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Fish diversity in the Nile system and ephemeral water bodies in Sudan: Records and a review

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Abstract
Freshwater fish diversity in the Nile and its tributaries, associated man-made Lakes and ephemeral water bodies in Sudan was investigated. There are 134 freshwater fish species falling in 64 genera and 27 families. The country fish fauna contains a mixture of Nilo-Sudanic and lower Nile basin to the South. The relative abundance showed that there are at least 111 species in White Nile, 73 in Blue Nile, 36 in Dinder River, 38 in Atbara River and 63 in the Nile. There are three introduced species *Gambosia affinis*, *Gibelion catla* and *Oreochromis urolepis*. In inland ephemeral water bodies five killifish were described from the Nuba mountains and *Aphinus* (= *Cyprinodon*) *dispar* was described from Khor Arbat few Km North of Port Sudan. The endemic species amount to 12+. The taxonomic status of 13 potentially new species need to be established.

Keywords: Fish, diversity, new species, endemism, Sudan

1. Introduction
According to Nyboer *et al.* [1] African has at least 3,300 freshwater fish species which constitute 10% of the world's total; with cichlids representing 10% of its species (Leveque and Paugy) [2]. The geomorphology and climatic changes in Pilo-Peliocene in northern and eastern Africa severely changed its hydrology (Kathlyn and Stewart [3]). This might have led to isolation of some fish fauna. The geological complexity and its associated ecoregions led to genetic diversity of its fish fauna (Basiita *et al*.,) [4].
Sudan is gifted with several water bodies. Its inland water is about 7,000 km in total length of rivers and a 7,400 km^2 of canalization system (El Moghraby) [5]. The aquatic biota is highly diverse including phytoplankton, hydrophytes, zooplankton, aquatic arthropods, fish and water associated vertebrates (Dumont) [6]. Its fish species is well documented (Sandon [7]; Abu Gideiri [8]; Abu Gideiri *et al.* [9]; Bailey, 1994 and Neumann *et al.* [11] and the references therein). List of fish species of several parts of the Nile system were produced. For the White Nile see (Adam [12]; Mosa *et al.* [13]; Moritz *et al.* [14] and Mahmoud *et al.*) [15]. Published lists for the Blue Nile included (Abu Gideiri [16]; Mishrigi [17]; Mahmoud and Hagar [18]). Lists for the Nile were due to (Mathiasson [19]; George [20]; Abu Gideiri and Ali [21]; Adam [22]; Ali [23]; A/Halim *et al.* [24] and Mahmoud [25]). Atbara River fish list was produced by (Ibrahim and Mahmoud [26]). The Ichthyofauna of Dinder was studied by Mahmoud [27], Adam *et al.* [28] and Hagar and Mahmoud [29]. During the course of fish parasites investigations several locality records of fish were given (Mahmoud [30]).
The objective of this works is to list, compare diversity and similarity of fish species in the Nile system and the ephemeral water bodies in Sudan.

Material and Methods
Source of data
Experimental fishing (Moritz *et al.* [14] and Mahmoud *et al.* [15]; A/Halim *et al.* [24]; Ibrahim and Mahmoud [26]; Mahmoud [27]) and inspection of commercial fish catch at different landing sites (Mahmoud *et al.* [15] and Mahmoud [25]) was performed. In addition, desk information including the work of Chambers [31], Bellemans [32, 33], Valdesalici [34] and Valdesalici *et al.* [35] from ephemeral water bodies of Nuba mountains, constituted the material of this paper.

Fish diversity

The fish diversity was quantified using:

1. Relative diversity index RDI= No. of a taxa in a river ÷ total of the taxa in all rivers.
2. The Similarity index QSI using: QSI = 2 C ÷[S_1+ S_2]

Where: C= common taxa between two rivers, S_1=taxa from river 1 and S_2=taxa from River 2, taxa = families, genera or species.

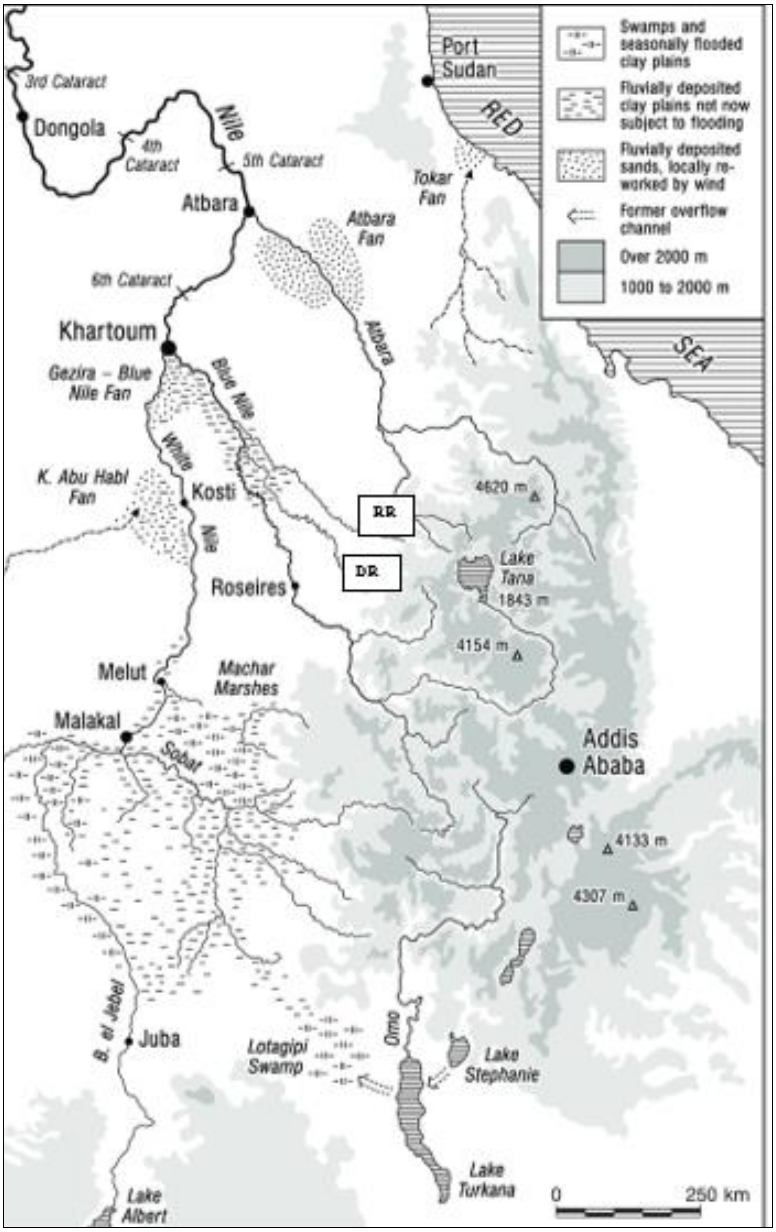

Fig 1: Nile and its tributaries in Sudn. Rahad =RH, Dinder = DR. Source: Google Earth Map.

Results and Discussion

The freshwater fish families, genera and species in Sudanese Nile system was given in Table 1. It is apparent from the table that:

1. The present study showed the occurrence of 134 freshwater fish species falling in 64 genera and 27 families. This includes six species from ephemeral waters and three introduced species (*Gambosia affinis*, *Gibelion catla* and *Oreochromis urolepis*).
2. There are 12 endemic species and 10 new species.
3. The White Nile is richest in number families, genera and species; The lowest in number of families and genera is Atbara River and in species is Dinder River.
4. Members of Nothobranchiidae, Poeciliidae, Cyprinodontidae and Channidae were found in the White Nile so far; while Moronidae is confined to the Nile.
5. The richest families are Cyprinidae with 22 species, Mochokidae with 17 species, Mormyridae with 15 species and Distichodontidae with 10 species.
6. The following 16 species are found in all rivers *Brycinus nurse*, *Labeobarbus bynni*, *Labeo horie*, *Labeo coubie*, *Labeo senegalensis*, *Auchenoglanis occidentalis*, *Bagrus bajad*, *Bagrus docmak*, *Clarias gariepinus*, *Clarias anguillaris*, *Synodontis schall*, *Malapterurus electricus*, *Lates nloticus*, *Oreochromis niloticus*, *Sarotherodon galilaeus* and *Coptodon zillii*.
7. The distichodontid *Paradistichodus dimidiatus* (Pellegrin 1904) and the cyprinid *Enteromius macrops* (Boulenger 1911) were reported as first records for the Main Nile Basin by Moritz *et al*. [14] from Kosti.
8. Recently, *from Al Gitina locality, White Nile, Oreochromis aureus* was reported for the first time in Sudan by (Hagar and Omer [36]. From Khashm El Girba (Atbara River) on basis of morphometric and molecular data Ahmed [37] made the first record of *Malapterurus minjiriya* from Sudan.

Table 1: Number of fish families, genera and species in Sudanese Rivers and ephemeral water bodies (N. = Nile; R= River). *=endemic and #= new species

Fish Families and Species	White N.	Blue N.	Dinder R.	Atbara R.	Main Nile
Protopteridae					
Protopterus aethiopicus	+		+		
Protopterus annectens	+				
Polypteridae					
Polypterus bichir	+ BB	+	+ AGA		
Polypterus endlicherii	+				
Polypterus senegalus	+				
Arapaimidae					
Heterotis niloticus	+	+	+ AGA		
Notopteridae					
Xenomystus nigri	+				
Gymnarchidae					
Gymnarchus niloticus	+		+		
Mormyridae					
Hyperopisus bebe	+	+	+		+
Marcusenius cyprinoides	+	+	+		+
Mormyrus hasselquistii	+	+		TB	
Mormyrus niloticus	+				
Mormyrus caschive	+ BB	+	+ AGA	TB	+
Mormyrus kannume	+	+ AR	+ AR	+TB	+
Mormyrops anguilloides	+	+	+		+
Petrocephalus keatingii#*	+				
Petrocephalus bane	+	+	+	+	+
Petrocephalus bovei	+	+			
Brevimyrus niger	+	+			+
Pollimyrus isidori	+	+			+
*Pollimyrus petherici**	+				+
Cyphomyrus petherici	+				
Hippopotamyrus harringtoni	+ BB				
Alestidae					
Alestes baremoze	+	+		+ TB	+
Alestes dentex	+		+	+	+
Brycinus nurse	+ BB	+ AR	+ AGA	+ TB	+
Brycinus macrolepidotus		+ AR	+	+ TB	
Hydrocynus vittatus	+	+		TB	+
Hydrocynus forskahlii	+	+ AR		+	+
Hydrocynus brevis	+ BB	+	+ AGA		+
Micralestes elongates	+	+			+
Distichodontidae					
Distichodus brevipinnis	+	+			
Distichodus engycephalus	+	+			
Distichodus rostratus	+		+	+	+
Distichodus nefasch	+	+	+ AGA	+	
Paradistichodus dimidiatus#	+				
Neolebias trewavasae	+				
Neolebias unifasciatus	+				
Ichthyborus besse	+				
Annocharax niloticus	+				+
Nannocharax niloticus#*	+	+			+
Citharinidae					
Citharinus citharius	+ BB	+	+ AGA		+
Citharinus latus	+	Nurse	+		
Cyprinidae					
Labeobarbus bynni	+	+ AR	+	+ TB	+
Labeo forskalii	+	+ AR			
Labeo horie	+ BB	+ AR	+ AGA	+ TB	+
Labeo coubie	+	+ AR	+	+	+
Labeo senegalensis	+	+ AR	+	+ TB	+
Labeo meroensis#*					+
Labeo latebra#*	+				
Enteromius anema	+	+			+
Enteromius leonensis	+				
Enteromius neglectus	+	+			+
Enteromius stigmatopygus	+				+
Enteromius prince	+	+			+

Enteromius pumilus	+				+
Enteromius macrops[#]	+				
Enteromius werneri	+				
Garra vinciguerrae					+
Garra napata[*#]					+
Garra Jamila[*#]				+	
Garra sannarensis[#*]		+			
Leptocypris niloticus	+	+			+
Raiamas senegalensis	+	+		TB	+
Chelaethiops bibie	+	+			+
Clarotidae					
Clarotes laticeps	+	+		+	+
Chrysichthys auratus	+	+		+	+
Chrysichthys rüppeli					+
Auchenoglanis occidentalis	+	+ AR	+		+
Auchenoglanis biscutatus	+			+ TB	+
Amphiliidae					
Andersonia leptura	+ BB	+			+
Bagridae					
Bagrus bajad	+ BB	+ AR	+ AGA	+ TB	+
Bagrus docmak	+	+ AR	+	+ TB	+
Schilbeidae					
Parailia pellucida	+				
Schilbe mystus	+	+	+ AGA	+	+
Schilbe uranoscopus					
Schilbe intermedius	+	+			
Siluranodon auritus	+	+			
Clariidae					
Clarias gariepinus	+ BB	+ AR	+ AGA	+ TB	+
Clarias anguillaris	+	+	+		+
Clarias engelseni	+				
Clarias werneri	+	+			
Heterobranchus longifilis	+	+		TB	
Heterobranchus bidorsalis	+	+	+	+ TB	
Mochokidae					
Androsonia leptura					+
Chiloglanis niloticus	+	+			+
Chiloglanis sp. “Sennar”		+	AGA	TB	
Mochokus niloticus	+				+
Mochokus brevis	+				
Synodontis clarias	+	+			+
Synodontis schall	+	+ AR	+	+ TB	+
Synodontis eupterus	+				
Synodontis filamentosus	+	+			
Synodontis serratus	+	+ AR		TB	+
Synodontis sorex	+	+			+
Synodontis nigrita	+	+			
Synodontis membranaceus	+	+	+		+
Synodontis batensoda	+	+	+	+	+
Synodontis frontosus,	+	+			
Synodontis khartoumensis	+	+			
Synodontis cuadovittatus	+	+			+
Malapt 8 eruridae					
Malapterurus electricus	+	+	+ AGA	+ TB	+
Malapterurus minjiriya			AGA		
Nothobranchiidae					
Epiplatys bifasciatus	+				
Epiplatys spilargyreius	+				
Poeciliidae					
Micropanchax hutereaui	+				
Micropanchax kingie	+				
Micropanchax loati	+				
Poropanchax normani	+				
Cyprinodontidae					
Aphanius fasciatus	+				
Latidae					
Lates niloticus	+	+	+ AGA	+ TB	+
Eleotridae					

Kribia nana	+				+
Anabantidae					
Ctenopoma muriei	+	+			
Ctenopoma petherici	+				+
Channidae					
Parachanna obscura	+				
Moronidae					
Dicentrarchus labrax					+
Cichlidae					
Oreochromis niloticus	+ BB	+ AR	+ AGA	+ TB	+
Oreochromis aureus	+				
Oreochromis sp. "botched"		+			
Sarotherodon galilaeus	+ BB	+ AR	+ AGA		+
Coptodon zillii	+8	+	+	+ TB	+
Hemichromis fasciatus	+	+			
Hemichromis letourneuxi	+	+			
Tetraodontidae					
Tetraodon lineatus	+	+ AR			+

Ethiopian Basins: BB=Baro Basin, AR=Abby River, AGA= Alatish Rivers and TB=Tekeze Basin.

The highest relative percentage diversity index between families, genera and species was in the White Nile and the lowest index between families and genera was in Atbara River. The lowest index between species was in Atbara River (Table 2).

Table 2: Number of families, species and genera in the different rivers and their relative percentage diversity index (%RDI).

Site	Families		Genera		Species	
	No.	%RDI	No.	%RDI	No.	%RDI
White Nile	26	96.29	62	98.41	111	88.80
Blue Nile	18	66.67	43	68.25	73	58.40
Dinder River	14	51.85	28	44.44	37	29.60
Atbara River	13	48.14	20	31.75	28	22.40
Main Nile	17	62.96	42	66.67	64	51.20
Total for all rivers	27		63		125	
Affinities with Ethiopian Basins						
White Nile	19		42		79	
Blue Nile	12		28		64	
Tekeze	9		22		32	
Ayima, Galegu and Alatish	15		27		53	

Family wise, the highest similarity index was found between the Blue Nile and Dinder River (0.938) and the lowest between the Blue Nile and Atbara River (0.571). With respect to genera, he highest similarity index was found between the Blue Nile and the main Nile (0.823) and the lowest between the White Nile and Atbara River (0.488). Species wise, he highest similarity index was found between the White and Blue Niles (0.778) and the lowest between the White Nile and Atbara River (0.345).

Table 3: Coefficient of similarity indices between fish families, genera and species in Niles and rivers.

Site	Main Nile	White Nile	Blue Nile	Atbara River	Dinder River
	Families similarity index				
Main Nile	-				
White Nile	0.774	-			
Blue Nile	0.686	0.818	-		
Atbara River	0.867	0.615	0.571	-	
Dinder River	0.774	0.700	0.938	0.741	-
Genera similarity index					
Main Nile	-				
White Nile	0.750	-			
Blue Nile	0.823	0.781	-		
Atbara River	0.613	0.488	0.667	-	
Dinder River	0.629	0.600	0.704	0.667	-
Species similarity index					
Main Nile	-				
White Nile	0.647	-			
Blue Nile	0.569	0.778	-		
Atbara River	0.543	0.345	0.455	-	
Dinder River	0.574	0.469	0.600	0.677	-

Species richness in Sudan is dominated by Cyprinidae (22 spp.), Mochokidae (17 spp.), Mormyridae (15 spp.) and Distichodontidae (10 spp.). This is with harmony with Leveque and Paugy [2] who stated that Africa rivers tends to be dominated by Cyprinidae and Siluriformes. Atbara river flows from Taekeze basin in Ethiopia. The basin contains 5 species of the cyprinid *Labeobarbus* (Gebru *et al*.) [38]. Of these only *L. bynni* is found in Atbara river. In Lake Tana *Labeobarbus* is represented by 15 species (de Graaf *et al*. [39]; *L. bynni* which is dominant in the Blue Nile is not found in Lake Tana the main source of the Blue Nile.

The present study showed the occurrence of 133 freshwater fish species including six species from ephemeral waters and three introduced species. The literature showed discrepancy in the number of freshwater fish species listed to Sudan. Boulenger [40] listed 114; Sandon [7] listed 132; Abu Gideiri [8] listed 107; Bailey [10] listed 122 and Neumann *et al*. [11] listed 150 species. Fishbase.org [41] list was criticized by Mahmoud *et al*. [42] for adding 6 marine fish species, missing three mochokids (*A. leptura*, *S. clarias* and *S. eupterus*), *the schilbidae S. mystus and G. vineinguerre (Cypriniidae) which are* of definite occurrence, inclusion of 4 introduced fish species of which there is no recent records and adding the reticulated Knifefish *Papyrocranus afer* which is native to West Africa according to Roberts [43].

Shared fish genera between the Nile and its tributaries with their original basins

The freshwater fish fauna of Sudan is a mixture of Nilo-Sudanic, ephemeral water bodies and endemic forms. Its rivers share several fish genera and species with their original basins. The basins in Ethiopia are indicated by bold letters in Table 1. The Nile flowing from Uganda (in Republic of South Sudan is termed Bahr El Jabal) and River Sobat from Ethiopia adjoins to form the White Nile They both contributes at least 111 fish species and 63 genera to the White Nile. Uganda has between 270>350 fish species, in Lakes Victoria, Albert and Kyoga (Wandera and Balirwa [44]; Fishbase.org [45]. Bahr El Jabal contributes around 50 genera to the White Nile.

The freshwater fish fauna of Ethiopia of more than 200 species, contains a mixture of Nilo Sudanic, East African and Endemic forms (Golubtsov and Mina [46]; Tewabe [47]; Melake [48]; Oumer [49]; Mengesha [50]; Awoke *et al*.) [51]. The White Nile via Sobat River share 13 genera with Baro Basin. The Blue Nile share 6 genera with Abby River which is isolated by Tisisat Falls from Lake Tana. Dinder River share 19 genera with Rivers Ayima, Gelegu and Alatish penetrate Alatish National Park to form the Dinder River which drain into the Blue Nile. Atbara River share 16 genera with Tekeze Basin. The common genera in the River Nile and its tributaries with their original basins in Ethiopia are *Labeo*, *Bagrus*, *Clarias* and *Oreochromis*. Based on Golubtsov and Mina [46] there are 60 fish species in the White Nile in Ethiopia which is known as Sobat River in Republic of South Sudan. In addition, there are two common genera *Hippopotamyrus* and *Genus Nothobranchius.*

All in all, these contributes at least a total of 73 fish species to The Blue Nile, Atbara River and Dinder River. *Garra ignestii* is endemic to Tekeze basin (Golubtsov and Mina) [46].

New, endemic species and potential additions

At least 12+ freshwater fish species are endemic. Sandon [52] reported a bright red coloured *Nathobranchius* sp., from Kordofan State. About 27 years later Chambers [31] collected *Nathobranchius. virgatus*. This was followed by discovery of *Nathobranchius.* aff. *Rubroreticulatus* by Bellemans [32] (2000) from Khor Maada Mulaha which drains in Wadi Al Galla. Bellemans [32] collected and provisionally named *Nathobranchius nubaensis* from Khor Angarko a branch of Khor Abu Habil and shortly collected from Ethiopeia. Later its nomenclature was confirmed by Valdesalici *et al*. [35]. Valdesalici [34] found *Nathobranchius bellemansi* from Wad el Mileisa southeast Nuba mountains and *Nathobranchius occultus* from Khor Kidda near Kadugli. All collections were from Kores flowing from Nuba mountains. These five Nothobranchiidae species are endemic and new records to science from ephemeral water bodies in Nuba mountains. Five Cyprinids: *L. meroensis* from near Shendi (Moritz) [53]*; L. latebra from Kosti (*Moritz and Neumann) [54], *G. napata from the Nile near Tarag island; G. jamila from Um Alaswad immediately in front of Khashm El Girba Dam on Atbara river and G. sannarensis from the Blue Nile near the outlet of Mangil canal from Sennar Dam (*Moritz *et al*.) [55] are *new riverine species.* Two Mormyrids *Pollimyrus petherici* (Gosse, 1984) and the elephant fish *Petrocephalus keatingii* and the Broadbar *Nannocharax niloticus* (Distichodontidae) are also endemic (Moritz *et al*.,) [14].

Synodontis khartoumensis, first described from Sudan by (Abu Gideiri) [56] is no longer endemic as it was later reported from the Democratic Republic of Congo and in Lake Albert in Uganda (https://en.wikipedia.org/wiki/Synodontis_khartoumensis, 2023) [57].

From Kosti area (White Nile) the distichodontid *P. dimidiatus* (Pellegrin 1904) *and Enteromius macrops* (Boulenger 1911) were reported for the first time from the main Nile Basin by Moritz *et al*. [14]. Also from the same locality *Oreochromis aureus* was reported for the first time in Sudan by (Hagar and Omer) [36].

Results of recent collections calls for taxonomic verification of 13 potentially new species. According to Moritz *et al*. [54] *Garra* cf. *vinciguerrae* from the Nile and the White Nile at Kosti (cf.=indicates to be compared with), *Garra* sp. "flathead" at Taraq island in the Nile, *Garra* sp. "Sennar" Blue Nile collected from the outlet of Managil canal from Sennar Dam, all needs further evaluation. Also evaluation of *Micropanchax* cf. *loati*, from Taraq Island. *Poropanchax* cf. *normani*, *Coptodon* cf. *zillii* and *Hemichromis* cf. *fasciatus* White Nile at Kosti, a "botched" *Oreochromis* sp., and *Hemichromis* cf. *letourneuxi* from the Blue Nile at Sennar (Moritz *et al*.) [14] is needed. Moritz *et al*. [14] also mentioned an apparently undescribed *Haplochromis* sp. and *Sarotherodon* sp.

According to *Neumann et al.* [11] the collection site of *Pseudocrenilabrus multicolor* and the red eye *Labeo* sp. *Nov. "red eye"* is enigmatic rendering coming across them a matter of chance.

Introduced fishes

Five fish species *Oncorhynchus mykiss* (Family: Salmonidae); *Oreochromis macrochir* (Family: Cichlidae); *Ctenopharyngodon idella* and *Cyprinus carpio* (Family: Cyprinidae) and *Gambusia affinis* (Family: Poeciliidae) were introduced some decades ago with no survival records except for *G. affinis* (Mahmoud *et al*.) [42]. Fish species introduced for the aquaculture purpose during the period of 2003 to 2006 and in occurrence were *Gibelion catla* (Family: Cyprinidae), *Oreochromis urolepis* in addition to crossbreeds of male

Oreochromis mossambicus with female *O. niloticus* (yielding red tilapia), genetically modified strains of *O. niloticus* such as GIFT tilapia, Chi strain and supper male (Mahmoud *et al.*) [42].

Freshwater fishes outside the Nile system

Freshwater fishes naturally occurring outside the Nile system included *Aphinus dispar* from Khor Arbat (Sandon [7]; *P. annectens* in Tordat Al Rahad (Abu Gideiri [8]) and in upper Wadi Kaja, a Chari-Chad affluent in West Darfur (Neumann *et al*. [11]); *S. serratus, S. nigrita, S. sorex, C. gariepinus* and *O. niloticus* in South Darfur (Mujtaba Shoaib, personnel communication).

Introduced freshwater fish species in ephemeral water bodies which are well propagating included *O. niloticus*, *C. gariepinus*, *L. senegalensis*, *Heterotis niloticus* and *Lates niloticus* in Tordat Al Rahad (Fisheries Research Centre, unpublished report); *O. niloticus*, *C. gariepinus* and *B. bajad* in Wadi Al Galla (Ali *et al*.) [58].

Taxonomic updating

Fourteen synonyms were observed to be in common use either due to unawareness and/or un-updated information, these are given between brackets after the valid name adopted by Fricke *et al*. [59]. These must be replaced with the currently valid names *Kribia nana* (*Eleotris nanus*); *Labeobarbus bynni* (*Labeo bynni*); *Labeo senegalensis* (*Labeo niloticus*); *Schilbe mystus* (*Eutropis niloticus*); *Brycinus nurse* (*Alestes nurse*); *Brycinus macrolepidotus* (*Alestes macrolepidotus*); *Micralestes elongates* (*Micralestes acutidens*); *Hydrocynus forskahlii* (*Hydrocynus lineatus*); *Parachanna obscura* (*Ophicephalus obscura*); *Clarias gariepinus* (*Clarias lazera*); *Oreochromis niloticus* (*Tilapia nilotica*); *Sarotherodon galilaeus* (*Tilapia galilaeus*); *Coptodon zillii* (*Tilapia zillii*) and *Distichodus nefasch* (*Distichodus niloticus*).

Conclusions

Morphological and molecular comparison of the fish species in Sudan with those found in freshwater masses in adjacent countries, to work out their phylogenic relationships is an area of collaborative research basis that should be given due attention. The deep water Nile perch *Lates longispinnis*, need in depth investigation in the upper reaches of Sobat River. Exact estimates are impossible because of uncertainties in the distributional records for some species.

Ethical Issues

Ethics approval and consent to participate, human and animal rights, consent for publication, availability of data and materials are not applicable.

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Conflict of Interest: The authors declares no conflict of interest, financial or otherwise.

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