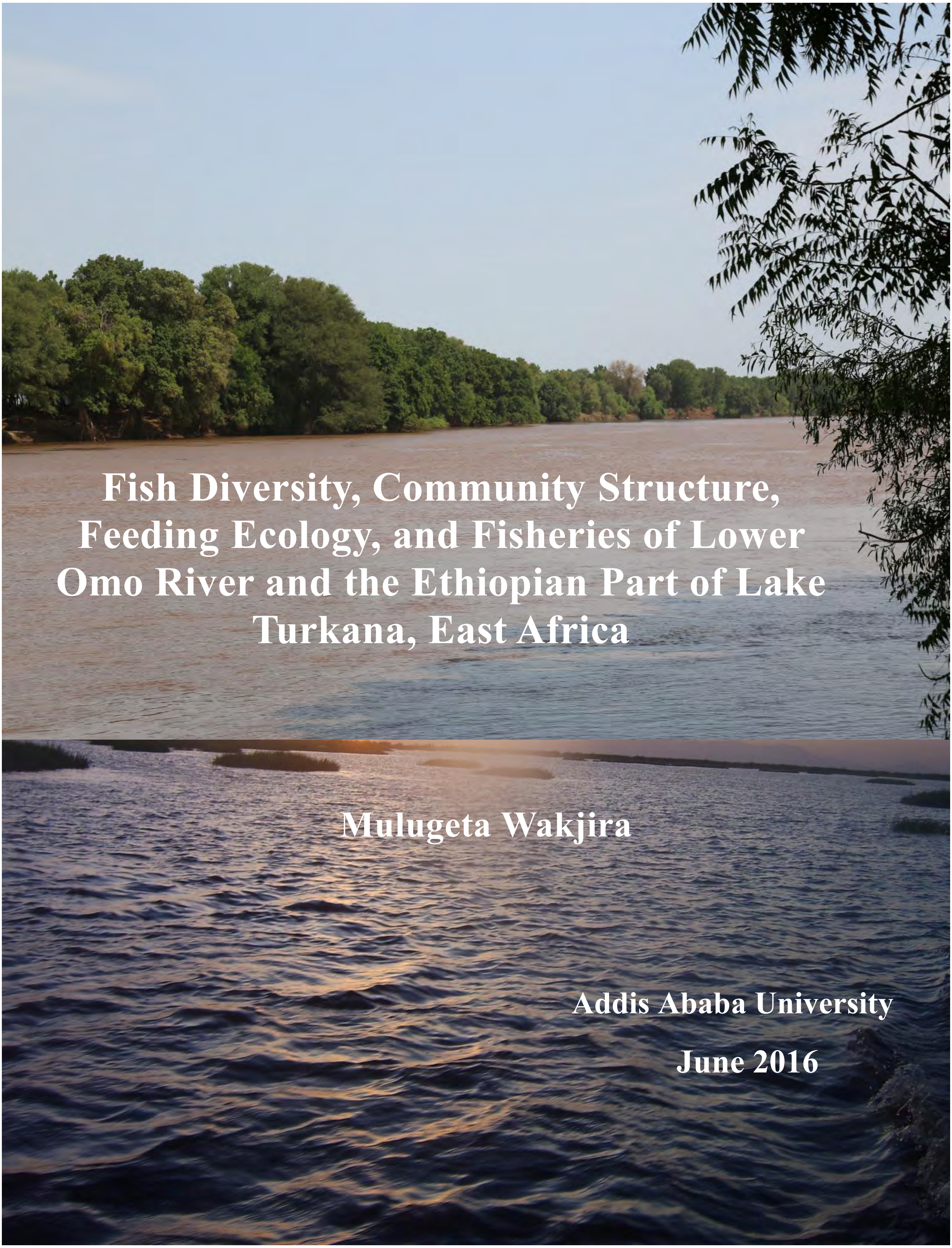

Fish Diversity, Community Structure, Feeding Ecology, and Fisheries of Lower Omo River and the Ethiopian Part of Lake Turkana, East Africa

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Cover photos: Lower Omo River at Omorate town about 50 km upstream of the delta (upper photo); Lake Turkana from Ethiopian side (lower photo).

Fish diversity, Community structure, Feeding ecology, and Fisheries of lower Omo River and the Ethiopian part of Lake Turkana, East Africa

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A Thesis Submitted to the Department of Zoological Sciences, Addis Ababa University, Presented in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Biology (Fisheries and Aquatic Sciences)

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ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE PROGRAM

This is to certify that the thesis prepared by Mulugeta Wakjira entitled, "Fish Diversity, Community Structure, Feeding Ecology, and Fisheries of lower Omo River and the Ethiopian part of Lake Turkana, East Africa", and submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Biology (Fisheries and Aquatic Science) complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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Abstract

Ethiopia has a freshwater system in nine major drainage basins which fall into four ichthyofaunal provinces and one subprovince. Omo-Turkana Basin, spanning considerable geographic area in southwestern Ethiopia and northern Kenya, essentially consists of Omo River (also known as Omo-Gibe) and Lake Turkana. The entire of Omo River and about 1.3% of the lake (ca. 98 km^2*) lie within Ethiopia. The Ethiopian part of the basin generally lacks comprehensive study and proper scientific documentation on its ichthyofaunal diversity, ecology and fisheries. This study was thus undertaken to address these gaps. Data were obtained using various methods over a period of two years, and analyzed using various computations, univariate tests and multivariate methods. Thirty-one fish species were identified from lower Omo River and the Ethiopian part of Lake Turkana, with some new records, from the present collections. Omo River system was found to be more species rich than Lake Turkana but poorer in abundance. The basin's extent of ichthyofaunal diversity within the limit of Ethiopia was specifically addressed, for which an artificial identification key was prepared. Annotated checklist for the native species was provided for the entire basin. Composition of the most important species (total index of relative importance, IRI > 94%) was essentially similar for the river and the lake, but differed in the relative importance of each species. Cluster analysis and principal component analysis (PCA) produced distinct habitat-associated species patterns across the riverine and lacustrine environments. The Ethiopian part of Lake Turkana community consisted of 18 fish species, of which two-thirds were species of highest relative importance. The lower Omo River community consisted of 13 species of largely lower IRI. Ionic concentration measured as total dissolved solids (TDS) was found to be the key environmental factor determining fish community structure in lower Omo-Turkana sub-basin. Feeding habits of eight selected fish species from the Ethiopian part of Lake Turkana have been identified and described. Although 11 major prey groups were identified for all species, only 7 prey categories viz. aquatic insects, phytoplankton, macrophytes, fish, zooplankton, detritus and prawn were the most important contributors to the fishes' dietary variations. Fish, aquatic insects, phytoplankton and zooplankton constituted the most diversified prey categories. The eight species ranged in the generalist-specialist feeding strategy spectrum with Synodontis schall (Bloch & Schneider, 1801) being the most generalist feeder, while Oreochromis niloticus (Linnaeus, 1758) was the most specialist feeder. Each fish species consisted of subpopulations with various dietary niche width contributions to the species' overall feeding strategy. Ontogenetic and seasonal dietary variations were observed for all the fish species examined except for S. uranoscopus whose diet virtually remained constant across fish size and seasons. The eight examined fish species formed two trophic guilds, with the mainly piscivorous group consisting of Schilbe uranoscopus Rüppell, 1832, Bagrus bajad (Forsskål, 1775) and Lates niloticus (Linnaeus, 1758), and the mainly planktivorous group consisting of*

S. schall, Distichodus nefasch (Bonnaterre, 1788), Alestes baremoze (Joannis, 1835), Citharinus citharus (Geoffroy St. Hilaire, 1809) and O. niloticus. The number of guilds and dietary items that defined guild structures did not vary on seasonal and non-seasonal situations; however, a change in guild organization was observed. The computed Horn's dietary niche overlap indices corroborated categorization of the examined fish species according to their prime dietary resource utilization. The river and the lake supported small-scale gill net fisheries that provided livelihood, income and employment to three major fisher-categories. Fisheries value chain was developed and major issues arising out of the chain components were addressed, fishers' perceptions about the resource condition and management status were identified and discussed. In order to sustain fisheries socioeconomic contributions to livelihoods of the local people, the government in particular the regional state should take a prime responsibility to address the major socioeconomic issues arising out of the fisheries value chain analysis and issues related to resource management. Particularly, conflict of the Ethiopian fishers with the rival Turkana tribe fishers of Kenya should be properly addressed as it could jeopardize any attempt of resource management effort.

Keywords: *Annotated checklist, community structure, diversity, Ethiopia, feeding habits, fish, Lake Turkana, Omo River, small-scale fisheries, socioeconomics, total dissolved solids, trophic guild.*

Dedication

I dedicate this dissertation to my parents Wakjira Kabeta (dad) and Jalane Gilo (mom) who are the main reasons for who I am today. I also dedicate it to my beloved wife Yetinayet Husien who bore full responsibility of taking care of our son Jonathan Mulugeta and our daughter Hawi Mulugeta while I was away for the study.

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Mulugeta Wakjira

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Chapter one

1. Background

1.1. Drainage basins of Ethiopia

Ethiopian topography is characterized by elevated plateaus from which rise various tablelands and mountains. The Ethiopian Highlands are bisected diagonally into western and southeastern blocks by a portion of the East African Great Rift Valley. The walls of the highlands rise abruptly from the outer plains of lowlands on nearly every side and thus form a clearly marked geographic division. There are 9–12 drainage basins of freshwater system situated within these major physiographic units. The major basins are nine and these include Tekeze-Atbara, Abay (Blue Nile within the limit of Ethiopia), Baro-Akobo (White Nile Basin within the limit of Ethiopia) and Omo-Gibe (Omo-Turkana Basin within the limit of Ethiopia) basins in the western Highlands; Rift lakes, Awash River and Danakil Depression basins in the Rift Valley; Wabishebelle and Genale-Dawa basins in the south eastern highlands. There is big variation in the size of the basins which is mainly function of the geological formation. Wabishebelle Basin is the largest with an area of 202,220 km^2 followed by the Abay (Blue Nile) Basin covering an area of 199,812 km^2 (Figure 1). The western highland basins are generally drained westward into the Nile system ultimately ending up in the Mediterranean Sea except for Omo-Gibe that drains southwest into Lake Turkana. The southeastern highland basins are drained eastward into Somalia lowlands ultimately entering the Indian Ocean. The Ethiopian Rift Valley ranges in elevation from 125 m below sea level in the Danakil Depression to approximately 1,800 m above sea level (a.s.l) in the Rift lakes, and elevation again decreases towards 1,000 m a.s.l at Lake Chew Bahr and about 365 m a.s.l at Lake Turkana. The Rift Valley system remains endorheic.

A. Tekeze-Atbara Basin

Tekeze River rises in the central Ethiopian Highlands and flows northwest to join Atbara River in northeastern Sudan, which also has its headwaters in Ethiopian Highlands. Tekeze-Atbara River then joins Nile River proper in the northern Sudan. Its major tributaries within Ethiopia include Angereb and Shinfa. The basin hosts past and present dam buildings of various purposes in both Sudan and Ethiopia.

B. Abay (Blue Nile) Basin

Blue Nile River originates in Lake Tana in the western Ethiopian Highlands. The Lake Tana tributaries include Gilgel-Abay, Dirma, Megech, Arno-Garno, Ribb, Gumara and Gelda rivers. At 30 km downstream Lake Tana the Blue Nile River is interrupted by a 40 m high and 400 m wide Tissisat Fall which is the second largest in Africa (Vijverberg *et al*., 2009). The current ichthyofaunal biogeographical analysis of Lake Tana and Blue Nile River appears to demonstrate the isolating role of the Fall between the upstream and downstream fauna. Its tributaries include Beshilo, Walaqa, Jamma, Muger, Guder, Didessa and Dabus on the left bank, and Gulla and Beles on the right bank, in the downstream order. The Dinder River that joins Blue Nile in Sudan has its headwaters in Ethiopia. Hydropower and irrigation dams have been built, and still under construction, along the course of Blue Nile.

C. Baro-Akobo (White Nile) Basin

Baro-Akobo forms a White Nile Basin in Ethiopia. The two upper tributaries that coalesce to form Baro River, Birbir and Gabba, have their headwaters in the southwestern Ethiopian Highlands. Baro River flows west through the Gambela Region of Ethiopia to join with Pibor River to form Sobat River in South Sudan. Alwero and Jikawo Rivers are the major downstream tributaries of Baro River in Gambela Region. The Akobo and Gilo rivers have their origin in the southwestern Ethiopian Highlands and flow westward to confluence successively with Pibor River. Ultimately, the Baro-Pibor confluence marks the beginning of the Sobat River, a tributary of the White Nile.

D. Omo-Gibe (Omo-Turkana) Basin

Omo-Gibe is part of Omo-Turkana Basin within the limits of Ethiopia. The principal stream of the basin namely Omo-Gibe River has its origin in the southwestern Ethiopian highlands at an elevation of about 2,200 m a.s.l. The 760 km long river (CSA, 2009) traverses Oromia and Southern Nations Nationalities and Peoples (SNNP) regions of Ethiopia, flows southward ultimately ending up in Lake Turkana in the lowlands of 365 m a.s.l. The major tributaries, in the upstream to downstream order, include Gojeb (the major one), Gilgel-Gibe, Amara, Alanga, Denchiya, Mui, Zigina-Shoshuma, Mantsa, and Usno (with sub-tributaries Mago and Neri). Omo-Gibe Basin offers a mixture of fertile grasslands, forests, terraced hillsides and broad rivers, and is rich in wildlife resources, with five national parks: Omo, Mago, Chebera-Churchura, Maze and Omo Sheleko national parks. Various streams that cross these national parks feed the main Omo-Gibe River. The wilderness and largely inaccessible nature of most of these national parks would mean that they are still in their pristine state with greater diversity of life and increased values for biodiversity conservation. The riverine vegetation along the Omo-Gibe River was described to be a combination of open canopy woodland, shrub thicket and grassland (with scattered tree emergents) prevailing on and near the modern delta; closed canopy woodland and forest predominating in the meandering segment middle to upper basin (Carr, 1998).

Figure 1. The drainage basins of Ethiopia (After UN-OCHA, 2006); A = Tekeze-Atbara, B = Abay (Blue Nile), C = Baro-Akobo (White Nile), D = Omo-Gibe (Omo-Turkana), E = Rift Valley lakes, F = Awash River, G = Danakil Depression, H = Genale-Dawa, I = Wabishebelle

E. Rift Valley

The Rift Valley lakes basin is located south of Awash Basin and it consist of notable lakes such as Zeway, Langano, Abijata, Shalla, Hawassa, Abaya, Chamo, Chew-Bahr and a portion of Lake Turkana. Lakes Zeway and Langano are connected to Lake Abijata via Sucsuci and Hora Kelo streams respectively. Lake Shala forms a closed basin. The main tributary of Hawassa Lake is the Tikur Wuha River, which drains swampy Lake Shallo. Lakes Abijata, Shala and Hawassa are all terminal lakes without any visible surface outlet and they lose water through evaporation. However, salinity is particularly high for Lakes Shala (21.5 g L^{-1}) and Abijata (16.2 g L^{-1}) (Paugy, 2010a). Lake Abaya is fed on its northern shore by the Bilate River, which rises on the southern slopes of Mount Gurage. Lake Chamo is located south of Lake Abaya and separated with a narrow corridor of land, which can be overflown during heavy rains to connect the two lakes. The two lakes are located in the vicinity of Nech-Sar National Park. Chew Bahr is located south of Lake Chamo and is fed from north by the Weyito River and its tributary the Galana Sagan, which in turn receives an overflow from Lake Chamo in some years. The Humu Range and the hills south of it separate the watershed of Lake Chew Bahr from that of Lake Turkana.

F. Awash River Basin

Awash River originates in the central Highland west of Addis Ababa near Ambo and drains northeast, crossing through Awash and Yangudi-Rassa National Parks, ending up in the chain of interconnected saline lakes such as Gargori, Laitali, Gummare, Bario, Afambo, and the terminal lake, Abhe. These lakes are located on the eastern side of Afar Triangle. Its major tributaries include Akaki, Mojo, Keleta, Durkham, Germama, Kabenna, Hawadi, Ataye, Borkana, Mille and Logiya rivers in the downstream order. The basin supports various development activities including the hydropower dam Lake Koka and the ongoing Tendaho sugar plantation irrigation dam.

G. Danakil Depression

The Danakil Depression is located at the extreme north of the Ethiopian Rift Valley system north of Awash Basin. It constitutes the northern part of the Afar Triangle, and consists of considerable number of lowland lakes including Lakes Afdera (also known as Afrera) and Assal (also known as Asale), which are characterized by high salinity reaching 158 g L^{-1} for the latter (Paugy, 2010a). Unlike other saline Rift Valley lakes in Ethiopia, such as Lakes Abijatta, Shala, and Chitu, Lake Afdera has low pH in the acidic range. Although little studied, a few species of fish occur in Lake Afdera, including two endemics: *Danakilia franchettii* (a cichlid) and *Aphanius stiassnyae* (synonym *Lebias stiassnyae*, a cyprodontid), and *Lebias dispar* occurs in both Lakes Afdera and Assal (Abebe Getahun and Lazera, 2001; Redeat Habtesilassie, 2012).

Genale-Dawa Basin

Genale River originates in Bale Mountain west of Wabishebele River. Its major tributaries include Welmel, Weyib (Gestro), Mena and Dawa. Dawa River, rising in the mountains east of Abaya-Chamo basin, flows south and east to join Genale River to form Juba River at the border with Somalia. The Del Verme Fall is a notable feature of the middle course of Genale River.

I. Wabishebelle Basin

Wabishebelle River starts in the Bale Mountain receiving large number of tributaries originating in the Ahmar Mountains. These include Ramis, Daketa, Fafen, Erer and Wabe. It flows southeast into the lowlands of Somalia where it rarely (especially during seasons of heavy rain) joins the Juba River, which ultimately enters the Indian Ocean.

1.2. Freshwater ichthyofaunal provinces in Ethiopia

The definition and delimitation of the African freshwater ichthyofaunal provinces has its root in the Boulenger‘s (1905a) division of the continent into 5 subregions. Modifications have been made since then as more knowledge on fish diversity of the continent has continued to advance. Roberts (1975) recognized 10 provinces, excluding

Madagascar, according to which Ethiopia appeared to have largely made up of the Abyssinian Highland province excepting for the Nilo-Sudanic affinities of its southern most Rift Valley lakes. The Abyssinian Highland province was defined to comprise both the western and eastern highland blocks and the Rift Valley basin. This was slightly modified by Lévêque (1997) who considered the Robert‘s (1975) Abyssinian Highland province a subprovince within the Nilo-Sudanic province asserting the ichthyofaunal similarity of the two. Recently Paugy (2010a) indicated heterogeneity of the province and thus, suggested its dissolution into 3 provinces and 1 subprovince, with 1 more province that encompasses the south eastern basins of the country. According to this new modification, the Nile subbasins within Ethiopia and the Ethiopian southernmost Rift Valley lakes (Abaya, Chamo, Chew Bahr and Turkana) belong to Nilo-Sudanic province, and Lake Tana in the western highland stands on its own as Lake Tana Hotspot province. Lakes Hawassa, Langano, Abijata, Zeway and Awash River basin fall in a new province namely Ethiopian Rift Valley or Oromo province; lakes in the Danakil depression (Afdera, Assal) belong to the Red Sea Coastal subprovince, and the southeastern basins (Wabishebelle-Genale basins) become part of the Eastern province (Figure 2). Moreover, Roberts‘ (1975) Eastern province was modified by Greenwood (1983) to include Lakes Edward and George (which were formerly in the Nilo-Sudan), and by Snoeks *et al*. (1997) to include Lake Kivu (which was part of the Congo province). These recent biogeographic analyses are pursued in the present study when discussing distribution of the fishes.

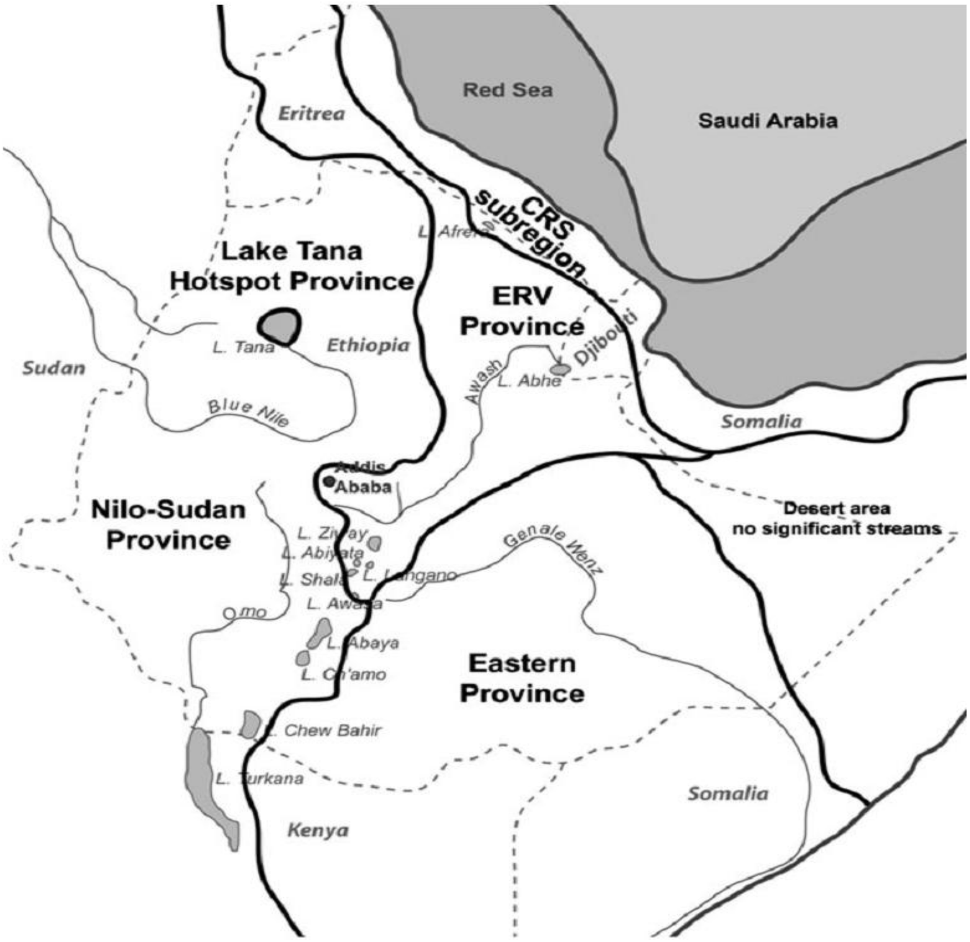


Figure 2. Ichthyofaunal provinces and subprovinces in Ethiopia sensu Paugy (2010a); CRS = Coastal Red Sea

1.3. General accounts of Ethiopian ichthyofaunal studies

In Ethiopia, fish specimen collections and descriptions seem to have been started during the first half of 19th century by foreigners. Fish specimen collections were undertaken as part of the general natural history expeditions covering other animals such as birds, mammals, insects as well as plants. A notable person to explore the country during this part of the century was a German naturalist Eduard Rüppell (1794–1884) who had one visit and two round expeditions to northeast Africa (Steinheimer, 2005). He advanced to the western Ethiopian Highlands as far as Seimen Mountains and Lake Tana during his second scientific trip, in 1831–1834, when he collected fish specimens from Lake Tana and its surroundings. This is evident from his subsequent descriptions of new fish species, all with Lake Tana and its basins as type locality. Examples of these include *Garra dembeensis* (Rüppell, 1835), *Garra quadrimaculata* (Rüppell, 1835), *Varicorhinus beso* Rüppell, 1835, *Labeobarbus nedgia* Rüppell, 1835, *Labeobarbus surkis* (Rüppell, 1835), *Labeobarbus gorguari* (Rüppell, 1835) and *Labeobarbus intermedius (*Rüppell, 1835). He described for the first time large barbs of Lake Tana species under genera *Barbus* and *Labeobarbus*.

Towards the end of the second half of 19th century an American doctor and explorer, A. Donaldson Smith (1866–1939), collected fish specimens along with other animals, from various water bodies of Ethiopia, during his geological expedition to Lake Turkana between 1894 and 1895 (Smith, 1897). He obtained fish specimens from Lake Turkana as well as other water bodies such as Lake Chew Bahr (previously Stephanie), Lake Abaya, Wabishebelle River and Dawa River en route to Lake Turkana or on a return trip. His collections were later identified, with four new descriptions, into 18 fish species by Günther (1896). During this period, fish collections were also made by the Italian explorers and military personnel, such as Prince E. Ruspoli (in 1893) and Captain V. Bottego (in 1895), from southern and south eastern Ethiopia including Lake Abaya and Wabishebelle-Genale basins whose collections were identified and described by Vinciguerra (1897a,b). Later on in 1911, Captain Hugh Casale sent more specimens from the southeastern Ethiopia to Italy for identification by Vinciguerra (1922). Their collections altogether were identified into more than 30 species including new descriptions.

Relatively exhaustive ichthyofaunal explorations in Ethiopia have been undertaken since 20th century. Mr. Edward Degen (1852–1922), a Swiss national affiliated to the British (London) and Melbourne (Australia) museums, was one of the explorers engaged in the collection of fish specimens during this period apparently in an expedition that was arranged by the then British Consul in Addis Ababa (Anon., 1901a,b). He collected fish specimens from various parts of the country including Lake Tana, Awash, Wabishebelle and southern Ethiopian lakes basins. Boulenger (1902) identified Degen‘s collections into 34 species, of which 21 were new descriptions. Professor Oscar R. Neumann (1867–1946) and C. von Erlanger (1872–1904), German ornithologists, also collected numerous zoological specimens including fish from southern Ethiopia in 1900–1901(Anon., 1947). Their fish collections, obtained from Awash, Wabishebelle, Rift Valley lakes and Omo-Turkana basins, were identified by Boulenger (1903a) into 19 species, 4 of which described as new. Mr. William. N. McMillan, a Scottish-born American explorer, had an expedition to Africa since 1903 and he particularly travelled between Sudan and southern Ethiopia in 1904 (Jessen, 1906). He, together with his assistant P. C. Zaphiro (1879–1933), a Greek-origin British, collected extensive fish specimens from different localities in Blue Nile, Awash, Rift Valley lakes (Zeway to Chew Bahr) and Omo-Turkana basins. His collections were donated to the British Museum (Natural History) and identified by Boulenger (1906) into 39 species with 8 new descriptions.

George A. Boulenger (1858–1937), a Belgian-British zoologist who worked in Natural History Museum (London), had never been to any scientific expedition to Ethiopia as well as to the rest of Africa (Paugy, 2010b). Nonetheless, he identified and described quite a large number of fish specimens from Ethiopian water bodies, from collections made by other people, largely in the early 20th century (Boulenger, 1902, 1903a, 1905a,b, 1906). Particularly, his remarkable contribution were his four volume books, ―Catalogue of African Fresh Water Fishes" (Boulenger, 1909, 1911, 1915, 1916) in which he summarized the freshwater ichthyofaunal diversity of Africa that have become foundational for subsequent studies of the Ethiopian freshwater fish diversity as well as that of Africa. J. Pellegrin (1873–1944), a French zoologist, was a contemporary of G. A. Boulenger who identified and described several freshwater fish species of Ethiopia. Collections made by Maurice de Rothschild in 1904–1905 from Awash, Wabishebelle and Lake Turkana basins were identified by Pellegrin (1905) into 21 species, with 5 new descriptions (though all synonymised at present), referable to 4 families, predominantly consisting of cyprinids. Moreover, he identified 3 species and described 1 new species, *Garra aethiopicus* (Pellegrin, 1927), from a collection obtained from Awash River Basin and sent to him by the then French Embassy in Addis Ababa, Ethiopia (Pellegrin, 1927). Noteworthy in the study of Ethiopian ichthyofauna during the first half of 20th century also were the Italian contemporaries of Pellegrin such as Gianferrari and Bini. The former described 1 species, *Garra ignestii* (Gianferrari, 1925) and 1 subspecies, *Garra blanfordii cimmaruta* (Gianferrari, 1936) (now synonym of *G. balnfordii*), from Tekeze basin. Bini (1940) studied Lake Tana large barbs in a relatively detailed manner in which he identified 10 species, with 23 subspecies, and classified them in a separate subgenus, *Labeobarbus*.

The second half of 20th century saw relatively a brief period of paucity until an Ethiopian investigator, Shibru Tedla (1973), made a comprehensive revision that listed 93 species as occurring in the freshwater system of the country. Subsequently, the Joint Ethio-Russian Biological Expedition (JERBE), originally Joint Ethio-Soviet Biological

Expedition, has been active in the nationwide ichthyofaunal exploration since the mid 1980s (Dgebuadze *et al*., 1994; Golubtsov *et al*., 1995; Baron *et al*., 1997; Mina *et al*., 1998; Dimmick *et al*., 2001; Golubtsov and Mina, 2003; Golubtsov and Berendzen, 2005; Golubtsov and Darkov, 2008; Rediet Habtesilassie, 2012; Prokofiev and Golubtsov, 2013). According to Golubtsov and Darkov (2008), though not supplemented with the actual list, the ichthyofaunal diversity of the nation has increased from 93 species (Shibru Tedla, 1973) to 184 (native) in 70 genera and 29 families, with 4–5 exotic species. Of course, the JERBE expedition should be credited for its great role towards advancing the present day knowledge on the ichthyofaunal diversity of the country. Towards the end of the twentieth and turn of the present century Wageningen University, The Netherlands, had important role in the study of taxonomy, evolution, ecology and fisheries of '*Barbus*' spp of Lake Tana, Blue Nile basin, which has ever since become a biodiversity hotspot (Nagelkerke, 1997; Tesfaye Wudneh, 1998; Eshete Dejen, 2003; de Graaf, 2003). At the same time, other investigators including Ethiopian researchers took part in the study of the country‘s ichthyofaunal diversity and conservation (Abebe Getahun and Stiassny, 1998; Abebe Getahun and Lazera, 2001; Abebe Getahun, 2007; Stiassny and Abebe Getahun, 2007). At present, there appears to be no major active projects addressing ichthyofaunal assessments except for the pieces of MSc/PhD theses often conducted under limited funding.

1.4. General description of the study area

Fish specimens for the present study were obtained from Omo-Turkana Basin within the limit of Ethiopia. It is part of the largest Turkana system with a catchment area of 131,000–145,500 km^2 traversing southwestern Ethiopia and northern Kenya (Feibel, 2011; Velpuri *et al*., 2012). The Turkana system also encompasses Turkwell and Kerio rivers on the southwestern shore of the lake in Kenya, and intermittent streams such as Kalakol and Kataboi (on western shore) in Kenya, and Kibbish (on northwestern shore) in Ethiopia (Ferguson and Harbott, 1982). Omo-Turkana Basin within the limit of Ethiopia constitutes the entire Omo-Gibe River Basin on the northern shore of the lake and a portion of the northern end of Lake Turkana.

1.4.1. Omo-Gibe River

The origin, major tributaries and associated features of Omo-Gibe River, the principal and perennial stream of Omo-Turkana Basin, have been described in section1.1. Omo-Gibe River Basin constitutes 52–58% of the total Turkana catchment area and supplies 80–90% of the total inflow to the lake (Ferguson and Harbott, 1982; UNEP, 2010). It largely receives an annual precipitation of up to 2,000 mm (UNEP, 2010).

Lower Omo River Valley harbors plains of fossil bearing volcanic tuff with four known geological formations: Mursi (4–4.5 million years old), Shungura (1.8–3.4 million years old), Usno (1–3.5 million years old), and Kibish (0.1 million years old). It, as a result, has been a focus of paleontological investigations of hominids, mammals as well as fish on a global scale (Bobe, 2011; Delagnes *et al*., 2011; Wood and Leakey, 2011). Recently Stewart and Murray (2008) derived fossil fish remains from the Shungura Formation with two new species, *Sindacharax omoensis* (Characiformes: Alestidae) and *Lates arambourgi* (Perciformes: Latidae), being reported. Lower Omo is one of the four sites in Ethiopia inscribed as UNESCO‘s World Heritage Centre in 1980.

Various development activities have been happening in the Omo-Gibe Basin. In the upper part of the basin Gilgel-Gibe I dam, commissioned in 2004, is now a source of water for hydropower generation at Gilgel-Gibe I and II power stations. In the middle reach of the basin the construction of Gilgel-Gibe III hydropower dam (EEPCO, 2009) is underway, virtually in its final phase. Reportedly, more hydropower dams are foreseen for future construction in the Omo basin (UNEP, 2010). In the lower Omo Valley sugarcane plantation is also underway along the main Omo River in the Selamago area. This bears potential ecological impacts on the fish fauna of Omo River and its streams through water extraction.

The total human population in the entire Omo-Gibe Basin is estimated at 9 million (UNEP, 2010).Whereas the basin is more populous in its upper part, the lower Omo that encompasses an administrative unit of South Omo Zone has only a population of 691,086 (3.78% of SNNP) according to the 2015 population projection data of Ethiopia (CSA, 2014). Diverse ethno-cultural and language groups composed of Nilo-Saharan (e.g. Mursi, Surma), Omotic (Hammar, Banna, Karo) and Cushitic (e.g. Daasanach, Tsamay, Erbore) lines, with pastoral and nomadic life style, inhabit the lower Omo-Gibe River Basin. The Ethiopian Daasanach tribe, with a population of 62,308 (9.02% of South Omo zone), occupies the Omo River Delta, and the northern and northeastern part of Lake Turkana. The Daasanach community settled along the lower Omo River practices some form of recession farming, besides cattle keeping, following flooding of the river during the peak season, thus, partly leading an agro-pastoral life style. The Kenyan Turkana tribe inhabits extensive part of the western shore of Lake Turkana. The Turkana fishers appear to, sometimes, have been falling into conflict with the Ethiopian fishers, seemingly over a competition for the resource.

1.4.2. Lake Turkana

Lake Turkana is the world‘s largest permanent desert lake and the largest alkaline lake (UNEP, 2010) located in a semi-desert area roughly at geographic coordinates of 02°27′–04°40′ N, 035°50′–36°40′ E. It is 257 km long, 13–44 km wide, has surface area of 7,560 km^2, volume of 237.36 km^3 and mean depth of 31.4 m. The entire lake was described as having four major regions as northern, central, turkwell, and southern, with two major inshore areas: Omo River Delta and Ferguson Gulf (Ferguson and Harbott, 1982). Lake Turkana in Ethiopia is a portion of the northern region of the lake estimated at 1.3% of the entire lake area (FAO, 2003). Thus, the Ethiopian part of the lake is roughly about 98 km^2, which is nearly comparable to the size of Lake Hawassa (also Awassa) in Ethiopia.

The modern Lake Turkana is in a closed basin with no known surface outlet and characterized by moderate salinity of 2.89 g L^{-1} (Paugy, 2010a). Evidences, however, rather suggest its historical connection to White Nile apparently via Lotigipi Swamps and Pibor River in northern Kenya and southern South Sudan. According to zoogeographic studies, the lake overflowed southeast into the Indian Ocean from the late Miocene until at least 1.9 million years ago before the subsequent tectonics in the basin shifted its overflow to the Nile system (Feibel, 1994; Wichura *et al.*, 2015). The Lake was connected to White Nile since the late Pliocene to as recent as 7500 years ago (Roberts, 1975). The first evidence for its connection to Nile system comes from zoogeographic and sediment analyses. The fossil ichthyofauna retrieved from the rocks of ancient Omo basin as well as several of the modern species of the lake are Nilotic forms (Stewart, 2009). The Plio-Pleistocene sediment sequences also indicate the Omo River mouth to have been located 90–120 km north of the present delta (Feibel, 2011).

The lake had 2–3 events of high water levels and expansions between 9,500 and 3,000 years ago in Holocene, during which it presumably overflowed into the Nile system (Richardson and Richardson, 1972). The lake also experienced a period of higher wetter conditions during the early and middle Holocene, 10,000 to 5,000 years ago, which probably permitted the lake to achieve its historical high levels. During those periods, the lake level fluctuated around the threshold value of +77 – +80 m before it eventually subsided to low levels of near today's (Harvey and Grove, 1982).

Lake Turkana‘s water level taken in 1972 was 365±5 m a.s.l (Ferguson and Harbott, 1982). Recent developments show that the lake‘s water level fluctuated by 15 m during the last century (Ricketts and Anderson, 1998), but they were smaller than the early time fluctuations (Nicholson, 2001). A satellite-data based modelling between 1998 and 2008 related the lake‘s water balance mainly to the inflows and over-the-lake evapotranspiration (Velpuri *et al*., 2012). The incidence of drought in Omo-Gibe basin, the lake‘s major source of water, over the last 30 years was shown to be frequent with more pronounced effects in the southern lowland, part of a basin in a closer vicinity to Lake Turkana. Predictions were also given for similar incidents that would happen over the next 100 years (Degefu and Bewket, 2014). Even at present, high average temperature (30°C) coupled with strong wind for the lake basin could accelerate the lake‘s evaporation rate. It therefore seems likely that the lake might continue experiencing various degrees of water level fluctuations in response to climate change. In conclusion, Lake Turkana exhibits a unique combination of a closed basin situated in a desert, high seasonal and inter-annual water level fluctuations and strong unidirectional winds, which cause complete mixing of the whole water column (i.e. holomixis). The water column is, therefore, nearly isothermal during most of the year with the temperature gradient of 1–2 °C from surface to bottom in 70 m (Ferguson and Harbott, 1982). This could sporadically vary during May when the thermocline can establish between 20 and 50 m depth and the oxygen level can be a limiting factor for fish near the bottom (0.2 mg L^{-1}) (Källqvist *et al*., 1988).

1.4. 3. Ichthyofaunal studies of Omo-Turkana Basin

Omo-Turkana Basin was perhaps first explored in the second half of 19th century during Dr. Donald Smith's Lake Turkana expedition between 1894 and 1895. Eight fish species, with one new description, were identified from Dr. D. Smith's Lake Turkana collection (Günther, 1896). In the early 20th century, 5 species were identified from Omo River collections of R. Neumann (1867–1946) & C. von Erlanger (1872–1904) (Boulenger, 1903a). Contemporarily, 14 fish species in the middle to upper Omo River and 5 species in the northeastern end of Lake Turkana were identified from the collections made by W. N. McMillan and P. C. Zaphiro (Boulenger, 1906). At the same time, Pellegrin (1905) identified 4 species from Lake Turkana's collections of Maurice de Rothschild in 1904–1905.

The first organized exploration to Omo-Turkana Basin was undertaken by Cambridge University in 1930–31(Worthington, 1931, 1932; Worthington and Richardo, 1936), as part of its Great East African lakes expedition, which also studied Lake Turkana's fish diversity. This was followed by a multidisciplinary scientific expedition of the French team to lower Omo River valley, known as Scientifique de l'Omo, which took place between 1932 and 1933. Pellegrin (1935) identified 16 species referable to 13 genera and 7 families from the expedition's fish collections, of which 2 species, viz. *Aplocheilichthys jeanneli* (Pellegrin, 1935) & *Barbus arambourgi* Pellegrin, 1935, and 1 subspecies, *Brycinus nurse nana* (Pellegrin, 1935), were new descriptions. Of the total identifications and descriptions, 12 species were identified from Omo River (Delta) while 3 species were from Lake Turkana. The East African Freshwater Fisheries Research Organization (EAFFRO), based in Uganda, also paid rare visit to Lake Turkana and identified some fish species (Hamblyn, 1962; Mann, 1964). A further well-organized scientific investigation that laid foundation to our contemporary knowledge of Lake Turkana's ichthyofaunal diversity was the 1972–1975 British project (Hopson, 1982). This much comprehensive study also generated information on the lake's limnology and fisheries. The project report, that combined original data and review of past works, listed 48 species for the lake with description of 3 new ones (Hopson and Hopson, 1982). The Norwegian project, from 1985–1988, mainly focused on fisheries (Kolding, 1989a) and limnology (Källqvist *et al*., 1988) of the lake.

A review by Shibru Tedla (1973) listed 23 species for the Omo-Turkana system, the majority of which being from Omo River system. The ichthyofaunal exploration by the Joint Ethio-Russian Biological Expedition (JERBE) listed 55 fish species occurring in Omo River Basin and 72 fish species for Omo-Turkana system (Baron *et al*., 1997). As the sampling program of JERBE for the Omo-Turkana system included only the Omo River Basin, its list of fish species also incorporated a review of early works such as Hopson and Hopson (1982) and Lévêque *et al*. (1991). A synthesis of the preceding studies and reviews (e.g. Roberts, 1975; Hopson and Hopson, 1982; Kolding, 1989a; Lévêque *et al*., 1991; Baron *et al*., 1997) produces 74 valid fish species for the entire Omo-Turkana system. However, Golubtsov and Darkov (2008) later on increased the number of species list for the Omo-Turkana system to 76–79.

1.5. Research questions, rationales and significance

Past ichthyofaunal explorations, e.g. Worthington, 1931, 1932; Worthington and Richardo, 1936; Hamblyn, 1962; Mann, 1964; Hopson and Hopson (1982); Kolding (1989a), dealt largely with the main lake in Kenya. An ichthyofaunal exploration of Omo River Delta (Pellegrin, 1935), undertaken as part of a French multidisciplinary scientific expedition to lower Omo River valley, is nearly over a century old. JERBE explorations (Baron *et al*., 1997; Golubtsov and Mina, 2003; Golubtsov and Darkov, 2008) did not sample fish in the Ethiopian part of Lake Turkana. Thus, the extent of fish distribution between the lake and lower Omo River is not precisely known. Moreover, important ecological parameters such as fish community structure and feeding ecology of the basin as well as socioeconomic contributions of the basin fisheries to the local inhabitants were not assessed. Some development activities also occur in the basin, and these could bear potential impacts on the diversity and ecology of the basin‘s fish fauna. Based on these rationales, this study attempted to answer the following research questions:

- What do the ichthyofaunal diversities of lower Omo River, the Ethiopian part of Lake Turkana and the entire Omo-Turkana Basin look like? (**Chapter 2).** For this chapter**,** we sampled fish specimens from the Ethiopian part of Lake Turkana and lower Omo River. We used data generated from the present collection combined with exhaustive review of past fish diversity studies to develop a checklist for the basin‘s freshwater fish, and an identification key for the fish fauna within the limit of Ethiopia.
- How do relative importance and community structures of fish fauna of the Ethiopian part of Lake Turkana and the lower Omo River compare? Is the river

community distinct from the lake community, and vice versa? What environmental and habitat variables determine the fish community structures? (**Chapter 3).** In this chapter, we assessed ecological importance of 31 fish species identified from the Ethiopia part of Lake Turkana and lower Omo River in the present collections. Multivariate statistical methods such as cluster analysis and ordination methods were used to assess distinctness of the lake and the river fish communities, and their potential environmental determinants.

- How do diets of selected fish species from the Ethiopian part of Lake Turkana vary at individual and population levels, ontogenetically and seasonally? What are the feeding strategies of these fish species? Do these fish species tend to form any trophic guilds? **(Chapter 4).** In this chapter, we aimed to generate relevant data on feeding ecology of fish species in both the lake and the river. However, specimens sampled from lower Omo River were insufficient to warrant data analysis. Therefore, we analyzed diet data for eight major fish species of the Ethiopian part of Lake Turkana to study dietary variations, feeding strategies and any occurrence of trophic guilds.
- What is the extent of socioeconomic contributions of the fishery activities, of both lower Omo River and the Ethiopian part of Lake Turkana, to the livelihood and income of the local inhabitants? Are there any factors that fishers perceive as impeding to exploitation and management of the fisheries resources of the lake and the river? **(Chapter 5).** In this chapter, socioeconomic benefits of fisheries to the local people, major issues related to the fisheries, and fishers' perceptions about resource status and management were studied.

The shift in emphasis away from the single issue or -species focus of traditional fisheries management towards an ecosystem approach to fisheries management (EAF) requires application of indicators of ecosystem state (Greenstreet and Rogers, 2006). The indicators are usually chosen to provide good coverage of the components and attributes, where components are defined as functional groups (such as population, species, or community) and attributes as properties of these components (e.g. abundance, diversity, or trophic structure) (Jennings, 2005). The number of different fish taxa found in an area, for instance, can be used as an indicator of biodiversity. In EAF, not only are the target species included but also their effects on other non-target species (Cury and Christensen, 2005), demonstrating the importance of knowledge on the trophic structure. For holistic assessment of fisheries status, EAF also requires indicator for socioeconomic status i.e. human dimension (Seung and Zhang, 2011). Moreover, data generated on feeding habits are important in evaluating aquaculture potential and capabilities of the studied fish species. In light of these facts, the information generated on fish diversity, relative abundance, community structure, trophic ecology, and fisheries socioeconomics in the present study would contribute to comprehensive understanding of the fish fauna and fisheries, and serve as an important input for an EAF management plan in the areas of present focus. Moreover, the outcome of the study would be of firsthand utility for appraisal and monitoring of any future changes in the fish fauna of the focal areas where anthropogenic activities are prevalent.

1.6. Ethical consideration

Ethical guidelines or procedures for research works that involve animal (fish) subjects are not available in Ethiopia. However, formal permits to sample fish in the study areas were obtained from the Ethiopian Ministry of Water and Energy and local administrations (a letter in Amharic language). I also adhered to the general provisions of world medical association (WMA) statement on welfare of animals used in research for humane treatment of fish during sampling and handling operations. Moreover, general principles pertaining to field activities with wild fish as laid down by AFS *et al*. (2004) was considered. To minimize prolonged stress to fish, the required data were collected from the specimens as promptly as possible, representative samples were transferred to 10% formalin solution and extra specimens were provided to the local inhabitants for their own consumption. None of the fish species sampled for the present study are officially listed as imperiled by the IUCN Red List of the Threatened species.

Chapter two

2. Ichthyofaunal diversity of Omo-Turkana Basin with specific reference to fish diversity within the limit of Ethiopia

2.1. Introduction

Global biological diversity is comprised of components measured at various scales. Alpha diversity measures species richness at a single locality or in a particular community, whereas beta diversity is a measure of the amount of turnover or heterogeneity in species composition along environmental gradients between two localities or communities (Whittaker, 1972). Thus, alpha diversity can be used to reflect how finely species are dividing ecological resources, whereas beta diversity can reflect the extent of habitat selection or specialization (Jost *et al*., 2011). Measures of taxa composition and compositional variation as one or more of these components of global diversity have important applications in setting conservation priorities or evaluating regional conservation plans. In ecology, they can also be used to study the homogenizing or diversifying effects of human activities, natural disturbance, or spatial variability of environmental conditions (Olden, 2006; Vellend *et al*., 2007).

Omo-Turkana Basin spans considerable geographic area in southwestern Ethiopia and northern Kenya (Feibel, 2011; Velpuri *et al*., 2012). In Ethiopia, it largely lies within the southwestern highlands while its lower portion is also located in the eastern arm of the East African Great Rift Valley. Historical accounts of ichthyofaunal exploration of the basin were discussed in section 1.4.3. Studies pertaining to fish diversity parameters do not exist for the basin except for the scattered reports on the species occurrence (e.g. Pellegrin, 1905, 1935; Hopson and Hopson, 1982; Kolding, 1989a; Baron *et al*., 1997;

Golubtsov and Mina, 2003; Golubtsov and Darkov, 2008; section 1.4.3). Most of these previous explorations on the ichthyofaunal diversity of the basin largely dealt with the main lake in Kenya. Despite the occurrence of some development activities and their potential impacts on biodiversity, the Ethiopian part of the basin generally lacks comprehensive study and proper scientific documentation on its ichthyofaunal diversity. Thus, the extent of fish diversity in the Ethiopian part of Lake Turkana is not precisely known. In the face of such deficient or lack of scientific documentation, recommendations and/or implementation of appropriate management and conservation measures as well as future appraisal of impacts would be hardly possible. Therefore, the present study on fish diversity was carried out with the objectives of:

- assessing alpha and beta diversities of lower Omo River and the Ethiopian part of Lake Turkana
- assessing the extent of ichthyofaunal diversity in the Ethiopian part of Lake Turkana and Omo-Turkana Basin within the limit of Ethiopia and,
- developing comprehensive ichthyofaunal checklist and an identification key as these do not exist for the basin.

2.2. Materials and Methods

2.2.1. Sampling sites

Fish specimens were obtained from lower Omo River, near Omorate town located at 50–60 km upstream of the Omo River Delta, and from the Ethiopian part of Lake Turkana. Eight sampling sites (Figure 3) were selected based on a prior reconnaissance, undertaken in November 2012, according to their accessibility and sampling safety. The lower Omo River sites were predominantly pools with sandy and muddy bottom, whereas the Lake Turkana sites had largely muddy bottom. Geographic coordinates and related features of the sampling sites are summarized in Table 1.

Table 1. Summary of the sampling sites and sampling seasons at lower Omo River (OR1–OR4) and the Ethiopian part of Lake Turkana (LT1–LT4); Alt = altitude a.s.l (m), Depth = water depth (m)

				Sampling seasons and dates			
Site	Alt	Depth	Geographic coordinates	Dry1 (Jan-13)	Wet1 (Nov-13)	Dry2 (Apr-14)	Wet2 (Sep-14)
OR-1	362.2	6.10	04°39′29.88″ N 036°00′52.56″ E	9–10	1–2	1–2	15–16
OR-2	372.2	5.30	04°40′28.20″ N 036°00′01.44″ E	11–12	3–4	3–4	17–18
OR-3	370.1	7.50	04°41′31.92″ N 035°59′40.20″ E	13–14	5–6	5–6	19–20
OR-4	367.4	4.80	04°42′27.36″ N 035°59′37.32″ E	15–16	7–8	7–8	21–22
LT-1	359.3	2.10	04°34′40.08″ N 036°04′25.32″ E	17–18	9–10	9–10	23–24
LT-2	357.4	1.73	04°31′46.92″ N 036°09′46.44″ E	19–20	11–12	11–12	25–26
LT-3	358.5	2.35	04°29′22.20″ N 036°05′16.44″ E	21–22	13–14	13–14	27–28
LT-4	356.5	2.75	04°27′46.80″ N 036°11′57.12″ E	23–24	15–16	15–16	29–30

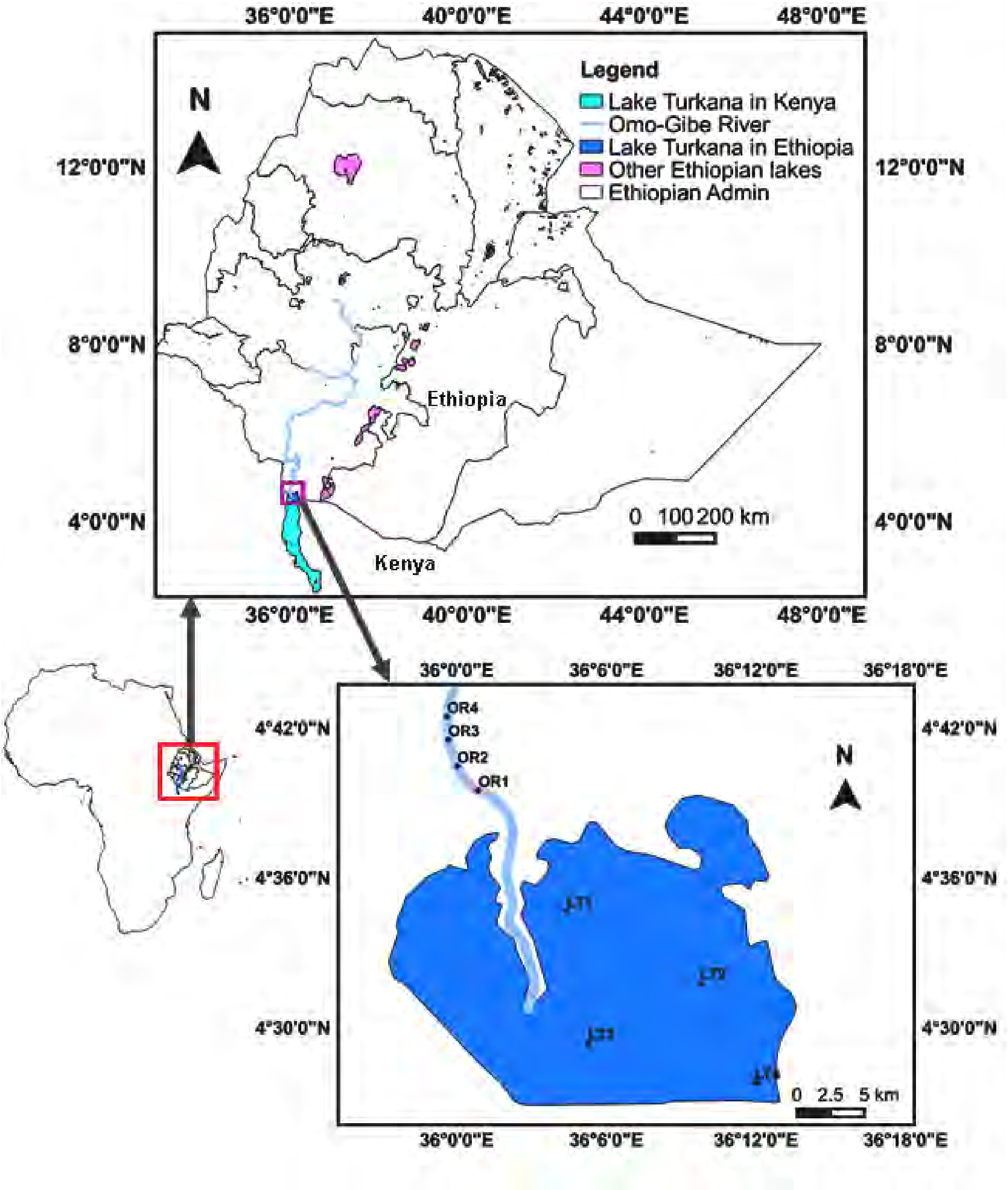


Figure 3. The sampling sites at lower Omo River (OR1–OR4) and the Ethiopian part of Lake Turkana (LT1–LT4).

2.2.2. Fish sampling and identification

Permits to sample fish specimens in the study sites were obtained from the local administrators of southern Ethiopia. Fish samples were collected in two dry and two wet seasons between January 2013 and September 2014. Dry season sampling was conducted during periods of a year when there was no rainfall whereas wet season sampling was undertaken following recession of prolonged heavy rainfall, yet still wet, for convenience of sampling. The exact dates of sampling for each sampling locality and site are provided in Table 1. A combination of monofilament and multifilament gill nets was mostly used for sampling. The gill nets had-stretched mesh sizes of 8–44 cm, a panel length of 100 m and width of 1m per mesh size. Four sets of gillnets, two parallel and two perpendicular to the shore, were set at a subsurface level at each sampling site. Hook and line, traps, and cast nets supplemented the gill net sampling especially in the shore areas. Each site was sampled for two days. Fish specimens were fixed in 10% formalin. Identification was made to species level following relevant ichthyofaunal keys (Boulenger, 1909, 1911, 1915, 1916; Shibru Tedla, 1973; Hopson and Hopson, 1982; Seegers *et al*., 2003; Redeat Habteselassie, 2012). Voucher specimens of the respective fish species, along with their sampling localities, were deposited at the Zoological Natural History Museum (AAU), Addis Ababa University (Appendix 1).

2.2.3. Data analysis

Fish samples obtained during the present study were used to compute Shannon diversity (H′) and evenness (J′) indices (Maurer and McGill, 2011), as measures of alpha diversity for lower Omo River and the Ethiopian part of Lake Turkana, as:

$$H' = -\sum_{i=1}^{S} Pi \times \ln(Pi); \quad J' = H'/\ln(S)$$

Where,

Pi = Abundance proportion of species i

S = Species richness

The rank order abundance plots were generated as natural logarithm of abundance values versus the abundance rank order for further assessment of evenness. Differences in the parameters of alpha diversity measures between the river and the lake samples were compared using a randomization (permutation) test (Magurran, 1988; Solow, 1993). Whittaker's beta diversity index (β_W), apparently a robust index (Wilson and Shmida, 1984), was used to assess the rate of fish species turnover between lower Omo River and the Ethiopian part of Lake Turkana (Whittaker, 1972) as:

$$\beta w = \left(\frac{S}{\alpha}\right) - 1$$

Where,

S = total number of species of the habitats

α = average species richness per habitat

An individual based rarefaction analysis was performed to standardize diversity comparison between the two systems (Magurran, 2004; Gotelli and Colwell, 2011). All statistical analyses were carried out in PAST version 3.08 (Hammer *et al*., 2001). Ultimately, data obtained during the present study was combined with an exhaustive review of past studies to develop annotated checklist of the native fish species valid for the entire Omo-Turkana Basin.

2.3. Results

2.3.1. Species diversity

During the present study, a total of 4,386 fish specimens (lower Omo River, n = 823; Ethiopian part of Lake Turkana, n = 3,563) were collected. The river specimens were identified into 26 species, and the lake specimens were identified into 24 species. Overall, 31 fish species in 22 genera, 17 families and 7 orders were identified from collections of both environments. The list of these species is presented here following Nelson‘s (2006) classification scheme and their respective photographs are provided in Figures 2A-1–31 in Appendix 2. Laan *et al*. (2014) was followed for the Arapaimidae family-group name. Valid scientific name (in italic boldface) for each species along with citations to literature used in identification, synonyms only reported for Omo-Turkana Basin or most often referred to for the species under consideration along with their source literature, voucher specimens examined (Appendix 1), and brief diagnostic characters that were used in identifying the specimens are also provided. The list also includes the number of families (F), genera (G), species (Sp), and example (ex.) of material examined for the respective order. Three species i.e. *Mormyrus caschive* Linnaeus, 1758*, Labeo coubie* Rüppell, 1832 and *Auchenoglanis biscutatus* (Geoffroy St. Hilaire, 1809) were new records for Lake Turkana; two species i.e. *Hydrocynus vittatus* Castelnau, 1861 and *Schilbe uranoscopus* Rüppell, 1832 were new records for Omo River; whereas one species i.e. *Synodontis filamentosus* Boulenger, 1901 was new record for both Omo River and Lake Turkana.

Order Polypteriformes — 1family (F), 1genus (G), 2species (Spp)

Family Polypteridae — 2Spp

Polypterus bichir Lacepède, 1803:340 — Redeat Habteselassie (2012):57; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Polypterus bichir Geoffroy St. Hilaire, 1802:97 — Günther (1896): 218; Boulenger (1909):6; Shibru Tedla (1973):19; Hopson and Hopson (1982):290.

P. bichir bichir Lacepède, 1803 — Gosse (1984):19; Seegers *et al*. (2003):28

Material examined: voucher specimen, ZNHM-F-0001, 73 cm SL; Appendix 1; Figure 2A-1.

Seventeen dorsal finlets; 67 scales in the lateral line; terminal mouth with small unicuspid teeth on jaws; body dark brown; sampled in the Ethiopian part of Lake Turkana.

Polypterus senegalus Cuvier, 1829:330 — Boulenger (1905):36; Boulenger (1909):14; Redeat Habteselassie (2012):56; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Polypterus senegalus senegalus Cuvier, 1829 — Seegers *et al*. (2003):28.

Material examined: voucher specimens, ZNHM-F-0002–3, ex., 30 cm SL; Appendix 1; Figure 2A-2.

Nine dorsal finlets; 57 scales in the lateral line; terminal mouth with small unicuspid teeth on jaws; body grayish; sampled in lower Omo River.

Order Osteoglossiformes — 2F, 5G, 6Spp

Family Arapaimidae — 1species (Sp)

Heterotis niloticus (Cuvier, 1829):328 — Boulenger (1906):559; Boulenger (1909):149; Shibru Tedla (1973):21; Seegers *et al*. (2003):28; Redeat Habteselassie (2012):59; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Heterotis niloticus Cuvier, 1929 — Hopson and Hopson (1982):291, erroneous citation of year of publication as 1929.

Material examined: voucher specimen, ZNHM-F-0004, 60 cm SL; Appendix 1; Figure 2A-3. Terminal mouth with unicuspid teeth; body scales large and strong; dorsal fin long, with more than 30 soft rays, positioned in the posterior body part closer to caudal; caudal fin round; sampled in the Ethiopian part of Lake Turkana.

Family Mormyridae — 5Spp

Mormyrus caschive Linnaeus, 1758:327 — Redeat Habteselassie (2012):64; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Mormyrus caschive Linnaeus, 1757:398— Boulenger (1909):136.

Material examined: voucher specimens, ZNHM-F-0005–6, ex., 37 cm; Appendix 1; Figure 2A-4.

Mouth terminal; proboscis-like snout straight, not curved downward; dorsal fin rays more than 75; laterally compressed; dark violet in color; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Mormyrus kannume Forsskål, 1775:74 — Hopson and Hopson (1982):293; Seegers *et al*. (2003):29; Redeat Habteselassie (2012):64; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Material examined: voucher specimen, ZNHM-F-0007, 41 cm SL; Appendix 1; Figure 2A-5.

Mouth terminal; proboscis-like snout slightly curved downward; dorsal fin rays fewer than 75; sampled in lower Omo River.

Mormyrops anguilloides (Linnaeus, 1758):327 — Seegers *et al*. (2003):29; Redeat Habteselassie (2012):68; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Mormyrops deliciosus (Leach, 1818):410 — Boulenger (1905):37; Boulenger (1909):32; Shibru Tedla (1973):20

Material examined: voucher specimens, ZNHM-F-0008–9, ex., 42 cm SL; Appendix 1; Figure 2A-6.

Mouth terminal; laterally compressed; snout relatively moderately long; white thin sheath covering snout including eye; head depressed; body less deep, anterior body tinged with dark reddish color; dorsal fin more or less as long as anal fin, both located near caudal; dark violet in color; sampled in lower Omo River.

Hyperopisus bebe (Lacepède, 1803):619 — Hopson and Hopson (1982):292; Seegers *et al*. (2003):28; Redeat Habteselassie (2012):66; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Material examined: voucher specimens, ZNHM-F-0010–12, ex., 37 cm SL; Appendix 1; Figure 2A-7.

Mouth terminal; snout round and short; thin, white sheath covering snout including eyes; laterally compressed; dorsal fin very much shorter than anal fin; dorsal fin located on the rear body near caudal; dark brown in color; sampled in lower Omo River.

Pollimyrus petherici (Boulenger, 1898):7 — Redeat Habteselassie 2012:70; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Marcusenius petherici Boulenger, 1898 — Boulenger 1909:82; Boulenger 1916:162

Material examined: voucher specimens, ZNHM-F-0013–14, ex., 19 cm SL; Appendix 1; Figure 2A-8.

Snout relatively short; dorsal fin originating well in advance of anal fin origin, relatively long with up to 36 rays; both dorsal and anal fins located near caudal; dorsal profile tend to be concave-like; sampled in lower Omo River.

Order Characiformes — 3F, 5G, 6Spp

Family Alestidae — 4Spp

Hydrocynus vittatus Castelnau, 1861:65 — Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Hydrocynus vittatus (Castelnau, 1861) — Seegers *et al*. (2003):36; Redeat Habteselassie (2012):75.

Hydrocyon lineatus Bleeker, 1862:125 — Boulenger (1909):182; Shibru Tedla (1973):23.

Hydrocynus lineatus Bleeker, 1862 — Hopson and Hopson (1982):296.

Material examined: voucher specimens, ZNHM-F-0015–18, ex., 33 cm SL; Appendix 1; Figure 2A-9.

Teeth entirely unicuspid, in a single row on each jaw, visible when mouth is closed; adipose eyelid present; two rows of scales between the scaly process at pelvic fins and lateral line; dorsal fin tip, adipose fin and caudal fin fork edges black; body silvery with slight black stripes; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Hydrocynus forskahlii (Cuvier, 1819):354 — Seegers *et al*. (2003):36; Redeat Habteselassie (2012):74; Froese and Pauly (2016).

Hydrocynus forskahlii Cuvier, 1819 — Eschmeyer *et al*. (2016).

Hydrocynus forskalii (Cuvier, 1819) — Paugy (1984):170.

Hydrocyon forskali Cuvier, 1819 — Pellegrin (1905):291; Pellegrin (1935):133; Shibru Tedla (1973):22.

Hydrocyon forskalii, Cuvier, 1819 — Boulenger (1909):180; Hopson and Hopson (1982):295.

Material examined: voucher specimens, ZNHM-F-0019–20, ex., 38 cm SL; Appendix 1; Figure 2A-10.

Teeth entirely unicuspid, in a single row on each jaw, visible when mouth is closed; adipose eyelid present; two rows of scales between the scaly process at pelvic fins and lateral line; tip of dorsal fin, inner edges of caudal fin, and adipose fin uniformly grayish; upper dorsal part silvery; lower caudal lobe-orange red; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Alestes baremoze (Joannis, 1835):31 — Seegers *et al*. (2003):35; Redeat Habteselassie (2012):76; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Alestes baremose (Joannis, 1835) — Boulenger (1905):40; Boulenger (1909):195; Pellegrin (1935):133; Shibru Tedla (1973):24; Hopson and Hopson (1982):298.

Alestes baremoze tchadense Blache, 1964:74 — Paugy (1984):142.

Material examined: voucher specimens, ZNHM-F-0021–22, ex., 35 cm SL; Appendix 1; Figure 2A-11.

Dorsal fin equidistant between ventral and anal fins or nearer to the latter; anal fin relatively moderately long, with 25–30 branched rays; edges of caudal fin only finely black; adipose eyelid present; more than 38 scales in the lateral line; body slightly laterally compressed; dorsal surface dark sliver; lower caudal lobe orange red; pelvic and anal fins tinged with orange red color; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Brycinus nurse (Rüppell, 1832):12 — Redeat Habteselassie (2012):77; Froese and Pauly (2016).

Brachyalestes nurse (Rüppell 1832) — Eschmeyer *et al*. (2016).

Alestes rueppellii (Günther, 1864):315 — Günther (1896):223.

Alestes nurse (Rüppell, 1832) — Boulenger (1905):40; Boulenger (1909):205; Shibru Tedla (1973):24; Hopson and Hopson (1982):298; Paugy (1984):155.

Brycinus nurse nana (Pellegrin, 1935):133 — Seegers *et al*. (2003):35.

Material examined: voucher specimens, ZNHM-F-0023–24, ex., 11.3 cm SL; Appendix 1; Figure 2A-12.

Dorsal fin above or only slightly in advance of the ventral fin; head round; teeth in outer row of premaxilla 8; lateral side silvery; unpaired fins bright red; paired fins colorless or, at most, light orange; body silvery; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Family Citharinidae — 1Sp

Citharinus citharus (Geoffroy St. Hilaire, 1809):40 — Boulenger (1909):291; Redeat Habteselassie (2012):85; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Citharinus citharis Geoffroy St. Hilaire, 1809 — Hopson and Hopson (1982):306.

Citharinus citharus intermedia Worthington, 1932:123 — Pellegrin (1935):134.

Citharinus citharus intermedius Worthington, 1932 — Daget (1984):214; Seegers *et al*. (2003):35.

Citharinus geoffroii Cuvier, 1829:313 — Günther (1896):223.

Material examined: voucher specimens, ZNHM-F-0025–30, ex., 40 cm SL; Appendix 1; Figure 2A-13.

Mouth terminal, with unicuspid teeth on lip; body laterally compressed, covered with cycloid scales; dorsal and lateral upper half dark olive, lateral lower half white; pelvic, anal and lower lobe of caudal fin pinkish; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Family Distichodontidae — 1Sp

Distichodus nefasch (Bonnaterre, 1788):169 — Redeat Habteselassie (2012):82; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

*Distichodus niloticus (*Linnaeus in Hasselquist, 1762):422 — Boulenger (1909):273; Seegers *et al*. (2003):35.

*Distichodus niloticus (*Linnaeus, 1762) — Shibru Tedla (1973):26; Hopson and Hopson (1982):307.

*Distichodus niloticus (*Linnaeus, 1766) — Boulenger (1905):42, erroneous citation of year of publication a 1766.

Distichodus rudolphi Günther, 1896:223.

Material examined: voucher specimens, ZNHM-F-0031–32, ex., 40 cm SL; Appendix 1; Figure 2A-14.

Mouth subinferior, with small bicuspid teeth in two rows in each jaw; dorsal fin rays more than 20; lateral line scales more than 90; scales between lateral line and ventral fin more than 15; body slightly laterally compressed, covered with ctenoid scales; dorsal surface dark sliver, lateral lower half light grey; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Order Cypriniformes — 1F, 1G, 3Spp

Family Cyprinidae — 3Spp

Labeo horie Heckel, 1846:304 — Boulenger (1909):306; Pellegrin (1935):135; Hopson and Hopson (1982):307; Seegers *et al*. (2003); Redeat Habteselassie (2012):109.

Labeo horie Heckel, 1847 — Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Material examined: voucher specimens, ZNHM-F-0033–34, ex., 31 cm SL; Appendix 1; Figure 2A-15.

No teeth on the jaws; inferior mouth with 1 pair of minute barbells present; branched dorsal fin rays not more than 14, its upper edge convex or slightly straight; labial folds rather poorly developed; 40–44 scales in the lateral line; no transverse plicae of papillae on the inner sides of the lips; dorsal surface dark olive; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Labeo niloticus (Linnaeus, 1758): 322 — Froese and Pauly (2016).

Labeo niloticus (Forsskål, 1775):71— Boulenger (1909):304; Redeat Habteselassie (2012):107.

Material examined: voucher specimens, ZNHM-F-0035–38, ex., 48 cm SL; Appendix 1; Figure 2A-16.

No teeth on the jaws; inferior mouth with 1 pair of minute barbells present; branched dorsal fin rays more than 14, its upper edge often more or less concave; 41–45 scales in the lateral line; no transverse plicae of papillae on the inner sides of the lips; dorsal surface dark olive; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Labeo coubie Rüppell, 1832:11— Boulenger (1909):317; Redeat Habteselassie 2012:108; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Material examined: voucher specimen, ZNHM-F-0039, 24 cm SL; Appendix 1; Figure 2A-17.

No teeth on the jaws; inferior mouth with 1 pair of minute barbells present; branched dorsal fin rays not more than 14, its upper edge convex or slightly straight; labial folds relatively well developed; 36–40 scales in the lateral line; transverse plicae of papillae present on the inner sides of the lips; sampled in the Ethiopian part of Lake Turkana.

Order Siluriformes — 7F, 7G, 11Spp

Family Auchenoglanididae — 2Spp

Auchenoglanis biscutatus (Geoffroy St. Hilaire, 1809): 301 — Boulenger (1911):367; Redeat Habteselassie (2012):140; Eschmeyer *et al*. (2016); Froese and Pauly (2016); year of original publication erroneously cited as 1827 in Boulenger (1911).

Material examined: voucher specimens, ZNHM-F-0040–41, ex., 28 cm SL; Appendix 1; Figure 2A-18.

Scales absent on the body; inferior mouth with 3 pairs of barbels; maxillary barbels long reaching the posterior edge of eye in contrast to *A.occidentalis*; caudal truncate; dark brownish body with dark brownish spots; lower lateral body part tinged with reddish color; specimens from lower Omo River with reddish fins; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Auchenoglanis occidentalis (Valenciennes, 1840):303 — Redeat Habteselassie (2012):141; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Auchenoglanis occidentalis (Cuvier &Valenciennes, 1840) — Boulenger (1905):48; Boulenger (1911):369; Hopson and Hopson (1982).

Auchenoglanis occidentalis (Valenciennes in Cuvier &Valenciennes, 1840) — Seegers *et al*. (2003).

Material examined: voucher specimens, ZNHM-F-0042–43, ex., 29 cm SL; Appendix 1; Figure 2A-19.

Scales absent on the body; inferior mouth yellowish, with 3 pairs of barbels; maxillary barbels short not reaching the posterior edge of eye; caudal truncate; moderate size black spots on body, small black spots on caudal fin; caudal fin orange red; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Family Clariidae — 1Sp

Clarias gariepinus (Burchell, 1822):425 — Boulenger (1911):228; Seegers *et al*. (2003):37; Redeat Habteselassie (2012):151; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Clarias lazera Cuvier & Valenciennes, 1840:372 — Boulenger (1911):232; Shibru Tedla (1973):63; Hopson and Hopson (1982):320.

Material examined: voucher specimens, ZNHM-F-0044–45, ex., 72 cm SL; Appendix 1; Figure 2A-20.

Scales absent on the body; elongated body; subinferior mouth with 4 pairs of barbels; dorsal fin long, extending to the base of caudal; anal fin long extending near to the caudal fin; no adipose fin; caudal fin round; sampled in the Ethiopian part of Lake Turkana.

Family Bagridae — 2Spp

Bagrus bajad (Forsskål, 1775):66 — Seegers *et al*. (2003):36; Redeat Habteselassie (2012):142; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Bagrus bayad (Forsskål, 1775) — Boulenger (1911):305.

Bagrus bayad (Forsskål, 1785) — Hopson and Hopson (1982), erroneous citation of year of publication as 1785.

Material examined: voucher specimens, ZNHM-F-0046–47, ex., 54 cm SL; Appendix 1; Figure 2A-21.

Scales absent on the body; head dorsally flat; mouth subinferior with 4 pairs of barbels; caudal fin forked, with the upper and lower lobes extending into long filaments; the first branched dorsal fin ray extending into short filament; long fleshy adipose fin present; dorsally brownish, laterally silvery; some specimens dark brownish; no scales on the body; body relatively grayish in contrast to *B. docmak* which is pale red; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Bagrus docmak (Forsskål, 1775):65 — Seegers *et al*. (2003):36; Redeat Habteselassie (2012):143; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Bagrus docmac (Forsskål, 1775) — Boulenger (1906):559, Boulenger (1911):308; Shibru Tedla (1973):60; Hopson and Hopson (1982):316.

Material examined: voucher specimens, ZNHM-F-0048–49, one ex., 43 cm SL; Appendix 1; Figure 2A-22.

Scales absent on the body; head dorsally flat; mouth subinferior with 4 pairs of barbels; caudal fin forked, but lower lobe not extending into long filament; the first branched dorsal fin ray not extending into short filament; long fleshy adipose fin present; body pale red in fresh specimens; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Family Claroteidae — 1Sp

Chrysichthys auratus (Geoffroy St. Hilaire, 1809):322 — Boulenger (1911):325; Hopson and Hopson (1982):317; Seegers *et al*. (2003):36; Redeat Habteselassie (2012):145; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Chrysichthys auratus auratus (Geoffroy St. Hilaire, 1809) — Risch (1986):14

Material examined: voucher specimens, ZNHM-F-0050–52, ex., 23 cm SL; Appendix 1; Figure 2A-23.

Scales absent on the body; head flat; mouth subinferior with 4 pairs of short barbels, not extending beyond head; head golden, dorsally golden dark, laterally golden white; dorsal fin with 6 non branched rays; caudal fin forked; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Family Malapteruridae — 1Sp

Malapterurus minjiriya Sagua, 1987:78 — Redeat Habteselassie (2012):156; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Material examined: voucher specimen, ZNHM-F-0053, 13 cm SL; Appendix 1; Figure 2A-24.

Scales absent on the body; 3 pairs of non-branching barbels; rayed dorsal fin absent; fleshy adipose fin present; pectoral fins placed low on the body; anal fin with 10 soft rays; caudal fin round or slightly truncate; sampled in lower Omo River. The occurrence of this species in Omo-Turkana system was demonstrated by Golubtsov and Berendzen (1999).

Family Mochokidae — 2Spp

Synodontis *filamentosus* Boulenger, 1901:10 — Boulenger (1911):460; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Synodontis filamentosa Boulenger, 1901— Redeat Habteselassie (2012):166

Material examined: voucher specimens, ZNHM-F-0054–55, ex., 26 cm SL; Appendix 1; Figure 2A-25.

Scales absent on the body; dorsal fin spine extends into very long filament more or less half size of the spine; soft rays not extending into filament; body dark-olive color; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Synodontis schall (Bloch & Schneider, 1801):385 — Boulenger (1911):404; Pellegrin (1935):135; Shibru Tedla (1973):66; Hopson and Hopson (1982):323; Redeat Habteselassie (2012):170; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Synodontis schal (Bloch & Schneider, 1801) — Günther (1896):218, 220.

Synodontis schall (Schneider in Bloch & Schneider, 1801) — Seegers *et al*. (2003):39

Material examined: voucher specimens, ZNHM-F-0056–62, ex., 32 cm SL Appendix 1; Figure 2A-26.

Scales absent on the body; dorsal fin spine not extending into filament, smooth in front; first soft ray extends into short or rarely long filament; no basal marginal membrane on maxillary barbel; dorsal fin spine feebly serrated behind; body dark (brown) color; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Family Schilbeidae — 2Spp

Schilbe mystus (Linnaeus, 1758):305 — Redeat Habteselassie (2012):174; Eschmeyer (2014)

Schilbe mystus (Linnaeus, 1762) — Boulenger (1911):293; erroneous citation of year of publication as 1762.

Material examined: voucher specimen, ZNHM-F-0063, 32 cm SL; Appendix 1; Figure 2A-27.

Scales absent on the body; mouth terminal with 4 pairs of barbels; small fleshy adipose fin present far behind the small rayed dorsal fin; anal fin long extending from ventrals to caudal, with more than 63 rays; body laterally compressed; head profile rises gradually to dorsal fin; dorsal surface light brownish, lateral side silvery white; fins tinged with reddish color; sampled in lower Omo River.

Schilbe uranoscopus Rüppell, 1832:4 — Boulenger (1911):296; Hopson and Hopson (1982):319; Seegers *et al*. (2003):37; Redeat Habteselassie (2012):174; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Material examined: voucher specimens, ZNHM-F-0064–67, ex., 30 cm SL; Appendix 1; Figure 2A-28.

Scales absent on the body; mouth terminal with 4 pairs of barbels; no adipose fin; anal fin long extending from ventrals to caudal, with more than 63 rays; body laterally compressed; head dorsally horizontal, with nape rising abruptly from occiput to the dorsal fin; dorsal surface light brownish, lateral side silvery white; fins tinged with reddish color; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Order Perciformes — 2F, 2G, 2Spp

Family Cichlidae — 1Sp

Oreochromis niloticus (Linnaeus, 1758):290 — Redeat Habteselassie (2012):195; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Chromis niloticus Hasselquist, 1757:346 — Günther (1896):218.

Tilapia nilotica (Linné, 1757):346 — Boulenger (1915):162; Pellegrin (1935):137

Tilapia nilotica (Linnaeus, 1757): Shibru Tedla (1973):70

Sarotherodon niloticus (Linnaeus, 1757) — Hopson and Hopson (1982):332.

O. niloticus cancellatus (Nichols, 1923):2 — Trewavas and Teugels (1991):330.

O. niloticus vulcani (Trewavas, 1933): — Seegers *et al.* (2003):44.

Material examined: voucher specimens, ZNHM-F-0068–69, ex., 33 cm SL; Appendix 1; Figure 2A-29.

Mouth terminal with bicuspid teeth on the outer jaws; dark vertical bands on flank, caudal peduncle and caudal fin; scales between pelvic and pectoral fins distinctly smaller than those on the rest of the body; dark body; blackish opercular spot; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Family Latidae — 1Sp

Lates niloticus (Linnaeus, 1758):290 — Seegers *et al*. (2003):42; Redeat Habteselassie (2012):189; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Lates niloticus (Linnaeus, 1762):404— Boulenger (1915):105; Hopson and Hopson (1982):327.

Lates niloticus (Linné, 1762) — Pellegrin (1935):137.

L. niloticus rudolfianus Worthington, 1932:133.

Material examined: voucher specimens, ZNHM-F-70–76, ex., 45 cm SL; Appendix 1; Figure 2A-30.

Terminal mouth with villiform teeth; dorsal fin long, deeply notched into anterior and posterior regions; 7 spines in the anterior dorsal fin region; caudal fin round; body scales ctenoid; single complete lateral line present; body silvery; sampled in lower Omo River and the Ethiopian part of Lake Turkana.

Order Tetraodontiformes — 1F, 1G, 1Sp

Family Tetraodontidae — 1Sp

Tetraodon lineatus Linnaeus, 1758:333 — Seegers *et al*. (2003):47; Eschmeyer *et al*. (2016); Froese and Pauly (2016).

Tetraodon lineatus (Linnaeus, 1758) — Redeat Habteselassie (2012):199

Tetrodon fahaka Linnaeus, 1762:441— Boulenger (1916):143.

Tetraodon fahaka Bennett, 1834:45 — Hopson and Hopson (1982):337

Tetraodon fahaka rudolfianus Deraniyagala, 1948:29.

Material examined: voucher specimen, ZNHM-F-0077, 28 cm SL; Appendix 1; Figure 2A-31.

Dorsal fin short, located in the posterior body part; body scaleless, head and body covered with small thin spines; lateral line absent; a pair of fused teeth at the front of each jaw; yellow longitudinal bands on the body; caudal fin truncate to round, yellowish in color; yellow longitudinal bands on the body; ventral fin absent; a pair of fused teeth at the front of each jaw; sampled in the Ethiopian part of Lake Turkana.

2.3.2. Alpha- and beta diversity

The number of fish specimens collected, values of Shannon diversity and evenness indices and the permutation p for lower Omo River and the Ethiopian part of Lake Turkana are summarized in Table 2. The number of specimens and Shannon diversity index between lower Omo River and the Ethiopian part of Lake Turkana were statistically significant (p < 0.005; Table 2).

Table 2. Summary of specimen numbers (n) and diversity indices for lower Omo River (OR) and the Ethiopian part of Lake Turkana (LT) based on the present data; *represents statistically significant p values (i.e < 0.005).

Parameter	**OR**	**LT**	**Permutation p**
Number of specimens (n)	823	3,563	<0.005*
Species richness (S)	26	24	0.972
Shannon diversity index (H′)	2.43	2.20	<0.005*
Shannon evenness index (J′)	0.75	0.69	0.051

The rank order abundance plots of the two habitats showed that abundance distribution among the fish species was more even for the lower Omo (Figure 4).

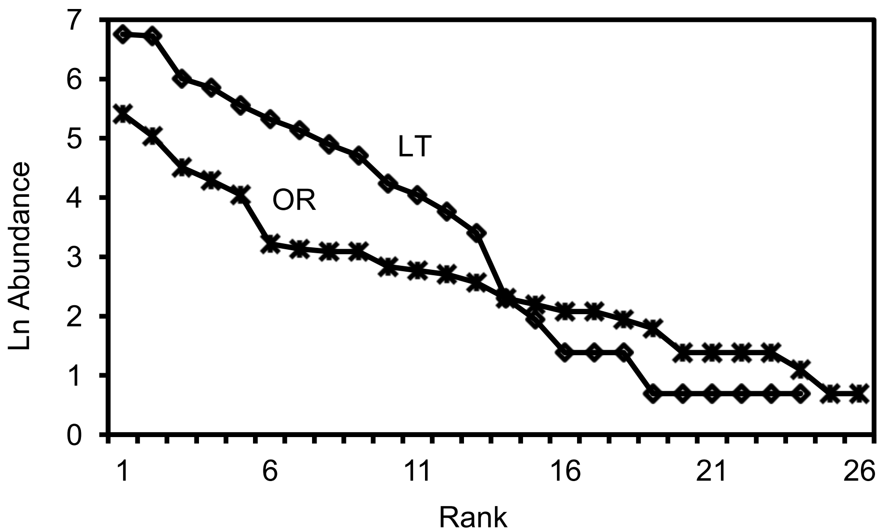


Figure 4. Rank order abundance plots for fish communities of lower Omo River and the Ethiopian part of Lake Turkana.

The expected species richness of lower Omo River (i.e. the smaller sample) rarefied from the Ethiopian part of Lake Turkana (i.e. the larger sample) at subsample of size n = 811 was 19 ± 1.5 at 95% Confidence interval (CI) (Figure 5).

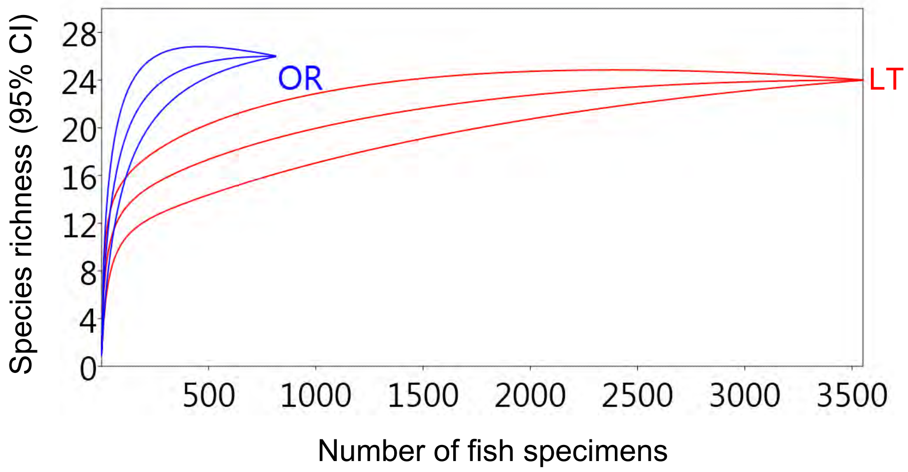


Figure 5. An individual based rarefaction analysis for lower Omo River (n = 823) and the Ethiopian part of Lake Turkana (n = 3,563) for their species richness; CI = confidence interval.

The Whittaker beta diversity index (βw = 0.24) for lower Omo River and the Ethiopian part of Lake Turkana showed the existence of turnover in species composition between the lake and the river systems.

2.4. Discussion

Analysis of fish species sampled in the present study showed that lower Omo River was poorer in relative abundance than the Ethiopian part of Lake Turkana. Nevertheless, the river was more speciose than the lake. The observed species richness of lower Omo River fell above the 95% CI of its rarefied species richness, i.e. 19 ± 1.5 species. Thus, the difference in species richness between the two systems could not be ascribed to difference in abundance or sampling effort (Magurran, 2004; Gotelli and Colwell, 2011). The Shannon diversity index was higher for lower Omo River (H′ = 2.43) than for the Ethiopian part of Lake Turkana (H′ = 2.20), and the difference was statistically significant (Bootstrap, $p < 0.05$; Table 2). Both the Shannon evenness index (Table 2) and the rank order abundance plots (Figure 4) showed that species abundance distribution was more even for the lower Omo River fish fauna. Therefore, the higher value of Shannon diversity index for lower Omo River, despite its lower overall relative abundance, should be accounted for by its greater evenness coupled with its relatively higher species richness (S). The high species diversity observed for the lower Omo River should relate to greater habitat diversity in the river than in the lake. During data collection, it was observed that the lower Omo River had various habitats with various types of bank vegetations and various flow rates at its various reaches (Personal observation).

Sites sampled during the present study represented only smaller portion of the whole basin. Therefore, analysis combining the present (original) data and past studies would rather become more valuable for holistic understanding of the basin‘s ichthyofaunal diversity. Based on such analysis, 79 valid native fish species referable to 44 genera, 22 families and 9 orders can be recognized for the entire Omo-Turkana Basin, for which annotated checklist is provided in Appendix 3. Besides the native species, Omo-Turkana system also harbors 1 exotic subspecies i.e. *Oreochromis spilurus spilurus* (Günther, 1894) and 3 potentially undescribed species i.e. *Chiloglanis* spec."Kerio", *Marcusenius* spec."Turkwell" and *'Barbus'* spec."Baringo", in Kerio and Turkwell basins (Seegers *et al*., 2003). In this exhaustive analysis, Omo River still retains greater richness at 62 fish species (78%) while Lake Turkana harbors only 56 species (71%), in accord with the finding based only on the present collection. Twenty-three species occurred only in Omo River system (Appendix 3), of which 4 species i.e. *Barbus arambourgi* Pellegrin, 1935, *Neobola bottegoi* Vinciguerra, 1895, *Afronemacheilus kaffa* Prokofiev & Golubtsov, 2013 and *Aplocheilichthys jeanneli* (Pellegrin, 1935) are endemic to the river basin. However, the status of *N. bottegoi* as endemic to Omo River (Lévêque *et al*., 1991) is questionable as the species also occurred in Somaliland (Awata River, Wabishebelle system), a type locality. Moreover, the current status of *Andersonia leptura* Boulenger, 1900 in Omo River is uncertain as it was not recorded in subsequent investigations since its first record in 1930s (Appendix 3). Seventeen species occurred only in Lake Turkana (Appendix 3). Ten of these lacustrine restricted species i.e. *Brycinus ferox* (Hopson and Hopson, 1982), *B. minutus* (Hopson and Hopson, 1982), *Neobola stellae* (Worthington, 1932), *Chrysichthys turkana* Hardman, 2008, *Aplocheilichthys rudolfianus* (Worthington, 1932), *Haplochromis rudolfianus* Trewavas, 1933, *H. macconneli* Greenwood, 1974, *H. turkanae* Greenwood, 1974, *Hemichromis bimaculatus* Gill, 1862 and *Lates longispinis* Worthington, 1932, are endemic to the lake. However, it is worth noting that the present status of some species reported for Lake Turkana is uncertain. In particular *Brycinus macrolepidotus* Valenciennes in Cuvier & Valenciennes, 1850, *Labeobarbus nedgia* Rüppell, 1835, *Labeobarbus intermedius* (Rüppell, 1835), *Labeo cylindricus* Peters, 1852 and *Synodontis frontosus* Vaillant, 1895 have not been recently sampled in the lake (Appendix 3). In contrast, these species have been recently recorded in Omo River system suggesting their riverine occurrence (Baron *et al*., 1997; Mohammed, 2014). In effect, the actual number of fish species valid for Lake Turkana should descend from 56 (71%) down to 51 (64.5%) of the basin‘s total richness. Overall, compared to the great East African lakes such as Victoria, Tanganyika and Malawi, which are dominated by endemic cichlids, Lake Turkana retains Nilotic riverine fauna with low diversity (Kolding, 1989a). The lake is also characterized with low endemism only with up to 11 (13.92%) endemic species and subspecies (Appendix 3). Low endemism of the lake and the entire basin is apparently due to its historical connection to White Nile River system between 10,000–5,000 years ago when it achieved its historical high levels (Harvey and Grove, 1982).

At family level, Cyprinidae is the largest group in the entire Omo-Turkana system comprising 21 species (26.58%) of the basin‘s total richness despite its poor record during the present study. It is represented both in the lacustrine and riverine habitats. Balitoridae and Amphiliidae are known only from Omo River while three families (Protopteridae, Gymnarchidae and Tetraodontidae) are known only from Lake Turkana. Mormyridae remains largely a riverine family with most of its species confined to Omo River system. Confinement of this family to a riverine habitat could likely be attributed to high conductivity of Lake Turkana (2342.47 $\mu S\ cm^{-1}$, present data) which interferes with the current generating capacity of electric organs of these fishes (Greenwood, 1994; Hopkins, 1999).

Studies that previously addressed the Ethiopian drainage basins, only provided ichthyofaunal diversity for the entire Omo-Turkana Basin apparently due to lack of data on the extent of distribution of fish species in the Ethiopian part of the lake (Golubtsov and Mina, 2003; Golubtsov and Darkov, 2008). Of the total fish species reported for Lake Turkana, only 24 native valid fish species could be verified for the Ethiopian part of the lake based on the present collections (Appendices 2–3). Accordingly, 64 species in 39 genera, 20 families and 7 orders can be recognized for the Omo-Turkana Basin within the limits of Ethiopia pending further sampling efforts. Thus, despite the past reports, the present study places Omo-Turkana Basin within the limit of Ethiopia third next to Baro-Akobo (White Nile within the limit of Ethiopia) and Abay (Blue Nile within the limit of Ethiopia) basins in terms of its ichthyofaunal diversity (Golubtsov and Darkov, 2008). Similar to most other basins of Ethiopia except for the Blue Nile, it is still characterized with low endemism. Ten species endemic to Lake Turkana are not known from the Ethiopian part of the lake so far. Therefore, Omo-Turkana Basin within the limit of Ethiopia is known only with 3–4 species endemic to Omo River system and 1 species (*Labeobarbus nedgia*) endemic to Ethiopia. An artificial identification key for the fish species occurring within the limit of Ethiopia is provided in Appendix 4.

The rate of turnover in fish species composition between lower Omo River and the Ethiopian part of Lake Turkana, measured as Whittaker beta diversity index (βw = 0.24), is indicative of habitat selection or specialization by the fish species in the two systems (Sepkoski, 1988). This rate of species turnover is in particular attributable to seven species (i.e. *Polypterus senegalus* Cuvier, 1829*, Mormyrus kannume* Forsskål, 1775, *Mormyrops anguilloides* (Linnaeus, 1758)*, Hyperopisus bebe* (Lacepède, 1803)*, Pollimyrus petherici* (Boulenger, 1898)*, Malapterurus minjiriya* Sagua, 1987 and *Schilbe mystus* (Linnaeus, 1758)) that were recorded only from lower Omo River, and five species (i.e. *Polypetrus bichir* Lacepède, 1803*, Heterotis niloticus* (Cuvier, 1829)*, Labeo coubie, Clarias gariepinus* (Burchell, 1822) and *Tetraodon lineatus* (Linnaeus, 1758)) that were recorded only from Lake Turkana sites. The turnover in species composition between the two systems is attributable particularly to members of the family Mormyridae most of which are restricted to Omo River system. Detailed community analysis and potential environmental determinants for the variation in species composition between the two systems are assessed in chapter 3 of this thesis.

2.5. Conclusion

The following remarks could be drawn about the ichthyofaunal diversity of Omo-Turkana Basin from the present study:

- Omo-Turkana Basin within the limit of Ethiopia is one of the richest in its fish diversity in the country. Omo River system is more species rich than Lake Turkana but poorer in abundance.
- The basin harbors native fishes of largely Nilo-Sudanic affinities than endemic species as compared to other basins, for instance Blue Nile Basin within the limits of Ethiopia.
- The present assessment of the basin‘s fish diversity, and thus the annotated checklist of fish fauna for the entire Omo-Turkana system, serves as a basis for further assessment and future appraisal of impacts of any environmental changes or anthropogenic factors on the basin‘s fish diversity.

Chapter three

3. Relative importance and environmental determinant of fish community structure in lower Omo River and the Ethiopian part of Lake Turkana

3.1. Introduction

Omo-Turkana Basin extends from southwestern Ethiopia into northern Kenya encompassing extensive catchment area (section 1.4). The lower reach of Omo-Gibe River and the Ethiopian part of Lake Turkana are located at an elevation of less than 400 m a.s.l. Lower Omo River is close to the delta, and characterized by sluggish flow and wide bank with a channel diameter reaching 250 m–500 m (personal observation). The Omo-Gibe River sub-basin supports various development activities including hydropower development, sugar cane plantation and water extraction for cotton farming. It also features other forms of land use types including cattle grazing and recession farming, and possible urbanization effect in the lower reach of the Omo River mainly emanating from the Ethiopian border town of Omorate (Personal observation). These factors may collectively lead to modification of natural hydrologic flow, changes in water quality and loss of habitats, which in turn could potentially affect the natural fish communities inhabiting the system. A hydrological impact assessment, for the African Development Bank (AfDB), remarked on the potential impacts of such development activities on the basin‘s fish fauna (Avery, 2010).

Despite the possible environmental alterations and their potential effects, no published ecological studies on fish community structures of the basin exist. Past studies, e.g. Hopson and Hopson, 1982; Kolding, 1989a; Baron *et al*., 1997; Golubtsov and Mina, 2003; Golubtsov and Darkov, 2008, mainly focused on ichthyofaunal diversity and lacked ecological data on fish community structure as well as on the limits of fish distribution between the river and the lake. An ichthyofaunal exploration of Omo River Delta (Pellegrin, 1935), undertaken as part of a French multidisciplinary scientific expedition to lower Omo River valley is nearly over a century old. In the main part of the lake in Kenya, a couple of studies addressed density of the pelagic fish community, the recent one being a hydroacoustic survey undertaken in 2009 (Muška *et al*., 2011). Attributes of fish community structure such as distribution and abundance, and environmental parameters or other factors regulating these do not exist in particular for the Ethiopian part of the lake and Omo River. Therefore, the main purpose of this study was to characterize fish communities of the lower reach of Omo River and the Ethiopian part of Lake Turkana, and to identify potential environmental factors that determine fish community structure.

3.2. Materials and Methods

3.2.1. Fish sampling

Fish samples were obtained from the same sites of lower Omo River and the Ethiopian part of Lake Turkana, as described in sections 2.2.1 and 2.2.2, for the study of fish community composition and structure.

3.2.2. Environmental and habitat variables

Physico-chemical parameters were measured in situ at all sampling sites concurrently with the fish sampling. Subsurface dissolved oxygen (DO), water temperature (T) and pH were measured using handheld Elmetron meters of model CO-411 DO meter and CP-411 pH meter. Water conductivity (Cond), salinity (Sal) and total dissolved solids (TDS) were measured using a conductivity meter of model SX713 of Shanghai San-Xin

Instumentation. Water clarity was measured as Secchi depth (SD) using a Secchi disc of 20 cm in diameter. Site depth (D) was measured by lowering a 10-m wooden rod into the water column. Once the bottom was reached, the rod was retrieved and the measurement was taken.

3.2.3. Data analysis

Multivariate analysis of variance (MANOVA) was used to test for significant spatial differences of the environmental and habitat variables between the lower Omo River and the Ethiopian part of Lake Turkana study sites (Anderson, 2001). When global significant spatial differences were observed, specific environmental variables that contributed to variations between sites were determined using t-test. Data were $\log_{10}$ transformed prior to analyses in PAST version 3.08 to improve normality of the data (Hammer *et al*., 2001).

The use of number or weight alone to assess ecological importance of each fish species in a community composition is often associated with inherent drawbacks of emphasizing relative importance of numerous but small sized fishes or large sized but fewer fishes, respectively. The value of frequency of occurrence is also limited by the possible bias caused by migratory species which might add substantially by numbers or weight but only appear on limited occasions. Therefore, an index of relative importance (IRI), a compound index that combines simultaneously numeric abundance (Ni), weight (Wi) and frequency of occurrence (Oi), was rather used to evaluate ecological importance of fish species. It was originally developed for fish diet analysis (Pinkas *et al*., 1971) and was later adapted for use in the assessments of ecological importance of fish species in the relevant catch composition (Kolding, 1989a). The index was computed for each fish species as $IRI_i = (\%Ni + \%Wi).\%Oi$,

Where,

%Ni & %Wi represent the percentage number and weight, respectively, for each fish species in the total sample and,

%Oi represents the percentage frequency of occurrence for each fish species in the total number of sampling sites

A hierarchical agglomerative cluster analysis of the mean fish number at each sampling site was used to explore the pattern of fish community structure in the study sites. The unweighted pair group method of arithmetic mean averaging (UPGMA) algorithm and the Bray-Curtis similarity index were used for the clustering as they maintained the highest percentage of similarity from the original matrix measured as cophenetic correlation (Bloom, 1981; Saraçli *et al*., 2013). Validity of the clusters and thus significant spatial differences in the composition of fish species was tested using one-way analysis of similarity (ANOSIM), a non-parametric multivariate procedure, based on the Bray-Curtis distance measure with permutations of 9,999 (Clarke, 1993). A similarity percentage (SIMPER), based on the Bray-Curtis dissimilarity measure, was used to find out specific fish species that contributed to dissimilarity between the river and the lake fish composition (Zuur *et al*., 2007). Cluster analysis was performed in PC-ORD for Windows of version 5.31 (McCune and Mefford, 2006), whereas one-way ANOSIM and SIMPER were performed in PAST version 3.08 (Hammer *et al*., 2001).

Variations in fish community structure in relation to environmental variables were assessed using ordination methods. Mean values of the wet and dry season data of species abundance and the measured environmental variables were used for this purpose. Detrended correspondence analysis (DCA) was performed to determine if species response followed linear or unimodal model (Legendre and Legendre, 1998; Lepš and Smilauer, 2003). A principal component analysis (PCA) triplot of species, sites and environmental variables data was used to discern variations in community structure that could be explained by the measured environmental variables. In PCA, environmental variables were projected a posteriori into the ordination space in order to capture the main part of variation in species composition. Then, the extent of variability in fish assemblages explainable by each environmental variable was explored with redundancy analysis (RDA), a constrained ordination technique, using forward selection for appropriate variable (Lepš and Šmilauer, 2003). Fish species whose variability was related to a particular environmental variable were defined in RDA biplot using percentage variance in species composition produced by that particular environmental variable as a minimum criterion. Species data were standardized to mean = 0 and standard deviation = 1 before ordination analyses in order to elude effects of differences in the sizes of sampling sites. A Monte Carlo permutation was used to test for significance of the explanatory effects of environmental variable(s) on the species composition. The test was conducted with 499 permutations. Multicollinearity of environmental variables was assessed using variance inflation factor (VIF). Only environmental variables with VIF < 20 were retained for ordination (ter Braak and Šmilauer, 1998). All statistical analyses were performed in CANOCO for Windows Version 4.5 (ter Braak and Smilauer, 1997–2002).

3.3 Results

3.3.1. Environmental and habitat variables

There were significant spatial variations in environmental and habitat variables between the lake and the river (Wilk‘s $\Lambda = 0.06$, $F_{8, 23} = 41.38$, $p < 0.001$). All variables, but the amount of dissolved oxygen and water temperature, differed significantly between the river and the lake (post-hoc t-test, $p < 0.01$; Table 3). All variables, except the average site depth (D), had higher mean values for the lake.

Table 3. Summary of statistical analysis of environmental and habitat variables of lower Omo River (OR) and the Ethiopian part of Lake Turkana (LT) study sites; number of observations (n) = 16 (OR), 16 (LT)

	Range		Mean ±SE			
Variable	LT	OR	LT	OR	F	p
DO (mg L^{-1})	4.46–8.23	2.39–8.17	6.14±.034	5.38±0.45	2.41	0.13
T (°C)	26.8–30.5	26–29.6	28.50±0.27	28.19±0.27	0.67	0.42
pH	6.71–9.51	5.2–8.28	8.60±0.27	6.92±0.23	20.09	0.0001*
Cond (µS cm^{-1})	1453.5–3130	98.9–184.1	2342.47±164.77	139.89±9.62	753.9	<0.00005*
Sal (ppt)	0.72–1.83	0.05–0.09	1.12±0.12	0.07±0.004	555.7	<0.00005*
TDS (g L-1)	1.01–2.7	0.074–0.123	1.62±0.18	0.10±0.01	521.1	<0.00005*
SD (cm)	13–33	4.0–25.0	19.88±1.38	12.13±1.94	13.4	0.0009*
D (m)	1.73–2.75	4.8–7.5	2.23±0.10	5.93±0.26	252.3	<0.00005*

*Statistically significant values at $p < 0.0001$

3.3.2. Relative importance

Present collections from the Ethiopian part of Lake Turkana and lower reach of Omo River were identified into 24 and 26 fish species, respectively. Of these, 19 species were common to the lake and the river, 5 species recorded only from the lake, and 7 species were only from the river. Relative importances of these species in the two major habitat types are presented in Figure 6A&B.

Lake Turkana

Fifty-four percent (54%, 13 species) of the Ethiopian part of Lake Turkana fish species had the highest relative importance comprising more than 99% of the total IRI, and were largely the most frequent species occurring in all sampling sites (100% O) (Figure 6A). These included *A. baremoze*, *S. schall*, *Lt. niloticus*, *O. niloticus*, *S. uranoscopus*, *C. citharus*, *D. nefasch*, *Lb. niloticus*, *H. forskahlii*, *B. bajad*, *A. occidentalis*, *B. docmak* and *S. filamentosus* in the descending order of their importance. The first three (12.5%) species namely *A. baremoze*, *S. schall* and *Lt. niloticus* made up more than 50% of the total IRI.

Lower Omo River

Sixty-two percent (62%, 16 species) of the lower Omo River fish species had the highest relative importance constituting more than 96% of the total IRI, and had at least 75% frequency of occurrence in the sampling sites (Figure 6B). The first 3 (11.5%) of these species namely *A. baremoze*, *S. schall* and *D. nefasch* constituted 59% of the total IRI.

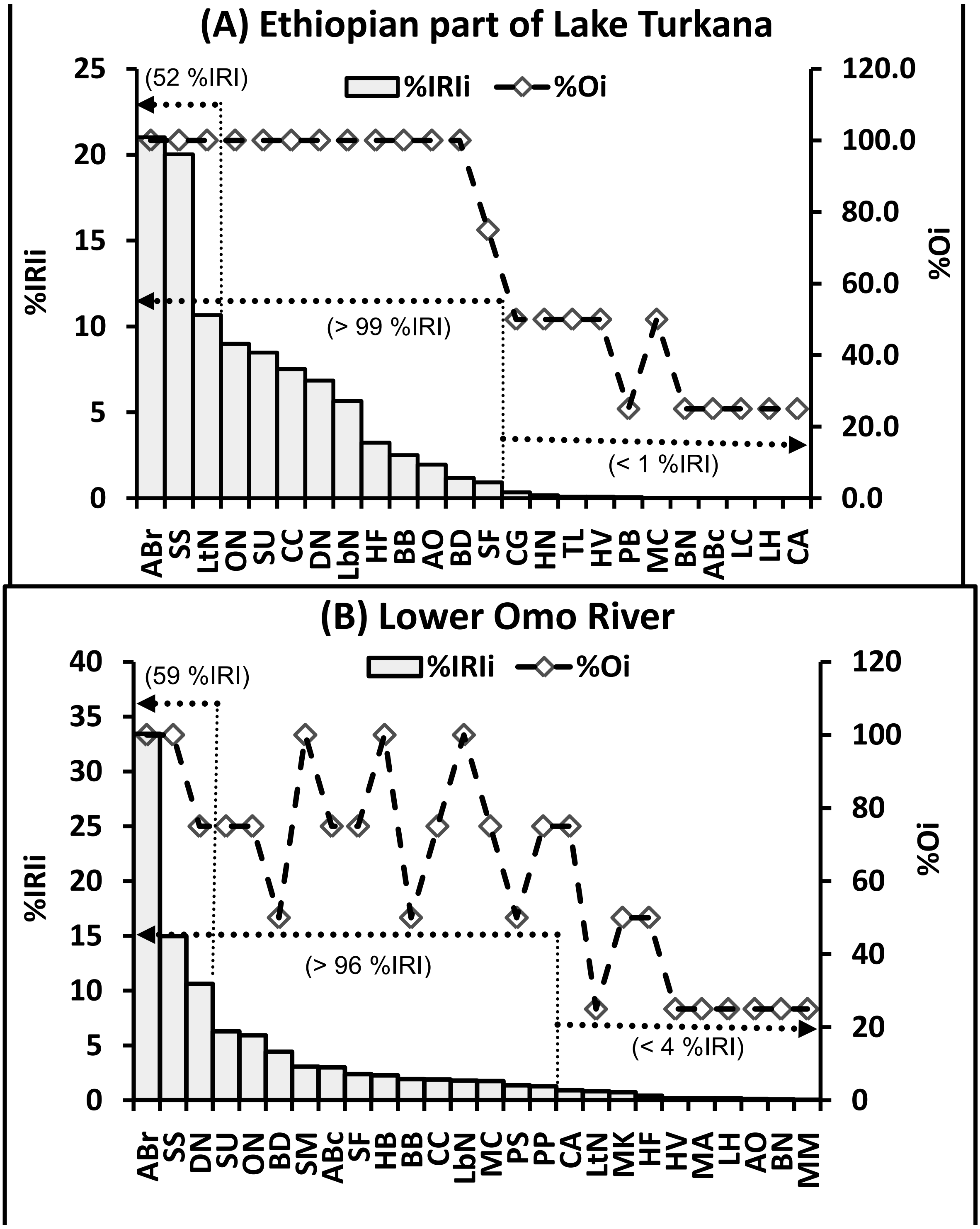


Figure 6. Diagram of index of relative importance (%IRIi) and frequency of occurrence (Oi) for fish composition of, (A) the Ethiopian part of Lake Turkana (LT), and (B) lower Omo River (OR); Species acronyms: ABr (*A. baremoze*), SS (*S. schall*), LtN (*Lt. niloticus*), ON (*O. niloticus*), SU (*S. uranoscopus*), CC (*C. citharus*), DN (*D. nefasch*),

LbN (*Lb. niloticus*), HF (*H. forskahlii*), BB (*B. bajad*), AO (*A. occidentalis*), BD (*B. bajad*), SF (*S. filamentosus*), CG (*C. gariepinus*), HN (*H. niloticus*), TL (*T. lineatus*), HV (*H. vittatus*), PB (*P. bichir*), SM (*S. mystus*), HB (*H. bebe*), MC (*M. caschive*), BN (*B. nurse*), ABc (*A. biscutatus*), LC (*L. coubie*), LH (*L. horie*), CA (*C. auratus*), PS (*P. senegalus*), PP (*P. petherici*), MK (*M. kannume*), MA (*M. anguilloides*), MM (*M. minjiriya*).

3.3.3. Community structure

Figure 7 represents a dendogram of the cluster analysis of fish compositions of the study sites. Agglomerative hierarchical cluster analysis of 31 fish species identified two distinct spatial clusters representing LT and OR fish communities. The p-values for validity of these clusters are shown at the respective nodes of the dendogram, and the distinction in species composition between the two communities was statistically significant ($R = 0.635$; $p = 0.028$). The spatial clusters at the second upper nodes were statistically not significant ($p > 0.05$). SIMPER produced a global average Bray-Curtis dissimilarity of 69.52% between lower Omo River and the Ethiopian part of Lake Turkana fish communities. Only 12 (39%) fish species accounted for 93% dissimilarity between the lower Omo River and the Ethiopian part of Lake Turkana fish communities. These included *S. schall*, *A. baremoze*, *Lt. niloticus*, *S. uranoscopus*, *Lb. niloticus*, *O. niloticus*, *C. citharus*, *H. forskahlii*, *D. nefasch*, *B. bajad*, *A. occidentalis* and *S. filamentosus*. The remaining 19 (61%) fish species contributed only 7% dissimilarity between the two communities.

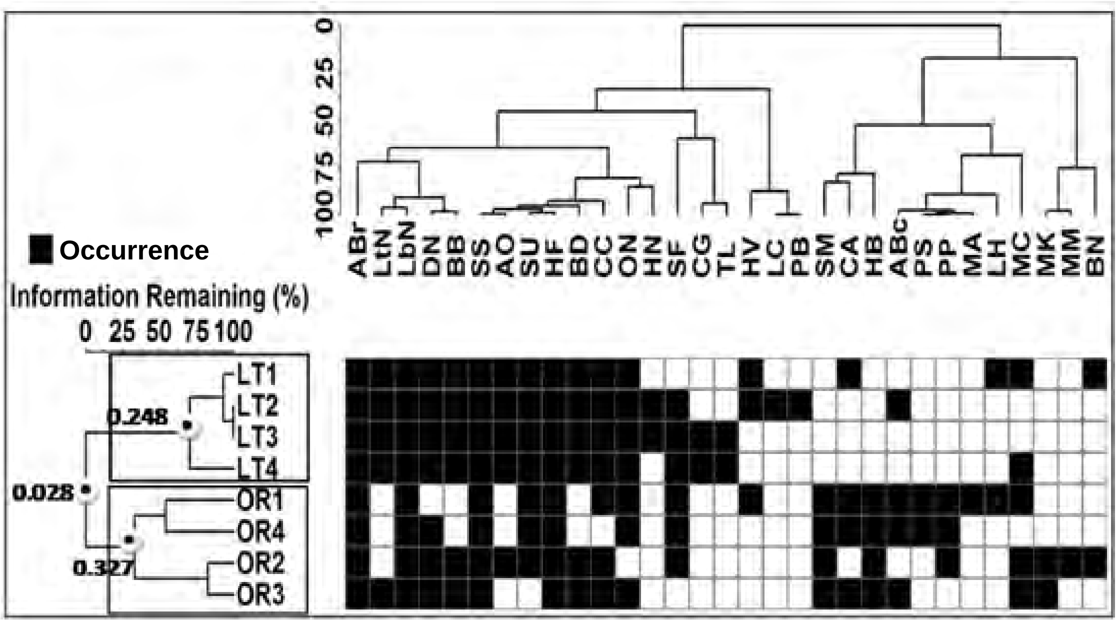


Figure 7. Cluster analysis of OR and the LT study sites based on their fish species composition sampled during the present study (Cophenetic correlation coefficient= 0.9304); acronyms for fish species are as in Figure 6.

Gradient lengths of all axes were shorter than three, in detrended correspondence analysis (DCA), suggesting linear species response model (Table 4). Four environmental variables i.e. dissolved oxygen (DO), temperature (T), Secchi depth (SD) and total dissolved solids (TDS) were retained for ordination purposes based on the assessment of variance inflation factor. Figure 8 represents a PCA triplot of fish species, sampling sites and the four environmental variables, and Table 5 summarizes output of the analysis. The first two axes (Axis-1 & Axis-2) represented 67% of the total variability in species composition with the four environmental variables accounting for 76% of the total variability in the structure of fish community. All axes are reasonably correlated with the environmental data (r = 0.73–0.96) suggesting that the species data is fairly governed by gradients on these axes.

Table 4. Summary of detrended correspondence analysis (DCA) for fish community structure.

Axes	1	2	3	4
Eigenvalues	0.296	0.044	0.004	0.000
Lengths of gradient	1.616	0.743	0.859	0.919

Table 5. Summary of the principal component analysis (PCA) for the species data and environmental variables; TVar = total variance; sp-envmt = species-environment.

Axes	1	2	3	4	TVar
Eigenvalues	0.47	0.21	0.12	0.09	1
Species-environment correlations	0.96	0.79	0.73	0.74	
Cumul. %variance of species data	47	**67**	80	88	
Cumul. %variance of sp-envmt relation	57	74	82	89	
Sum of all eigenvalues					1
Sum of all canonical eigenvalues					**0.76**

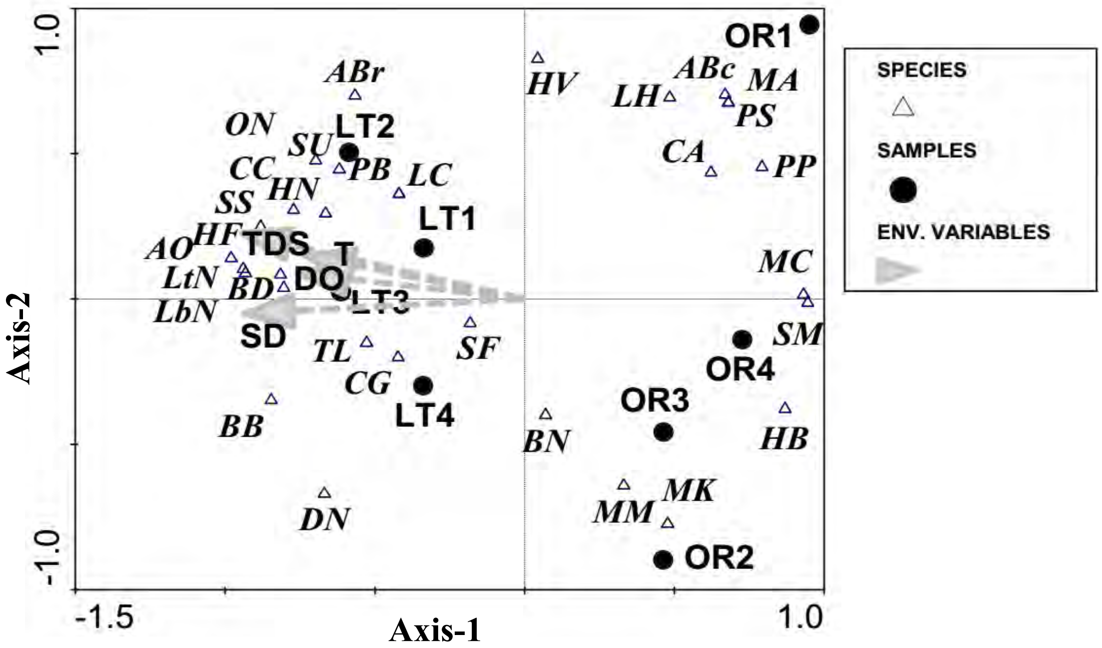


Figure 8. The species-environment-site PCA triplot of fish community for lower Omo River (OR1–OR4) and the Ethiopian part of Lake Turkana (LT1–LT4); acronyms for fish species are as in Figure 6.

TDS explained 43% variance of 15 fish species, and the effect was statistically significant ($p < 0.05$; Table 6). The explanatory effects of Secchi depth (SD), amount of dissolved oxygen (DO) and water temperature (T) were statistically not significant ($p > 0.05$; Table 6).

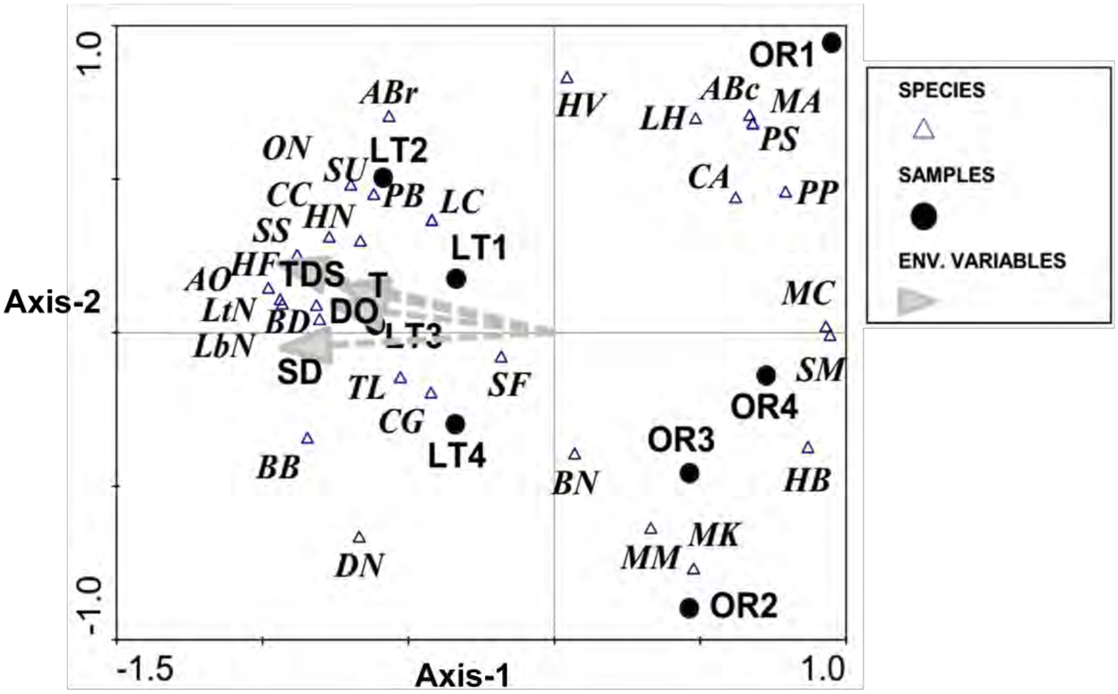


Figure 9. The species-environment RDA biplot for the extent of differences in the composition of fish assemblages explainable by amount of total dissolved solids (TDS; acronyms for fish species are as in Figure 6.

Table 6. Summary of Monte Carlo permutation test for the strength of variability in fish assemblages explainable by the environmental variables

Env. variable	% Variance	F-ratio	Monte Carlo "p"	VIF
TDS*	43	3.81	**0.01**	12
SD	15	1.46	0.17	8
T	10	0.89	0.64	3
DO	8	0.64	0.69	4

*environmental variable with significant effect on the fish community structure, $p < 0.05$.

3.4. Discussion

A few species dominated fish compositions of both the lower Omo River and the Ethiopian part of Lake Turkana in terms of their relative importance. Four species (*A. baremoze, S. schall, Lt. niloticus* and *D. nefasch*) comprised more than 50%IRI of the lake and the river fish compositions. Relative importance of *A. baremoze* was only slightly higher than that of *S. schall* in Lake Turkana where the two species comparatively had similar numeric abundance and biomass. However, in lower Omo River *A. baremoze* highly increased its importance over *S. schall* by virtue of both its numeric abundance and weight. *Lt. niloticus* stood third, following *S. schall*, in its ecological importance in Lake Turkana where it increased its importance by its numeric abundance and biomass over *O. niloticus*. In lower Omo River, it turned to be the least important species, and its rank was taken over by *D. nefasch,* whose importance was increased by both its number and weight over *S. uranoscopus* and *O. niloticus*. In a similar assessment in the western shores of the main part of the lake in Kenya (Kolding, 1989a), *S. schall* was described as contributing most to the total IRI of fish assemblage followed by *Lt. niloticus*. The present study showed that the Ethiopian part of Lake Turkana retained the same species of highest ecological importance, as the western shores of the main Turkana in Kenya, except that *S. schall* is slightly outweighed by *A. baremoze* in relative importance. The overall compositions of the most dominant species of lower Omo River and the Ethiopian part of Lake Turkana, which accounted for more than 96–99% total IRI, were generally similar except for differences in the relative importance of each species. Ten species, i.e. *A. baremoze, S. schall, O. niloticus, S. uranoscopus, C. Citharus, D. nefasch, Lb. niloticus, B. Bajad, B. docmak* and *H. forskahlii*, comprised the highest percentage of IRI in both the lake and the river.

Species with the least importance index (1–4%IRI), represented in the right margins of Figure 6A & B, captured less frequently in the sampling sites, and occurred largely in either the lake or the river.

Cluster analysis and the PCA ordination produced distinct habitat-associated species patterns across the riverine and lacustrine environments. The PCA triplot produced 18 species constituting the Ethiopian part of Lake Turkana fish community and 13 species comprising the lower Omo River fish community (Figure 8). Species with the highest relative importance indices caused most of the variations between the lake and the river fish communities. These species were more abundant in Lake Turkana, than in lower Omo River as demonstrated in SIMPER, and they made up two thirds of the lake‘s fish community composition. In contrast, the lower Omo River fish community was composed of the least abundant species including those recorded only from the river. The commercially important fish species including *Lt. niloticus, O. niloticus, D. nefasch* and *C. citharus* largely formed the Lake Turkana community while species constituting the lower Omo River community were mainly commercially less important. This variation in the compositions of fish communities, and thus in the relative abundance of commercially important species, between the river and the lake should be an underlying ecological factor for the concentration of the local fishery in Lake Turkana than in the lower Omo River (chapter 5).

Generally, the lake‘s fish community associated positively with the environmental variables, evaluated for their potential structuring role, while the lower Omo River community demonstrated negative association. Nevertheless, dissolved oxygen and water temperature did not vary significantly between the lake and the river nor did they account for significant variance of fish community compositions. The structuring effect of water clarity on the fish compositions was not significant despite significant variation of the variable itself between the lake and the river. TDS was the most important factor that explained most of the fish community variances (43%), which was statistically significant. The main part of Lake Turkana has high concentration of dissolved ions, expressed as conductivity of 3800 µS cm^{-1} and salinity of 2.89 g L^{-1} (Yan *et al.*, 2002; Paugy, 2010).

Dissolved ion concentrations of lake water can be influenced by factors such as geology of the catchment and/or the lake, size of the catchment relative to lake area, and evaporation (Kalff, 2002). Rocks in the highlands of Omo River Basin, which constitutes 52–58% of the lake‘s catchment area and 80–90% of inflow, are predominantly volcanic in origin with rocks in the upland areas being largely acidic and those in the lower basin mainly alkaline (Yuretich, 1976). The bottom of Lake Turkana itself is made up of sediments of volcanic origin related to formation of the East African Great Rift Valley (Ferguson and Harbott, 1982). Sodium, carbonate and bicarbonate were reported to dominate the ionic composition of the lake, thus giving it alkaline nature (Källqvist *et al.*, 1988). The most important factor for the high ionic strength in Lake Turkana, however, is evaporative accumulation of salts. The lake lacks any obvious surface outflow since it was disconnected from White Nile about 7,500 years ago. Thus, dissolved solids brought in by the inflows from extensive catchment of the lake (≈ 131,000–145,500 km^2) are accumulated when water is lost through evaporation (Källqvist *et al.*, 1988).

The Ethiopian part of Lake Turkana rather has lower concentration of dissolved ions as it is in fact located much closer to Omo River Delta. In the present study, the lake had mean conductivity of 2,342 µS cm^{-1} which is equivalent to TDS of 1.62 g L^{-1}. This concentration of dissolved ions is virtually 16 times higher than that of the lower Omo River (Table 3). These variations between the lake and the river were statistically significant, and TDS explained the distribution of nearly 50% of fish species between the two systems. Four of these species (*M. caschive, M. kannume, S. mystus* and *H. bebe*) formed the lower Omo River community, and 11 species (*A. baremoze, S. uranoscopus, C. citharus, O. niloticus, Lb. niloticus, H. forskahlii, Lt. niloticus, S. schall, A.occidentalis, B. docmak* and *B. bajad*) were largely part of the Lake Turkana fish community.

Hence, the present results strongly suggested that ionic concentration measured as TDS is the key factor determining fish community structure in lower Omo-Turkana sub-basin. Nevertheless, about 24% of the variance in fish community structure between the lake and the river remained unexplainable by the environmental factors we analyzed. This part of variability is attributable to other factors not evaluated in this study. Thus, other potential fish community-structuring factors such as predation, habitat selection, competition, fisheries, etc need to be investigated further.

3.5. Conclusion

The use of multivariate statistical approaches proved useful in identifying fish communities and their underlying structuring variables in the study sites. Cluster analysis suggested possible differences between the lower Omo River and the Ethiopian part of Lake Turkana fish communities, with 12 dominant species causing most of the variations. In SIMPER and PCA, it was found that the Lake Turkana fish community was largely composed of the most dominant species, in terms of their relative importance, while the lower Omo River community was comprised of the least important species. The main factor that explained most and statistically significant variance between the lake and river fish communities was the amount of dissolved ions measured as total dissolved solids (TDS).

Chapter four

4. Feeding habits and trophic guild structure of selected fish species in the Ethiopian part of Lake Turkana

4.1. Introduction

Fishes are important link in the aquatic food web connecting production at the lower trophic levels to the top predators. Moreover, many fish species are socioeconomically important. As a result, different aspects of trophic ecology of fishes have been studied (Hovde *et al*., 2002; Ramírez-Luna et al., 2008; Eya *et al.*, 2011). Knowledge on trophic dynamics of ecologically important fish species has an important application, for instance, in developing ecosystem-based management models. The shift in emphasis away from the single-issue or -species focus of traditional fisheries management towards an ecosystem approach to fisheries management (EAF) requires application of environmental indicators such as trophic structure of fish population, species, or community (Jennings, 2005; Greenstreet and Rogers, 2006). In EAF, not only are the target species included but also their effects on other non-target species (Cury and Christensen, 2005), thus demonstrating the importance of knowledge on the trophic structure.

Several simple relative measures of prey quantity (RMPQ) in count, weight and volume as well as frequency of occurrence have been used with the purpose of describing fish feeding habits. The use of simple indices alone, such as percent prey volume or frequency of occurrence, is constrained by their inherent limitations of emphasizing different aspects of fish diet (Hyslop, 1980; Cortés, 1997). As an offset, various compound indices were developed out of the simple indices. Some examples include index of preponderance (IP) (Natarajan and Jhingran, 1961), index of relative importance (IRI) (Pinkas et al., 1971), and a geometric index of importance (GII) (Assis, 1996). In contrast to IRI and IP, GII is a generalized index that can be computed from any type and number of simple indices (e.g. prey volume and frequency of occurrence) and its graphic presentation permits easy ranking of prey importance (Assis, 1996). IRI is not suitable for prey items, such as detritus or macrophytes, not expressed in count. IP lacks a clear way of ranking prey importance.

Trophic guild identification approach simplifies an otherwise complex interaction among numerous species to a more manageable unit (Bonato *et al*., 2012). As a result, trophic guilds have been studied elsewhere in the world as important functional groups of fish community (Garrison and Link, 2000; Hajisamae et al., 2003; Mourão *et al*., 2014). The concepts and identification of ecological guild have been variably employed since its inception by Root (1967) as groups of species that exploit the same class of resources in a similar way. According to this definition guild consists of sympatric species regardless of their taxonomic relationship. Some authors attempted to produce comprehensive reviews on guild concepts and practice (e.g. Simberloff and Dayan, 1991; Wilson, 1999). Two major categories of ecological guild concepts could be recognized sensu Wilson (1999): Beta (environmental conditions) and Alpha (resource use) guild concepts, the latter being more related to the original sense of guild definition. Despite the variability in concepts, guilds are useful in comparative study of ecological communities as it is usually impossible to study all species occurring within an ecosystem at once (Terborgh and Robinson, 1986).

Omo-Turkana Basin extends from southwestern Ethiopia into northern Kenya encompassing a catchment area of 131,000–145,500 km^2. The basin is comprised of Lake Turkana, Omo River (also known as Omo-Gibe) in Ethiopia, and Turkwell and Kerio rivers in Kenya. Omo River lying entirely within Ethiopia constitutes the largest part (i.e. 52–58%) of the lake's catchment (chapter 1 of this thesis). The entire Omo-Turkana Basin harbors up to 79 valid native fish species, with up to 64 fish species occurring in the Ethiopian part of the basin (chapter 2 of this thesis). Feeding habits and trophic guild structure of the basin fishes, in particular fish fauna in the Ethiopian part of the basin, were not studied. Despite my sampling efforts in both the river and the lake, sufficient gut samples could not be obtained for the former. We thus focused on fishes sampled in the Ethiopian part of Lake Turkana with the following objectives.

- assessing dietary variations & feeding strategies of selected fish species,
- identifiying potential trophic guilds (if any)
- assessing interspecific dietary interactions (overlap)

4.2. Materials and Methods

4.2.1. Fish gut sampling

Samples of fish guts were obtained from the Ethiopian part of Lake Turkana in two wet and two dry seasons, between January 2013 and September 2014, as described in sections 2.2.1 and 2.2.2. Eight fish species of both limited and commercial scale of fishery importance, relatively more abundant and represented by sufficient gut samples, were selected for diet analysis. The eight selected species represented eight different families. These included *A. baremoze* (Alestidae; dry season only, n = 61), *C. citharus* (Citharinidae; both seasons, n = 22), *D. nefasch* (Distichodontidae; both seasons, n = 104), *B. bajad* (Bagridae; both seasons, n = 34), *S. schall* (Mochokidae; both seasons, n

= 318), *S. uranoscopus* (Schilbeidae; both seasons, n = 83), *O. niloticus* (Cichlidae; wet seasonl only, n = 126) and *Lt. niloticus* (Laitdae; wet season only, n = 113). Except for All the examined fish species, except for *A. baremoze*, *S. Schall* and *S. uranoscopus* had commercial scale fishery importance. Intact gut samples containing dietary items were collected and preserved in 10% formalin solution for subsequent analysis in laboratory.

4.2.2. Gut content analysis

Gut samples were microscopically examined in the laboratory for types and quantities of dietary (prey) items. Compound and dissecting microscopes were used to identify the prey items, which were identified to the lowest possible taxa using relevant taxonomic keys (Pennak, 1953; Belcher and Swale, 1976; Fernando, 2002; Bouchard, 2004; Subramanian and Sivaramakrishnan, 2007; Bellinger and Seege, 2010). Volumetric analysis with direct displacement was used to quantify dietary items because it is a more suitable means of diet quantification especially for the herbivorous fishes (Windell and Bowen, 1978). In this process, we generated volume (ml) and frequency of occurrence as RMPQ, which were then used to compute GII as described in section 4.2.3 below, for each consumer fish species.

4.2.3. Data analysis

Cumulative prey curves were generated to determine if adequate stomach samples were collected for proper diet description (Ferry and Cailliet, 1996; Cortés, 1997). The curves represented cumulative number of unique prey categories plotted against the cumulative number of fish stomachs examined. Data was randomized for the sequence in which the stomach samples were considered to create cumulative prey curves.

Variations in diet compositions for each individual fish were assessed using log-ratio principal component analysis (%PCA) of the prey volumes (De Crespin De Billy *et al.*, 2000; Chipps and Garvey, 2007). For prey volumes equal to zero, very small numbers (0.00001) were entered prior to analysis (Aitchison, 1983). The species-level dietary variations were assessed using GII (Assis, 1996). GIIi for a particular prey category 'i' was computed as: $\text{GII}i = (\sum \text{RMPQ}i)/(\sqrt{\text{n}})$, where, RMPQ$i$ = percentage of volume, and frequency of occurrence (as a percentage of total occurrences); n = total number of RMPQ.

Feeding strategy for each fish species was assessed using Amundsen *et al.*'s *(*1996) graphical method (Figure 10) and Levins' (1968) dietary niche width index.

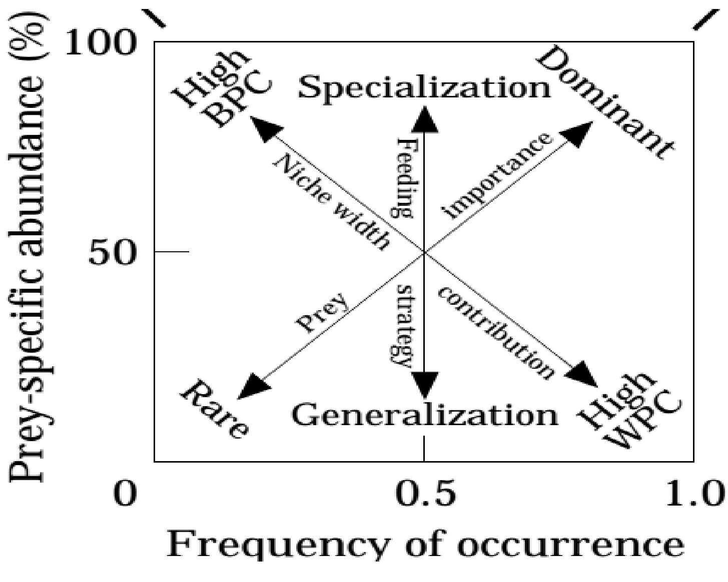


Figure 10. Amundsen *et al.*'s (1996) graphic method for interpretting fish feeding strategy.

This graphical method involved plotting prey-specific abundance against frequency of occurrence as fractions of total non-empty stomachs examined. Prey-specific abundance

(S_i) is defined as the volume proportion of a particular prey (diet) item in only fishes that contained it, and thus computed as: $Si = (\sum Vi/\sum Vti)x100$, where, Vi = the total volume (ml) of prey 'i' in the fish stomach, Vti = the total volume (ml) of all preys in fish that contained prey 'i'. Levins' (1968) dietary niche width index (B) was computed as $B = 1/(\sum Pi^2)$, and standardized as $Bs = (B - 1)/(n - 1)$, where, Pi = fraction of prey volume for each prey category; n = total number of prey categories. The standardized index ranges 0–1, with values close to 0 indicating feeding specialization and values close to 1.0 representing generalization (Hurlbert, 1978).

Ontogenetic and seasonal dietary variations were assessed using multivariate analysis of variance (MANOVA) with randomization of prey volumes (Somerton, 1991; Chipps and Garvey, 2007). Randomization was required to counterbalance the non-normal distributional nature of the diet data. A Wilk's lambda (Λ) test statistic was considered for the randomization procedure. When MANOVA returned significant variations, Mann-Whitney U test was performed to identify specific prey categories that caused significant ontogenetic or seasonal variations in fish diet. For ontogenetic analysis, each fish species was categorized into two size classes based on the frequency distribution of standard length (SL) of the sample specimens.

Diet compositions as percent volume were explored using hierarchical agglomerative cluster analysis to identify potential trophic guilds for the eight fish species examined for diet study based on UPGMA algorithm and Bray-Curtis similarity index. Significant differences among clusters of potential trophic guilds were tested with a permutational multivariate analysis of variance (perMANOVA) based on Euclidean distance measure and permutation of 9,999. Prey items that caused dissimilarity between diets of the trophic guilds were then identified with similarity percentages (SIMPER). The extent of overlap in the utilization of dietary resources among the consumer fish species was assessed using dietary niche overlap index, a robust measure against the effects of mutually exclusive prey categories (Somerton, 1991). Thus, Horn's (1966) overlap index, which has a reduced bias and is particularly suitable for prey quantities expressed in volume measurements (Krebs, 1989), was computed as:

$$\mathrm{H}ab = \frac{\sum_{i=1}^{\mathrm{n}}(\mathrm{P}ia + \mathrm{P}ib)\ln(\mathrm{P}ia + \mathrm{P}ib) - \sum_{i=1}^{\mathrm{n}}(\mathrm{P}ia \ln \mathrm{P}ia - \sum_{i=1}^{\mathrm{n}}(\mathrm{P}ib \ln \mathrm{P}ib)}{2\ln 2}$$

Where, $\mathrm{H}ab$ = Horn's dietary niche overlap between any two species 'a' & 'b', $\mathrm{P}ia$ & $\mathrm{P}ib$ = volume fraction of prey 'i' of the total prey categories (n) consumed by fishes of species 'a' &'b', respectively.

Trophic level for each consumer fish species 'j' (TrophLj) was computed as: $\mathrm{TrophLj} = 1 + \sum \mathrm{P}i \times \mathrm{TrophL}i$, where, P$i$ = the volume fraction of prey 'i' in the diet of fish species 'j', TrophLi = the trophic levels of each prey category 'i' (Pauly and Palomares, 2005). Computation of trophic positions of the respective fish species required estimating trophic positions of their prey items (TrophLi). Thus, TrophLi for phytoplankton, macrophytes and detritus was defined as 1. For fish preys which were not clearly identified to the maximum possible taxonomic resolution and other preys whose realized trophic levels are poorly understood, the simplest possible assumptions of TrophLi were used as: fish 2.5, aquatic insects (most of which omnivorous) 2.5, zooplankton (mainly cladocera and copepods) 2.5, clam 2, aquatic snail (gastropod) 2, prawn 2 and shrimp 2 (Zanden *et al*., 1997).

Statistical analyses were carried out in CANOCO for Windows version 4.5 (ter Braak and Smilauer, 1997–2002), PAST version 3.08 (Hammer *et al.*, 2001) and PC-ORD for Windows version 5.31 (McCune and Mefford, 2006).

4.3. Results

4.3.1. Cumulative prey curves

A high diversity of dietary items was identified from gut content analysis of the eight selected fish species. In the interest of simplicity, specific prey items were categorized into 11 major groups according to their taxonomic and ecological affinities (Chipps and Garvey, 2007). These included fish, aquatic insects, phytoplankton, zooplankton, prawn, shrimp, crab, clam, aquatic snail (gastropods), macrophytes and detritus. Specific list of the four highly diversified prey categories, i.e. fish, aquatic insects, phytoplankton and zooplankton, is provided in Table 7. Fish and aquatic insect dietary items were largely juveniles and larval stages, respectively.

Table 7. List of specific dietary items of the four highly diversified prey categories; major dietary sub-categories are indicated in boldface, BGA = blue-green algae.

Major prey categories				
Fish	Aquatic insects	Phytoplankton		Zooplankton
Polypetrus sp	**Odonata**	**Diatoms**	**BGA**	**Cladocera**
Brycinus sp	Anisoptera (dragonflies)	Cyclotella	Anabena	Ceriodaphnia
Alestes sp	Zygoptera (damselflies)	Cymbella	Aphanizomenon	Daphnia
Clarias sp	**Ephemeroptera** (mayflies)	Diatoma	Coelosphaerium	Diaphnosoma
Synodontis sp	**Hemiptera** (waterbugs)	Fragilaria	Gloetrichia	**Copepoda**
Digested fish	Corixidae, Micronecta,	Gomphonema	Microcystis	Calanoid
(scales &	Creeping waterbug	Gyrosigma	**Green Algae**	Cycloid

bones)	**Tricoptera** (caddisflies)	Meridion	Closterium	**Ostracoda**
	Plecoptera (stoneflies)	Navicula	Cosmarium	
	Coleoptera (water beetles)	Nitzschia	Microspora	
	Diptera	Pinnularia	Mougeotia	
	Ceratopogonidae (biting	Skeletonema	Oedogonium	
	midges), Chironomidae,	Stephanodiscus	Planktosphaeria	
	Tipulidae	Surirella	Scendesmus	
	Hymenoptera	Synedra	Spirogyra	
	Aquatic wasps	Tabellaria	Ulotrix	
	Unidentified insects		Zygonema	
	(very few)			

Cumulative prey curves generated for each consumer fish species based on the major categories of dietary items are given in Figure 11. The curves approached an asympotote suggesting the collection of sufficient gut samples for all the examined fish species.

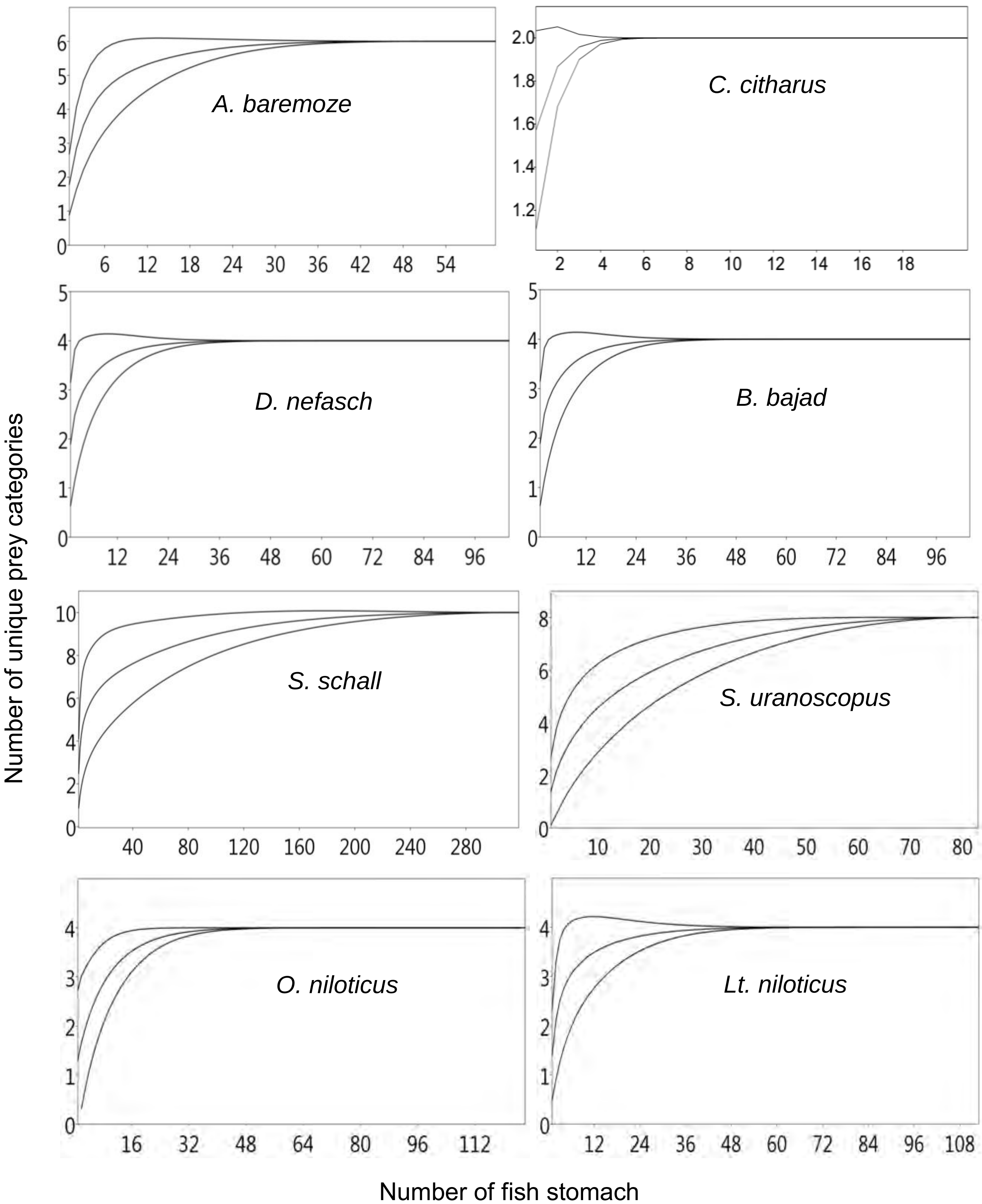


Figure 11. Cumulative prey curves for the eight selected fish species in the Ethiopian part of Lake Turkana; n = number of stomach samples collected

4.3.2. Dietary variations and feeding strategies

Log-ratio principal component analysis (%PCA) for the individual level dietary variations is given in Figure 12. Diets of individual fishes varied largely on PC-1 and PC-2, which together accounted for 54.2–100% of total variance (Table 8).

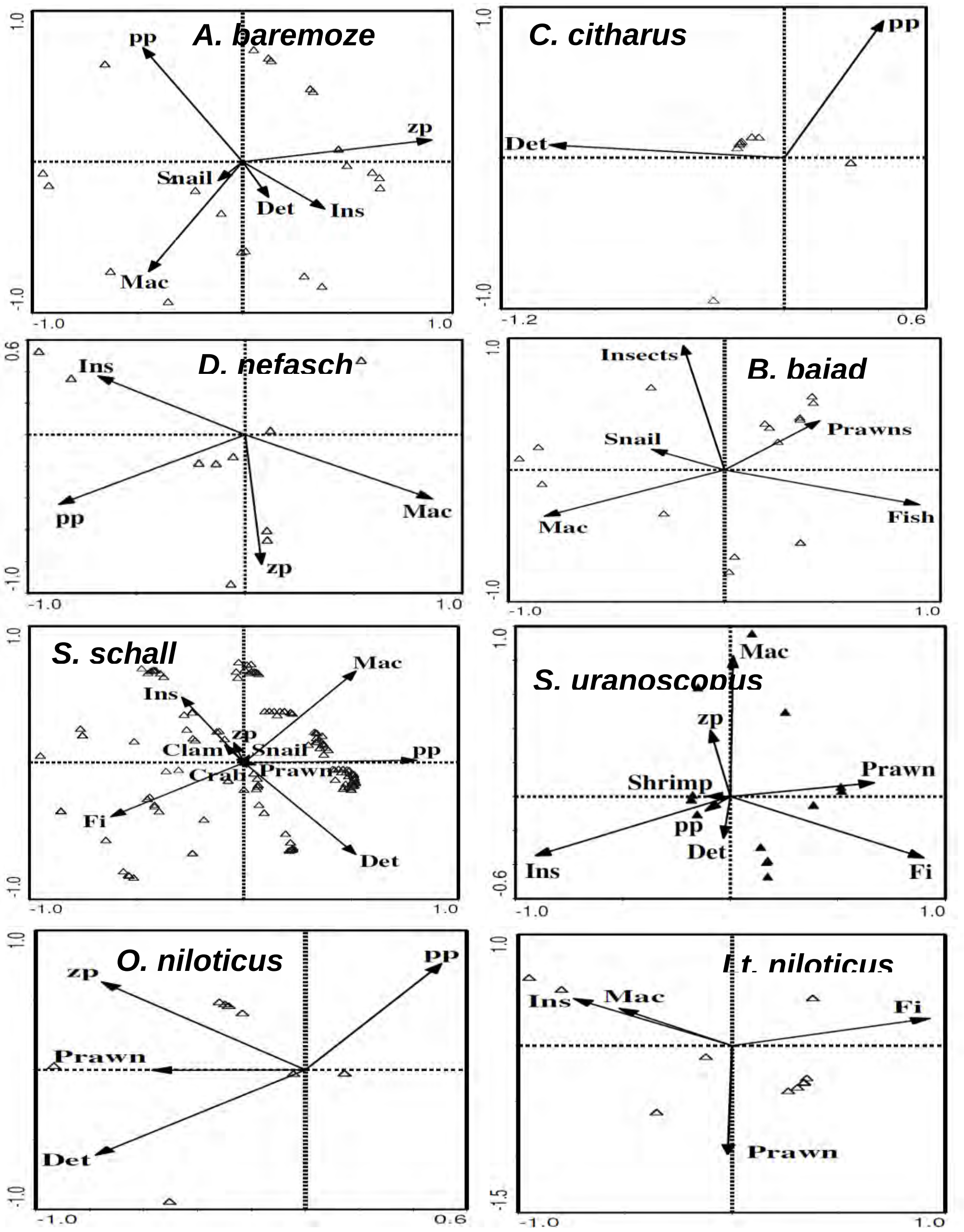


Figure 12. The log-ratio principal component analysis (%PCA) for diets of the eight selected fish species in the Ethiopian part of Lake Turkana; Fi (fish), Ins

(aquatic nsects), pp (phytoplankton), zp (zooplankton), Mac (macrophytes), Det (detritus); X-axis = PC-1; Y-axis = PC-2.

The log-ratio PCA clearly depicted individual variations as some individuals tended to specialize on preys that were different from those prey items important in the overall diet of the fish population.

Geometric indices of relative importance are presented graphically in Figure 13, and the corresponding values of prey volume and frequency of occurrence are summarized in Appendix 5. The vertical lines in Figure 13 indicate approximate cut-off points, i.e. large gaps in the values of GII, in order to assign prey importance to various levels as primary, secondary and least important.

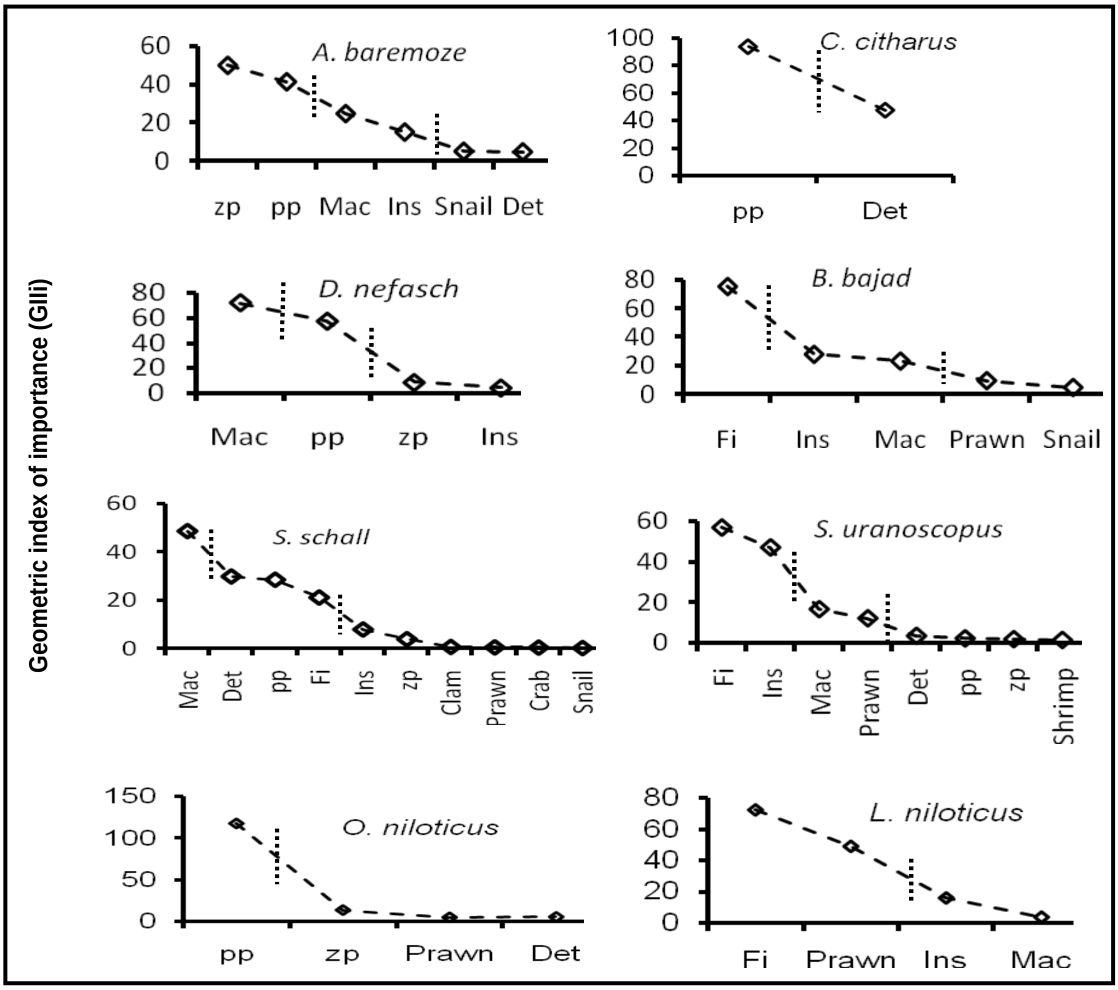


Figure 13. Graphical presentation of geometric index of importance (GIIi) for diets of the eight selected fish species in the Ethiopian part of Lake Turkana; prey acronyms as in Figure 12.

Table 8. Summary of percent variance accounted by the first two principal components (PC) for the %PCA; *S. uranoscopus* (SU), *B. bajad* (BB) and *Lt. niloticus* (LtN); Guild-2: *S. schall* (SS), *D. nefasch* (DN), *A. baremoze* (ABr), *O. niloticus* (ON) and *C. citharus* (CC).

Cumlative %variance	ABr	CC	DN	BB	SS	SU	ON	LtN
PC-1	31.9	84.5	57.1	44.1	29.4	55.1	48.4	43.6
PC-2	58.7	100	84.6	71.8	54.2	68.7	83.6	84.5

Feeding strategy diagrams and the accompanying Levins dietary niche width indices are given in Figure 14 for each fish species. These feeding strategy diagrams were interpreted in relation to Figure 10 for the relative contribution of dietary niche width contributions of subpopulations to each fish species‘ overall feeding strategy.

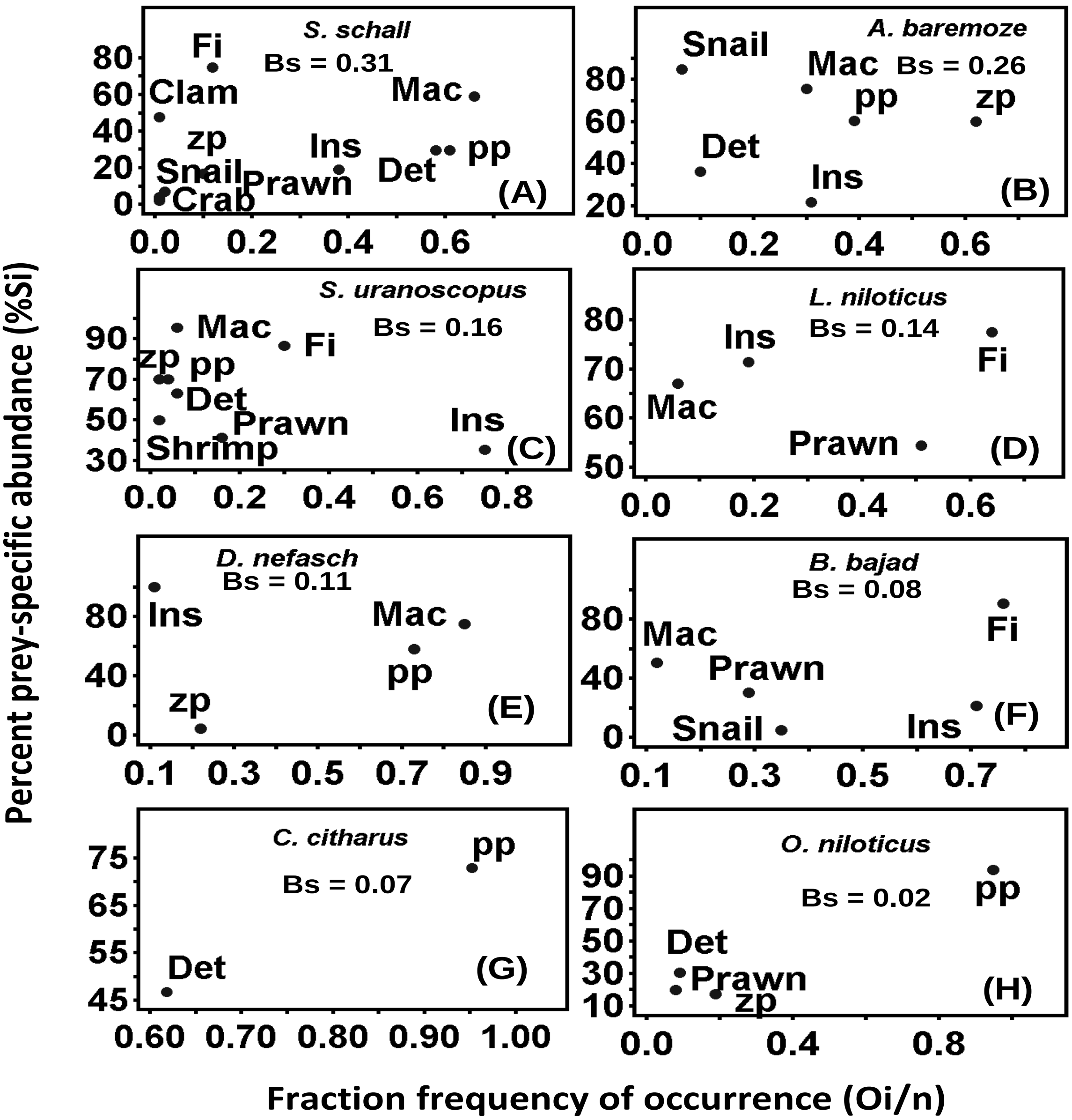
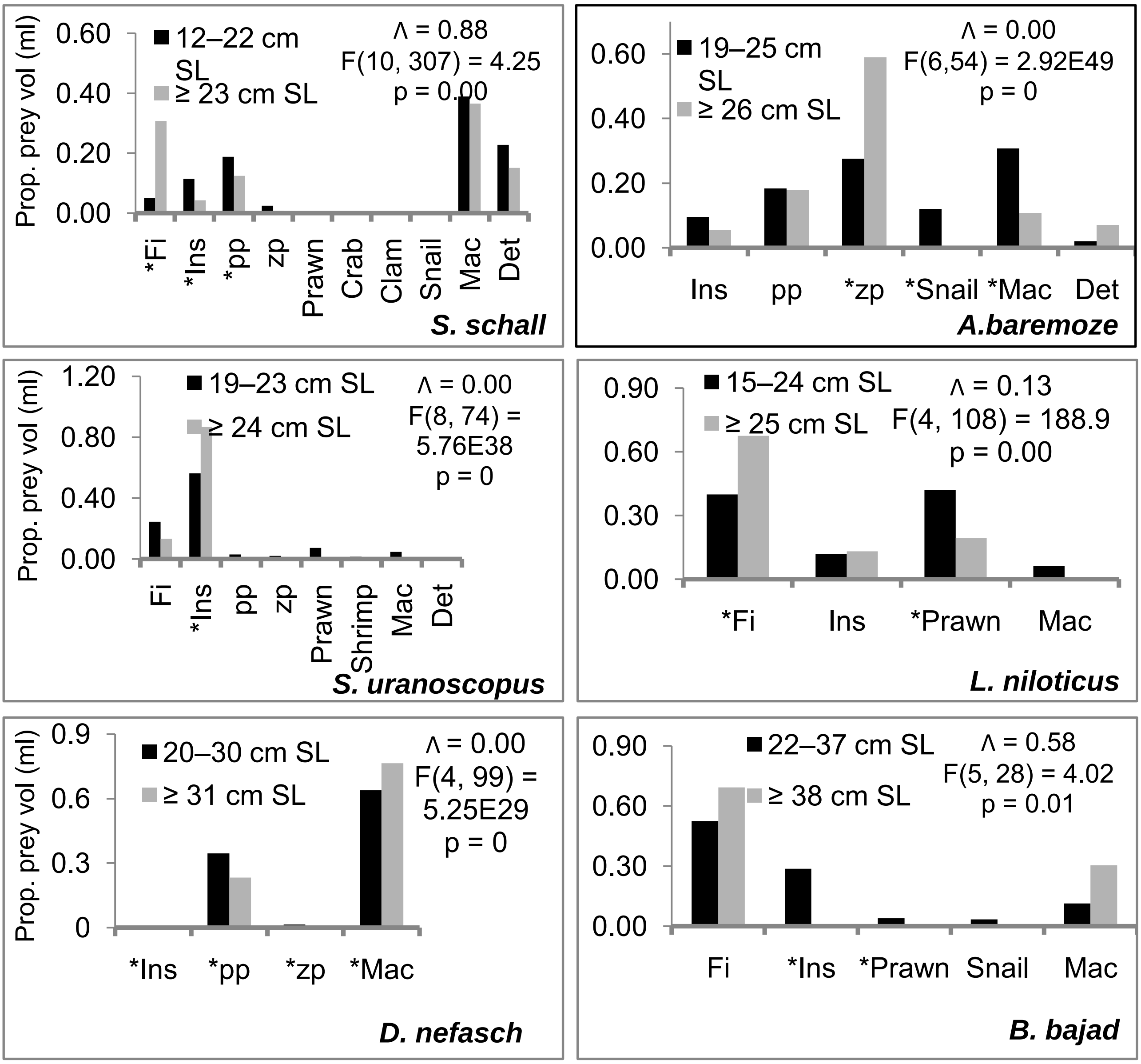


Figure 14. Feeding strategy diagrams of the eight selected fish species from the Ethiopian part of Lake Turkana; Bs = standardized Levins dietary niche width index; prey acronyms as in Figure 12.

Ontogenetic dietary variations

Diets of all the eight fish species varied ontogenetically (MANOVA, $p < 0.05$) for each pair of size groups considered. The ontogenetic groups, Wilk‘s lambda (Λ), F-values, p-values for MANOVA, and the Mann-Whitney U test for specific prey items with significant ontogenetic variations are summarized in Figure 15.



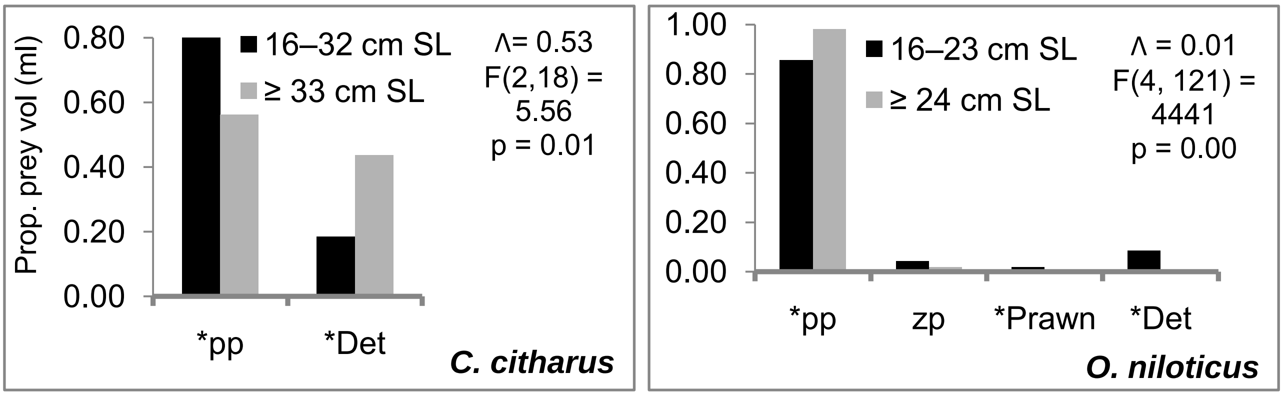


Figure 15. Comparison of ontogenetic dietary variations using average prey volume (ml); a pair of size groups compared, summary of MANOVA with Wilk's lambda (Λ), F and p-values are provided for each fish species; for the Mann-Whitney U test, specific prey items with significant ontogenetic variations are indicated with * along the prey acronyms ($p < 0.05$).

Seasonal dietary variations

No seasonal analysis was carried out for diets of *A. baremoze, O. niloticus* and *Lt. niloticus* as gut samples were obtained only during one season (Fig. 11). Among the five fish species considered for possible seasonal dietary variations, MANOVA returned statistically significant variations only for diets of four species. Wilk's Λ, F-values, p-values for MANOVA, and Mann-Whitney U-test for specific prey items with significant seasonal variations are summarized in Figure 16. Diet of *S. uranoscopus* did not exhibit any seasonal variations.

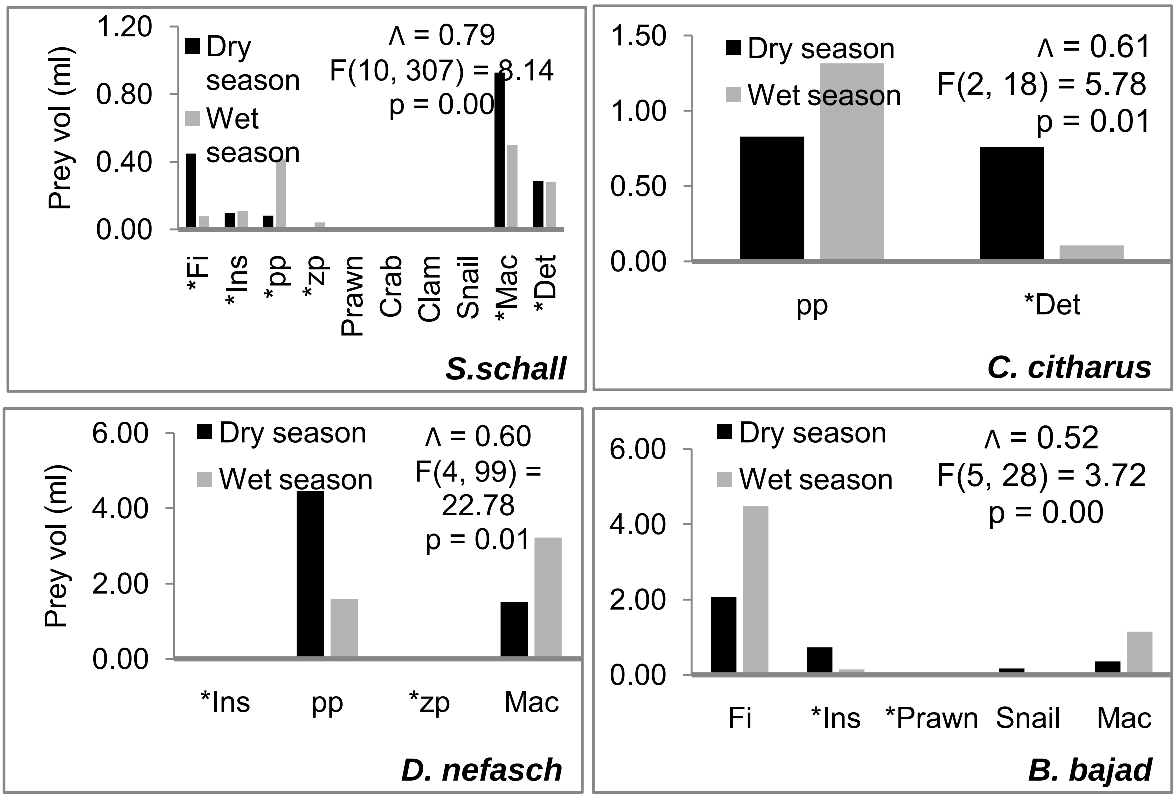


Figure 16. Comparison of seasonal dietary variations using average prey volume (ml); summary of MANOVA with Wilk's lambda (Λ), F and p-values are provided for each fish species; for the Mann-Whitney U test, specific prey items with significant seasonal variations are indicated with * along the prey acronyms ($p < 0.05$).

4.3.3. Potential trophic guilds

Cluster analyses for the eight selected consumer fish species based on the %Vi of their dietary items is given in Figure 17.

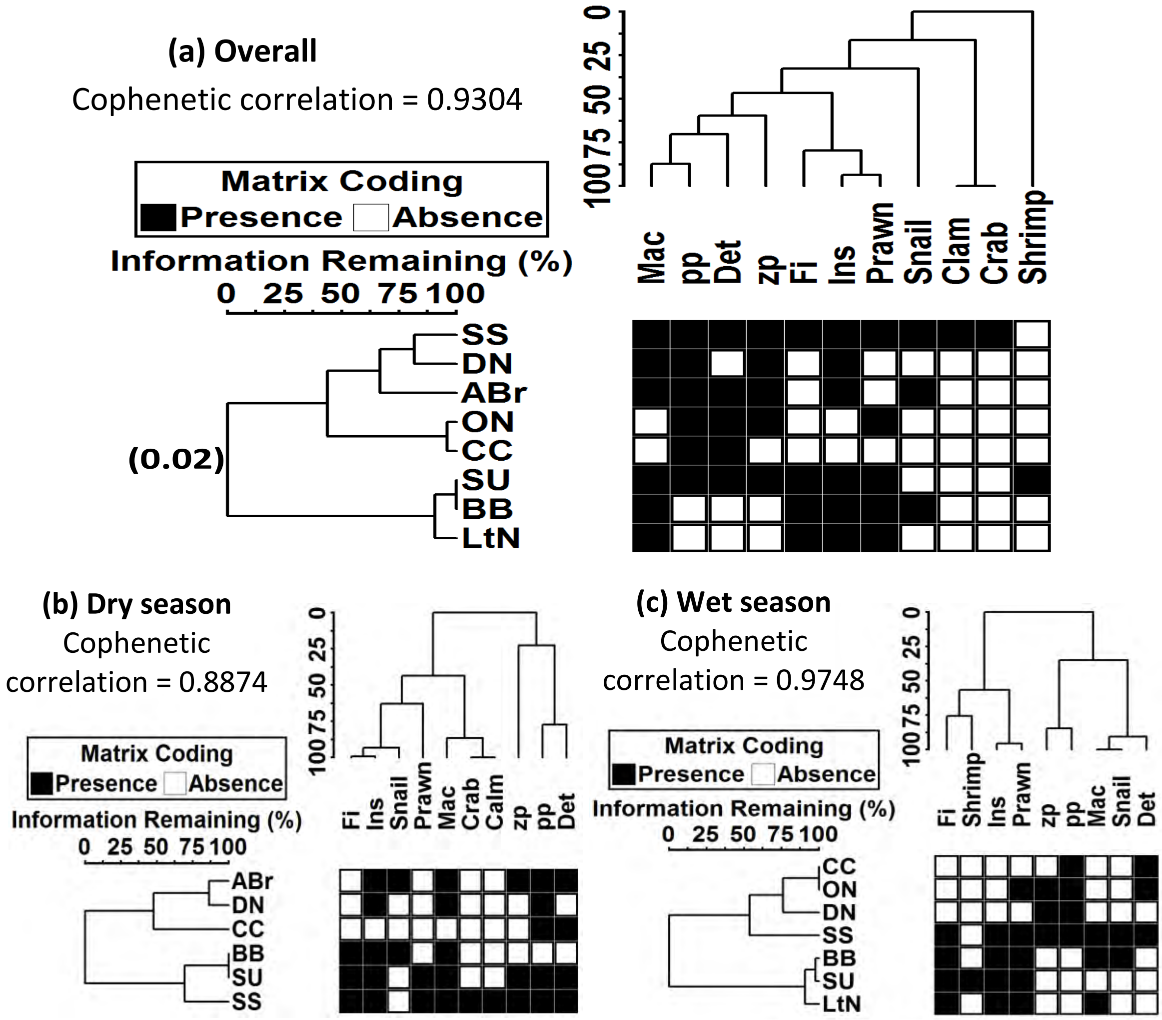


Figure 17. Cluster analyses of the eight selected consumer fish species based on their diet composition; value (0.02) at the upper node in (a) represents p-value for validity of the clusters; acronyms for the fish species as in Table 8; prey acronyms as in Figure 12.

In Figure 17, only two species-clusters (potential trophic guilds) at the first upper node are valid based on the overall (non-seasonal) diet data (perMANOVA, $p < 0.05$). Guild-1 consisted of 3 species (*Lt. niloticus, B. bajad* and *S. uranoscopus*) and guild-2 consisted of five species (*C. citharus, O. niloticus, A. baremoze, D. nefasch* and *S. schall*). In SIMPER analysis, the overall average distance between the two potential guilds was 86.82%. Only 7 (64%) prey categories viz. fish, phytoplankton, macrophytes, prawn, aquatic insects, detritus and zooplankton accounted for 99.97% of prey-specific total dissimilarity between the two potential trophic guilds, and constituted 99.53% and 99.26% volume of guild-1 and guild-2 diets, respectively. Aquatic snail, clam, shrimp and crab were least important in the dietary variations of the guilds. Synthesis of the cluster and SIMPER analyses would yield an overall trophic guild structure of the fishes as depicted in Figure 18. On seasonal basis, similar guild structures were retained but the potential guilds were not statistically significant.

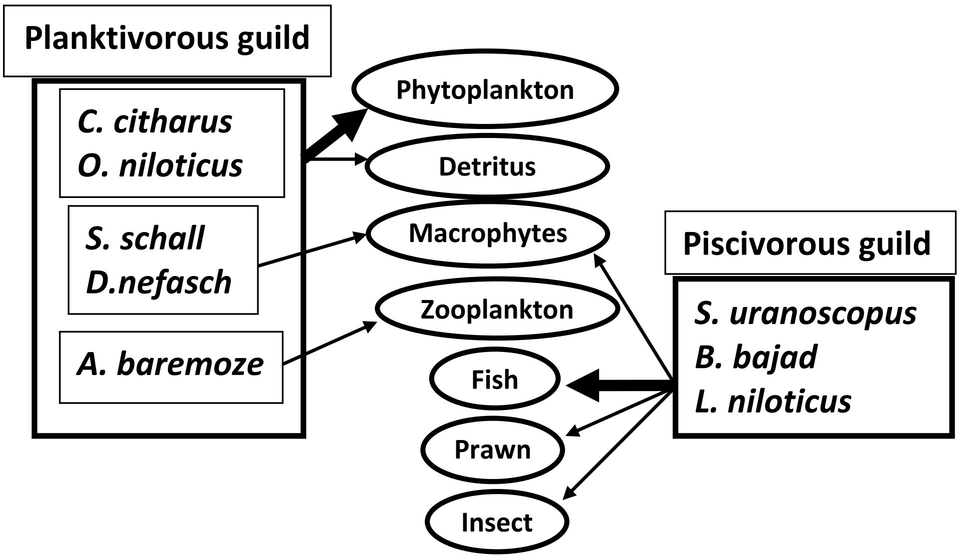


Figure 18. The trophic guild structure of the 8 selected fish species in the Ethiopian part of Lake Turkana sampled during the present study; thick arrows represent major food item that defines the respective guild and thin arrows represent minor food items that supplement the major item.

The trophic levels computed for each consumer fish species are summarized in Table 9. These values would help to further evaluate the validity of the potential trophic guilds suggested in Figure 17.

Table 9. Summary of trophic level (TrophL) for each consumer fish species; acronyms for the fish species as in Table 8; se = standard error.

TrophL	**SU**	**LtN**	**BB**	**ABr**	**SS**	**ON**	**DN**	**CC**
Mean	3.36	3.27	3.21	2.82	2.32	2.06	2.01	2.00
se	0.04	0.03	0.08	0.08	0.03	0.01	0.00	0.00

4.3.4. Interspecific dietary niche overlap

The Horn's index of dietary niche overlap among the consumer fish species is summarized in Table 10.

Table 10. Summary of Horn's index of dietary niche overlap for the eight selected consumer fish species in the Ethiopian part of Lake Turkana; acronyms for the fish species as in Table 8.

	SU	**LtN**	**BB**	**ABr**	**SS**	**ON**	**DN**	**CC**
SU	1	0.72	0.94	0.31	0.67	0.04	0.34	0.04
LtN		1	0.76	0.09	0.37	0.04	0.04	0
BB			1	0.23	0.61	0	0.3	0
ABr				1	0.65	0.67	0.71	0.54
SS					1	0.40	0.76	0.53
ON						1	0.62	0.85
DN							1	0.54
CC								1

4.4. Discussion

4.4.1. Dietary variations and feeding strategies

The number of stomach samples collected was considered adequate to warrant dietary analysis as the graphs approached an asymptote in cumulative prey curves for all the eight examined fish species (Ferry and Cailliet, 1996; Cortés, 1997). Not all prey items were equally important in the diets of the fishes, both at individual and species levels. Relative importance of prey items at individual fish level are represented by relative sizes of the arrows in %PCA (De Crespin De Billy *et al*., 2000; Chipps and Garvey, 2007; Figure 12), whereas identification of prey importance at species-level is based on discerning large discontinuities in the decreasing sequence of points in the graphic presentation of GIIi (Assis, 1996; Figure 13). Relative importance of dietary items, as rated in Table 11, shows that generally there was reasonable concurrence between the individual- and species (population) level importance of prey items. For most of the fish species prey items that were of primary importance at individual-fish level were at least of secondary importance at species or population level. In a few cases, such as for *D. nefasch*, prey items that were of high importance at individual fish level turned to be least important at population level.

Table 11. Summary of prey importance levels at both individual and population levels

Consumer fish species	Relative prey importance level	Important preys	
		Individual-level	Species-level
S. schall	Primary	Fi, pp, Mac, Det	Mac
	Secondary	Ins	Det, pp, Fi
	Least	zp, prawn, crab, clam, snail	Ins, zp, prawn, crab, clam, snail

A. baremoze	Primary	pp, zp, Mac	pp, zp
	Secondary	Ins	Mac, Ins
	Least	Snail, Det	Snail, Det
S. uranoscopus	Primary	Fi, Ins, Mac	Fi, Ins
	Secondary	zp, Prawn	Mac, Prawn
	Least	Det, pp, shrimp	Det, zp, pp, shrimp
Lt. niloticus	Primary	Fi, Ins, Prawn	Fi, Prawn
	Secondary	Mac	Ins, Mac
	Least	-	-
D. nefasch	Primary	Ins, pp, zp, Mac	Mac
	Secondary	-	pp
	Least	-	Ins, zp
B. bajad	Primary	Fi, Ins, Mac	Fi
	Secondary	Prawn	Ins, Mac
	Least	Snail	Prawn, Snail
C. citharus	Primary	pp, Det	pp
	Secondary	-	Det
	Least	-	-
O. niloticus	Primary	pp, zp, Det	pp
	Secondary	Prawn	zp, Det, Prawn
	Least	-	-

Assessment of feeding strategies aids in an in-depth exploration of fishes‘ feeding habits. The overall feeding strategy of a particular fish species could consist of a between-phenotype component of niche width (BPC) i.e. small subpopulations utilizing higher quantities of particular dietary items (specialized feeding), a within-phenotype component of niche width (WPC) i.e. large subpopulations exploiting fewer amounts of various dietary items (generalized feeding), or a large subpopulation utilizing higher quantities of particular dietary item (specialized feeding) sensu Amundsen *et al*. (1996). In my present assessment, Levins index of dietary width suggested *S. schall* as the most generalist feeder and *O. niloticus* as the most specialist feeder, with the remainders 6 species ranging between the two extremes (Figure 14). Analysis showed that each fish species was composed of subpopulations with BPC and WPC dietary niche width contributions to its overall feeding strategy (Figure 14).

S. schall (Figure 14A)

Synodontis schall subpopulations as small as 1–12% specialized in clam (48% S*i*) and fish (75% S*i*) diets, while 38–61% subpopulations utilized relatively lower amounts of phytoplankton, detritus and aquatic insects (19–30% S*i*). A larger percentage of *S. schall* subpopulation (66%) exploited relatively higher quantity of macrophytes (59% S*i*), which were the most important item in the diet of the fish. This is somehow in contrast with a previous report from Ghana on the feeding habit of the fish as mainly animal feeder (Ofori-Danson, 1992). Four dietary items i.e. zooplankton, prawn, crab and gastropods were only occasional in the diet of *S. schall* occurring in less than 10% subpopulation in lower quantities (2–17% S*i*). This also contrasts with the report from Lake Chamo, a lake in close proximity in the Ethiopian rift valley, where zooplankton was the most important contributor to the fish‘s diet (Elias Dadebo *et al*., 2012). This variability in the kind of the most important prey item in the diet of *S. schall* in different water bodies might relate to the fish‘s ability to incorporate various prey items in its diet as an important component based on resource availability.

A. baremoze (Figure 14B)

Alestes baremoze is less generalist than *S. schall*. It is composed of rather specializing subpopulations, with 6% of its subpopulation specializing in aquatic snail (gastropods) diet (85% S*i*), and further 30–39% subpopulations utilizing relatively higher quantities of macrophytes and phytoplankton (60–76% S*i*). Still, a very large percentage of *A. baremoze* subpopulation (62%) had higher quantities of zooplankton (60% S*i*) in its diet as the most important component. Detritus and aquatic insect dietary items were relatively least important and consumed by fewer fishes in small amounts. Although *A. baremoze* in the present study was predominantly zooplankton feeder (Cladocera and Copepoda), it is also known for flexibility in its dietary utilization that would allow it to shift to less important items such as macrophytes, aquatic insects and detritus as plankton densities decline (Bailey, 1994).

S. uranoscopus (Figure 14C)

Schilbe uranoscopus is a much less generalist species also composed of many subpopulations with specialized feeding. Its subpopulations ranging 2–16% specialized on 6 different dietary items (macrophytes, zooplankton, phytoplankton, detritus, shrimp and prawn), which they consumed in relatively higher proportions (41–95% S*i*). About 30% subpopulation also tended to specialize in fish diet (87% S*i*). In contrast, 75% subpopulation utilized lower quantities of aquatic insects (35% S*i*) constituting a within-phenotype component of a generalist feeding strategy of the fish. Comparison of the fish‘s feeding strategy with its prey importance assessment (Fig. 4) shows that fish preys are the most important item in the diet of *S. uranoscopus* in concurrence with early report from Lake Kainji in Nigeria (Olatunde, 1979).

Lt. niloticus (Figure 14D)

Lates niloticus is in the middle of the generalist-specialist feeding spectrum. All the four dietary items identified for *Lt. niloticus* had relatively higher specific abundance ranging 54–77%. Two of these dietary items, aquatic insects and macrophytes, were consumed by specializing subpopulations of 6–19%. About 51% of *Lt. niloticus* subpopulation had higher quantity of prawn (54% S*i*) in its diet, while the largest percentage of subpopulation (64%) tended to specialize in fish diet (77% S*i*). *Lt. niloticus* from Lake Chamo in Ethiopia was reported as being virtually exclusively piscivorous (Elias Dadebo *et al*., 2005). However, in this study it appeared to consume considerable amounts of other dietary items too despite its predominantly piscivorous habit.

D. nefasch (Figure 14E)

Distichodus nefasch also lies in the middle of generalist-specialist feeding spectrum with subpopulations specializing on various diets. About 11% of *D. nefasch* subpopulation consumed only aquatic insect preys (100% S*i*). Moreover, greater percentages of its subpopulations (85% and 73%) utilized higher quantities of macrophytes (75% S*i*) and phytoplankton (58% S*i*). This species is known as macro-herbivore utilizing both aquatic and terrestrial plant materials (Bailey, 1994). Zooplankton was least important in the diet of the fish.

B. bajad (Figure 14F)

Bagrus bajad had a largely specialist feeding strategy consisting of both specialist and generalist subpopulations. Subpopulations of 12% and 29% consumed relatively higher amounts of macrophytes (50% S*i*) and gastropods (29% S*i*). Aquatic insects and prawn represented the fish‘s subpopulations with generalist feeding strategy viz. a within-phenotype component of dietary niche width. Relatively higher predator subpopulation (76%) consumed fish preys in a relatively higher amount (9% S*i*) indicating a tendency of *B. bajad* specialization for the fish preys (Hickley and Bailey, 1987).

C. citharus (Figure 14G)

Only two prey categories were identified for *C. citharus* which had a specialist feeding strategy. Phytoplankton (Table 7) was both the most abundant (73% S*i*) and the most frequent dietary component occurring in 95% of the fish population. In contrast, detritus was relatively less important item utilized relatively in lower quantity (47% S*i*). The dietary components identified for *C. citharus* in the present study concurs with its feeding habits reported from Lake Volta in Ghana (Petr, 1967) and Lake Kainji in Nigeria (Arawomo, 1976).

***O. niloticus* (**Figure 14H)

Oreochromis niloticus had a specialist feeding strategy wherein phytoplankton (Table 7) was the most important part of its diet. About 95% of its subpopulation included 94% phytoplankton (%S*i*) in its diet. The largely phytoplankton feeding habit of *O. niloticus* in this study concurs with previous reports for Lake Volta in Ghana (Petr, 1967), Lake Hawassa in Ethiopian rift valley (Getachew Teferra and Fernando, 1989), and Lake Chamo also in the Ethiopian rift valley (Getachew Teferra, 1993). Three of its dietary items i.e. zooplankton, prawn and detritus were less important and consumed only by a few fractions of the fish population (8–19%).

Ontogenetic and seasonal dietary variations

The qualitative categories of dietary items were basically similar between fish size groups (small size vs. large size) and seasons (wet vs. dry) for all fish species examined.

Ontogenetic variations in the feeding habit of *S. schall* are attributable to aquatic insects, fish and phytoplankton. These dietary items constituted least to secondary levels of importance in the overall diet of the fish. The smaller fishes (12–22 cm SL) abundantly consumed aquatic insects and phytoplankton, while the larger fishes (≥ 23 cm SL) utilized fish preys in large quantities. Moreover, the consumption of these three prey items varied seasonally, insects and phytoplankton being important during wet season and fish were more important during dry season. The consumption of macrophytes which were the most important item in the overall diet of *S. schall* did not vary with fish size save for its seasonal variation, being more important in the diet of the fish during dry season. This variation in the relative importance of prey items with fish size fairly concurs with the fish‘s feeding habit in Lake Chamo except for macrophytes which were equally important in all size groups in the present study (Elias Dadebo *et al.*, 2012). Larger *A. baremoze* specimens (≥ 26 cm SL) commonly consumed zooplankton which is the most important item in the diet of the fish, while the smaller fishes (19–25 cm SL) mainly consumed gastropods and macrophytes. Diets of *S. uranoscopus* virtually remained constant both ontogenetically and seasonally, except for aquatic insect preys that largely constituted diet of the large fish group (≥ 24 cm SL). Importance of the two chief prey items of *Lt. niloticus*, i.e. fish and prawn, varied ontogenetically. Fish preys were more important in the diet of the larger fishes (≥ 25 cm SL), while prawns were more common in the diet of the smaller fishes (15–24 cm SL) (Bailey, 1994). My finding contrasts with that of Elias Dadebo *et al*. (2005) where both the smaller and larger fish groups essentially consumed only fish preys, and ontogenetic dietary variation was only in relation to the type (species) of fish prey consumed. In *D. nefasch*, phytoplankton was more abundant in the diet of the smaller fishes (20–30 cm

SL), while macrophytes were consumed in higher quantity by the larger fishes (≥ 31 cm SL). Macrophytes and phytoplankton constituted primary and secondary importance levels in the diet of the fish. Seasonal variations in the diet of *D. nefasch* were caused by aquatic insects and zooplankton both of which were least important in its diet. Only aquatic insects and prawn, preys of secondary and least level importance in the diet of *B. bajad*, exhibited both ontogenetic and seasonal variations. Both dietary items were more common in the diets of the smaller fishes (22–37 cm SL), with the larger fishes being virtually piscivorous (Olaosebikan and Raji, 1998). Aquatic insect preys were abundantly consumed during dry season, while prawn was consumed largely during wet season. Fish preys, the most important component in the diet of *B. bajad*, did not vary between size groups and seasons. Of the only two preys of *C. citharus*, phytoplankton was more important in the diet of smaller fish group (16–32 cm SL) during all seasons, while detritus was more common in the diet of larger fish group (≥ 33 cm SL) during dry season. The most important dietary item of *O. niloticus*, phytoplankton, was an important component of larger fishes (≥ 24 cm SL), while prawn and detritus commonly occurred in the diet of small fishes (16–23 cm SL).

4.4.2. Potential trophic guilds

Besides the dietary variations and feeding strategies explored for each fish species in section 4.4.1, holistic understanding of fish feeding habits requires assessment of trophic guilds i.e. species-groups exploiting similar dietary resources. Clustering of fish species for trophic guild assessment was based on the relative level of prey importance in the overall diet of the consumer fishes. In the present study, cluster analysis of the overall diet data of the eight selected fish species from the Ethiopian part of Lake Turkana entailed three potential trophic categories and one species (Figure 17a).

However, only two clusters and thus two potential trophic guilds demonstrated highest variation (86.82%) in their prey items and were statistically valid. The first, 3-species, guild comprised of *S. uranoscopus*, *Lt. niloticus* and *B. bajad* was largely piscivorous wherein fish preys constituted 63% mean volume of its diet. Prawn, macrophytes and aquatic insects supplemented the guild‘s diet (Figure 18). The second, 5-species, guild composed of *S. schall, D. nefasch, A. baremoze, C. citharus* and *O. niloticus* was largely planktivorous wherein phytoplankton constituted the highest fraction of the guild‘s diet (52%, mean volume). The guild‘s diet was supplemented by macrophytes, detritus and zooplankton and these were the most important contributors to the overall diets of some of the guild members (Figure 18). Seasonally, the number of guilds and dietary items that defined guild structures remained the same as for the overall (non-seasonal) diet data (Fig. 16; Fig. 17). However, a change of guild organization was observed with fish species placed in one guild might be classified in another guild during different seasons. Some species such as *O. niloticus* and *Lt. niloticus* were not in the guild structures altogether during dry season while *A. baremoze* was absent during wet season. This variability in the trophic guild organization could be explained in terms of the opportunistic convergence hypothesis which states that guilds originate through opportunistic convergence of species on abundant and energetically rewarding resources (Jaksic *et al*., 1996; Zapata *et al*., 2007).

The computed TrophL values for fish species of the piscivorous guild ranged 3.21–3.36 substantiating the guild‘s implied feeding habit while the values for members of the planktivorous guild were below 3.0 (2.00–2.82) supporting the guild‘s feeding habit lower in a trophic ladder (Table 2).

4.4.3. Interspecific dietary niche overlap

Interpretation of dietary niche overlap between two or more species is not clear-cut. Some associated it to competition (e.g. Schoener, 1974), while others (e.g. Abrams, 1980; Holt, 1987) held an opposing view. According to the latter, dietary niche overlap does not necessarily imply competition as a particular resource under consideration may not always be limiting, and thus species may overlap with no competition. In the present study, I computed dietary niche overlap to quantify the extent to which fish species shared a set of dietary resources thereby maintaining viable population in the presence of one another (sensu Mouillot *et al*., 2005). Accordingly, the largely piscivorous trophic guild had highest overlap values ranging 72–94% (mean overlap, 81%) with the highest overlap occurring between *S. uranoscopus* and *B. bajad*. Similarly, the overlapping pairs of the planktivorous trophic guild had dietary niche overlap values of 50–85% (mean overlap, 63%). Interguild dietary interactions were lower than 40% except for those of *S. schall* versus *B. bajad and S. uranoscopus* suggesting apparent distinction of the two proposed guilds in terms of their dietary resource utilization (Table 10). Moreover, a clustering analysis applied to a matrix of Horn's dietary niche overlap values (Table 10) produced a cluster dendogram (not shown here) similar to Fig. 16.

4.5. Conclusion

Ecological guilds have been associated with environmental assessment and management because factors that are known to affect their resources will similarly affect members of the guilds using those resources (Hawkins and MacMahon, 1989). The impact of a given factor on the species that constitute a guild can also be inferred from the impact caused to a single member species (Severinghaus, 1981). As a result, trophic guilds have been considered to be excellent indicators of the integrity of an environment, and thus the number and abundance of trophic guilds have been used as indices of ecosystem integrity (Henriques *et al*., 2008; Viana *et al*., 2012). Thus, the information generated on feeding habits and trophic guild structure in the present study in the Ethiopian part of Lake Turkana, where anthropogenic activities are common, can be useful in the management of the lake‘s fish community.

Chapter five

5. Characterization of socioeconomics and management of small-scale fisheries in lower Omo-Turkana sub-basin

5.1. Introduction

Ethiopia, a nation in the Horn of Africa, has a population of more than 90 million according to the population data projected for the year 2015 (CSA, 2014). It has an economy that relies heavily on a rain fed agriculture, which accounted for 80% of employment, 40.2% of GDP and 70% of export earnings in 2013/14 (Admit Zerihun *et al*., 2015). The agriculture sector is dominated by small scale farmers with low productivity (Salami *et al*., 2010; Atsbaha Gebre-Selassie and Tessema Bekele, 2012). The country often suffers risks of food insecurity largely due to a recurring drought that affects its crop productions. The nation‘s freshwater system consists of 7,185 km long river and 8,800 km^2 standing waters (Greboval *et al*., 1994). The most notable lakes, in terms of their fisheries productions, include rift valley lakes such as Zeway, Langano, Hawassa, Abaya, Chamo and Turkana (formerly Rudolf) from central to southern portions of the rift as well as Lake Tana in the country‘s northwestern highland. However, fisheries of most of these lakes are unregulated and poorly managed leading to resource overexploitation, degradation of biological diversity and reduction in fish supplies and income. Intensive fishing was reported to have already resulted in substantial changes in species composition of the commercial catches of some of these lakes (Felegeselam Yohannes, 2003; Zerihun Dejene, 2008; Golubstov and Redeat Habteselassie, 2010).

Omo-Turkana Basin within the limit of Ethiopia is part of the major Omo-Turkana system, which traverses extensive part in southwestern Ethiopia and northern Kenya (section 1.4). Lower Omo River near the delta and the Ethiopian part of Lake Turkana are thus located in the remote southwestern part of the country in the eastern arm of the East African Great Rift Valley. Their fisheries did not receive as much attention as they should from both development and scientific aspects in contrast to the main part of the lake in Kenya, which had seen foreign supports since as early as 1930s (Bayley, 1982; Kolding, 1989). A reconnaissance we took in November 2012 showed that fisheries potential was high in lower Omo River near the delta and in the Ethiopian part of Lake Turkana with considerable socioeconomic returns for the local people. However, the amount of fisheries productions, the type and quantity of fishing gears and boats, and their socioeconomic contributions as well as conservation and fisheries management status in both localities are not known. Information on stock assessment and fisheries management does not exist. Therefore, this study was conducted to address the following objectives based on the data collected during the study period:

- characterizing the sociodemographic characterstics of the fisher categories
- characterizing the types and quantities of fishing gears and boats of the fisher categories
- describing the fisheries productions, fish processing, marketing and fish prices
- assessing the fisheries socioeconomic contributions to income and livelihood of the fisher categories
- assessing fishers‘ perceptions related to sustainability of fisheries in lower Omo River and the Ethiopian part of Lake Turkana

5.2. Methodology

5.2.1. Study area

The study area is located in Dasenech Wereda (district), a constituency within South Omo Zone of the Southern Nations, Nationalities and Peoples Region (SNNP) of Ethiopia (Figure 4), situated approximately at 860 km southwest of the capital Addis Ababa. According to a projection of Ethiopian population data for the year 2015, the wereda constitutes 9.02% (62,308) of the zone population, covers an area of 2,102.31 km^2 and has a population density of 29.6 persons per square kilometer (CSA, 2014).

The Ethiopian Daasanach tribe, the major inhabitant in the study area, settles along the lower Omo River near the delta, and in the northern and northeastern part of Lake Turkana. The population generally constitutes a pastoralist livelihood with four sub-livelihood systems as: pastoralists only with livestock keeping, semi-pastoralists along Omo River with recession farming and riverine fishing, pastoralists dependent on livestock, farming and fishing, and pastoralists largely dependent on lacustrine fishing in the northeastern part of Lake Turkana (USAID, 2006).

The area has an average elevation of 373.3 m above sea level in a lowland (locally, bereha) agroecological zone. It experiences an annual temperature range of 30–40 °C (mean 34.5 °C) with a mean annual precipitation of about 350 mm. Its wet season extends from April to November receiving relatively higher amount of rainfall between April to May and Sept to November. Despite its bimodal pattern, the rainfall generally remains low and erratic (EEPCO, 2009).

5.2.2. Data collection

Permit to collect data in the study area was obtained from the local government administrations of Ethiopia. Moreover, informed consent was secured from all the research participants prior to data collection. Qualitative and quantitative data were collected using structured questionnaire (Freund and Wilson, 2003), focus group discussion, and personal observation during a period of January 2013–September 2014. This triangulation approach, which involved three methods of data collection, permitted to ensure that the data collected were comprehensive and robust. Items of the questionnaire were tested and refined based on information obtained during a preliminary survey. Major data addressed in the questionnaire included socio-demographic characteristics of the fisher respondents and key informants of focus group discussion, types, number and acquisition of fishing gears and boats, quantity of fish production and consumption by the fishers, market prices of fish and fish products, number of days at fishing, amount of income earned from fisheries productions and other alternative means of livelihood (when available), and fishers perceptions on resource and management status (Appendix 6).

Fisher respondents were included from three sampling frames consisting of 119 full-time fishers organized into cooperatives and 351 full-time individual fishers in the Ethiopian part of Lake Turkana, and 195 part-time individual fishers in lower Omo River. Sixty-seven fishers consisting 10% from each sampling frame i.e. 12 from Lake Turkana cooperative fishers, 35 from Lake Turkana individual full-time fishers and 20 from lower Omo River individual part-time fishers were drawn using simple random sampling. Data were collected with the assistance of local guides who were familiar with the traditions and languages of the fishers. Focus group discussion was held with key informants including two private and one cooperative member of the Ethiopian fish traders, and two staff members of the wereda (district) agriculture bureau.

5.2.3. Data analysis

Fisheries values were assessed as the amount of fish consumed and income earned. Local fisheres quantified their productions, consumption as well as market price of fish per ―kg" for the filleted fish, and per ―fish" for the whole fish. We followed the same quantification in our data collection and analysis.

The mount of annual fish consumption per fisher household was computed as:

$$\mathrm{FCons} = \mathrm{FProdCons} \times \mathrm{FDays}$$

Where,

FCons = Annual fish consumption (kg/year, Fish/year)

FProdCons = Portion of fisheries production consumed per fisher household per day (kg/day, Fish/day)

FDays = number of days at fishing per year (days/year)

The annual fish consumption was standardized, for possible comparison, as per capita consumption per each fisher family member.

The annual gross income earned per fisher from the fisheries production was computed as:

$$\mathrm{IncFr} = \mathrm{FProdInc} \times \mathrm{FDays} \times \mathrm{FMkPr}$$

Where,

IncFr = Gross annual income earned from fisheries sector in Ethiopian Birr (ETB/year)

FProdInc = Portion of fisheries production sold for income by a fisher per day (kg/day, Fish/day)

FDays = Number of days at fishing per year (days/year)

FMkPr = Market price of fish (ETB/kg, ETB/Fish)

The annual gross income earned from sorghum recession farming was estimated as:

$$\mathrm{IncRf} = \mathrm{Prod} \times \mathrm{SMkPr}$$

Where,

IncRf = Gross annual income earned from recession farming (ETB/year)

Prod = Amount of sorghum harvested (Kg/year)

SMkPr = Market price of sorghum (ETB/Kg)

The gross annual income (ETB/year) obtained from animal keeping was estimated as total value of the animal in ETB divided by the average number of years the animal was raised. The gross annual income (ETB/year) of fishers who were employed as guard to other organizations was estimated from their monthly salary.

Statistical variations of the measured variables, among the fisher-categories, were tested using various univariate procedures. Categorical variables of socio-demographic characteristics such as gender, marital status, education levels, and livelihood backgrounds of the fisher respondents as well as types of the fishing boats and mechanisms of boat and gear acquisition were assessed using Fisher‘s exact test of independence as frequencies of some of these variables were less than five (Fisher, 1922). Quantitative variables were tested using non-parametric methods as most of the variables deviated from normality. Quantitative variables, compared only between the individual fishers of Lake Turkana and lower Omo River, were tested for significant differences using Mann-Whitney U-test. These included number of tilapia-gill nets possessed by the fishers, and production, consumption and market prices of the small-fish groups. The rest of the quantitative variables were compared among all the three fisher-categories and their statistical significances were tested using Kruskal-Wallis test. These included age, family size and fishing experience of the fishers, number of perch-gill net possession, production, consumption and market prices of Nile perch, number of days at fishing, and gross annual income earned from fisheries and alternative means of livelihood. Mann-Whitney post-hoc test was used to identify specific groups with significant variations when Kruskal-Wallis test returned significant global variations. Spearman‘s rank correlation was used to test for linear association between gross income earned from fisheries productions and statistically significant related variables. Statistical tests were performed in PAST version 3.08 (Hammer *et al*., 2001).

5.3. Results

5.3.1. Fisher-categories

There were full-time fishers both as cooperative organizations (26%) and individuals (74%) in the Ethiopian part of Lake Turkana; whereas there were only part-time individual fishers in lower Omo River who were also engaged in other alternative means of livelihood such as sorghum recession farming (60%), labor employment as guards to local organizations (30%) and cattle raising (10%). For the entire river-lake system, there were more individual fishers (82%) than fishers organized into cooperatives (18%). The full-time fishers in the Ethiopian part of Lake Turkana on average spent 160–166 days at fishing per year, whereas the lower Omo River part-time individual fishers spent only 65 days a year. The average number of days spent at fishing for lower Omo River fishers was much lower than those of the Lake Turkana fishers, and the variation was statistically significant ($p < 0.05$; Table 12).

Table 12. Summary of the quantitative demographic and socioeconomic characteristics compared among the fisher-categories; **Fisher categories**: LT_Cop = cooperative fishers of the Ethiopian part of Lake Turkana, LT_FtIn = full-time individual fishers of the Ethiopian part of Lake Turkana, OR_PtIn = part-time individual fishers of lower Omo River; quantity of Nile perch expressed in kg, and that of small-fish groups as number of fish (Fish); Statistical significance was considered at p = 5%, significant p-values are underlined, SD = standard deviation; n = number of fisher respondents per each fisher-category.

	Unit	LT_Cop (n = 12)				[a]LT_FtIn (n = 34)				OR_PtIn (n = 20)				
		Range	Mean	SD	Med	Range	Mean	SD	Med	Range	Mean	SD	Med	p
Age	year	26–46	35	6	35	20–70	36	12	32	20–56	34	11	33	0.79
Fishing experience	year	1–30	13	10	11	3–40	13	8	10	2–30	13	8	12	0.83
Family size	number	1–9	4	2	4	3–16	9	4	10	2–12	6	3	5	≤0.005
Tilpia gillnet	number	-	-	-	-	1–10	3	2	3	1–10	3	3	2	0.17
Perch gillnet	number	1–6	3	2	2	1–5	3	1	2	1–2	1	0	1	≤0.005
Fishing days	Days $year^{-1}$	120–204	166	23	168	96–240	160	30	156	48–95	65	13	63	≤0.005
Fisheries Production	Fish $year^{-1}$	-	-	-	-	[b]0–7680	1900	2140	1638	0–1257	625	317	600	0.24
	Kg $year^{-1}$	1560–7800	4998	1659	4872	0–6942	1973	1938	1974	0–2281	1288	698	1400	≤0.005
Fish Consumption	Fish $year^{-1}$	-	-	-	-	0–4080	640	1049	0	0–343	94	119	0	0.34
	Fish $year^{-1}$ (per capita)					0–453	63	102	0	0–106	24	34	0	0.46
	Kg $year^{-1}$	0–2244	187	648	0	0–3120	1088	1101	1074	0–1478	396	512	211	≤0.005
	Kg $year^{-1}$ (per capita)	0–449	37	130	0	0–624	143	176	105	0–343	70	97	25	≤0.005
Fish market price	[c]ETB $Fish^{-1}$	-	-	-	-	3	3	0	3	40–50	49	2	50	≤0.005
	ETB kg^{-1}	40	40	0	40	40	40	0	40	40–50	44	2	45	≤0.005
Income_fisheries	ETB $year^{-1}$	62400–312000	192420	76201	194880	792–227760	39173	48761	26340	14784–139339	66240	30391	68258	≤0.005
Income_recesion farming	ETB $year^{-1}$	-	-	-	-	-	-	-	-	0–3000	1518	1303	2125	
Income_animal production	ETB $year^{-1}$	-	-	-	-	-	-	-	-	0–2000	200	616	0	
Income_others	ETB $year^{-1}$	-	-	-	-	-	-	-	-	0–7848	2121	3358	0	

[a] One individual-based fisher was the only part-timer in the Ethiopian part of Lake Turkana, and thus was excluded from this and all subsequent analyses
[b] Zero production is because some of the fishers, included in this analysis, caught only the small fish groups and not *Lt. niloticus*, or vice versa
[c] The average exchange rate for the Ethiopian currency (ETB) during the study period was approximately 1 ETB ≈ US $ 0.05

5.3.2. Socio-demographic characteristics

The quantitative socio-demographic characteristics, such as age, family size and fishing experience, of fisher respondents are given in Table 12. Maximum age was lower (46 years) for the fishers in cooperative organizations than for the individual fishers of both the lake (70 years) and lower Omo River (56 years). Individual fishers of the lake also had the highest family size (16 people per fisher household) and fishing experience (40 years). However, only family size varied significantly among the fisher categories ($p < 0.001$; Table 12) with the Lake Turkana full-time individual fishers having the highest average family size (i.e. 10 individuals per fisher household; Table 12). Table 13 summarizes the categorical socio-demographic characteristics of fishers related to gender, marital status, education level, and livelihood backgrounds. There were more than 75% male fishers, more than 70% married fishers and more than 50% fishers with no formal education. Fishers with fishing and livestock keeping (pastoralist) livelihood background ranged 33–90% while those from farming, daily labor or other job backgrounds constituted only smaller portion (≤ 33%) of the total fisher respondents. However, no socio-demographic characteristics of the respondents we assessed, both quantitative and qualitative, varied significantly among the fisher-categories ($p > 0.05$; Table 12; Table 13).

Table 13. Summary of gender, marital status, education level and livelihood backgrounds of the fisher respondents, expressed as percentage (%) of fisher respondents (n) per each fisher-category.

Abbreviations for fisher-categories are as in Table 12; G = Grade; p = p-values for Fisher's exact test of independence.

	Category	%n LT_Cop (n = 12)	LT_FtIn (n = 34)	OR_PtIn (n = 20)	p
Gender	Male	100	79	75	0.182
	Female	0	21	25	
Marital status	Married	75	79	70	0.745
	Unmarried	25	21	30	
Education level	No formal education	50	76	80	0.259
	Primary school (G 1–6)	42	21	20	
	Secondary school (G 9)	8	3	0	
Livelihood background	Fishers	33	59	50	0.065
	Livestock herders	58	50	90	
	Farmers	33	12	0	
	Daily laborers	0	3	0	
	Others	0	3	0	

5.3.3. Possession and acquisition of fishing gears and boats

Fishing gears possessed by the fishers were predominantly tilapia-gill nets and perch-gill nets (Table 14). Other forms of fishing gears were virtually nonexistent. Tilapia-gill nets were relatively smaller gears with panel dimensions of 2 m X 50 m and stretched mesh sizes of 30–34 cm and generally used for catching smaller fishes including Nile tilapia, citharinids, distichodontids and bagrids. Perch-gill nets were relatively larger gears with panel dimensions of 2 m X 100 m or 2 m X 120 m and stretched mesh sizes of mainly 40–42 cm and used for catching relatively large-sized fishes such as Nile perch. Fishers in cooperative organizations of Lake Turkana possessed only perch-gill nets whereas individual fishers of both the lake and lower Omo River possessed both tilapia and perch-gill nets.

5.3.3.1. Gear possession

The average number of tilapia-gill nets possessed per fisher did not vary significantly between the individual fishers in Lake Turkana and lower Omo River ($p > 0.05$; Table 12). In contrast, the lower Omo River part-time fishers owned the lowest average number of perch-gill nets per fisher, and the variation was statistically significant ($p < 0.05$; Table 12).

5.3.3.2. Gear acquisition

Table 14 summarizes mechanism of fishing gear acquisition by fishers. Fishers acquired fishing gears via three mechanisms such as purchase of ready-made gears or constructing own gears, renting gears from fish traders of fellow fishers, and via donation by a local non-governmental organization (NGO) namely Agri Service Ethiopia. Fisher‘s exact test showed that ways of gear acquisition varied for each fisher-category ($p < 0.05$; Table 14). Purchase of ready-made gears or constructing own gears was a major means of gear acquisition for fishers (i.e. 67–91% fishers) for each fisher-category. The border town of Silicho in northern Kenya was sole supplier of both the ready-made gears and gear fibers. Gear renting, mainly from the fish traders, was largely practiced by cooperative fishers (33%) in Lake Turkana while fishing gears were donated by NGO only to fishers in lower Omo River (15%).

Table 14. Summary of mechanisms of gear acquisition, expressed as percentage (%) of fisher respondents (n) per each fisher-category.

Abbreviations for the fisher-categories are as in Table 12; PurSelfcon = Purchased or self constructed.

	%n				
Mechanism	LT_Cop (n = 12)	LT_FtIn (n = 34)	OR_PtIn (n = 20)	p	Supplier of gear or gear fiber
PurSelfcon	67	91	75		Silicho town in northern Kenya
Rented	33	9	10		Fish traders and/or fellow fishers
Aid	0	0	15		Agri Service Ethiopia (NGO)
				0.03	

5.3.3.3. Boat possession and acquisition

Fishers generally owned or had access to three types of fishing boats namely timber boats (locally known as zatera), dugouts and motor boats. Some full-time individual fishers in Lake Turkana (21% fishers) did not own or acquire any kind of fishing boats. Table 15 summarizes fishers‘ access to and acquisition of these boats. Types of the fishing boats and means of acquisition or access to the boats varied according to the fisher-categories (Fisher‘s test, $p < 0.05$; Table 15).

Timber boats were more common among all the three fisher-categories, owned by 75% fishers in cooperatives, 55% full-time individual fishers in Lake Turkana and 50% part-time individual fishers in lower Omo River. Dugouts were owned by the individual fisher-categories, occurring largely in lower Omo River fisheries (50% fishers). Motor boats were virtually non-existent occurring only in Lake Turkana fisheries, accessed by fishers in cooperative organizations (25% fishers) and full-time individual fishers (12% fishers) via renting from fish traders. Most fishers in cooperatives (67% fishers) and part-time individual fishers in lower Omo River (90% fishers) shared boats in groups, while full-time individual fishers in Lake Turkana largely owned private boats (38% fishers).

Table 15. Summary of fishing boats possession and acquisition, expressed as percentage of fisher respondents (n) per each fisher-category.

Abbreviations for the fisher-categories are as in Table 12; MtB = motor boats; TmB = timber boats; DoB = dugouts; Rent = rented; Priv = private; Shar = shared.

	LT_Cop (n = 12)				LT_ FtIn (n = 34)				OR_ PtIn (n = 20)				p
Boats	Rent	Priv	Shar	Tot	Rent	Priv	Shar	Tot	Rent	Priv	Shar	Tot	
MtB	25	0	0	25	12	0	0	12	0	0	0	0	
TmB	0	8	67	75	0	26	29	55	0	0	50	50	
DoB	0	0	0	0	0	12	0	12	0	10	40	50	
Total	25	8	67	100	12	38	29	79	0	10	90	100	**0.00**
p												**0.00**	

5.3.4. Fish processing and marketing

The lower Omo River fishers sold fresh whole-fish directly to local restaurants and other consumers in Omorate town located only at a distance of 1–2 km from their landing sites. Lower Omo River fishers sold Nile perch at market prices of 40–50 ETB/kg of whole-fish, and the small-fish groups at 40–45 ETB per whole-fish. The Ethiopian fishers in Lake Turkana processed their fish using traditional tools such as knife and sickle. Fishers sold filleted Nile perch to the Ethiopian middlemen at a landing site price of 40 ETB/kg. For Lake Turkana fisheries, marketing between the fishers and middlemen took place directly at landing sites where the fish traders were based namely Bubua, Nazafet, Obbo, Toltale and Abaloko sites from east to west. The major market destinations for Nile perch were the local towns such as Jinka and Arba Minch as well as the capital Addis Ababa. The gutted and sun-dried small-fish such as Nile tilapia, citharininds, distichodontids and bagrids were, however, bought directly by the Kenyan fish traders whose presence there was apparently illegal. About 43% of the Lake Turkana fisher respondents sold their fish catches to the Kenyan fish traders at a landing site price of only 3 ETB/Fish regardless of fish size. The local fishers do not gain any benefit from the fish processing activity as it is solely accomplished by the illegal fishers themselves. The final market destinations for these illegally marketed fish were reportedly Kenya, Uganda and Democratic Republic of Congo (DRC).

5.3.5. Fisheries value chain

Figure 19 represents a value chain developed for lower Omo River and the Ethiopian part of Lake Turkana fisheries based on the present study.

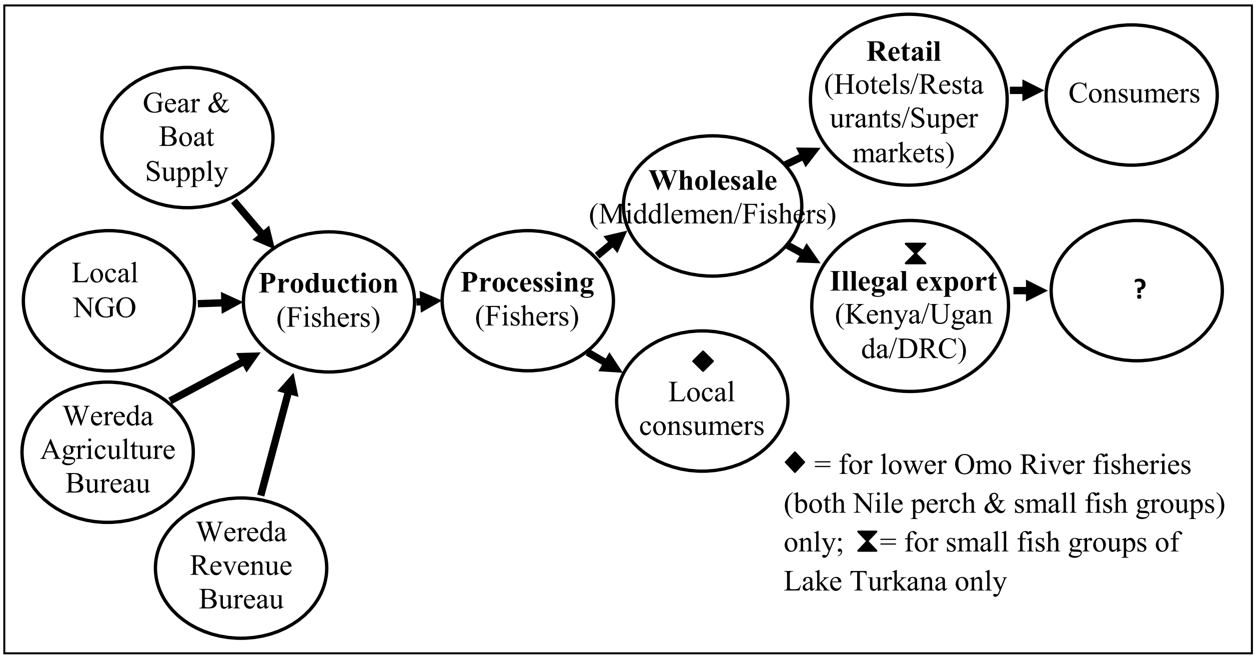


Figure 19. Value chain of lower Omo River and the Ethiopian part of Lake Turkana fisheries based on the present study; the value chain holds for both Nile perch and small fish group fisheries; exceptions specific to lower Omo River fisheries and to fisheries of small fish groups of Lake Turkana are indicated in the diagram.

5.3.6. Socioeconomic contributions of fisheries

Complete retrospective data on fisheries productions was not obtained for both the Ethiopian part of Lake Turkana and lower Omo River. Therefore, we assessed socioeconomic contributions of fisheries to livelihood and income of the fishers based on data collected during the present study (Table 12).

5.3.6.1. Fisheries productions

Fisheries productions were quantified in units of weight (kg) for Nile perch and in units of the number of fish (Fish) for the small-fish groups. The highest annual productions of small-fish groups and Nile perch originated from the Lake Turkana full-time individual fishers and cooperative fishers, respectively. However, only variations for Nile perch productions, among the fisher-categories, were statistically significant ($p < 0.05$; Table 12).

5.3.6.2. Fish consumption

The rate of consumption of small-fish groups, both per fisher household and per capita, did not vary significantly between individual fishers in Lake Turkana and lower Omo River ($p > 0.05$; Table 12). In contrast, the average rate of Nile perch consumption, both per fisher household and per capita, varied significantly among the fisher categories, with the cooperative fishers consuming the lowest average amount ($p < 0.05$; Table 12).

5.3.6.3. Gross annual income

The average gross annual income earned from fisheries varied significantly among the fisher categories ($p < 0.005$; Table 12). The cooperative fishers in Lake Turkana earned the highest average gross annual income, and the average gross annual income of the individual fishers in lower Omo River exceeded that of individual fishers in Lake Turkana (Mann-Whitney post-hoc, Bonferroni corrected $p < 0.005$; Table 12). The number of perch-gill nets possessed per fisher, number of days at fishing per year, quantity of Nile perch production, rate of Nile perch consumption, market prices of small-fish groups and Nile perch that varied significantly among the fisher-categories, were assessed in relation to the income earned by cooperative fishers in Lake Turkana and individual fishers in lower Omo River. There was significant positive correlation between the cooperative fishers gross annual income and amount of annual Nile perch production (Spearman‘s $r_s = 0.94$; $p < 0.005$). There was also significant positive correlation between gross income of individual fishers in lower Omo River and market price for Nile perch (Spearman‘s $r_s = 0.59$, $p = 0.01$). For the individual part-time fishers in lower Omo River, gross annual income earned from fisheries was higher than income earned from other alternative means of livelihood, and the variation was statistically significant ($p < 0.001$; Table 12).

5.3.7. Fishers perceptions related to resource status and management

We asked fishers if they perceived some trend in the number of fish species and fisheries productions since they started fishing in the river or the lake as well as what they think of would be the future situation. Based on their fishing experience, 96% of the fishers perceived that both the number of fish species and fisheries productions decreased since they started fishing while 4% perceived an increasing trend. Similarly 90% of the fishers thought that the fish species and productions would continue decreasing unless some management measures are enforced, 9% of the fishers thought an increasing future trend if more fishing facilities are provided while 1% of the fishers were unsure about the future situation. Fishers were also asked for what they thought would be the possible factors that might have contributed to their perceived decrease in fisheries productions (Table 16).

Table 16. Fishers' perceptions on possible factors that might have contributed to their perceived decrease in fisheries production (N = 66).

N = total number of fisher respondents in all fisher-categories

Factors	Response rate (%N)		
	yes	no	uncertain
Accessibility problems to fishing grounds	0	100	0
Unfavorable weather conditions hindering fishing	3	30	67
Lack of training for the fishers	13	0	87
Scarcity or lack of fishing gears and/or boats	6	0	94
Effects of water abstraction including irrigation	19	15	66
Hydropower dam development	19	14	67
Water pollution	12	0	88
Overfishing	93	0	7

Fishers were asked for their attitudes and opinions on the possibilities of considering implementation of the various management scenarios to the river and lake fisheries as summarized in Table 17.

Table 17. Fishers‘ perceptions related to some fisheries management issues and their attitudes towards implementing various management strategies to the lake and river fisheries.

N = total number of fisher respondents in all fisher-categories

	Response rate (%N)		
	yes	no	uncertain
Fisheries management and regulation is in place for the lake and river	26	46	28
There is fishery extension service for the lake and river fisheries that would aid in fisheries management	0	100	0
Fishers were given awareness trainings on sustainable resource utilization	22	78	0
Fishers know about the national fisheries development and utilization proclamation	0	100	0
Implementing licensing and limiting fishers	16	84	0
Implementing closed season of no fishing	21	79	0
Implementing fishing area closure	19	81	0
Limiting the type, number and mesh sizes of gears	100	0	0
Implementing co-management approach involving both government and fishers	100	0	0

5.3.8. Focus group discussions

Focus group discussions held with key informants largely focused on the management and development factors of the fisheries resources. Participants indicated that fisheries productions from both lower Omo River and the Ethiopian part of Lake Turkana showed a fluctuating to decreasing trend at least in the past ten years. Possible factors for the informants' perceived decreasing trend in the fisheries productions included overfishing, lack of sufficient fishing (i.e. gears and boats) and storage facilities (i.e. deep freezers and generators), lack of adequate training for fishers, and possible pollution of Omo River. According to the focus group discussions, fishers possessed only a few local wooden boats and lacked motorized boats for which they had to depend on fish traders for loan, and a cooperative of fish traders faced serious shortage of storage facilities. Even so, the focus group participants emphasized on over fishing, rather than scarcity of fishing gears and boats, as a main factor for a decrease in fisheries productions. Study participants underscored their concerns over illegal fishing and fish trading by the Kenyan men, and lack of fisheries management to regulate the fisheries. Moreover, lack of stock assessment data upon which management decision would be based, administrative problems related to licensing of fish traders and lack of infrastructure to effectively facilitate fish marketing, were mentioned as impeding factors for the fisheries development. Like fishers, participants of the focus group discussion also did not have any awareness about the Ethiopian proclamation on fisheries development and utilization (315/2003).

5.4. Discussion

This study characterizes the fisheries of lower Omo River solely based on the data collected during the present study as a record of data related to the fishers, fisheries productions and fishing techniques did not exist for both localities.

5.4.1. Fishers and the fisheries

The fisheries supported both full-time and part-time fishers operating in organizations (cooperatives) and on individual basis. Fishers' gender, marital status, education level and livelihood background did not vary significantly within as well as among the fisher-categories. Both males and females were part of the fisher community. However, close scrutiny of the gender composition infers that women's engagement in fishing activity was relatively limited i.e. proportions of female fishers ranged only 0–25% (Table 13). All the fisher-categories largely consisted of married males. Majority of fishers within all the fisher-categories also had no education, which could have negative implications particularly in relation to fisheries management where the fishers should properly understand trainings and related matters about sustainable resource exploitation, develop positive attitude and actively participate in the management processes. Analysis of the fishers' livelihood backgrounds showed that majority of the fishers originated from the local fishing and pastoralist community signifying socioeconomic importance of the lake and river fisheries to the local people.

Similar to most of the African inland fisheries, fisheries in lower Omo River and the Ethiopian part of Lake Turkana are small-scale, gill net fisheries, largely dependent on local wooden boats (Sverdrup-Jensen and Nielsen, 1998). Timber boats occurred both in the riverine and lacustrine fisheries but possessed largely by the cooperative fishers (i.e. 75% fishers). The local dugouts were largely owned by the lower Omo River fishers where they also provided navigation services to the local people and tourists to cross Omo River. Motor boats, which occurred only in Lake Turkana fisheries, were largely accessed by fishers in cooperative organizations (25% fishers) than by the individual full-time fishers of the lake (12% fishers).

The fisheries were largely dependent on a few commercially important fish species despite the occurrence of up to 79 native fish species in Omo-Turkana Basin (Mulugeta

Wakjira and Abebe Getahun, unpublished data). These included Nile perch (*Lt. niloticus*, Latidae) and the small-fish groups such as Nile tilapia (*O. niloticus*, Cichlidae), a citharinid (*C. citharus*, Citharinidae), a distichodontid (*D. nefasch*, Distichodontidae) and bagrids (*B. bajad* and *B. docmak*, Bagridae). Lake Turkana fishers in cooperative organizations apparently specialized in Nile perch fishery as they possessed only perch-gill nets whereas the individual fisher-categories harvested both Nile perch and the small-fish groups.

Fishers in Lake Turkana, both in organizations (cooperatives) and as individuals, were fully engaged in fishing activity with absolute reliance on fisheries for their livelihood and income, and thus conducted fishing during most part of the year. Part-time individual fishers in lower Omo River depended on fishing as an important part of their income but also had other means of livelihood to sustain their living, and thus did not fish during most part of the year. Subsistence aspect of the fisheries productions was particularly evident with the full-time individual fishers in Lake Turkana. Fishers of this category consumed the highest amounts of Nile perch (household consumption, median = 1074 kg/year; per capita highest consumption = 624 kg/year; per capita median consumption = 105 kg/year) than fishers of the other two categories (Table 12). The lake fishery was also an important source of income for the fishers in cooperative organizations. The highest gross annual income earned by this group is probably attributable to the highest production rate of Nile perch as these two variables significantly correlated (section 5.3.6.3). The highest income secured by fishers in cooperative organizations, compared to the individual fishers, may also highlight the necessity of strengthening organizations and collective action in small-scale fisheries (SSFs) to ensure their contributions to fishers‘ livelihood (FAO, 2014). The study also found that fisheries production was a major source of livelihood and income for the part-time fishers in lower Omo River. These fishers earned higher income from fisheries than from the other alternative means of livelihood. Moreover, compared to the full-time individual fishers of Lake Turkana, the lower Omo River part-time fishers earned higher average gross annual income despite its lower amount of annual productions. This could possibly relate to the relatively higher average market price of Nile perch for the lower Omo River fishers as it significantly correlated with the group‘s income (section 5.3.6.3).

5.4.2. Major socioeconomic issues related to the fisheries

Important socioeconomic issues related to the river and the lake fisheries were identified from analysis of some of the fisheries value chain components. Fisheries value chain is a high-level model of how fishery businesses receive raw materials as input (capture and culture fisheries), add value to the raw materials through various processes and sell finished products to customers. Simply put, fisheries value chain represents a network of all the activities that would eventually lead to a supply of value added fish and fish products to the end user (De Silva, 2011). Constraints identified from value chain analysis included lack of adequate fishing gears and boats, lack of planned support from government structure and NGOs, problem of fish processing, lack of adequate preservation facilities, lack of infrastructure, and social tension of the Ethiopian fishers with the rival Turkana tribe and illegal traders from northern Kenya.

Fishers owned on average only 1–3 perch-gill nets and 3 tilapia-gill nets per head. Gill nets were not readily available from suppliers nor were there cooperatives for gear making. A large number of Ethiopian fishers purchased gill nets from a northern

Kenyan border town of Silicho for which they had to seek illegal foreign currency exchange. Many fishers also had to depend on shared local boats or those rented from fish traders tied up with compulsory sell to them. Moreover, 21% of the Lake Turkana‘s full-time individual fishers had no access to boats and thus restricted to shore fishing. Fisheries potential appears to be high in the Omo River Delta and Ethiopian part of Lake Turkana. The Kenyan part of the lake had received fisheries development supports from UK and Norway since as early as 1930s (Bayley, 1982; Kolding, 1989). However, fisheries in the Ethiopian part of the basin received virtually no development supports except for the recent aid by Agri Service Ethiopia that reportedly provided some gill nets and training to the fishers. The role of Dasenech Wereda agriculture bureau in the development and management of the fisheries was also limited. It only provided advisory supports to the fishers in relation to sustainable use of resource. The wereda did not have a road connecting the lake to its nearby Omorate town, which serves as a transit route for fish trading to the major local towns and cities for domestic market. The wereda‘s revenue bureau only participated in the process of tax collection including the value added tax (VAT).

Fish processing into fillets or sun-dried fish were undertaken in an artisanal way and it was sole responsibility of the fishers themselves. There were no middlemen operating in the fisheries of lower Omo River as the part-time individual fishers themselves sold both Nile perch and small-fish groups to local consumers and restaurants and hotels in the nearby town of Omorate. Active middlemen in the marketing of Lake Turkana fisheries included only 5–6 Ethiopian private fish traders and a cooperative organization largely composed of youth with no alternative jobs. However, lack of ample preservation facilities including deep freezers and power generators constrained activities of the cooperative resulting in spoilage or post harvest loss particularly at time of abundant catch. Fish marketing between fishers and middlemen was a wholesale process and it took place at the major landing sites. A local private business namely the fish production and marketing enterprise (FPME) and an international NGO viz. Ethio-fishery used to participate in fish marketing but they were inactive during the present study period.

The Kenyan Turkana tribe has been falling into a frequent conflict with the Ethiopian Daasanach tribe apparently over competition for pasture and water resources for their cattle (Yongo *et al*., 2010). Clash between the two tribes was not just limited to claims of pasture land and water resources but also extends to fierce competition over the fisheries resources. Fish populations in the Kenyan part of the lake were reported to have already been overfished leading to changes in fish composition and abundance (Kolding, 1992, 1995). This factor apparently seems to have intensified a competition between the two major rivals for fish in the Ethiopian part of the lake, which has never seen any intensive development effort for its fisheries resource. During a period of this study, we encountered incidents of fights, between the rival fishers, that claimed dozens of lives. I was saddened to come to learn during my last field trip the slaying of a young fisherman and my local guide because of such clashes between the fishers reportedly while he was fishing in the lake. Participants of the study mentioned that gear theft, illegal fishing and illegal fish trading by the Kenyan fishers and men in the Ethiopian part of Lake Turkana as serious concerns that could hinder any fisheries management and development efforts. The illegal fishing and fish marketing made it virtually impossible to keep catch and effort data of the lake fisheries. Additionally, dependence of fishers on these fish traders for gear and boat loans meant that they had to use small mesh gears as required by the lenders. Study participants from all categories i.e. fishers, fish traders and development workers indicated that Ethiopian government was in fact losing considerable amount of tax due to illegal fishing and fish marketing in Lake Turkana.

5. 4.3. Fisheries productions and resource management

This study found that socioeconomic values, of both the lake and the river fisheries, in terms of contributions to livelihood and income of the local people were considerable. However, based on their fishing experiences, majority of the fishers had a perception that fisheries productions showed a declining trend and will continue to do so. All fishers, of the river and the lake considered together (n = 66), had a fishing experience ranging 1–40 years with a median value of 10.5 years. Key informants of the focus group discussion had same perception as the fishers. A number of potential factors assessed for the perceived decrease in fisheries productions related to natural factors such as accessibility problems and non-conducive weather conditions, lack of training and fishing facilities, development activities, water pollution and overfishing (Table 16). Entire fishers disagreed to accessibility problem to fishing grounds as a limiting factor while most fishers were not certain about the possible effects of factors related to weather conditions, lack of training and fishing facilities, development activities and water pollution. Majority of the fishers ascribed their perceived decrease in fisheries productions to overfishing. Focus group discussion of the key informants also concurred with the fishers‘ perceptions on possible factors that might have contributed to their perceived decrease in fisheries productions.

Majority of the fishers and focus group participants emphasized lack of institutional organization, firm regulatory framework, budget and trained fishery personnel to regulate both the lake and river fisheries resources. Fishers were not trained on sustainable resource utilization; all fishers, fish traders and development workers had no knowledge about the national fisheries proclamation no. 315/2003 ratified a decade ago. The national proclamation was intended to serve as a framework for the regional states to develop their own proclamations, specific guidelines and management plans for the waters within their jurisdictions. Nevertheless, most of the regional states including SNNP did not realize it except the Amhara Region (Abebe Getahun and Eshete Dejen, 2012). Thus, as the present assessment of fishers' perceptions on resource sustainability clearly revealed the necessity of management intervention, the regional state should urgently take all the necessary steps towards implementing the proclamation, formulating and enforcing the necessary management measures for lower Omo River and the Ethiopian part of Lake Turkana fisheries.

Assessment of fisher's attitudes towards the possibility of considering one or more of the management strategies showed that most fishers had negative attitude towards most of the potential strategies (Table 17). Fishers mentioned lack of alternative means of livelihood as sole reasons for their negative attitude towards the potential management strategies. All fishers agreed to ‗limiting the type, number and efficiency of fishing gears' as possible fisheries management strategy. All fishers supported a fisheries co-management approach as best potential practice for the river and lake fisheries. Fisheries co-management is an arrangement in which responsibilities and obligations for sustainable fisheries management are negotiated, shared and delegated between government, fishers, and other stakeholders. The degree of delegation or involvement of fishers in the management process could vary giving rise to different forms of co-management as instructive, consultative, cooperative, and delegated (FRDC, 2008). In a collaborative model, decision-making is negotiated and shared between concerned parties with some decisions such as fishing times or area closures being assigned to fishers or their organizations. Moreover, a collaborative management usually results in a partnership between state and fishers as well as cooperation with other stakeholders and independent organizations such as NGOs and research organizations (Pomeroy and Rivera-Guieb, 2006). I, therefore, consider a collaborative mode of co-management a more appropriate approach for lower Omo River and Lake Turkana fisheries management. In line with this kind of management scenario, proclamation, guidelines and management plans to be developed by the Ethiopian SNNP regional state should entail the essence of participatory management despite the national proclamation that entailed mainly a command and control approach.

The socioeconomic information generated in this study should serve as a necessary input for successful and sustainable fisheries resource, sound management and development plans by the regional state (Brainerd, 1994). As Lake Turkana and most of its fish stocks are shared between Ethiopia and Kenya, any management approach that has not involved both nations and the fishers would not be anticipated to be effective. Especially, due to the competing interests on the fisheries resources of Lake Turkana between the rival fishers of the two nations, a co-management approach involving both nations should be urgently initiated. Ecosystem approach to fisheries (EAF) is notionally a more sound approach to ensure more sustainable fisheries management. However, due to limitations in integrative research and information encompassing all interests and sectors, it does not appear to be feasible to recommend EAF as a first line approach for the current problems of lower Omo River and Lake Turkana fisheries (Andrew and Evans, 2011).

5.5. Conclusion

- Fisheries of lower Omo River and the Ethiopian part of Lake Turkana contributed to livelihood, income and employment opportunities of the local inhabitants. Individual fishers in the lower Omo River largely constituted a livelihood that combines riverine fishing with recession farming, and semi-pastoralists largely depended on lacustrine fishing as full-time fishers in the Ethiopian part of Lake Turkana. Fishers in cooperative organizations aimed income generation from the lacustrine fisheries. Moreover, the Lake Turkana fisheries contributed to national economy in the form of revenue tax and VAT from the Ethiopian fish traders.
- In order to sustain fisheries contribution to subsistence, food security and livelihoods of the local people, the government in particular the regional state (SNNP) should address the major socioeconomic issues arising out of the various components of the fisheries value chain.
- Moreover, urgent stock assessment is required to generate baseline data on the resource base that would in turn be used for development and management decisions. Based on the preliminary information obtained in this study such as illegal fishing, the use of small mesh size gears and illegal marketing of fish, urgent management intervention is imperative.

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Appendix 1: Catalogue numbers and sampling localities of voucher specimens of fish species identified from lower Omo River and the Ethiopian part of Lake Turkana during the present study, and deposited at the Zoological Natural History Museum (ZNHM) of Addis Ababa University, Addis Ababa, Ethiopia:

Polypterus bichir Lacepède, 1803: ZNHM-F-0001, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ***Polypterus senegalus*** Cuvier, 1829: ZNHM-F-0002–0003, lower Omo River, Omo-Turkana Basin, 04°41′31.92″ N, 035°59′40.2″ E, Ethiopia; ***Heterotis niloticus*** (Cuvier, 1829): ZNHM-F-0004, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°29′22.2″ N, 036°5′16.44″ E, Ethiopia; ***Mormyrus caschive*** Linnaeus, 1758: ZNHM-F-0005, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ZNHM-F-0006, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E , Ethiopia; ***Mormyrus kannume*** Forsskål, 1775: ZNHM-F-0007, lower Omo River, Omo-Turkana Basin, 04°42′27.36″ N, 035°59′37.32″ E, Ethiopia; ***Mormyrops anguilloides*** (Linnaeus, 1758)*:* ZNHM-F-0008, lower Omo River, Omo-Turkana Basin, 04°41′31.92″ N, 035°59′40.2″ E, Ethiopia; ZNHM-F-0009, lower Omo River, Omo-Turkana Basin, 04°42′27.36″ N, 035°59′37.32″ E, Ethiopia; ***Hyperopisus bebe*** (Lacepède, 1803): ZNHM-F-0010, lower Omo River, Omo-Turkana Basin, 04°41′31.92″ N, 035°59′40.2″ E, Ethiopia; ZNHM-F-0011–12, lower Omo River, Omo-Turkana Basin, 04°42′27.36″ N, 035°59′37.32″ E, Ethiopia; ***Pollimyrus petherici*** (Boulenger, 1898): ZNHM-F-0013, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E, Ethiopia; ZNHM-F-0014, lower Omo River, Omo-Turkana Basin, 04°42′27.36 ″ N, 035°59′37.32″ E, Ethiopia; ***Hydrocynus vittatus*** Castelnau, 1861*:* ZNHM-F-0015, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ZNHM-F-0016–17, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°29′22.2″ N, 036°5′16.44″ E, Ethiopia; ZNHM-F-0018, lower Omo River, Omo-Turkana Basin, 4°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ***Hydrocynus forskahlii*** (Cuvier, 1819): ZNHM-F-0019, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E, Ethiopia; ZNHM-F-0020, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ***Alestes baremoze*** (Joannis, 1835): ZNHM-F-0021, lower Omo River, Omo-Turkana Basin, 04°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ZNHM-F-0022, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ***Brycinus nurse*** (Rüppell,1832): ZNHM-F-0023, lower Omo River, Omo-Turkana Basin, 04°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ZNHM-F-0024, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ***Citharinus citharus*** (Geoffroy St. Hilaire, 1809): ZNHM-F-0025, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ZNHM-F-0026–27, Lake Turkana in

Ethiopia, Omo-Turkana Basin, 04°27′46.8″ N, 036°11′57.12″ E, Ethiopia; ZNHM-F-0028–29, lower Omo River, Omo-Turkana Basin, 04°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ZNHM-F-0030, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E, Ethiopia; ***Distichodus nefasch*** (Bonnaterre, 1788): ZNHM-F-0031, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E, Ethiopia; ZNHM-F-0032, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°27′46.8″ N, 036°11′57.12″ E, Ethiopia; ***Labeo horie*** Heckel, 1847: ZNHM-F-0033, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ZNHM-F-0034, lower Omo River, Omo-Turkana Basin, 04°41′31.92″ N, 035°59′40.2″ E, Ethiopia; ***Labeo niloticus*** (Linnaeus, 1758): ZNHM-F-0035, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°29′22.2″ N, 036°5′16.44″ E, Ethiopia; ZNHM-F-0036, lower Omo River, Omo-Turkana Basin, 4°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ZNHM-F-0037–38, lower Omo River, Omo-Turkana Basin, 04° 41′31.92″ N, 035°59′40.2″ E, Ethiopia; ***Labeo coubie*** Rüppell, 1832*:* ZNHM-F-0039, Lake Turkana in Ethiopia, Omo-Turkana Basin, 4°27′46.8″ N, 036°11′57.12″ E, Ethiopia; ***Auchenoglanis biscutatus*** (Geoffroy St. Hilaire, 1809): ZNHM-F-0040, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E, Ethiopia; ZNHM-F-0041, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°29′22.2″ N, 036°5′16.44″ E, Ethiopia; ***Auchenoglanis occidentalis*** (Valenciennes, 1840): ZNHM-F-0042, lower Omo River, Omo-Turkana Basin, 04°42′27.36″ N, 035°59′37.32″ E, Ethiopia; ZNHM-F-0043, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ***Clarias gariepinus*** (Burchell, 1822): ZNHM-F-0044–45, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ***Bagrus bajad*** (Forsskål, 1775): ZNHM-F-0046, lower Omo River, Omo-Turkana Basin, 04°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ZNHM-F-0047, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ***Bagrus docmak*** (Forsskål, 1775): ZNHM-F-0048, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E, Ethiopia; ZNHM-F-0049, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ***Chrysichthys auratus*** (Geoffroy St. Hilaire, 1809): ZNHM-F-0050–51, lower Omo River, Omo-Turkana Basin, 04° 41′31.92″ N, 035°59′40.2″ E, Ethiopia; ZNHM-F-0052, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°27′46.8″ N, 036°11′57.12″ E, Ethiopia; ***Malapterurus minjiriya*** Sagua, 1987: ZNHM-F-0053, lower Omo River, Omo-Turkana Basin, 04° 41′31.92″ N, 035°59′40.2″ E, Ethiopia; ***Synodontis filamentosus*** Boulenger, 1901: ZNHM-F-0054, lower Omo River, Omo-Turkana Basin, 04°42′27.36″ N, 035°59′37.32″ E, Ethiopia; ZNHM-F-0055, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ***Synodontis schall*** (Bloch & Schneider, 1801): ZNHM-F-0056, lower Omo River, Omo-Turkana Basin, 04°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ZNHM-F-0057, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0'1.44" E, Ethiopia; ZNHM-F-0058–59, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ZNHM-F-0060–61, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ZNHM-F-0062, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°27′46.8″ N, 036°11′57.12″ E, Ethiopia; ***Schilbe mystus*** (Linnaeus, 1758): ZNHM-F-0063, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E, Ethiopia; ***Schilbe uranoscopus*** Rüppell, 1832: ZNHM-F-0064, lower Omo River, Omo-Turkana Basin, 04°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ZNHM-F-0065, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ZNHM-F-0066–67, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ***Oreochromis niloticus*** (Linnaeus, 1758): ZNHM-F-0068, lower Omo River, Omo-Turkana Basin, 04°39′29.88″ N, 036°0′52.56″ E, Ethiopia; ZNHM-F-0069, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°29′22.2″ N, 036°5′16.44″ E, Ethiopia; ***Lates niloticus*** (Linnaeus, 1758): ZNHM-F-0070, lower Omo River, Omo-Turkana Basin, 04°40′28.2″ N, 036°0′1.44″ E, Ethiopia; ZNHM-F-0071, lower Omo River, Omo-Turkana Basin, 04°42′27.36″ N, 035°59′37.32″ E, Ethiopia; ZNHM-F-0072, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°34′40.08″ N, 036°4′25.32″ E, Ethiopia; ZNHM-F-0073, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°31′46.92″ N, 036°9′46.44″ E, Ethiopia; ZNHM-F-0074–76, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°29′22.2″ N, 036°5′16.44″ E, Ethiopia; ***Tetraodon lineatus*** Linnaeus, 1758: ZNHM-F-0077, Lake Turkana in Ethiopia, Omo-Turkana Basin, 04°29′22.2″ N, 036°5′16.44″ E, Ethiopia.

Appendix 2: Images of fish species identified from lower Omo River and the Ethiopian part of Lake Turkana during the present study. Section 2.3 should be consulted for more details on each species.

Figure 2A-1. *Polypterus bichir*

Figure 2A-2. *Polypterus senegalus*

Figure 2A-3. *Heterotis niloticus*

Figure 2A-4. *Mormyrus caschive*

Figure 2A-5. *Mormyrus kannume*

Figure 2A-6. *Mormyrops anguilloides*

Figure 2A-7. *Hyperopisus bebe*

Figure 2A-8. *Pollimyrus petherici*

Figure 2A-9. *Hydrocynus vittatus*

Figure 2A-10. *Hydrocynus forskahlii*

Figure 2A-11. *Alestes baremoze*

Figure 2A-12. *Brycinus nurse*

Figure 2A-13. *Citharinus citharus*

Figure 2A-14. *Distichodus nefasch*

Figure 2A-15. *Labeo horie*

Figure 2A-16. *Labeo niloticus*

Figure 2A-17. *Labeo coubie*

Figure 2A-18. *Auchenoglanis biscutatus*

Figure 2A-19. *Auchenoglanis occidentalis*

Figure 2A-20. *Clarias gariepinus*

Figure 2A-21. *Bagrus bajad*

Figure 2A-22. *Bagrus docmak*

Figure 2A-23. Chrysichthys auratus

Figure 2A-24. *Malapterurus minjiriya*

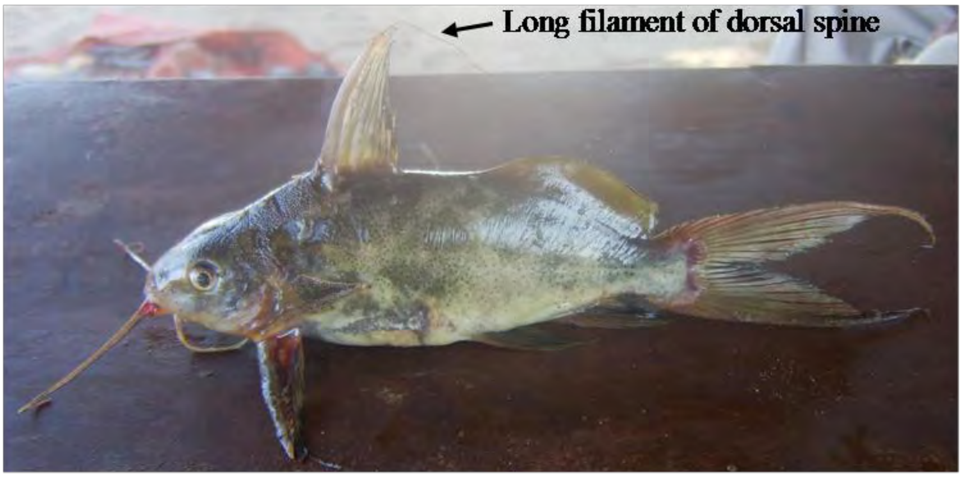

Figure 2A-25. *Synodontis filamentosus*

Figure 2A-26. *Synodontis schall*

Figure 2A-27. *Schilbe mystus*

Figure 2A-28. *Schilbe uranoscopus*

Figure 2A-29. *Oreochromis niloticus*

Figure 2A-30. *Lates niloticus*

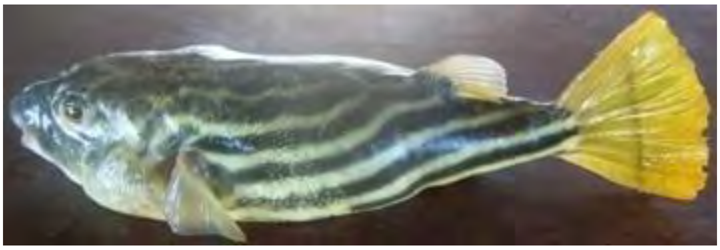

Figure 2A-31. *Tetraodon lineatus*

Appendix 3: Annotated checklist for the native freshwater fishes of Omo-Turkana Basin with their local names when available, historical and present records, accounts on valid scientific names and synonyms, brief distribution account, and maximum length (TL, SL or FL) as reported for the basin (when available); TL = total length; SL = standard length; FL = fork length; classification and family-group names are according to Nelson (2006) except for Arapaimidae and Nemacheilidae that followed Laan *et al*.

(2014); numbers of family (F), genera (G) and species (Sp) are given under the respective order in parentheses.

Order, family, species, local name(s), language	**Annotations on occurrence in the basin, scientific names, distribution elsewhere, and maximum length (TL/SL/FL)**
Ord. Ceratodontiformes (1F, 1G, 1Sp) **Fam. Protopteridae** *Protopterus aethiopicus* Heckel, 1851	Known only from three records from Lake Turkana by the Kenyan Marine and Fisheries Research Institute (KMFRI) station on the western shore of the lake at Kalakol; reported as *Protopterus aethiopicus aethiopicus* (Seegers *et al*., 2003); not reported from the Ethiopian part of the lake; Nilo-Sudanic in distribution; 200 cm TL.
Ord. Polypteriformes (1F, 1G, 2Sp) **Fam. Polypteridae** *Polypterus bichir* Lacepède, 1803 Sharfante (Daasanach)	Lake Turkana (Günther, 1896; Boulenger, 1909; Hopson and Hopson, 1982) as *Polypterus bichir* Geoffroy St. Hilaire, 1802; but the generic name lacked Latinization during the original description (Eschmeyer *et al*., 2016); thus, it is an old name for *Polypterus bichir* Lacepède, 1803; also reported as *P. bichir bichir* Lacepède, 1803 (Gosse, 1984; Seegers *et al*., 2003); also recorded from Kerio River mouth in Kenya; sampled in the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; 76 cm TL (present data).
Polypterus senegalus Cuvier, 1829 Sharfante (Daasanach)	North east end of Lake Turkana (Boulenger, 1905b, 1906, 1909; Hopson and Hopson, 1982); Omo River Delta (Pellegrin, 1935), and in the lower Omo River (Baron *et al*., 1997); reported as *Polypterus senegalus senegalus* (Seegers *et al*., 2003); sampled in the lower Omo River during the present study; not reported from the Ethiopian part of the lake; Nilo-Sudanic in distribution; also in Congo basin; 50.5 cm TL.

Ord. Osteoglossiformes (3F, 7G, 9Sp) **Fam. Arapaimidae** *Heterotis niloticus* (Cuvier, 1829)	North east end of Lake Turkana (Boulenger, 1906, 1909); subsequently recorded from the lake by Hopson and Hopson (1982) as *Heterotis niloticus* Cuvier, 1929, a synonym with erroneous year of publication; lower Omo River (Baron *et al*., 1997); sampled in the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; 98 cm TL.
Fam. Mormyridae *Mormyrus caschive* Linnaeus, 1758 Achumulo (Daasanach)	Lower Omo River (Baron *et al*., 1997); sampled in both the lower Omo River and the Ethiopian part of Lake Turkana during the present study, a first record for Lake Turkana; Nilotic in distribution; 37 cm SL (present data).
Mormyrus kannume Forsskål, 1775 Achumulo (Daasanach)	Turkwell River in Kenya; only observed as swimming in the water of Omo River Delta by Hopson and Hopson (1982); lower Omo River (Baron *et al*., 1997); sampled in the lower Omo River during the present study; also reported as occurring in Kerio system in Kenya (Seegers *et al*., 2003); Nilotic in distribution; 100 cm TL.
Mormyrops anguilloides (Linnaeus, 1758)	Lower Omo River (Baron *et al*., 1997); sampled in the lower Omo River during the present study; Nilo-Sudanic in distribution; also in Congo basin; reported in Wabishebelle and Juba systems at Geladin in Ethiopia as *Mormyrops deliciosus* (Leach, 1810) (Boulenger, 1905b, 1909), which is now a junior synonym; 42 cm SL (present data).
Hyperopisus bebe (Lacepède, 1803)	Omo River Delta (Hopson and Hopson, 1982); lower Omo River (Baron *et al*., 1997); no scientific collections of the species exist from Lake Turkana excepting the verbal reports by the fishers of its

	occurrence in the northern end of the lake (Seegers *et al*., 2003); sampled in the lower Omo River during the present study; thus, past and present records tend to indicate the species to be rather riverine probably confined to Omo River; Nilo-Sudanic in distribution; 37 cm SL (present data).
Marcusenius cyprinoides (Linnaeus, 1758)	Lower Omo River (Baron *et al*., 1997); not sampled during the present study; Distribution: freshwater, Nilo-Sudanic in distribution; also in upper Congo River.
Pollimyrus petherici (Boulenger, 1898)	Lower Omo River (Baron *et al*., 1997); sampled in the lower Omo River during the present study; Nilotic in distribution; 19 cm SL (present data).
Pollimyrus isidori (Valenciennes, 1847)	Gojeb River, upper tributary of Omo River system (Dgebuadze *et al*., 1994); not sampled during the present study; Nilo-Sudanic in distribution; also in Congo basin (Uele River).
Fam. Gymnarchidae *Gymnarchus niloticus* Cuvier, 1829	Northeast of Lake Turkana (Boulenger, 1906, 1909); subsequently Hopson and Hopson (1982) only observed its fishery in the northern end of the lake near Omo Delta; not sampled during the present study; current status not clear; not reported from the Ethiopian part of the lake; Nilo-Sudanic in distribution; 151 cm TL.
Ord. Characiformes (3F, 7G, 12Sp) **Fam. Alestidae** *Hydrocynus vittatus* Castelnau, 1861	Lake Turkana (Worthington and Richardo, 1936); subsequently not caught but speculated by Hopson and Hopson (1982) that ecological changes in the lacustrine environment might have deterred the riverine species from entering the lake; reported as *Hydrocyon lineatus* Bleeker, 1862 or *Hydrocynus lineatus* Bleeker, 1862, both junior synonyms;

Kornech (Daasanach)	caught both at the lower Omo River and the Ethiopian part of Lake Turkana during the present study; a first record for Omo River; Nilo-Sudanic in distribution; also in Congo, Zambezi and Southern provinces; 70 cm SL.
Hydrocynus forskahlii (Cuvier, 1819) Kornech (Daasanach)	Lake Turkana (Pellegrin, 1905; Boulenger, 1909; Hopson and Hopson, 1982); Omo River and its delta (Pellegrin, 1935); lower Omo River (Baron *et al*., 1997); reported as *Hydrocyon forskalii*, Cuvier, 1819 or *Hydrocynus forskalii* Cuvier, 1819 or *Hydrocyon forskali* Cuvier, 1819, all synonyms bearing misspelled specific epithet; sampled in both lower Omo River and the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; also in Lower Guinea and Congo provinces; 78 cm SL.
Alestes baremoze (Joannis, 1835) Lamete (Daasanach)	Lake Turkana (Boulenger 1905; Boulenger, 1909; Hopson and Hopson, 1982); Omo River and its delta (Pellegrin, 1935); lower Omo River (Baron *et al*., 1997); reported as *Alestes baremose* (Joannis, 1835), a misspelled synonym; also reported as a subspecies *Alestes baremoze tchadense* Blache, 1964 (Paugy, 1984); sampled in both from the lower Omo River and the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; 43 cm TL.
Alestes dentex (Linnaeus, 1758)	Lake Turkana (Boulenger, 1909; Worthington, 1932; Pellegrin, 1935; Hopson and Hopson, 1982); Omo River system (Baron *et al*., 1997); not sampled during the present study; not reported from the Ethiopian part of the lake; Nilo-Sudanic in distribution; also Lower Guinea province; 53 cm TL.

Brycinus macrolepidotus Valenciennes in Cuvier & Valenciennes, 1850	Omo River system (Boulenger, 1903a, 1906, 1909; Pellegrin, 1935; Baron *et al*., 1997); Lake Turkana (Boulenger, 1906, 1909); Hopson and Hopson (1982) only observed a specimen of 20 cm FL swimming slowly at the surface in a manner characteristic of this species in Omo River, 10 km upstream from the mouth of the delta; recorded in Omo River system (Baron *et al*., 1997); reported as *Alestes macrolepidotus* Cuvier and Valenciennes, 1849, which is an old name; not sampled during the present study; status in Lake Turkana not clear, likely a riverine species in Omo; Sudanian in distribution.
Brycinus nurse (Rüppell,1832)	Lake Turkana (Günther, 1896; Boulenger, 1909; Hopson and Hopson, 1982); reported as *Alestes rueppellii* (Günther, 1864) and *Alestes nurse* (Rüppell, 1832), both junior synonyms; Lake Turkana population described as a subspecies *Brycinus nurse nana* (Pellegrin, 1935), which Seegers *et al*. (2003) considered valid on account of its small size (max FL 12 cm) in contrast to conspecifics found elsewhere growing to over FL 20 cm; Omo River system (Baron *et al*., 1997); sampled in both lower Omo River and the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; also Lower Guinea province.
Brycinus ferox (Hopson and Hopson, 1982)	A freshwater species described from Lake Turkana, where it is endemic, as *Alestes ferox* Hopson and Hopson, 1872, which is now a junior synonym; not reported from the Ethiopian part of the lake; not sampled during the present study; 12 cm FL; 8.1 cm SL.
Brycinus minutus (Hopson	A freshwater species described from Lake Turkana, where it is

and Hopson, 1982)	endemic, as *Alestes minutus* Hopson and Hopson, 1872 which is now a junior synonym; not reported from the Ethiopian part of the lake; not caught during the present study; 3.7 cm FL; 3.3 cm SL.
Micralestes elongatus Daget, 1957	Omo River system (Boulenger, 1903a, 1909); Lake Turkana (Hopson and Hopson 1982); both reported as *Micralestes acutidens* (Peters, 1852) which apparently was a misidentification because the descriptions given by the authors particularly the inner dentary teeth ―monocuspid" is diagnostic for *Micralestes elongatus* vs. pluricuspid for *M. acutidens* (Paugy and Schaefer, 2007); also recorded in lower Omo River (Baron *et al*., 1997); not reported from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; also Lower Guinea province; 6 cm TL.
Fam. Citharinidae *Citharinus citharus* (Geoffroy St. Hilaire, 1809) Nakurach (Daasanach)	Lake Turkana (Günther, 1896; Hopson and Hopson, 1982); Lake Turkana population described as *Citharinus citharus intermedius* Worthington, 1932; lower Omo River (Pellegrin, 1935; Baron *et al*., 1997); reported as *Citharinus geoffroii* Cuvier, 1829, *Citharinus citharis* Geoffroy St. Hilaire, 1809 or *Citharinus catharus intermedia* Worthington, 1932; sampled in both lower Omo River and the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; 58 cm SL.
Fam. Distichodontidae *Distichodus nefasch* (Bonnaterre, 1788)	Described from Lake Turkana as *Distichodus rudolphi* Günther, 1896 , which is now a junior synonym; reported in the lake by subsequent investigators (Boulenger, 1905; Boulenger 1909; Hopson and Hopson 1982); recorded in lower Omo River (Baron *et al*., 1997); reported as

Golo (Daasanach)	*Distichodus niloticus* (Linnaeus in Hasselquist, 1762), *Distichodus niloticus* (Linnaeus, 1762) or *Distichodus niloticus (*Linnaeus, 1766), names which are unavailable under the rules of the Code of ICZN (Fricke 2008; Welter-Schultes and Feuerstein 2008); also the name in its original combination as Salmo niloticus Hasselquist, 1762 is a subjective junior homonym of an independent taxon Salmo niloticus Linnaeus, 1758 which is now valid as Alestes dentex (Linnaeus, 1758) (ICZN, Opinion 1813); sampled in both lower Omo River and Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; 83 cm TL.
Nannocharax niloticus (Joannis, 1835)	Lower Omo River (Baron *et al*., 1997); not sampled during the present study; Nilotic in distribution.
Ord. Cypriniformes (2F, 9G, 22Sp) **Fam. Cyprinidae** *Barbus stigmatopygus* Boulenger, 1903b	Lake Turkana (Boulenger, 1911); Omo River and its delta (Pellegrin, 1935), and in streams Kalakol and Kataboi in Kenya (Hopson and Hopson, 1982); lower Omo River (Baron *et al*., 1997); reported as *Barbus werneri* Boulenger, 1905, which is a junior synonym; also mentioned as ‗*Barbus*' aff. *stigmatopygus* Boulenger, 1903b casting doubts both on its identification and taxonomic status (Seegers *et al*., 2003); not sampled during the present study; Nilo-Sudanic in distribution; also in Eastern province (Ruvuma River in Tanzania); a small barb; 2.8 cm SL.
Barbus turkanae Hopson and Hopson, 1982	A freshwater species first recorded and described by Hopson and Hopson (1982) from Lake Turkana where it is endemic; not sampled during the present study; not reported from the Ethiopian part of the

	lake; a small barb; 4.2 cm SL.
Barbus arambourgi Pellegrin, 1935	Described during the Scientifique mission de l'Omo in Omo River system at a marsh about 50 km northwest of Sergoit, on the plateau Uasin Gishu, Ethiopia, by Pellegrin (1935); also subsequently recorded in the lower Omo River by Baron *et al*. (1997); not sampled during the present study; endemic to Omo River system; not reported from the Ethiopian part of the lake; a freshwater small barb; 6.2 cm SL.
Barbus paludinosus Peters, 1852	Gojeb River (Dgebuadze *et al*., 1994); not sampled during the present study; occurs in east, central and southern Africa; a small barb; 15 cm SL.
Barbus perince Rüppell, 1835	Omo River system (Baron *et al*., 1997); not sampled during the present study; Distribution: freshwater, Nilo-Sudanic in distribution; a small barb; 8.9 cm SL.
'*Barbus*' *neumayeri* Fischer, 1884	Mentioned as occurring in Lake Turkana system by Seegers *et al*. (2003); not reported from the Ethiopian part of the lake; wide distribution in eastern Africa; a small barb; 10.3 cm SL.
Labeobarbus nedgia Rüppell, 1835	Lake Turkana (Pellegrin, 1905); Gibe River, upper to mid tributary of Omo River (Boulenger, 1906, 1911); subsequently unnoticed and not included in the reviews of the basin fish diversity (e.g. Shibru Tedla, 1973; Roberts, 1975; Lévêque *et al*., 1991); recently collected from Gojeb River (Taju Mohammed, 2014); its current status in Lake Turkana is uncertain; not sampled during the present study; endemic to Ethiopia in Nile basin (Blue Nile, Tekeze basin and Baro-Akobo basins), southern rift valley; a large barb; 70.7 cm SL.

Labeobarbus bynni (Forsskål, 1775)	Described in Lake Turkana as *Barbus meneliki* Pellegrin, 1905, now a junior synonym (Banister, 1973); subsequently the Turkana population described as a subspecies *B. bynni ruolfianus* Worthington, 1932, which is also synonymised; also recorded in the lake by other investigators (Boulenger, 1911; Hopson and Hopson, 1982), and in lower Omo River (Baron *et al*., 1997); reported as *Barbus bynni* Forsskål, 1775, which is an old name; a large barb with max SL 82 cm, thus we consider it valid as *Labeobarbus bynni* (Forsskål, 1775) (sensu Berrebi, 1995; Skelton, 2001; de Weirdt *et al*., 2007; Tsigenopoulos *et al*., 2010); not reported from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; a large barb; 82 cm SL.
Labeobarbus intermedius (Rüppell, 1835)	Upper Omo River (Boulenger, 1906, 1911); lower Omo River (Baron *et al*., 1997); also reported in Omo River as *Barbus bottegi* Boulenger, 1906, *Barbus gregorii* Boulenger, 1902, *Barbus duchesnii* Boulenger, 1902, *Barbus gudaricus* Boulenger, 1906, *Barbus oreas* Boulenger, 1902; and in Lake Turkana as *Barbus plagiostomus* Boulenger, 1906, which are now all junior synonyms; also occurs in Kerio-Turkwell river systems (western Turkana drainage basins in Kenya) (Seegers *et al*., 2003); given its old record in Lake Turkana (Boulenger, 1911), the current status of the species in the actual lake is uncertain; not sampled during the present study; a large barb; 48.9 cm SL; occurs in Nile basin in Ethiopia extending into northern Kenya as far as Lake Baringo.
Labeo cylindricus Peters,	Middle and upper Omo River system (Boulenger, 1906, 1909); lower

1852 Karitach (Daasanach)	Omo River (Baron *et al*., 1997); occurs in Lake Turkana probably as stragglers (Hopson and Hopson, 1982); Kerio-Turkwell system in Kenya (Seegers *et al*., 2003); not reported from the Ethiopian part of the lake; not sampled during the present study; Nilotic (Lake Abaya basins in Ethiopia); also in Eastern (Wabishebelle River in Ethiopia), Congo and Zambezi provinces; 40 cm TL.
Labeo horie Heckel, 1846 Karitach (Daasanach)	Omo River and Lake Turkana (Pellegrin, 1935); Lake Turkana (Worthington and Richardo, 1936; Hopson and Hopson, 1982); lower Omo River (Baron *et al*., 1997); sampled in lower Omo River and the Ethiopian part of Lake Turkana during the present study; Nilotic in distribution; 57 cm TL.
Labeo niloticus (Linnaeus, 1758) Karitach (Daasanach)	Upper Omo River (Boulenger, 1906, 1909); in lower Omo River (Baron *et al*., 1997) as *Labeo niloticus* (Forsskål, 1775), a name which is objectively invalid (not new description) (Fricke, 2008), and in its original combination as *Cyprinus niloticus* Forsskål, 1775, it is a junior homonym of *Cyprinus niloticus* Linnaeus, 1758, which is now valid as *Labeo niloticus* (Linnaeus, 1758); despite Reid‘s (1985) reference to its occurrence in Lake Turkana, Seegers *et al*. (2003) considered the species‘ reporting in the lake (from the collections of the Natural History Museum, London) as a dubious misidentification of *Labeo horie* Heckel, 1847; sampled in lower Omo River and the Ethiopian part of Lake Turkana during the present study supporting its occurrence in Lake Turkana; Nilotic in distribution; 48 cm SL (present data).
Labeo coubie Rüppell,	Lower Omo River (Baron *et al*., 1997); sampled in the Ethiopian part of

1832 Karitach (Daasanach)	Lake Turkana during the present study, a first record for Lake Turkana; Nilo-Sudanic in distribution; also in Lower Guinea province; 24 cm SL (present data).
Labeo forskalii Rüppell, 1835 Karitach (Daasanach)	Recorded in Gojeb River (Dgebuadze *et al*., 1994); not sampled during the present study; Nilotic in distribution.
Garra dembeensis (Rüppell, 1835)	Giber River (Boulenger 1906, 1909) as *Discognathus dembeensis* (Rüppell, 1835), which is an old name; subsequently recorded in the lower Omo River (Baron *et al*., 1997); not sampled during the present study; Nilo-Sudanic in distribution.
Garra quadrimaculata (Rüppell, 1835)	Omo River system (Baron *et al*., 1997); not sampled during the present study; south eastern Ethiopia (Eastern province); also in south eastern Eritrea and Arabian Peninsula (Saudi Arabia and Yemen).
Raiamas senegalensis (Steindachner, 1870)	Middle and upper Omo River (Boulenger 1903a, 1906, 1911) as *Barilius loati* Boulenger, 1901, which is now a junior synonym; subsequently recorded from lower Omo River (Baron *et al*., 1997); recently collected from Gojeb River (Mohammed, 2014); also in Turkwell drainage (Turkana basin in Kenya) (Seegers *et al*., 2003); not sampled during the present study; Nilo-Sudanic in distribution; also in the Lower Guinea province; 24.5 cm TL.
Leptocypris niloticus (Joannis, 1835)	Middle Omo River system (Boulenger, 1903a, 1911); Lake Turkana (Worthington and Richardo, 1936; Hopson and Hopson, 1982); reported as *Barilius niloticus* (Joannis, 1835), which is an old name; recorded in the lower Omo River (Baron *et al*., 1997); not reported

	from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; also in the Lower Guinea province; 9.5 cm TL.
Neobola stellae (Worthington, 1932)	Described from Lake Turkana as *Engraulicypris stellae* Worthington (1932), which is now an old name; subsequently recorded in the lake (Pellegrin, 1935; Hopson and Hopson, 1982); lacustrine species endemic to Lake Turkana; not reported from the Ethiopian part of the lake; not sampled during the present study; 2.3 cm SL.
Neobola bottegoi Vinciguerra, 1895	Omo River system (Boulenger, 1903a, 1906, 1911) who also indicated its presence in Lake Turkana as *Engraulicypris bottegi* Vinciguerra, 1895, which is now an old name; however, its presence in the Lake Turkana has been suspected by subsequent workers to be misidentification of *Neobola stellae*; recorded in lower Omo River (Baron *et al*., 1997); not sampled during the present study; likely a riverine species restricted to Omo River; mentioned as endemic to Omo River by Lévêque *et al*. (1991), but the species also occurred in Somaliland (Auata River, Wabishebelle system), a type locality.
Chelaethiops bibie (Joannis, 1835)	Lake Turkana (Hopson and Hopson 1982); Omo River system (Baron *et al*., 1997); not reported from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; also occurs Wabishebelle in Somalia; 5.5. cm TL.
Fam. Nemacheilidae *Afronemacheilus kaffa* Prokofiev & Golubtsov,	Misidentified as *Afronemacheilus abyssinicus* (non Boulenger, 1902) from Gojeb River (Dgebuadze *et al*., 1994), later described as *Afronemacheilus kaffa* Prokofiev & Golubtsov, 2013; not sampled

2013	during the present study; endemic to Omo River basin.
Ord. Siluriformes (8F, 11G, 21Sp) **Fam. Amphiliidae** *Andersonia leptura* Boulenger, 1900	Omo River Delta (Pellegrin 1935); not sampled in subsequent studies nor was during the present study; current status in the basin is uncertain; Nilo-Sudanic in distribution.
Fam. Auchenoglanididae *Auchenoglanis biscutatus* (Geoffroy St. Hilaire, 1809) Dir (Daasanach)	Lower Omo River (Baron *et al*., 1997); sampled in lower Omo River and the Ethiopian part of Lake Turkana during the present study, a first record for Lake Turkana; also in the Lower Guinea province; 28 cm SL (present data).
Auchenoglanis occidentalis (Valenciennes, 1840) Dir (Daasanach)	Lake Turkana (Boulenger, 1911; Hopson and Hopson, 1982); lower Omo River (Baron *et al*., 1997); sampled in the lower Omo River and the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; also in Congo province; 48 cm SL.
Fam. Clariidae *Clarias gariepinus* (Burchell, 1822)	Omo River system (Boulenger, 1911); lower Omo River (Baron *et al*., 1997); Lake Turkana (Worthington and Richardo, 1936; Hopson and Hopson, 1982); all reported as *Clarias lazera* Cuvier and Valenciennes, 1840, which is now a junior synonym; sampled in the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; also in Congo basin; but absent from Maghreb, Lower Guinea, Upper Guinea, Cape and Nogal provinces; 150 cm TL.
Heterobranchus longifilis (Valenciennes, 1840)	Upper tributaries of Omo River (Boulenger, 1906, 1911); subsequently Hopson and Hopson (1982) only had the fishers report of its occurrence

	in the region of Omo River delta; lower Omo River (Baron *et al.*, 1997); not sampled during the present study; Nilo-Sudanic in distribution; also in upper and middle Zambezi systems; 100 cm TL.
Fam. Bagridae *Bagrus bajad* (Forsskål, 1775) Nyarabomos (Daasanach)	Lake Turkana (Worthington and Richardo, 1936; Hopson and Hopson 1982); lower Omo River (Baron *et al.*, 1997); reported as *Bagrus bayad* (Forsskål, 1775), which is a misspelled name; sampled in lower Omo River and the Ethiopian part of Lake Turkana; Nilo-Sudanic in distribution; also in the Lower Guinea province; 72 cm SL.
Bagrus docmak (Forsskål, 1775) Nyarabomos (Daasanach)	Upper Omo River (Boulenger, 1906, 1911); Lake Turkana (Hopson and Hopson 1982); reported as *Bagrus docmac* (Forsskål, 1775), which is a misspelled name; lower Omo River (Baron *et al.*, 1997); sampled in lower Omo River and the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; 110 cm TL.
Fam. Claroteidae *Chrysichthys auratus* (Geoffroy St. Hilaire, 1809)	Lake Turkana (Hopson and Hopson, 1982); lower Omo River (Baron *et al.*, 1997); Risch (1986) mentioned as *Chrysichthys auratus auratus* (Geoffroy St. Hilaire, 1809); sampled in lower Omo River and the Ethiopian part of Lake Turkana during the present study; Distribution: Nilo-Sudanic in distribution; 30 cm SL.
Chrysichthys turkana Hardman, 2008	Described in Lake Turkana (western shore) as Chrysichthys turkana Hardman, 2008; not sampled during the present study; Distribution: restricted, probably endemic to Lake Turkana (Hardman, 2008); not reported from the Ethiopian part of the lake; 9.34 cm SL.
Fam. Malapteruridae *Malapterurus minjiriya*	Omo River system (Baron *et al.*, 1997; Golubtsov and Berendzen 1999); sampled in lower Omo River during the present study; Nilo-

Sagua, 1987	Sudanic in distribution; 51 cm SL.
Malapterurus electricus (Gmelin, 1789)	Omo River Delta (Pellegin, 1935); Omo River system (Baron *et al*. 1997); Lake Turkana and Turkwell River system (a south western tributary of Lake Turkana in Kenya) (Hopson and Hopson, 1982); not reported from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; also occurs in Lake Tanganyika; 122 cm SL.
Fam. Mochokidae *Chiloglanis niloticus* Boulenger, 1900	Omo River system (Baron *et al*., 1997); not sampled during the present study; Distribution: freshwater, Nilo-Sudanic in the Niger basin and upper Nile.
Mochokus niloticus Joannis, 1835	Lake Turkana (Boulenger, 1911; Hopson and Hopson, 1982); reported as *Mochocus niloticus* Joannis, 1835, which is a misspelled name; not reported from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; 6.5 cm TL.
Synodontis filamentosus Boulenger, 1901 Dir (Daasanach)	Sampled in both the lower Omo River and the Ethiopian part of Lake Turkana during the present study, first record for the Omo-Turkana basin; also mentioned as *Synodontis filamentosa* Boulenger, 1901 (Habtesilassie, 2012); Nilo-Sudanic in distribution.
Synodontis schall (Bloch & Schneider, 1801) Dir (Daasanach)	Lake Turkana (Günther, 1896; Boulenger, 1911; Pellegrin, 1935; Hopson and Hopson 1982); reported as *Synodontis schal* (Bloch & Schneider, 1801), a misspelled name; lower Omo River (Baron *et al*., 1997); sampled abundantly in both lower Omo River and the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; 43 cm TL.

Synodontis frontosus Vaillant, 1895 Dir (Daasanach)	Northeast end of Lake Turkana (Boulenger, 1906, 1911); upper part of Omo River Delta (Hopson and Hopson, 1982); lower Omo River (Baron *et al*., 1997); not reported from the Ethiopian part of the lake; likely a riverine species confined to Omo River; not sampled during the present study; Nilo-Sudanic in distribution; also in Eastern province (Wabishebelle Basin in Ethiopia); 34. 2 cm TL.
Synodontis serratus Rüppell, 1829 Dir (Daasanach)	Lower Omo River (Baron *et al*., 1997); not sampled during the present study; Nilotic in distribution basin.
Synodontis sorex Günther, 1864 Dir (Daasanach)	Lower Omo River (Baron *et al*., 1997); not sampled during the present study; Nilo-Sudanic in distribution.
Fam. Schilbeidae *Schilbe mystus* (Linnaeus, 1758) Iyinte (Daasanach)	Lower Omo River (Baron *et al*., 1997); sampled in lower Omo River during the present study; Nilotic in distribution; also in Zambezi system; 32 cm SL (present data).
Schilbe uranoscopus Rüppell, 1832 Iyinte (Daasanach)	Lake Turkana (Hopson and Hopson, 1982); sampled in both lower Omo River and the Ethiopian part of Lake Turkana during the present study, a first record for Omo River; Nilo-Sudanic in distribution; also in the Lower Guinea province; 36 cm SL.
Schilbe intermedius Rüppell, 1832 Iyinte (Daasanach)	Lower Omo River (Baron *et al*., 1997); not sampled during the present study; Nilo-Sudanic in distribution; also in Eastern (Wabishebelle in Ethiopia and coastal rivers of Kenya), Congo and Zambezi provinces.
Ord. Cyprinodontiformes	Freshwater species described from Lake Turkana where it is endemic,

(1F, 1G, 2Sp) **Fam. Poeciliidae** *Aplocheilichthys rudolfianus* (Worthington, 1932)	as *Haplochilichthys rudolfianus* Worthington, 1932, which is an old name; subsequently recorded in the lake by Hopson and Hopson (1982); considered valid as *Micropanchax rudolfianus* (Worthington, 1932) by Huber (1999); not reported from the Ethiopian part of the lake; not sampled during the present study; 3 cm TL.
Aplocheilichthys jeanneli (Pellegrin, 1935)	Freshwater species described from Omo River Delta where it is endemic, as *Haplochilichthys jeanneli* Pellegrin, 1935, which is an old name; subsequently recorded in Omo River Delta by Hopson and Hopson (1982); not sampled during the present study; 3 cm TL.
Ord. Perciformes (2F, 6G, 9Sp) **Fam.** Cichlidae *Oreochromis niloticus* (Linnaeus, 1758)	Lake Turkana (Günther, 1896; Worthington and Richardo, 1936; Hopson and Hopson, 1982); upper Omo River and north east end of Lake Turkana (Boulenger, 1906, 1915); Omo River (Pellegrin, 1935; Baron *et al*., 1997); reported as *Chromis niloticus* Hasselquist, 1757, *Tilapia nilotica* (Linnaeus, 1757), *Tilapia nilotica* (Linné, 1757), or *Sarotherodon niloticus* (Linnaeus, 1757), all old names with erroneous year of publication; also mentioned as *O. niloticus cancellatus* (Nichols, 1923) (Trewavas and Teugels 1991), and as *O. niloticus vulcani* (Trewavas, 1933) endemic to Turkana Basin (e.g. Seegers et al. 2003); sampled in both lower Omo River and the Ethiopian part of Lake Turkana during the present study; the Turkana Basin species is considered valid as *O. niloticus vulcani* (Trewavas, 1933) endemic to the basin by some authors (e.g. Trewavas and Teugels 1991; Seegers et al. 2003); Nilo-Sudanic in distribution; also in Lake Tana Hotspot, Ethiopian Rift Valley (Awash River and Ethiopian central and northern

	Rift lakes), Congo province and East (Lake Kivu) provinces; outside Africa, naturally in coastal rivers of Israel; 33 cm SL (present data).
Sarotherodon galilaeus (Linnaeus, 1758)	Lake Turkana (Worthington and Richardo 1936; Hopson and Hopson 1982); reported as *Tilapia galilaea* (Artedi, 1757) or *Sarotherodon galilaeus* (Artedi, 1757), both unavailable names due to the priority rule of ICZN; recorded in the lower Omo River (Baron *et al*., 1997); not reported from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; also in Congo and Lower Guinea provinces; outside Africa, in Eurasia including Jordan system and coastal waters of Israel; 34 cm SL.
Tilapia zillii (Gervais, 1848)	Lake Turkana (Günther, 1896; Pellegrin, 1935; Boulenger, 1915; Hopson and Hopson 1982); reported as *Chromis tristrami* Günther, 1862, which is a junior synonym; lower Omo River (Baron *et al*., 1997); not reported from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; also in middle of Congo Basin; 30.5 cm TL.
Haplochromis rudolfianus Trewavas, 1933	A freshwater species described from Lake Turkana, where it is endemic, as *Haplochromis rudolfianus* Trewavas, 1933; subsequently recorded from the lake by Hopson and Hopson (1982); Lévêque *et al*. (1991) referred to it as *Thoracochromis rudolfianus* (Trewavas, 1933), which is a junior synonym; not reported from the Ethiopian part of the lake; not sampled during the present study; 5.8 cm SL.
Haplochromis macconneli Greenwood, 1974	A freshwater species described from Lake Turkana, where it is endemic, as *Haplochromis macconneli* Greenwood, 1974; subsequently

	recorded from the lake by Hopson and Hopson (1982); Lévêque *et al*. (1991) referred to it as *Thoracochromis macconneli* (Greenwood, 1974), which is a junior synonym; not reported from the Ethiopian part of the lake; not sampled during the present study; 7.7 cm SL.
Haplochromis turkanae Greenwood, 1974	A freshwater species described from Lake Turkana, where it is endemic, as *Haplochromis turkanae* Greenwood, 1974; subsequently recorded from the lake by Hopson and Hopson (1982); Lévêque *et al*. (1991) referred to it as *Thoracochromis turkanae* (Greenwood, 1974), which is a junior synonym; not reported from the Ethiopian part of the lake; not sampled during the present study; 8.6 cm SL.
Hemichromis bimaculatus Gill, 1862	Described from Lake Turkana as *Pelmatochromis exsul* Trewavas, 1933; later on recognized to be misidentification of *Hemichromis bimaculatus* Gill, 1862 (Hopson and Hopson, 1982); mentioned as *Hemichromis exsul* (Trewavas, 1933) probably endemic to Lake Turkana (Seegers *et al*., 2003); not reported from the Ethiopian part of the lake; not sampled during the present study; Nilo-Sudanic in distribution; 10 cm SL.
Fam. Latidae *Lates niloticus* (Linnaeus, 1758)	Lake Turkana (Boulenger, 1915; Hopson and Hopson, 1982); the Lake Turkana population was described as two subspecies, *L. niloticus rudolfianus* Worthington, 1932, now a junior synonym, and *L. niloticus longispinis* Worthington, 1932; Omo River and its delta (Pellegrin 1935; Baron *et al*., 1997); reported as *Lates niloticus* (Linnaeus, 1762) or *Lates niloticus* (Linné, 1762), both with erroneous year of publication; sampled in both lower Omo River and the Ethiopian part

	of Lake Turkana during the present study; Nilo-Sudanic in distribution; also in Congo Basin; introduced to the lakes of Eastern province (Victoria and Kyog; 180 cm TL.
Lates longispinis Worthington, 1932	A freshwater species described from Lake Turkana, where it is endemic, as *L. niloticus longispinis* Worthington, 1932, which is a synonym; subsequently recorded from the lake by Hopson and Hopson (1982); not reported from the Ethiopian part of the lake; not sampled during the present study; 27.5 cm TL.
Ord. Tetraodontiformes (1F, 1G, 1Sp) **Fam. Tetraodontidae** *Tetraodon lineatus* Linnaeus, 1758	Described from lake Turkana as a subspecies *Tetraodon fahaka rudolfianus* Deraniyagala, 1948, which is now a synonym; recorded by subsequent studies (Hamblyn, 1962; Mann, 1964; Hopson and Hopson, 1982) from Lake Turkana as *Tetraodon fahaka* Bennett, 1834, which is a junior synonym; sampled in the Ethiopian part of Lake Turkana during the present study; Nilo-Sudanic in distribution; 43 cm TL.

Appendix 4. A bracketed artificial identification key for the fish species in Omo-Turkana Basin within the limit of Ethiopia (see Appendix 3).

Numbers in parenthesis refer to the lead characters from which the respective couplets follow; the characters used to develop the key are relatively easy and conspicuous to facilitate easy on-field identification of the basin fish species. The key is intended for identification of fish species in Omo-Turkana Basin within the limit of Ethiopia and thus its application outside this range might be limited.

1 **a** 8 or more closely spaced finlets on the dorsal surface, continuous with caudal; caudal

fin bluntly pointed or more or less truncate; scales thick, bony and rhomboid; body elongate…………………………………………………………………………….…2

b No dorsal finlets; caudal fin and body shape variable; body scales present or absent......3

2 (1[a]) **a** 8–11 dorsal finlets (often 9); 53–61 (often 57) scales in the lateral line; body rather grayish..*Polypterus senegalus*

b 13–18 (often 17) dorsal finlets; 63–70 (often 67 scales) in the lateral line; body rather dark brownish..*Polypterus bichir*

3 (1[b]) **a** Body often covered with various types of overlapping scales, or with small thinner spines instead of scales………..……………………………..…...……..……………..4

b Body naked, without scale or spines …………..…………………..……………..…...46

4 (3[a]) **a** Various types of teeth on jaws; barbels absent; fleshy adipose fin present or absent; caudal fin forked, truncate or round….…………..……………………………….....5

b No teeth on jaws; barbels present or absent; no adipose fin; caudal fin forked………..28

5 (4[a]) **a** Dorsal fin long with more than 30 soft rays, located rear on body ending near a round caudal fin; no adipose fin; body scales strong and large, absent on head; single uninterrupted lateral line, with 35–39 (often 38) scales; terminal mouth with unicuspid teeth....... *Heterotis niloticus*

b Dorsal fin short, or long originating nearer to head or rear on body closer to caudal; body scales thin and small or absent; lateral line single and continuous or two interrupted (incomplete) lines when present; mouth position variable…..……………..6

6 (5[b]) **a** Small mouth, with restricted gape (opening), terminally located often on elongated snout; thin cycloid scales on the body, none on head; caudal fin deeply forked; no

adipose fin…………………………………………………………………......…7

b Large mouth, with wide gape, variable location on a round (non-elongated) snout; body scales cycloid or ctenoid; caudal fin forked, truncate or round; fleshy adipose fin present or absent……………………………………………………………………13

7 (6[a]) a Snout much elongated resembling proboscis; dorsal fin base twice longer than anal fin base, its origin nearer to head than to caudal……………….……...……..…………….8

b Snout not proboscis-like; dorsal fin base is as long as, or even shorter, than anal fin base, both located on the posterior body nearer to caudal..…...………..………..……..9

8 (7[a]) a Proboscis-like snout straight, not curved downward; dorsal fin rays > 75....*Mormyrus caschive*

b Proboscis-like snout slightly curved downward; dorsal fin rays < 75........…..*Mormyrus kannume*

9 (7[b]) a Dorsal fin very much shorter than anal fin; snout round and short...….*Hyperopisus bebe*

b b. Dorsal fin more or less as long as anal fin……………………………...………..10

10 (9[b]) a Chin or mental swelling well developed…………......…..…….*Marcusenius cyprinoides*

b Chin absent………………….……………………………………………...……..11

11 (10[b]) a Snout relatively moderately long; head depressed; body less deep, anteriorly tinged with dark reddish color; teeth more than 10 on the entire of upper jaw, and 14 on lower jaw……………………………………………………..…......*Mormyrops anguilloides*

b Snout relatively short; head compressed; body relatively deep; teeth less than 7 in the middle of upper jaw, and and10 on lower jaw..…..…………………………….……..….12

12 (11[b]) a Dorsal fin originating well in advance of anal fin origin, relatively long with up to 36

rays; dorsal profile tend to be concave-like…..……….............…...*Pollimyrus petherici*

b Dorsal fin originating slightly behind anal fin origin, relatively short only with up to 22 rays; dorsal profile rather straight……………………….............*Pollimyrus isidori*

13 (6[b]) **a** Small fleshy adipose fin behind the rayed dorsal fin; caudal fin forked to lunate; dorsal and anal fins with soft rays only……………..……………….………………...……14

b No adipose fin; caudal fin truncate or round; dorsal and anal fins with or without spiny rays…….……..……………………………………………………………..…23

14 (13[a]) **a** Body more or less elongate, less deep; lateral line rather on the lower part of the side; mouth terminal, with unicuspid or pluricuspid teeth on both jaws; cycloid scales on the body…………………………………………………………………………......15

b Body rather deep; lateral line along the middle of the side; mouth terminal, inferior or subinferior, with teeth on the lip or jaw; cycloid or ctenoid scales on the body……......21

15 (14[a]) **a** Teeth entirely unicuspid, in a single row on each jaw, visible when mouth is closed; adipose eyelid present…….……………………………………..…………………..16

b Teeth largely pluricuspid, in two rows on each jaw, not visible when mouth is closed; inner row of the lower jaw only with two small conical teeth; inner row of premaxilla teeth molariform; adipose eyelid present or absent…….…………………..….…………17

16 (15[a]) **a** Tip of dorsal fin, inner edges of caudal fin, and adipose fin black; two rows of scales between the scaly process at pelvic fins and lateral line……........*Hydrocynus vittatus*

b Tip of dorsal fin, inner edges of caudal fin, and adipose fin uniformly grayish; two rows of scales between the scaly process at pelvic fins and lateral line…*Hydrocynus forkahlii*

17 (15[b]) **a** Inner row of premaxilla teeth NOT excavated; black humeral spot and caudal blotch absent; gill rakers short; scales in the lateral line fewer than 35..…*Micralestes elongatus*

b Inner row of premaxilla teeth excavated; black humeral spot and caudal blotch present or absent………..……………………………………………………………………...18

18 (17[b]) **a** Adipose eyelid present; black humeral spot or caudal blotch absent; scales in the lateral line more than 38………………………...…………………..………………………19

b Adipose eyelid absent or rudiment; black humeral spot usually and caudal blotch always present; scales in the lateral line fewer than 35; gill rakers moderately long.....20

19 (18[a]) **a** Dorsal fin equidistant between ventral and anal fins or nearer to the latter; gill rakers on the lower half of first gill arch no less than 30; anal fin relatively moderately long, with 25–30 branched rays; body less deep; edges of caudal fin only finely black……..*Alestes baremoze*

b Dorsal fin slightly behind the origin of the ventral fin; gill rakers on the lower half of first gill arch no more than 27; anal fin relatively short, with 22–26 branched rays; body more deep; edges of caudal lobes (both) black……………….…………......*Alestes dentex*

20 (18[b]) **a** Dorsal fin distantly located behind the ventral fin; head flattened; teeth in outer row of premaxilla 8–14; long orange band running along the body sometimes; fins orange-red to pink………………………….………………………...….*Brycinus macrolepidotus*

b Dorsal fin above or only slightly in advance of the ventral fin; head round; teeth in outer row of premaxilla 8; lateral side silvery; unpaired fins bright red; paired fins colorless or, at most, light orange…………..……………...……………..………*Brycinus nurse*

21 (14[b]) **a** Mouth small, terminal, with unicuspid teeth on the lip; body highly deep, covered with cycloid scales; base of adipose fin shorter than its distance from the rayed dorsal fin...…………………*Citharinus citharus*

b Mouth small, subinferior or inferior, with bicuspid teeth on the jaws; body less deep, covered with ctenoid scales covering a body; adipose fin base shorter than its distance from the rayed dorsal fin…………..……………….………...……………………..22

22 (21[b]) **a** Snout moderately long; mouth subinferior; teeth small, bicuspid usually in two rows in each jaw; dorsal fin long with more than 22 rays; more than 90 scales in the lateral line..*Distichodus nefasch*

b Snout short; mouth inferior; teeth small, bicuspid usually in one row in each jaw; dorsal fin short with less than 13 rays; a small dark spot on base of caudal…. …..N*annocharax niloticus*

23 (13[b]) **a** Dorsal and anal fins with no spiny rays; lateral line absent; caudal fin truncate to round……..……..……………………...…………….………... *Aplocheilichthys jeanneli*

b Dorsal and anal fins with spiny rays; lateral line present or absent; caudal fin truncate or round…....……………………………………….……………………………..24

24 (23[b]) **a** No ventral fin; dorsal fin short, located in the posterior body part; body scaleless, head and body covered with small thin spines; lateral line absent; a pair of fused teeth at the front of each jaw; yellow longitudinal bands on the body ….……....*Tetraodon lineatus*

b All major rayed fins present; dorsal fin long, continuous or notched, its origin in the anterior body part; cycloid or ctenoid scales covering a body; lateral line present…....25

25 (24[b]) **a** Mouth terminal with villiform teeth on jaws; spinous dorsal fin long, deeply notched into anterior spiny and posterior mainly soft rayed portions; body scales ctenoid; single complete lateral line present; caudal fin round…....................................*Lates niloticus*

b Mouth terminal with bicuspid teeth on the outer jaws; spinous dorsal fin long and continuous; body scales often cycloid; 2 short, incomplete lateral lines; caudal fin truncate; blackish opercular spot …….………..……...……………………………..…..26

26 (25[b]) **a** Gill rakers relatively short and thick, fewer, 8-12 on the lower half of the first gill arch; body scales often cycloid or feebly denticulate; scales between pectoral and pelvic fins

same size as scales on the body side; a black spot (tilapia mark) at the junction of the spinous and soft dorsal rays present…….…………………….……….…….*Tilapia zillii*

b Gill rakers relatively thin and long, many, 14-27 on the lower half of the first gill arch; body scales cycloid; scales between pectoral and pelvic fins smaller in size than those on the body side……………………………………….…………...…...…...…..27

27 (26[b]) **a** Scales between pectoral and pelvic fins distinctly smaller than those on the body side; pectoral fins relatively shorter not reaching anal fin; dorsal fin with 29–33 total rays; dark vertical bars or stripes on the body and caudal fin…………..*Oreochromis niloticus*

b Scales between pectoral and pelvic fins not much smaller than scales on the flank; pectoral fins relatively longer reaching anal fin; dorsal fin with 27–31 total rays………………………………………………………...*Sarotherodon galilaeus*

28 (4[b]) **a** Mouth sub inferior; 3 pairs of barbels; 7 branched dorsal-fin rays (vs. usually 8 or 9 in a congener); the anterior and posterior nares (nostrils) well separated (vs. closely spaced in a congener); body naked or with minute scales; bar-like spots on flanks usually of similar size…………………….………………...………………..*Afronemacheilus kaffa*

b Mouth terminal to inferior; barbels 1–2 pairs when present; spinelike rays in dorsal fin in some; body covered with cycloid scales, head naked………………....………...…29

29 (28[b]) **a** Branched anal fin rays no more than 7; mouth inferior, subinferior or terminal; barbels present; lateral line on the middle of the caudal peduncle……………………………..30

b Branched anal fin rays no less than 9; mouth often terminal or rarely subinferior; barbels absent; lateral line on the middle of or lower on the caudal peduncle...........…43

30 (29[a]) **a** Mouth typically inferior, with well developed sucker-like lips, 1or 2 pairs of minute barbels; dorsal fin origin well in advance of the origin of ventral fins……………...…31

b Mouth inferior, subinferior or terminal; lips thin or thick but never sucker-like; barbels 2 pairs; dorsal fin origin above or slightly behind or in advance of the origin of the ventral fins……………………………………………………………………...…37

31 (30[a]) **a** Lower lip modified posteriorly into a well developed round mental disc, with free lateral and posterior margins; 2 pairs (nasal and maxillary) of small barbels………....32

b Both upper and lower lips well developed into a sucker-like structure, but not forming a mental disc; 1 pair of small maxillary barbels……………………………………....33

32 (31[a]) **a** No visible scales on the chest, belly and post-pelvic regions; 36–38 scales in the lateral line…………...…………………..……………………………….…..*Garra dembeensis*

b At least some scattered scales on the chest, belly and post-pelvic regions; 34–35 scales in the lateral line……………….……………….…………...……*Garra quadrimaculata*

33 (31[b]) **a** Eye lateral, visible both from bottom and above; rostral flap attached at sides and its free margin smooth; transverse plicae of papillae present or absent on the inner sides of the lips; dorsal fin with more than 10 branched rays...…………..…...…...………...…34

b Eye supero-lateral visible only from above; rostral flap detached at sides and its free margin feebly denticulate; transverse plicae of papillae present on the inner sides of the lips; dorsal fin with 9–10 branched rays………….……...…………………...………..36

34 (33[a]) **a** Branched dorsal fin rays more than 14, its upper edge often more or less concave; 41–45 scales in the lateral line; no transverse plicae of papillae on the inner sides of the lips.. *Labeo niloticus*

b Branched dorsal fin rays not more than 14, its upper edge convex or slightly straight; scales in the lateral line 36 or more………………...………………..…………………...35

35 (34[b]) **a** Labial folds rather poorly developed; 40–44 scales in the lateral line; no transverse plicae of papillae on the inner sides of the lips ……...................................…*Labeo horie*

b Labial folds relatively well developed; 36–40 scales in the lateral line; transverse plicae of papillae present on the inner sides of the lips…………………….…......*Labeo coubie*

36 (33[b]) **a** Eye relatively large (often OD, orbit diameter > 18% HL, head length); transverse groove above the snout present; scales in the lateral line 38–42...……...*Labeo forskalii*

b Eye relatively small (often OD < 18% HL); transverse groove above the snout absent; scales in the lateral line 35–39……………………………….....…....*Labeo cylindricus*

37 (30[b]) **a** Radiating or divergent streae in the outer parts of the scales; 7 or 8 branched dorsal fin rays; fewer than 10 gill rakers in the lower half of the first gill arch; mouth terminal or subinferior; 2 pairs of barbels in adults ..……….………………………………...…....38

b Parallel streae in the outer parts of the scales; 9 or 10 branched dorsal fin rays; up to 20 gill rakers in the lower half of the first gill arch; mouth inferior or slightly inferior; 2 pairs of barbels……………………………………...……………….………41

38 (37[a]) **a** Lateral line incomplete on the body; mouth terminal; dorsal fin with III 8 rays, last unbranched ray not serrated; flanks with up to 5 spots…………..*Barbus stigmatopygus*

b Lateral line complete on the body……………………………………..…………….39

39 (38[b]) **a** Dorsal fin with III 7 rays, last unbranched dorsal fin ray serrated on its posterior side; mouth terminal and oblique; ……………………………..…...…*Barbus paludinosus*

b Last unbranched dorsal fin ray not serrated on its posterior; mouth subinferior……...40

40 (39[b]) **a** Barbels well developed Dorsal fin with III 7 rays, last unbranched ray not serrated; barbels relatively well developed, anterior one about 1.3–1.5 times eye diameter and the posterior one about 1.75–2 times eye diameter…………….……….*Barbus arambourgi*

b Dorsal fin with III 8 (rarely 7) rays, last unbranched ray not serrated; barbels relatively small, anterior one short only reaching to anterior margin of eye and the posterior reaching to posterior half of eye...…….…………………...……………*Barbus perince*

41 (37[b]) **a** Lower lip forming large median lobe; upper lip well developed, its lobe curling back over the snout; mouth perfectly inferior; 30–37 scales in the lateral line ....*Labeobarbus nedgia*

b Lower lip not forming a distinct median lobe or very small lobe; upper lip without lobes; mouth inferior or terminal.................................. ……………………………..42

42 (41[b]) **a** Mouth inferior; body very deep (31–38% SL, standard length); more angular body profile ; considerably long dorsal fin, longer than head, the last unbranched non-serrated ray ossified into a massive spine, and upper fin border concave; 28–37 scales in the lateral line…..*Labeobarbus bynni*

b Mouth terminal; body rather shallow (19–32% SL); less angular body profile; considerably short dorsal fin, shorter than head; 30–36 scales in the lateral line……………………………………………………….*Labeobarbus intermedius*

43 (29[b]) **a** Dorsal fin behind the ventral fin; lateral line low on the caudal peduncle; mouth terminal and oblique…..44

b Dorsal fin above or slightly behind the ventral fin; lateral line low or on the middle of caudal peduncle; mouth subinferior or terminal...………………..…………...……45

44 (43[a]) **a** 11-15 black vertical blotches on the flank……………..…………*Raiamas senegalensis*

b No black vertical blotches on the flank; mouth opening positioned at a level of upper border of eye……………….……………….....……………………..*Chelaethiops bibie*

45 (43[b]) **a** Dorsal fin above origin of the ventral fin; lateral line on the middle of caudal peduncle; mouth subinferior…………………..…….……………………….…… *Leptocypris niloticus*

b Dorsal fin above or slightly behind origin of the ventral fin; lateral line low on the caudal peduncle; mouth terminal, extending to beyond the anterior margin of eye…………………………………………………………………....*Neobola bottegoi*

46 (3[b]) **a** 3 pairs of barbels (1 pair maxillary and 2 pairs mandibular), adipose fin present……..47

b 4 pairs of barbels (1 pair nasal, 1 pair maxillary and 2 pairs mandibular); adipose fin present or absent…………………………………………………………..………57

47 (46[a]) **a** Adipose fin rayed, followed by bony spines; series of bony scutes along each side of the back and belly; extremely shallow or slender caudal peduncle; caudal fin crescentic.………………………………………………………......*Andersonia leptura*

b Adipose fin fleshy, not followed by bony spines; no bony scutes on the body; caudal peduncle not extremely shallow; caudal fin nearly truncate, emarginated or deeply forked………………………………………………………………..…...……48

48 (47[b]) **a** Rayed dorsal fin absent; caudal fin nearly truncate; spinous rays absent...……........49

b Rayed dorsal fin present; caudal fin emarginate or deeply forked; spinous rays in dorsal and pectoral fins………………………………………………...………......…..50

49 (48[a]) **a** Pectoral fins placed low on the body, obliquely oriented; broad tooth patches on jaws……….…………………..……………..……………......….*Malapterurus minjiriya*

b Pectoral fins placed more dorsally, near the body mid-depth, vertically oriented; narrow crescent shaped tooth patches on jaws..........………..…………..*Malapterurus electicus*

50 (48[b]) **A** Caudal fin emarginate…….………….....……...……………...…...……….….…………51

b Caudal fin deeply forked………………...……………………………………………..52

51 (50[a]) **a** Relatively long and more pointed snout; maxillary barbels always shorter than the outer mandibular barbel, not extending beyond the posterior border of eye…..*Auchenoglanis*

occidentalis

b Relatively short and less pointed snout; maxillary barbels always longer than the outer mandibular barbel, extending beyond the posterior border of eye...……*Auchenoglanis biscutatus*

52 (50[b]) **a** Mandibular barbels non-branched; eyes without free border; mouth inferior, surrounded by extended circular lip..……………………………………………*Chiloglanis niloticus*

b Mandibular barbels branched; eyes with free border; mouth inferior, sucker-like but lips not as extended as in "52[a]" ……….…………….………...…….….…………53

53 (52[b]) **a** Dorsal fin spine extends into very long filament, which is up to twice longer than the spine itself; soft rays not extending into filament……..……….*Synodontis filamentosus*

b Dorsal fin spine not extending into filament; first soft ray extends into short or rarely long filament………...……………………………………………….………..54

54 (53[b]) **a** Dorsal fin spine smooth in front except for a few apical or basal serrations; basal marginal membrane on maxillary barbel narrow or none; caudal fin forked but not very deeply…………………………………………………………………..…...55

b Dorsal fin spine with fine serration in front; basal marginal membrane on maxillary barbel broad; caudal fin very deeply forked, with longer upper lobe often ending in filament………………………………………………………………………....56

55 (54[a]) **a** Basal marginal membrane on maxillary barbel none; dorsal fin spine feebly serrated behind….....……………………………...……………….……………*Synodontis schall*

b Basal marginal membrane on maxillary barbel distinct but narrow; body covered with very small black spots, but none on caudal fin………………...…. *Synodontis frontosus*

56 (54[b]) **a** Dorsal fin spine coarsely serrated behind……………………….……..*Synodontis sorex*

b Dorsal fin spine finely serrated behind ……..………..…………..…*Synodontis serratus*

57 (46[b]) **a** Caudal fin round; dorsal fin long, with up to 45 or more than 50 rays; anal fin long extending near to the caudal fin………...……………...…….…….….……….…58

b Caudal fin forked; dorsal fin short, with not more than 11rays; anal fin short, or long extending up to caudal…………..………………..……………………...…………..59

58 (57[a]) **a** Fleshy adipose fin absent; dorsal fin long, with more than 50 rays; 24–110 long and thin gill rakers on the first gill arch in adult fishes of 60 cm SL or more ….……......*Clarias gariepinus*

b Fleshy adipose fin present; caudal fin with a whitish cross bar………...*Heterobranchus longifilis*

59 (57[b]) **a** Anal fin long extending from ventrals to caudal, with more than 63 rays; mouth terminal…………………………………………………………………………60

b Anal fin short, not extending to caudal; mouth subinferior...….………………….. …….62

60 (59[a]) **a** Fleshy adipose fin present; sloped upper head profile, with gradually ascending nape from occiput to the dorsal fin………………………..…………………*Schilbe mystus*

b Adipose fin absent; upper hear profile horizontal or sloped……..………..……..……61

61 (60[b]) **a** Horizontal upper head profile, with abruptly ascending nape from occiput to the dorsal fin……………...………...…………………………………………*.Schilbe uranoscopus*

b Sloped upper head profile, with gradually ascending nape from occiput to the dorsal fin………..……………….……………………………………….……*.Schilbe intermedius*

62 (59[b]) **a** Maxillary barbels short, not extending beyond head; caudal fin lobes not extending into long filaments; dorsal fin with 6 non branched rays………………*Chrysichthys auratus*

b Maxillary barbels extremely long, extending beyond head, reaching ventral or anal fins; upper caudal lobe extending into long filament, but the lower lobe may or not……….63

63 (62[b]) **a** Both upper and lower caudal fin lobes extending into long filament; the first branched dorsal fin ray extending into short filament; dorsal fin with 9–11 (often 10) branched rays……..……………………...…………………………………………....*Bagrus bajad*

b Upper caudal fin lobe extending into long filament but the lower lobe not; the first branched dorsal fin ray not extending into short filament; dorsal fin with 8–10 (often 9) branched rays……….………………………………………………….……*Bagrus docmak*

Appendix 5. Summary of the simple relative measures of prey quantities (%V*i*, %O*i*) and GII*i* for the overall diet composition of the eight selected fish species in the Ethiopian part of Lake Turkana.

%V*i* = prey volume (abundance) as a percentage of prey volumes in all stomachs examined; %S*i* = prey-specific volume (abundance) as a percentage of prey volumes in only the stomachs that contained a prey under consideration; GII*i* = Geometric index of importance; %O*i1* = frequency of occurrence as percentage of the total non-empty stomach examined; %O*i2* = frequency of occurrence as percentage of total occurrence (O*t*).

A. *Synodontis schall* (n = 318)

Prey category	V*i* (ml)	%V*i*	%S*i*	O*i*	%O*i1*	%O*i2*	GII*i*
Macrophytes	216.25	42.27	58.73	211	66.35	26.47	48.65
Detritus	90.47	17.68	29.37	185	58.18	23.21	29.85
Phytoplankton	87.16	17.04	29.53	195	61.32	24.47	28.50

Fish	74.51	14.56	74.53	39	12.26	4.89	21.15
Aquatic insects	33.23	6.50	19.05	122	38.36	15.31	7.88
Zooplankton	8.00	1.56	16.53	31	9.75	3.89	3.86
Clam	0.86	0.17	47.67	4	1.26	0.50	0.65
Prawn	0.78	0.15	6.96	6	1.89	0.75	0.46
Crab	0.26	0.05	2.00	2	0.63	0.25	0.39
Aquatic snail	0.11	0.02	3.86	4	1.26	0.50	0.19
Total	511.63			318(n)		797(Ot)	

B. *Alestes baremoze* (n = 61)

Prey category	V*i* (ml)	%V*i*	%S*i*	O*i*	%O*i1*	%O*i2*	GII*i*
Zooplankton	26.47	35.77	60.15	38	62.30	34.86	65.70
Phytoplankton	27.02	36.51	60.45	24	39.34	22.02	51.34
Macrophytes	13.76	18.60	132.25	18	29.51	16.51	32.29
Aquatic insects	3.01	4.07	21.81	19	31.15	17.43	23.08
Detritus	1.02	1.38	36.43	6	9.84	5.50	7.36
Aquatic snail	2.72	3.68	85	4	6.56	3.67	6.85
Total	74			61(n)		109 (Ot)	

C. *Schilbe uranoscopus* (n = 83)

Prey category	V*i* (ml)	%V*i*	%S*i*	Oi	%O*i1*	%O*i2*	GII*i*
Fish	46.63	59.35	86.54	25	30.12	21.37	57.07
Aquatic insects	10.82	13.76	35.42	62	74.70	52.99	47.20
Phytoplankton	0.32	0.40	70	3	3.61	2.56	2.10
Zooplankton	0.56	0.71	70	2	2.41	1.71	1.71
Prawn	4.71	5.99	41.14	13	15.66	11.11	12.09

Shrimp	0.10	0.13	50	2	2.41	1.71	1.30
Macrophytes	15.08	19.19	95.44	5	6.02	4.27	16.59
Detritus	0.37	0.47	63.02	5	6.02	4.27	3.35
Total	78.57			83 (n)		117 (Ot)	

D. *Oreochromis niloticus* (n = 126)

Prey category	V*i* (ml)	%V*i*	%S*i*	O*i*	%O*i1*	%O*i2*	GII*i*
Phytoplankton	476.88	93.62	93.84	120	95.24	72.73	117.62
zooplankton	23.58	4.63	17.53	24	19.05	14.55	13.56
Detritus	4.95	0.97	30.56	11	8.73	6.67	5.40
Prawn	3.99	0.79	19.75	10	7.94	6.06	4.84
Total	509.4			126 (n)		165 (Ot)	

E. *Lates niloticus* (n = 113)

Prey category	V*i* (ml)	%V*i*	%S*i*	O*i*	%O*i1*	%O*i2*	GII*i*
Fish	78.01	57.10	77.34	72	63.72	45.28	72.40
Prawn	45.00	32.94	54.38	58	51.33	36.48	49.09
Aquatic insects	12.19	8.93	71.3	22	19.47	13.84	16.10
Macrophytes	1.41	1.03	67	7	6.19	4.40	3.84
Total	136.61			113 (n)		159 (Ot)	

F. *Distichodus nefasch* (n = 104)

Prey category	V*i* (ml)	%V*i*	%S*i*	O*i*	%O*i1*	%O*i2*	GII*i*
Aquatic insects	0.90	0.17	100	11	10.58	5.56	4.05
Phytoplankton	222.86	42.42	57.8	76	73.08	38.38	57.14
Zooplankton	1.27	0.24	4.17	23	22.12	11.62	8.38

Macrophytes	300.37	57.17	75.21	88	84.62	44.44	71.85
Total	525.40			104 (n)		198 (Ot)	

G. *Citharinus citharus* (n = 21)

Prey category	V*i* (ml)	%V*i*	%S*i*	O*i*	%O*i1*	%O*i2*	GII*i*
Phytoplankton	22.77	72.16	72.85	20	95.24	60.61	93.88
Detritus	8.79	27.84	46.75	13	61.90	39.39	47.54
Total	31.55			21 (n)		33 (Ot)	

H. *Bagrus bajad* (n = 34)

Prey category	V*i* (ml)	%V*i*	%S*i*	O*i*	%O*i1*	%O*i2*	GII*i*
Fish	118.56	72.82	90.64	26	76.47	34.21	75.68
Aquatic insects	13.17	8.09	21.17	24	70.59	31.58	28.05
Macrophytes	27.964	17.18	50.46	12	35.29	15.79	23.31
Prawn	0.69	0.42	4.49	10	29.41	13.16	9.60
Aquatic snail	2.42	1.49	30.25	4	11.76	5.26	4.77
Total	162.804			34 (n)		76 (Ot)	

Appendix 6. A questionnaire used to collect data for the fisheries socioeconomic study

Part I: For fisher respondents

1. Gender: Male ☐ Female ☐ 2. Age ☐

3. Education level:

3.1. No formal education ☐

3.2. Formal education ☐

3.2.1. Levels of formal education (e.g. Grade 5, 6, 12, Diploma, etc) ☐

4. Marital status: Married ☐ Single ☐ Widowed ☐ Other ☐

5. Household (family) size ☐

6. Family background: Fisher ☐ Farmer ☐ Livestock keeper ☐ Trader ☐

Laborer ☐ Other ☐

7. What is your fishing experience (in years)? ☐

8. What was your reason to start fishing?

9. Which mode of fishing are you involved in?

9.1. Individual fisher ☐ Organized or cooperative member ☐

9.2. Part-time ☐ Full-time (Regular) ☐

9.3. If you are not a full-time fisher, what other means of livelihood (in addition to fishing) are you engaged in? Please list them down.

a. ____

b. ____

c. ____

10. Please give the number of fishing gears you possess:

Gill net ☐

Others: ____

11. Please specify the size of gill nets you use

Type	Length (m)	Width (m)	stretched mesh size (cm)	Quantity
Monofilament				
Multifilament				

12. Where or how do you acquire the fishing gears?

13. Please specify the number of fishing boats you possess or have access to:

Timber boats ☐ Dugouts ☐ Motor boats ☐

14. Amount of fish harvested by a fisher per day (Kg day^{-1}, Fish day^{-1}) ☐

14.1. Types and number of fishing gears used to harvest this amount of fish per day ☐

14.2. Number of days fishing is conducted in a year ☐

14.3. Amount of fish consumed per family of a fisher (Kg day^{-1}, Fish day^{-1}) ☐

14.4. Amount of fish sold by a fisher to earn income (Kg day^{-1}, Fish day^{-1}) ☐

14.5. Market price of fish (ETB Kg^{-1}; ETB $Fish^{-1}$) ☐

15. Recession farming

15.1. How much sorghum do you produce from recession farming (if any) in kg $year^{-1}$? ☐

15.2. What is the market price (ETB) for sorghum? ☐

16. What is the estimated total value of animal production (ETB) and number of years the animal was raised? ☐

17. How much monthly income do you earn from labor work (ETB $month^{-1}$)? ☐

18. How do you sell your fish? Choose one or more of the following options.

a. whole fish (unprocessed) ☐ b. processed ☐

(Please give the list of your processing activities-e.g. gutting, filleting, etc)

____

c. other form (please specify)____________________

d. What tools do you use for fish processing?

19. Where do you sell your fish or fish product?

a. Direct to consumer ☐ b. To local outlets (restaurants, fish shops, etc) ☐

c. To fish trading organizations or individuals ☐ d. Other (please specify)

____

20. How far do you travel to sell your fish or fish product (i.e. market distance for selling fish in hours or kms)? ☐

21. How many fish species do you think were there in the lake or river when you started fishing? ☐

22. How do you think the number of fish species and fisheries productions have changed since you have started fishing on the river or lake?

a. Increased ☐ c. Same ☐

b. Decreased ☐ d. No opinion ☐

23. How do you think the fisheries production from the river or lake will change in the forthcoming years?

a. Increase ☐ b. Decrease ☐ c. Remain same as the present production ☐

d. No opinion ☐

24. If you perceive a decreasing trend in fisheries productions in Q. No. 22 & 23 above, how do you rate the following factors as potential limiting factors? yes/no

a. Accessibility problems ☐ b. Bad weather conditions ☐

c. Hydropower dam development ☐ d. Water abstraction for irrigation ☐

e. Water pollution ☐ f. Lack of training for fishers ☐

g. Lack of fishing facilities ☐ h. Over fishing ☐

25. a. Are fisheries of the river or lake regulated? yes/no ☐

b. if yes, who is responsible for the regulation?

c. Do you have knowledge about any fishery legislation or law which is meant to regulate the fisheries of the river or lake?

d. Do you know about the Ethiopia‘s national fisheries development and utilization proclamation no. 315/2003?

e. Have you ever been given awareness or training on wise use of fisheries resources?

f. Who do you think should be involved in the proper and effective management of the fishes and fisheries to ensure sustainability? (e.g. local government, agriculture bureaus, fishers, entire local people, etc)

____

g. Is there any fishery extension in the Dasenech Wereda‘s agriculture bureau that would assist in the development and management of fisheries of the river and/or lake?

26. In your opinion what are the possible solutions or management options to conserve the fishes and sustain the fisheries productions?

____

- Which of these problems are most significant?

____

27. Who do you think should be involved in the proper and effective management of the fishes and fisheries to ensure sustainability (e.g. local government, agriculture bureaus, fishers, etc)?

____

28. As part of an effort to manage the fisheries of the river or lake to ensure sustainability, how do you feel about implementation of the following management strategies?

a. Licensing and limiting the fishers?

Agree ☐ Disagree ☐ No opinion ☐

b. Closed season when fishing is prohibited for some times

Agree ☐ Disagree ☐ No opinion ☐

c. Permanent or temporary closure of areas where fishing is prohibited

Agree ☐ Disagree ☐ No opinion ☐

● if you agree to the area closure, would you please suggest any such areas that require closure at present?

____

d. Limiting the number of people fishing

Agree ☐ Disagree ☐ No opinion ☐

e. Limiting the type, number and mesh sizes of the gears used

Agree ☐ Disagree ☐ No opinion ☐

Part II. For focus group discussion

1. Gender: Male ☐ Female ☐

2. Education level:

   2.1. No formal education ☐

   2.2. Formal education

   2.2.1. Levels of formal education (e.g. Grade 1, 6, 12, Diploma, etc) ☐

3. Responsibility/Job_____________

4. As an agriculture officer or fish trader, do you know about the Ethiopia‘s fisheries development and utilization proclamation no. 315/2003 (1995 EC)?

5. Are there any external factors that are out of the wereda‘s agriculture office mandate or authority that affect the regulation of Omo River and Lake Turkana‘s fisheries production? If yes, what are these factors related to?

Natural factors ☐ Institutional factors, policies, laws ☐

Political factors ☐ Others (specify) ________________________

6. Is there any fishery extension in the Dasenech Wereda‘s agriculture bureau that would assist in the development and management of fisheries of the river or lake? If yes, please give some details.

7. How do you think fish production from the river or lake has changed in the last 10 years? What about in the forthcoming future?

8. What are your opinions on the following factors as constraints associated with fisheries in the lake or the river? (lack or scarcity of fishing boats, fishing gears, and storage facilities such as deep freezers and generators, market problems, lack of training for fishers, illegal fishing and marketing, development activities in the basin).

9. Are fisheries in lower Omo River and the Ethiopian part of Lake Turkana regulated/managed? If yes, who regulates the fishing activities? If not regulated, what are the major reasons?

10. What regulatory framework (rule or direction) is available? How does the availability or unavailability of regulatory framework affect management of fishery in the area?

11. Who do you think should be involved in the proper and effective management of the fishes and fisheries to ensure sustainability (e.g. local government, agriculture bureaus, fishers, etc)?

12. Have the fishers ever been given awareness or training on wise use of fisheries resources? If yes, please give some details about the awareness creation or training.

13. Are there any major conservation threats to the fishes of the river or lake (overfishing, natural factors, etc)?

14. What are your suggestions to improve the conservation of the fishes as well as to develop and sustain fisheries in the area?

DECLARATION

I, the undersigned, hereby declare that this thesis is my original work and that all sources of material used for the thesis have been correctly acknowledged.

Name: Mulugeta Wakjira

Signature: ______________

Date of submission: May 03, 2016.