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Diversity and Abundance of Small Indigenous Fish (SIF) in Human Stressed Major Tributaries of the Awash River

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Abstract

Small indigenous fish (SIF) are a source of protein, essential fatty acids, vitamins and minerals in most parts of the world. This study assessed the community structure and nutritional content of SIF in the tributaries of Awash River. Fish samples were collected from eight sampling sites using electrofishing device. A total of 2240 fish specimens comprising four species namely Garra quadrimaculata, Garra dembecha, Garra makiensis and Barbus sp. were collected during the sampling period. A high SIF abundance (218 individuals/100m^2) and biomass (1769 g/100m$^{2)}$ was recorded at Legedadi above the dam (UA4) and Garra species were numerically the dominant taxa in all sampling sites. Turbidity and river size (width and depth) were the predominant factors affecting SIF diversity, abundance and biomass. Barbus sp. contained higher fat content (10%) compared with a widely consumed O.niloticus which was less than 1%. A higher level of mineral contents (mg/kg) were identified in Garra species (Ca = 37.7; Fe =53.09; Zn= 55.18) than O. niloticus (Ca = 0.2; Fe =28; Zn= 14) (ANOVA, $p < 0.05$). This could be attributed to the bottom feeding behavior of SIF in river beds enriched with diverse minerals. High abundance of SIF in rivers with considerably high macro-and micronutrients is an opportunity to promote their role in food and nutrition security. Thus, future studies should focus on sustainable fishing practices, processing techniques and recipe preparation.

Keywords: Abundance and distribution, fish biomass, mineral content, small indigenous fish, tributary rivers

Introduction

Ethiopia is endowed with 12 major drainage basins and most constitute hundreds of tributary rivers and streams (MoWE,2012). The unique hydrological feature of the country arises from its extensive network of tributary rivers in diverse geomorphological landscapes. Small tributary rivers are intensively used for various development activities to sustain human life mainly in the middle and highland areas of the country with altitude range between 1000 and 2500m asl. Hydrologically, tributary rivers serve as source of water for large rivers, retain flooding and recharge groundwater. They also provide a variety of benefits to communities such as water supply for drinking, irrigation and various domestic uses (Ayalew Desalegn, 2018). Tributary rivers are renowned for harboring unique forms of aquatic fauna, particularly small fish species, crustaceans and macroinvertebrates (Chakona *et al.*, 2022).

Unlike major rivers in Ethiopia, tributary rivers are poorly studied for their ecological importance, aquatic fauna and contribution towards food and nutrition security. For example, many scholars studied the hydrology of Awash River because of its social and economic importance in large scale irrigation, flood management and ground water recharge potential (Sileshi Bekele, 2010). However, its tributaries are poorly studied for their ecological and aquatic biodiversity functions and their contribution to local community residing in the catchment.

The fish production potential of the capture fisheries from the major water bodies including lakes, rivers, reservoirs and wetlands in Ethiopia is about 128,000 ton/year (FAMP, 2024). Diversity wise, Redeat Habteselassie (2012) provided a description of some 200 fish species belonging to 75 genera, 31 families and 12 orders, and presented a fairly accurate and updated profile of the current freshwater fish diversity in Ethiopia. Several studies also grouped these fish species into commercially important and commonly available indigenous fish species based on the production level, demand in the market and preference of the consumer in the country (Hussein Abegaz *et al.*, 2010; Gashaw Tesfaye and Wolff, 2014; Aschalew Lakew *et al*., 2015; MoA, 2021). Very little attention has been given to small indigenous fish species until Eshete Dejen (2003) studied the biology and fishery potential of small barbs in Lake Tana. Recently, abundance-based studies on small indigenous fish species have been conducted in rivers and lakes (Alemayehu Wubie *et al*., 2017; Gernot *et al*., 2020; Bacha Temesgen *et al*., 2021). Small indigenous fish species were studied only for biodiversity purpose and their ecological and socio-economic importance were either ignored or partly considered.

Small indigenous fish play an important role in providing valuable nutrients to rural communities in the world (Bavinck *et al*., 2023). These groups of fish are rich in animal protein, vitamin A, vitamin D, calcium, iron, and zinc, making them an essential part of the diet for many people (Nolle *et al*., 2020). Small indigenous fish are often consumed whole, including the head, organs, and bones, providing complete nutrition to the consumer (Roos *et al*., 2007). In addition, the amount of vitamins and minerals included in one kilogram of SIF is equivalent to about 50 kilograms of large fish, such as Indian carp (Mohanty et a., 2013). Despite their immense importance, the potential of small indigenous fish is often overlooked and undervalued particularly in Ethiopia. They are often overshadowed by larger commercial and culturally favored fish species, leading to their underutilization. Information on SIF abundance and diversity in the tributary rivers and streams, nutritional values and utilization is limited in Ethiopia. Therefore, the objective of the present study was to assess the abundance and community structure of SIF in selected tributaries of the upper and middle Awash River and determine their nutritional composition and mineral content of the fish to be used for human consumption.

Materials and Methods

Study area

The Awash River is the fourth largest river basin in Ethiopia following Wabi-Shebele, Abbay and Genale-Dawa Basins (Sileshi Bekele, 2010). The river is characterized by a highly seasonal flow, with its water levels fluctuating dramatically between wet and dry seasons. The mean annual temperature in the basin ranges from 10°C to 30.5°C (Yitea Seneshaw *et al.*, 2021). During the rainy season, which typically occurs between June and September, the river receives significant amounts of rainfall, causing it to fill and flood its banks. The annual volume of the river amounts to 4.9 billion cubic meters, of which 3.65 billion cubic meters are usable (Sileshi Bekele, 2010).

Based on physical and socio-economic factors, the Awash Basin is divided into upper (all lands above 1500m asl), Middle (area between 1500m and 1000m asl) and Lower (area below 1000m) valley (MoWE, 2012)

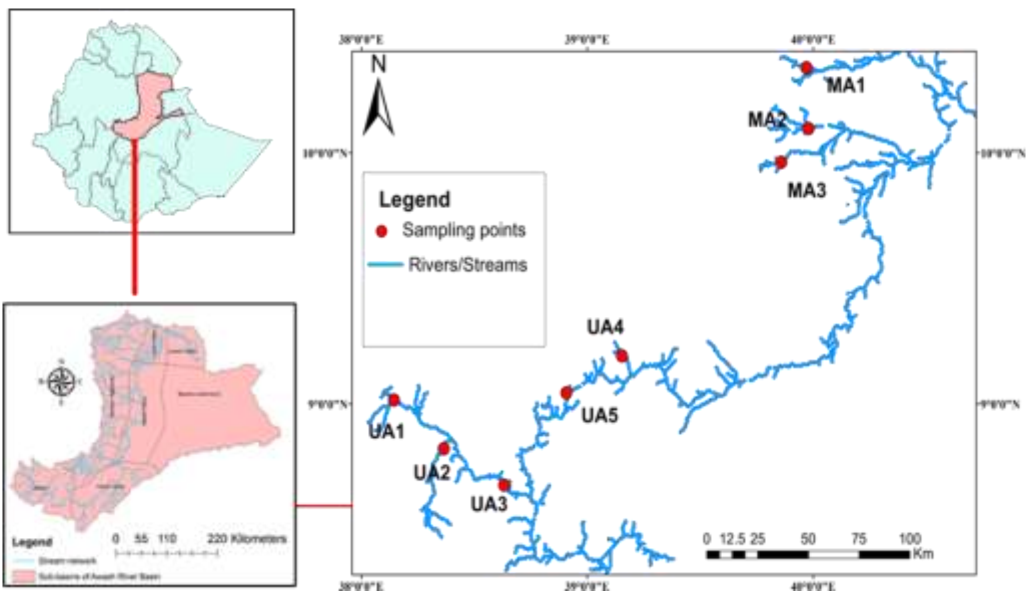

Figure 1. Geographic location of the sampling sites along the Awash River basin.

In this study, eight representative sampling sites along Awash River basin (five in the upper Awash and three in the middle Awash) were selected based on the major catchment activities leading to degradation of river health that affects fish diversity and abundance. A detailed description of the sampling sites including location, altitude and major catchment uses are indicated in Table 1.

Table 1. Description of sampling sites in the upper and middle Awash

River name/ sampling sites	Site code	Coordinate (Degree decimal)		Altitude (m)	Key descriptions of the sampling sites
		Latitude (°N)	Longitude (°E)		
Arera near Ginchi town	UA1	9.01449	38.1451	2200	No vegetation in the riverbank, crop farming in both sides of the river, cattle watering point above the sampling site, water pumping for irrigation agriculture
Teji	UA2	8.82029	38.36479	2062	No vegetation in the riverbanks but scattered shrubs and herbs, river diversion and pumping during the dry season for irrigation, cattle watering is common, crop farming in both sides
Awash kuntire	UA3	8.42257	38.36468	1990	No riverbank vegetation, cattle watering and crossing above sampling site, layers and boulders dominate the river bed, high water volume in terms of depth and width
Lege-dadi above dam	UA4	9.21155	39.16609	2629	Forest covered on both sides of the river, protected from frequent cattle and human access, flows in a gorge, bathing and cloth washing above the site
Lege-dadi below dam	UA5	9.04264	38.90828	2329	Shrubs in the river bank, limited access for cattle watering, highly turbid due to reservoir flushing, degraded bush land dominate both sides
Ataye	MA1	10.339	39.971	1436	No vegetation in the river bank, sand mining is common, crop farming in both sides, no pumping, cattle watering and crossing sites are common, bathing and washing in the site
Jewuha	MA2	10.097	39.979	1138	Vegetation covers both sides, plant nursery site and local residents near the river, limited cattle watering access, bathing and washing are common
Robit	MA3	9.962	39.86	1367	No vegetation cover, vegetable farming in both sides, narrow wet channel and macrophytes in the dry channel, pumping is common in dry season for irrigation

Fish sampling and identification

Fish samplings were carried out from May to October, 2021 using electrofishing, which relies on two electrodes that deliver direct current at high voltage from the anode to the cathode through the water. The upstream and downstream stop nets (mosquito nets of 1.5 mm size) were set simultaneously to prevent fish immigration and emigration from the survey section before sampling. This was done by fixing hardwoods at each side of the net for better handling. Fish identification was done on-site following the available identification key (e.g. Redeat Habtesillase, 2012). After collecting the necessary data such as number per species per habitat type, length and weight measurements, most of the fish specimens were released back into their habitats. 155 fish samples representing the different fish species were taken to the National Fisheries and Aquatic Life Research center laboratory for further proximate chemical analysis.

Laboratory analysis

Proximate chemical composition and major mineral contents of whole SIF were analyzed in the National Fisheries and Aquatic Life Research Center (NFALRC) laboratory. Considering the size and species of the fish, a total of 155 fish specimen were used for proximate chemical analysis. The whole fish was taken for the analysis of chemical nutrients and minerals. Each fish specimen was chopped into small pieces with a clean stainless-steel knife and minced to homogenized in preparation for proximate analysis. Crude protein content was determined using the Kjeldahl method and calculated from total nitrogen content using a nitrogen–protein conversion factor of 6.25 following AOAC (2000). Fat content was determined by the Soxhlet method using an automated extractor with methyl ether. The extracted fat was esterified and analyzed by gas chromatography. Moisture contents were obtained after drying in an oven at 110 °C for 24 hours. The loss in weight was the moisture content and what was left is the dry matter (DM) of the sample. Ash was determined by heating the samples in a muffle furnace set at 550 °C for 4 hours. For selected mineral analysis, the samples were weighed on a microbalance, homogenized, and allowed to react for 12 h in a mixture of 3 mL HNO_3 and 3 mL H_2O_2 as described by AOAC (2000). The samples were heated in a microwave oven, prepared following sample preparation manual (Elmer, 2013) and analyzed by atomic absorption spectrometry at NFALRC.

In situ physico-chemical and morphological measurements

Water quality parameters including electrical conductivity (EC), dissolved oxygen (DO) and temperature (T^o) were measured using a multi-probe system (HQ40D, HACH Instruments) before fish sampling. The turbidity of water was measured using a turbidity meter (Oakton, WD-35635-00 T-100 model). Hydro-morphological features such as water depth were measured using a tape meter at five different points. River width was measured using a measuring tape in three cross-sections at about 20 m distance. The average value of each variable was considered for the final analysis. The mesohabitat (pool and riffle) proportion was visually estimated in the sampling section.

Statistical analysis

The data collected was organized and analyzed using descriptive statistics in Microsoft office excel. Data was organized and summarized in figures using R software. Results were interpreted to be significant at $p \leq 0.05$.

Results and Discussion

The diversity, abundance and biomass of SIF

A total of 2240 fish specimens representing four species of the family Cyperinidae, namely *Garra quadrimaculata, Garra dembecha, Garra makiensis* and *Barbus sp.* were collected during the sampling period. UA1 and UA4 sites constitute the highest diversity (4 species) and abundance (>200 individuals/100m^2) and biomass (>1300g/100m^2) compared with other study sites. These sites are characterized by limited human in-stream activities and better river bank protection (Table 1), which likely allows the presence of diverse fish habitat for feeding and breeding. River diversion and intensive water pumping reduces the volume of the water in the river channel and leads to significant reduction in fish abundance or extinction of some fish species (Webb *et al*., 2011). Site UA2 was heavily used for irrigation of wheat farms in dry season and this reduced water volume in the main channel which could be the main reason for low fish abundance (63 fish/100m^2) and lower fish biomass (360g/ 100m^2) than other sites. Anthropogenic activities such as wastewater discharge to the river channel decreases fish diversity and may cause species extinction (Galib *et al*., 2018). This was observed in site UA5, which is impaired by flashing of silt/mud from water treatment plant installed for drinking water supply to the Addis Ababa city. The silt/mud discharged to the river channel caused high water turbidity and habitat loss that resulted in low fish diversity and biomass. Unlike other sites, *Barbus sp*. was not collected from UA5 in all sampling months, which may indicate the sensitive nature of this species to turbidity and poor habitat condition. In all sampling sites, *Garra* species dominated the catch and constitute about 90% of the fish biomass during the sampling seasons. This indicates that *Garra* spp. are hardy and tolerate a wide range of environmental conditions and water level fluctuation in the river channel.

Table 2. Abundance and biomass of SIF in the upper and middle tributaries of the Awash River

River name	Site code	Diversity	Individual number/ 100 m^2.	*Barbus sp.* Biomass (g)/100m^2	*Garra spp.* Biomass (g)/100m^2	SIF Biomass g/100m2
Arera near Ginchi town	UA1	4	209	202.8	1183	1385.8
Teji	UA2	3	63	26.8	335	361.8
Awash kuntire	UA3	4	152	191	687	878
Lege-dadi above dam	UA4	4	218	218	1551	1769
Lege-dadi below dam	UA5	2	102	0	581	581
Ataye	MA1	3	124	252	817	1029
Jewuha	MA2	3	135	186	626	812
Robit	MA3	3	143	70	840	910

The biomass of fish varied between 361.8 g/100m^2 in site UA2 and 1769.7 g/100 m^2 in site UA3 (Table 2). Previous studies showed that fish growth and feed intake increase with increasing water volume (Jha *et al.*, 2006; Espmark *et al.*, 2017) which agreed with the results of the present study at UA3 expressed in depth and wet width (Table 3). The presence of adequate space reduces the competition of fish for resources and reduces stress levels, leading to better overall health and biomass (Espmark *et al.*, 2017). A study by Bacha Temesgen *et al.* (2021) reported the absence of fish in a highly reduced water volume which hinders the free movement of fish for search of food and habitat. The water volume reduction may also result in fish egg mortality (Michael *et al.*, 2005) and expose the fish to predatory birds and lower the fish population from the river as observed in UA2 (Table 2).

A river polluted by sewage disposal showed a 45% decline in the biomass of important fish species (Foo *et al.*, 2021). Discharges of accumulated mud/silt to rivers pose a negative impact on fish biomass as evidenced in site UA5 which receive from the nearly water treatment plant. The silt/mud accumulated in the river bed may disrupt the physiological activities of fish or destroy their spawning and feeding ground. Previous studies also showed that turbidity can reduce water clarity, making it more difficult for fish to see and locate their prey leading to a decline in feeding efficiency and potential decrease in the population (Bash *et al.*, 2001).

Environmental variables in the study sites

Selected environmental variables collected from all sampling sites are presented in Table 3. Sites located in the middle Awash showed a higher temperature and conductivity values than the upper Awash sites. This could be attributed to the difference in altitude and geological conditions as was observed in earlier studies (Murugavel and Pandian, 2000; Liu *et al.*, 2021). The highest conductivity (1509 µS/cm) is associated with the local geology and presence of soda soil (locally called 'Bole') which is fed to the cattle mixed with forage in the field. Dissolved oxygen is not a limiting factor in rivers, and the high DO values mainly in MA1 and MA2 could be associated with high turbulence in the riffle section and presence of dense algal biomass in the pool section.

The sampling river sites are dominated by riffle mesohabitat with diverse substrate types, which are typical characteristics of small tributary rivers in high altitude. Erosion in the riverbank or from the catchment activities lead to sand/silt accumulation in the riverbeds. This is clearly observed in relatively unprotected and degraded sampling sites like UA2 and UA5.

Table 3. Water quality parameters, hydro-morphology and habitat types in the upper and middle Awash River tributaries

Site code	Meso-habitat		Hydro-morphology		Micro-habitat (substrate types)				Water quality parameters				
	% Po	% RI	DE (cm)	WI (m)	Ro	Co	Pe	Sa	Temperature (°C)	pH	Conductivity (µS cm-1)	DO (mg/l)	Turbidity (NTU)
UA1	45	55	43	4.5	35	30	20	15	20±3.1	7.7±0.1	187.2±19	8.2±1.0	215 ± 15.1
UA2	25	75	48	3.5	-	40	40	20	22.6±2.2	8.8±0.1	285.5±23	6.8±1.2	380 ± 12.5
UA3	30	70	151	15.4	60	-	20	20	21.3±2	7.8±0.2	265±39	7.1±0.8	340 ± 26.0
UA4	45	55	64	8.2	40	30	15	15	19.3±2.1	7.8±0.2	214±15	7.5±0.6	215 ± 14.7
UA5	50	50	68	12	35	20	15	30	21.3±1.5	8.5±0.3	300±33	6.3±2.0	250 ± 6.54
MA1	40	60	45	6.3	15	25	40	20	24.8±0.5	9.1±0.1	510±11.8	10.2±0.4	263 ± 11.4
MA2	45	55	58	9.5	20	30	35	15	32.2±0.2	9.4±0.3	1509.6±28.4	11.4±1.0	259 ± 5.91
MA3	30	70	48	7.4	20	35	30	25	26.2±0.3	8.8±0.1	570±5.2	7.2±0.2	240 ± 4.24

Note: Po=pool, RI=Riffle, DE=Mean depth, DO= Dissolved oxygen, WI=Mean width, Ro=rock, Co=Cobble, Pe=Pebble, Sa=Sand

Habitat based SIF distribution

The habitat preference of numerically dominant fish species are presented in Figure 2. The *Garra* spp. dominated the riffle habitat than *Barbus* sp. which might be associated with its preference to fast flow water (Abebe Getahun and Stiassny, 1998) and the feeding behavior. *Garra* species are opportunistic feeders with detritus forming a large proportion of their diet (Vijverberg *et al*., 2012). They are primarily bottom feeders grazing over gravel or rock substrates and such kinds of substrates are most likely found in riffle habitat. In addition, riffle habitats support high densities of benthic macroinvertebrates than pool habitats and are fertile areas of food production for small fishes (Gordon *et al*., 2004). The study conducted by Felegush Erarto (2020) showed positive correlation between *Garra* spp and water velocity which is representative in the riffle habitat.

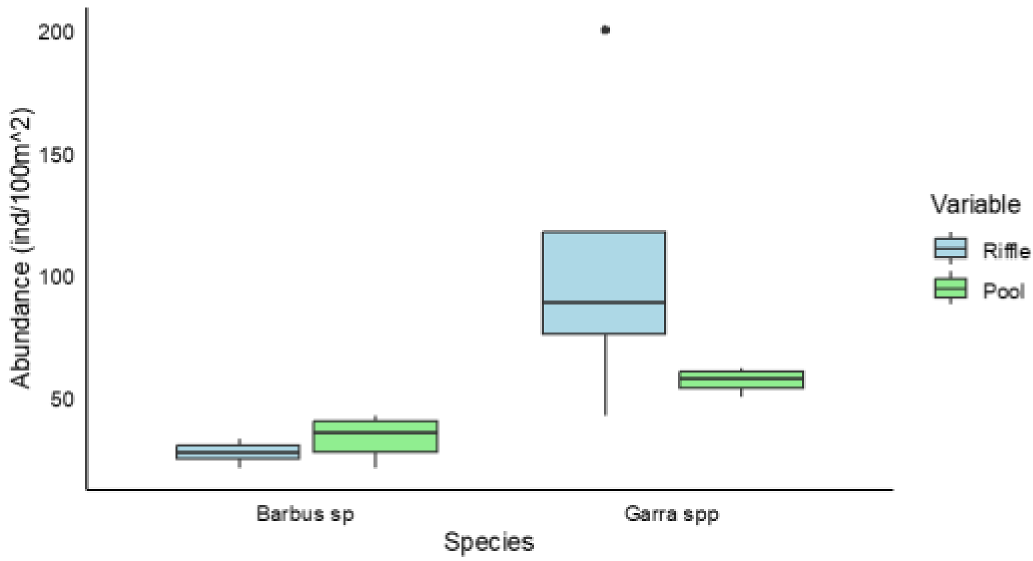

Figure 2. Distribution of SIF in pool and riffle habitats of the Awash River tributaries (n = 907).

Distribution of fish size class in pool and riffle habitat was visualized in Figure 3. It was observed that small sized fish prefer riffles to pool; while as the size increases most fish prefer the pool to riffle section of the river. The pool section has higher water depth than the riffle to protect SIF from predators and it is a site for suspended and accumulated forms of fish feed because of low velocity.

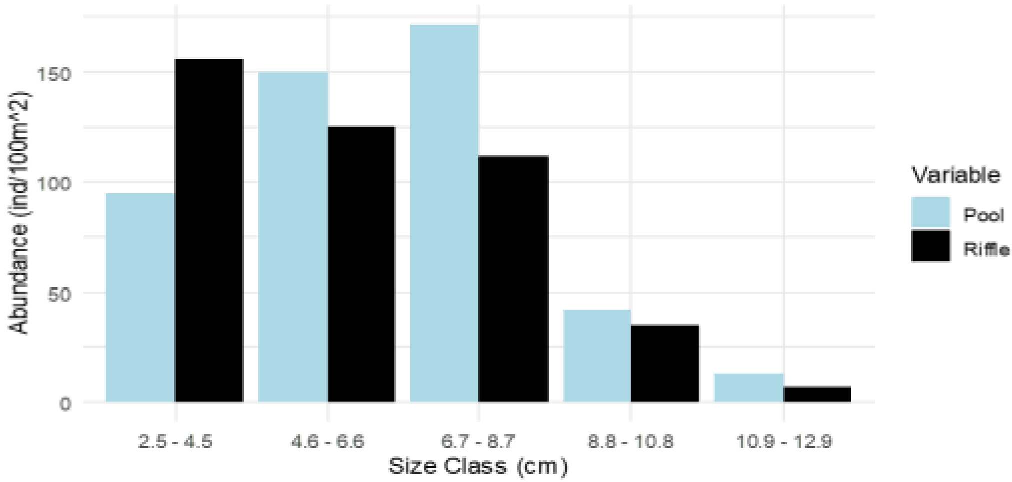

Figure 3. Size class distribution of SIF in pool and riffle habitats of Awash River tributaries (n=907)

Nutritional composition of SIF

Our analysis focused on the concentration of two macronutrients (protein and fat) and three key micronutrients (calcium, iron, and zinc) which are known to be lacking in diets, yet rich in fish. SIF have high protein and fatty acid content, which is in agreement with our study, to support food and nutrition security mainly in rural communities (Bavinck *et al.*,2023). Table 4 showed that the fat content of SIF is higher than *O.niloticus* which could be due to their food and feeding habit as carnivore. The concentration of Zn is not significantly different across SIF, while Fe and Ca were significantly higher in *Garra* spp than *Barbus* spp. (ANOVA, $p < 0.05$). On the other hand, the major mineral contents were significantly higher in SIF than *O. niloticus*, the most widely consumed fish species in Ethiopia (ANOVA, $p < 0.05$). The higher contents of the major mineral in SIF might be associated with their feeding behavior. For example, *Garra* species are bottom-dwelling organisms that primarily feed on sediment-dwelling organisms such as benthic invertebrates using disc shaped mouth in riffle section, thereby increasing their exposure to abundant mineral concentrations in their food source. Studies have shown that small fish usually contain high calcium, iron, and zinc continent compared to other commercial fish species (Nolle *et al.*, 2020). This is because they are eaten whole, including their bones and viscera, which is a rich source of major minerals like calcium to reduce the prevalence of rickets (Craviari *et al.*, 2008). Longley *et al.* (2014) showed that the consumption of small freshwater fish by lactating women was positively correlated with polyunsaturated fatty acids (PUFAs) content of breast milk which are crucial for cardiac health and promote cognitive development and function (Zhao *et al.*, 2016).

Table 4. Proximate chemical composition and mineral content of SIF sampled from Awash River tributaries.

Species	Proximate composition in percentage				Major mineral composition		
	Moisture	Ash	Protein	Fat	Ca (mg/kg)	Fe (mg/kg)	Zn (mg/kg)
Garra spp.	73.82± 0.71[a]	3.97 ± 0.93[a]	12.97 ± 0.54[a]	7 ± 0.52[a]	33.7±0.23[a]	53.09 ±2.32[a]	55.18 ± 2.32[a]
Barbus sp.	71.81 ±0.45[a]	4.47 ± 0.41[b]	15.10 ± 0.77[a]	10±0.28[a]	26.1 ± 0.00[b]	37.32 ± 0.00[b]	53.84 ± 0.00[a]
O. niloticus	78.43 ± 1.25[b]	1.15 ± 0.01[c]	18.32 ± 1.68[b]	0.86±20[b]	0.20±0.00[c]	28 ± 0.00[c]	14 ± 0.00[b]

Note: Data for *O. niloticus* is taken from Tokuma *et al.* (2021) and Bezuayehu and Fikadu (2021); Different superscripts within a column indicate significant differences at $p < 0.05$.

Khara *et al.* (2018) reported that eating a fish alleviates micronutrient deficiencies and reduces childhood stunting. Childhood stunting is a major challenge in developing countries and Ethiopia is not exceptional. Studies indicated that stunting rates reaches 80% in some drought prone areas of Ethiopia (Hana *et al.*, 2020). In addition, consuming fish improves the health conditions and prevents rickets, cardiovascular diseases, high blood pressure, gestational diabetes, childhood blindness and anemia (Roos, 2007). Trace elements including Ca, Fe and Zn are typically scarce minerals in human nutrition mainly in developing nations like Ethiopia. Due to poor fish-eating tradition in Ethiopia, SIF are not used directly for human consumption. However, SIF are occasionally collected as by-catch from major lakes are either discarded or used for fishmeal preparation. During our field sampling, we found the local communities utilizing SIF for family consumption. For example, some communities residing along Robit, river in the middle Awash have a tradition of utilizing SIF specifically by sun drying or roasting followed by grinding to use the powder as an ingredient to enrich their daily crop-based food with protein (personal communication). Based on nutritional properties and mineral contents of SIF shown in this study, it is important for the rural communities to sustainably utilize SIF from lakes, reservoirs, rivers, streams and wetlands to improve family health condition in rural Ethiopia.

Conclusion and Recommendations

In this study, small indigenous fish (SIF) community structure was assessed in the upper and middle Awash River. A total of 4 fish species (Three *Garra* and *Barbus* species) were identified along the sampling sites although the diversity and abundance differ based on the human-driven impacts in the river. *Garra* spp. were the dominant fish in all sampling sites and *Barbus* sp. was not found in highly turbid river sites. Turbidity and water diversion were identified as key environmental factors that affects SIF community structure. SIF mainly inhabits the riffle habitat of the river section which could be associated with their biological requirements including feeding and reproduction. In addition to the high abundance of SIF in less impacted river section, they contained higher fat and mineral content compared with widely consumed and commercial fish (*O.*

niloticus) which is an opportunity to promote their role in food and nutrition security.

This study showed the importance of healthy river conditions for high production of SIF which indicates the importance of protecting rivers from human induced ecological degradation. Moreover, there is a limited information and experience on utilization of SIF for human consumption in the country, thus, future studies should focus on developing suitable fishing methods, processing techniques and recipe preparation.

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