.

Getahun, A., Tesfaye, G., & Wolff, M. 2023. Alien fish introductions and biodiversity loss in Ethiopian inland waters. *Reviews in Fish Biology and Fisheries,* **33**: 987–1002.

Golubtsov, A. S., Darkov, A. A., Dgebuadze, Y. Y., & Mina, M. V. 1995. An artificial key to fish species of the Gambela region (the White Nile basin in the limits of Ethiopia). *Joint Ethio-Russ Biol Expe Jerde, Addis Abeba*.

Gordon, N. D., MacMahon, T. A., Finlayson, B. L., & Nathan, R. J. 1992. *Stream hydrology: an introduction for ecologists*.

Goshu, G., Tewabe, D., & Aragaw, C. 2009. Survey of a newly constructed reservoir, Tekeze hydropower dam, Ethiopia. The Ethiopian Fisheries and Aquatic Sciences Association (EFASA),Proceeings of the First Annual Conference of EFASA Held at Zwai Fisheries Res ources Research Center Zwai, Ethiopia, February 15-16.

Gu, S., Deng, Y., Wang, P., Li, C., Shi, D. & Wang, S. 2023. Assessing riverine fish community diversity and stability by eDNA metabarcoding. *Ecological Indicators*, **157:**111222.

Habteselassie, R. 2012. *Fishes of Ethiopia*: Annotated Checklist with Pictorial Identification Guide.

Hammer, Ø., & Harper, D. A. 2001. Past: paleontological statistics software package for educaton and data anlysis. *Palaeontologia electronica*, **4(1**): 1.

Hering, D., Borja, Á., Feld, C. K., & Solheim, A. L. 2024. Managing freshwater ecosystems under multiple stressors. *Freshwater Biology,* **69**(1): 3–20.

Hicks, C. C., Allison, E. H., & McClanahan, T. R. 2024. Fishing pressure, resilience, and regime shifts in small-scale fisheries. *Fish and Fisheries,* **25**(1): 1–17.

Hobson, K. A.1999.Tracing origins and migration of wildlife using stable isotopes: a review. *Oceologia,* **120**:314-326.

IUCN (International Union for Conservation of Nature). 2010. *Freshwater biodiversity assessment of Ethiopia.*

Janko, A. M. 2014. Fish production, consumption, and management in Ethiopia. *Res. J. Agric. Environ. Manag.*, **3**: 460–466.

Jargal, N., Kim, J.E., Ariunbold, B. & An, K.G. 2024. Ecological river health assessments based on fish ordination analysis of ecological indicator entities and the biological integrity metrics, responding to the chemical water pollution. *Environmental Science and Pollution Research*, **31(19)**: 28306-28320.

Jargal, N., Mamun, M., Choi, C.Y. & An, K.G. 2022. Combining functional diversity of lotic fish communities with river health assessment based on multi-metric chemical pollution and biological integrity index models. *Frontiers in Environmental Science*, **10**: 1012420.

Jayaratne, R., and Surasinghe, T. 2010. General Ecology and Habitat Selectivity of Fresh Water Fishes of the Rawan Oya, Kandy, Sri Lanka. *Sabaramuwa University Journal,* **9(1)**: 11-43.

Jha, B. R., Waidbacher, H., Sharma, S. & Straif, M. 2005. Length-weight relationship of sucker head, *Garra Gotyla* (Gray, 1830) in different rivers of NepalFreshwater and the influence of monsoon. *International Journal of Environmental Science & Technology,* **2(2)**: 147-153.

Jones, N. E., Tonn, W. M., Scrimgeour, G. J. & Katopodis, C. 2003. Productive capacity of an artificial stream in the Canadian Arctic: assessing the effectiveness of fish habitat compensation. *Canadian Journal of Fisheries and Aquatic Sciences,* **60**: 849 - 863.

Karenge, L. & Kolding, J. 1995. Inshore fish population and species changes in Lake Kariba, Zimbabwe. In *The impact of species changes in African lakes* (pp. 245-275). Dordrecht: Springer Netherlands.

Karr, J. R. 1981. *Assessment of biotic integrity using fish communities*. *Fisheries***, 6(6)**: 21–27.

Kwak, T. J. & Peterson, J. T. 2007. Community *indices, parameters, and comparisons*. In: Guy, C. S. and Brown, M. L. (eds.), Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland. 2007; pp. 677-763.

Legendre, P., & Legendre, L. F. 2012. *Numerical ecology,* (Vol. 24). Elsevier.

Leonard, P. M. & D. J. Orth. 1988. Use of habitat guilds of fishes to determine in stream flow requirements. *North American Journal of Fisheries Management,* **8**: 399-409.

Lepš, J., & Šmilauer, P. 2003. *Multivariate analysis of ecological data using CANOCO*. Cambridge university press.

Lévêque, C. 1990. Relict tropical fish fauna in Central Sahara. *Ichthyological Exploration of Freshwaters*, **1(1)**: pp.39-48.

Liu, Z., Wu, Y., You, W., Li, S., Shi, G. & Zhang, C. 2025. Revealing the Structure and Biodiversity Patterns of Fish Communities in River Networks Based on Environmental DNA. *Fishes*, **10(4)**: p.175.

Lockwood, R. N. & Schneider, J. C. 2000. *Stream fish population estimates by mark and-recapture and depletion methods.* In: Schneider, James, C. (ed.), and Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor. pp. 3-4.

Magurran, A. E. 1988. *Ecological diversity and its measurement*: Cambridge University Press. 179 pp.

Marchetti, M. P., & Moyle, P. B. 2001. Effects of flow regime on fish assemblages in a regulated California stream. *Ecological applications,* **11(2):** 530-539.

Matthews, W. J. 1998. *Patterns in freshwater fish ecology*. New York: Chapman & Hall.

May, J. T., & Brown, L. R. 2002. Fish communities of the Sacramento River Basin: implications for conservation of native fishes in the Central Valley, California. *Environmental Biology of Fishes, **63***: 373-388.

Mehner T, Holmgren K, Lauridsen TL, Jeppesen E, & Diekmann M. 2007. Lake depth and geographical position modify lake fish assemblages of the European "Central Plains" ecoregion. *Freshwater Biology,* **52**:2285–2297.

Mekonnen, A. A., Tesfaye, G., & Wolff, M. 2024. Impacts of illegal and destructive fishing gears on inland fish stocks in East Africa. *Fisheries Management and Ecology*, **31**(2): 173–185.

Mengesha, T. 2021. Fish species diversity in major river basins of Ethiopia: A review. *Journal of Aquatic Biology and Fisheries,* **9(1)**:12–26.

Mengesha, T. A. 2012. Fish species diversity in major river basins of Ethiopia: A review. *World Journal of Fish and Marine Sciences*, 7**(5):** 365-374.

Mulu, B. D., Abraha, G. A. & Yirgalem, W. G. 2012. Health risk assessment of heavy metals bioaccumulation in water, sediment, and three fish species (*Labeobarbus spp*., *Clarias gariepinus* and *Oreochromis niloticus*) of Tekeze River dam, Tigray, Northern Ethiopia. *Journal of Atmospheric and Earth Environment*, **1(1)**: 19-29.

National Statistics of Ethiopia (NSE). 2008. Climate, Length of Major Rivers in Ethiopia.

Negash, M. 1989. The need for meteorological information to plan agroforestry on steep slopes in Ethiopia. In *International Workshop on the Applications of Meteorology to Agroforestry Systems Planning and Management. Nairobi (Kenya). 9-13 Feb 1987*.

Nile Basin Initiative. 2020. *Water Atlas of the Tekeze–Atbara–Setit sub-basin.* Entebbe, Uganda.

Paller, M. H. 1994. Relationships between fish assemblage structure and stream order in South Carolina coastal plain streams. *Transactions of the American Fisheries Society,* **123(2)**: 150-161.

Pinto, B. C. T., F. G. Araújo & R. M. Hughes. 2006. Effects of landscape and riparian condition on a fish index of biotic integrity in a large southeastern Brazil river. *Hydrobiologia*, **556**: 69-83.

Pool, T. K., Gido, K. B., & Sanderson, J. S. 2021. Stream fish community responses to human disturbance: A meta-analysis. *Ecosphere*, 12(6): e03563.

Pusey, B. J., and Kennard, M. J. 1996. Species richness and geographical variation in assemblage structure of the freshwater fish fauna of the Wet Tropics region of northern Queensland. *Marine and Freshwater Research*, **47(3)**: 563-573.

Pusey, B.J., Arthington, A.H. & Read, M.G. 1995. Species richness and spatial variation in fish assemblage structure in two rivers of the Wet Tropics of north Queensland. *Environmental Biology of Fishes*, **42**: 181–199.

Pusey, B.J., Arthington, A.H. and Read, M.G. 1993. Spatial and temporal variation in fish assemblage structure in the Mary River, south-eastern Queensland: the influence of habitat structure. *Environmental Biology of Fishes*, **37**: 355–380.

Pusey, B.J., Douglas, M., Olden, J.D., Jackson, S., Allsop, Q. & Kennard, M.J. 2020. Connectivity, habitat, and flow regime influence fish assemblage structure: Implications for environmental water management in a perennial river of the wet–dry tropics of northern Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **30(7)**: 1397-1411.

Rahel, F. J., & Hubert, W. A. 1991. Fish assemblages and habitat gradients in a Rocky Mountain–Great Plains stream: biotic zonation and additive patterns of community change. *Transactions of the American Fisheries Society*, **120(3)**:319-332.

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T. J., Kidd, K. A., MacCormack, T. J., Olden, J. D., Ormerod, S. J., Smol, J. P., Taylor, W. W., Tockner, K., Vermaire, J. C., Dudgeon, D., & Cooke, S. J. 2024. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, **99**(1): 1–28.

Roberts, T. R. 1975. Geographical distribution of African Freshwater fishes. *Zoological Journal of the Linnean Society*, **57**:249-319.

Robinson, C. L. K. & W.M. Tonn. 1989. Influence of environmental factors and piscivory in structuring fish assemblages of small Alberta lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, **46**: 81- 89.

SFCC. 2007. *Electrofishing Team Leader Training Manual*. Fisheries Management SVQ Level 3: Managing Electrofishing Operations. Scottish Fisheries Coordination Centre, Pitlochry and Inverness College, Inverness.3 pp.

Shannon, C. E., &Weaver, W. 1949. The mathematical theory of information.

Sharma, S., Legendre, P., De C´aceres, M., Boisclair, D. 2011. The role of environmental and spatial processes in structuring native and non-native fish communities across thousands of lakes. *Ecography*, **34(5)**:762-771.

Sheppard, J. D. & J. H. Johnson. 1985. Probability-of-use for depth, velocity, and substrate by subyearling coho salmon and steelhead in Lake Ontario tributary streams. *North American Journal of Fisheries Management*, **5**:277-282.

Shibabaw, G., Getahun, A., & Teferi, M. 2019. Diversity and abundance of fishes in Tekeze Reservoir. *Ethiopian Journal of Biological Sciences*, **18(1)**: 45–58.

Stiassny, M. L., & Getahun, A. 2007. An overview of labeonin relationships and the phylogenetic placement of the Afro-Asian genus *Garra* Hamilton, 1922 (Teleostei: Cyprinidae), with the description of five new species of *Garra* from Ethiopia, and a key to all African species. *Zoological Journal of the Linnean Society*, **150(1)**: 41-83.

Súarez, Y. R., & Petrere Júnior, M. 2007. Environmental factors predicting fish community structure in two neotropical rivers in Brazil. *Neotropical Ichthyology*, **5**: 61-68.

Teame, T., & Tesfay, Z. 2020. Assessment of fishery activities in Tekeze Reservoir, Northern Ethiopia. *Ethiopian Journal of Fisheries and Aquatic Sciences*, ***5*(2)**: 33–44.

Teferi, M., Declerck, S. A., De Bie, T., Gebrekidan, A., Asmelash, T., Dejenie, T., ... & De Meester, L. 2013. The ecology of the riverine *Garra* species (Teleostei, Cypriniformes) in reservoirs of the semi-arid highlands of northern Ethiopia: temporal dynamics of feeding activity. *Inland Waters*, **3(3)**: 331-340.

Terra, B. F., A. B. I. Santos & F. G. Araújo. 2010. Fish assemblage in a dammed tropical river: an analysis along the longitudinal and temporal gradients from river to reservoir. *Neotropical Ichthyology*, **8**: 599-606.

Tesfay, S., Teferi, M. & Tsegazeabe, H.H. 2019. Habitat selectivity of fresh water fishes of two second-order tropical streams in Tigray, Northern Ethiopia. *Journal of Ecology and Environment*, **43(1)**:9.

Tesfay, S., Teferi, M. & Haileselasie, T.H. 2024. Diversity and abundance of the fish community in Elala and Gereb Tsedo streams, Tekeze Sub-Basin: Northern Ethiopia. *Fisheries and Aquatic Sciences*, **27(8)**: 488-500.

Tesfaye, G. 2006. Diversity, relative abundance, and biology of fishes in Angereb and Sanja Rivers, Tekeze basin, Ethiopia. M. Sc. Thesis, Addis Ababa University, Ethiopia.2006; 89 Pp.

Tesfaye, G., & M. Wolff. 2014. The state of inland fisheries in Ethiopia: A synopsis with updated estimates of potential yield. *Ecohydrology and Hydrobiology,* **14**:200–219.

Tesfaye, G., & Wolff, M. 2024. Overexploitation and sustainability challenges of inland fisheries in sub-Saharan Africa. *Reviews in Fisheries Science & Aquaculture,* **32**(1): 45–63.

Tonkin, J. D., Altermatt, F., Finn, D. S., Heino, J., Olden, J. D., Pauls, S. U., & Lytle, D. A. 2024. The role of biodiversity in sustaining freshwater ecosystem functioning. *Trends in Ecology & Evolution,* **39**(2): 137–149.

Townsend, A. R., Asner, G. P., & Cleveland, C. C. 2008. The biogeochemical heterogeneity of tropical forests. *Trends in ecology & evolution*, **23**(8): 424-431.

Vadas, R. L. Jr. and D. J. Orth. 2000. Habitat use of fish communities in a Virginia stream system. *Environmental Biology of Fishes*, **59**: 253-269.

Vadas, R. L. Jr. & D. J. Orth. 2001. Formulation of Habitat Suitability Models for stream fish guilds: do standard methods work? *Transactions of the American Fisheries Society*, **130**: 217-235.

Van de Meutter, F., Stoks, R. & De Meester, L. 2007. Metacommunity structure of pond macroinvertebrates: effects of dispersal mode and generation time. *Ecology*, **88**: 1687-1695.

Welcomme, R. L., Cowx, I. G., & Coates, D. 2023. Inland fisheries exploitation and biodiversity loss: Emerging global patterns. *Sustainability Science,* **18:** 201–214.

Welcomme, R. L., Cowx, I. G., Coates, D., Bene, C., Funge-Smith, S., & Halls, A. 2023. Inland fisheries, biodiversity, and livelihoods. *Sustainability Science,* **18**: 245–259.

Wolde Mariam, M. 1970. *An Atlas of Ethiopia*. Polgrafico, Priv. Ltd. co Asmara, Ethiopia,101 Pp.

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

Yao, M., Jeunen, G. J., & Lambert, J. 2022. Environmental DNA metabarcoding for freshwater fish biodiversity monitoring. *Environmental Monitoring and Assessment,* ***194*****(8)**: 567–582.

Yu, S. L. & T. W. Lee. 2002. Habitat Preference of the Stream Fish, Sinogastromyzon puliensis (Homalopteridae). *Zoological Studies*, **41**: 183-187.

Zippin, C. 1958. The removal method of population estimation. *The Journal of Wildlife Management*, **22(1):** 82-90.

Appendix

Appendix I: Figures (Photographs) during field sampling

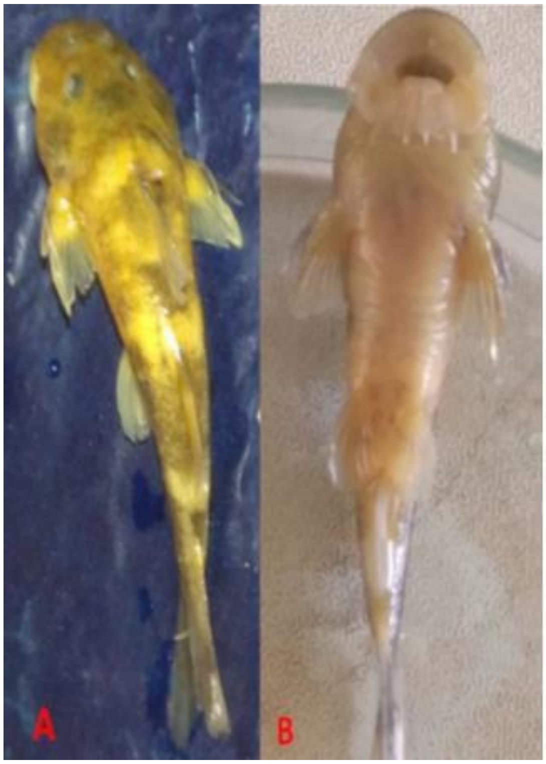
Worie River (Dec. 2019)

Atsela River (Dec. 2019)

Worie River (Apr. 2020)

Worie River (Apr. 2020)

Appendix Figure.1: Electrofishing (fish collection) from representative sites and seasons: (Photo by: **Weldegebriel Hadera)**



Appendix Figure. 2: *Chiloglanis niloticus* (from Geba River): (A) Dorsal position (B) Ventral position Geba (Apr. 2020; Photo by: **Solomon Tesfay**)

Appendix Figure. 3: *Chelaethiops bibie* (from Worie River): (A) Dorsal position (B) Ventral position (Apr. 2020; Photo by: **Solomon Tesfay**)

Challenges in the field (not cited in the text)

Appendix Figure. 4 : Shows challenges in the functining and maintenance of electrofishing equipment during sampling (worie, Apr. 2020 ;Photo by: **Weldegebriel Hadera**)

Appendix Figure. 5 : Wearing the boats for long time in warm environments and walking long distances along sampling streches while carrying the electrofisher, pose significant physical challenges. (worie, Apr. 2020; Photo by: **Weldegebriel Hadera)**