First DNA barcode library for the ichthyofauna of the Jos Plateau (Nigeria) with comments on potential undescribed fish species (#62982)

First revision

Guidance from your Editor

Please submit by **29 Oct 2021** for the benefit of the authors .

Structure and Criteria
Please read the 'Structure and Criteria' page for general guidance.

Custom checks
Make sure you include the custom checks shown below, in your review.

Raw data check
Review the raw data.

Image check
Check that figures and images have not been inappropriately manipulated.

Privacy reminder: If uploading an annotated PDF, remove identifiable information to remain anonymous.

Files

Download and review all files from the materials page.

1 Tracked changes manuscript(s)
1 Rebuttal letter(s)
12 Figure file(s)
4 Table file(s)
1 Raw data file(s)

Custom checks

DNA data checks

- Have you checked the authors data deposition statement?
- Can you access the deposited data?
- Has the data been deposited correctly?
- Is the deposition information noted in the manuscript?

Field study

- Have you checked the authors field study permits?
- Are the field study permits appropriate?

Structure and Criteria

Structure your review

The review form is divided into 5 sections. Please consider these when composing your review:

1. **BASIC REPORTING**
2. **EXPERIMENTAL DESIGN**
3. **VALIDITY OF THE FINDINGS**
4. General comments
5. Confidential notes to the editor

You can also annotate this PDF and upload it as part of your review

When ready submit online.

Editorial Criteria

Use these criteria points to structure your review. The full detailed editorial criteria is on your guidance page.

BASIC REPORTING

- Clear, unambiguous, professional English language used throughout.
- Intro & background to show context. Literature well referenced & relevant.
- Structure conforms to PeerJ standards, discipline norm, or improved for clarity.
- Figures are relevant, high quality, well labelled & described.
- Raw data supplied (see PeerJ policy).

EXPERIMENTAL DESIGN

- Original primary research within Scope of the journal.
- Research question well defined, relevant & meaningful. It is stated how the research fills an identified knowledge gap.
- Rigorous investigation performed to a high technical & ethical standard.
- Methods described with sufficient detail & information to replicate.

VALIDITY OF THE FINDINGS

- Impact and novelty not assessed. *Meaningful* replication encouraged where rationale & benefit to literature is clearly stated.
- All underlying data have been provided; they are robust, statistically sound, & controlled.
- Conclusions are well stated, linked to original research question & limited to supporting results.

Standout reviewing tips

The best reviewers use these techniques

Tip	*Example*
Support criticisms with evidence from the text or from other sources	*Smith et al (J of Methodology, 2005, V3, pp 123) have shown that the analysis you use in Lines 241-250 is not the most appropriate for this situation. Please explain why you used this method.*
Give specific suggestions on how to improve the manuscript	*Your introduction needs more detail. I suggest that you improve the description at lines 57- 86 to provide more justification for your study (specifically, you should expand upon the knowledge gap being filled).*
Comment on language and grammar issues	*The English language should be improved to ensure that an international audience can clearly understand your text. Some examples where the language could be improved include lines 23, 77, 121, 128 – the current phrasing makes comprehension difficult. I suggest you have a colleague who is proficient in English and familiar with the subject matter review your manuscript, or contact a professional editing service.*
Organize by importance of the issues, and number your points	*1. Your most important issue* *2. The next most important item* *3. …* *4. The least important points*
Please provide constructive criticism, and avoid personal opinions	*I thank you for providing the raw data, however your supplemental files need more descriptive metadata identifiers to be useful to future readers. Although your results are compelling, the data analysis should be improved in the following ways: AA, BB, CC*
Comment on strengths (as well as weaknesses) of the manuscript	*I commend the authors for their extensive data set, compiled over many years of detailed fieldwork. In addition, the manuscript is clearly written in professional, unambiguous language. If there is a weakness, it is in the statistical analysis (as I have noted above) which should be improved upon before Acceptance.*

First DNA barcode library for the ichthyofauna of the Jos Plateau (Nigeria) with comments on potential undescribed fish species

Michael Olaoluwa Popoola Corresp., 1 , **Frédéric Dieter Benedikt Schedel** 2, 3 , **Paul David Neil Hebert** 4 , **Ulrich Kurt Schliewen** 3

1 Obafemi Awolowo University, Ile-Ife, Nigeria

2 Universität Basel, Basel, Switzerland

3 SNSB-Bavarian State Collection Zoology (ZSM), München, Germany

4 University of Guelph, Guelph,, Canada

Corresponding Author: Michael Olaoluwa Popoola
Email address: popoolam@oauife.edu.ng

Located in the central region of northern Nigeria, the Jos Plateau covers approximately 9400 km² with an average altitude of 1280 m and constitutes a unique terrestrial ecoregion known as the Jos Plateau forest-grassland mosaic. The biota of the Jos Plateau include endemic elements, but very limited information is available on its ichthyofauna. This is despite the fact that the ancient plateau contributes to several large rivers spanning multiple major drainage systems including the Niger and Benue Rivers, and Lake Chad. This study provides the first species list for the fishes of the Jos Plateau based mainly on 175 DNA barcoded museum voucher specimens representing 20 species, and another three species without a DNA barcode. In total, 23 species from eight families and 17 genera were collected from the Jos Plateau including five putatively new species, four in the family Cyprinidae and one in the Clariidae. With ten species, the Cyprinidae is the most diverse fish family on the Jos Plateau, followed by Clariidae and Cichlidae, each with three species. The study also provides data on species distribution and habitat parameters including information on water chemistry that strongly suggests that selected water bodies are heavily impacted by anthropogenic activities. Urgent management steps are required to preserve the unique and diverse fish communities of the Jos Plateau and their habitats.

First DNA barcode library for the ichthyofauna of the Jos Plateau (Nigeria) with comments on potential undescribed fish species

Michael Olaoluwa Popoola[1], Frédéric Dieter Benedikt Schedel [2,3], Paul David Neil Hebert[4], Ulrich Kurt Schliewen[2]

[1] Obafemi Awolowo University, Ile-Ife, Nigeria

[2]SNSB-Bavarian State Collection Zoology (ZSM), München, Germany

[3]Current address: University of Basel, Basel, Switzerland

[4]University of Guelph, Guelph, Canada

Correspondence:

Michael M. Popoola, Department of Zoology, Obafemi Awolowo University, Ile-Ife, Nigeria.

popoolam@oauife.edu.ng.

Abstract

Located in the central region of northern Nigeria, the Jos Plateau covers approximately 9400 km^2 with an average altitude of 1280 m and constitutes a unique terrestrial ecoregion known as the Jos Plateau forest-grassland mosaic. The biota of the Jos Plateau include endemic elements, but very limited information is available on its ichthyofauna. This is despite the fact that the ancient plateau contributes to several large rivers spanning multiple major drainage systems including the Niger and Benue Rivers, and Lake Chad. This study provides the first species list for the fishes of the Jos Plateau based mainly on 175 DNA barcoded museum voucher specimens representing 20 species, and another three species without a DNA barcode. In total, 23 species from eight families and 17 genera were collected from the Jos Plateau including five putatively new species, four in the family Cyprinidae and one in the Clariidae. With ten species, the Cyprinidae is the most diverse fish family on the Jos Plateau, followed by Clariidae and Cichlidae, each with three species. The study also provides data on species distribution and habitat parameters including information on water chemistry that strongly suggests that the surveyed water bodies are heavily impacted by anthropogenic activities. Urgent management steps are required to preserve the unique fish communities of the Jos Plateau and their habitats.

Keywords: Checklist, COI, mitochondrial DNA, Freshwater fishes, West Africa

Introduction

Scientific interest in the aquatic biodiversity of the African continent dates back to the 18th century. One important step towards an objective basis for the comparative study of its aquatic biodiversity involved dividing the continent into more or less homogenous fish fauna regions or ichthyological provinces (Leveque, 1997; Roberts, 1975). The Jos Plateau forest-grassland mosaic falls within the Nilo-Sudan ichthyological province (Stiassny *et al.*, 2007) and is well known as a biogeographically distinct terrestrial ecoregion (Wright & Jones, 2005). However, the fish fauna of the Jos Plateau has received very little attention. This is surprising because the rivers that drain from this high plateau (~ 1000 m) are unique in that they are mostly isolated from downstream sections by waterfalls, draining geologically old granitic and basalt formations of different origin that span very different watersheds including the Niger River and the Chad and Benue Basins (Buchanan & Pugh, 1955).

With a surface area of 9400 km^2, the Jos Plateau is located in the central part of northern Nigeria and lies at an average elevation of 1280 m above sea level, with geologically ancient granite hills and rock outcrops sometimes reaching another 300 m in elevation (Lee, 1972). The area is drained by several major rivers which are important sources of domestic water for this densely populated region. The watershed pattern on the Jos Plateau is unusual as its rivers drain into three major river systems in Nigeria: rivers flowing northeast drain into the Kano River and Lake Chad (Chad drainage); east flowing rivers drain into the Gongola River, a tribituary of the Benue River drainage; rivers flowing south drain as well to the Benue River; and west flowing rivers drain into the Kaduna River which feeds the Niger River (Niger drainage system). Seventeen rivers; Delimi, N'gell, Gurum, Rukuba, Jarawa, Shen-fusa, Foron, Kassa, Assop, Daffo, Gindiri, Tahoss, Korot, Magurji, Maijuju, Bokkos and Farin-ruwa; (see table 1) were surveyed in this study. The Delimi River, however, is the main drainage system of the Jos Plateau and a major tributary of the Shari River system which flows north-east before it drains into Lake Chad, covering a distance of about 900 km.

The Jos Plateau has a wet-dry climate which is largely determined by its elevation and position across the seasonal shifts of the Inter-Tropical Convergence Zone (ITCZ). Generally, the average temperatures on the Jos Plateau are lower than those in the rest of Nigeria. The dry season is dominated by the north-east trade winds while the beginning of the rainy season is marked by thunderstorms of high intensity. The plateau lies within the northern Guinea Savanna vegetation zone, an open woodland with tall grasses. Though the area has its own unique vegetation, this has been considerably altered by human activities including mining, agriculture, grazing, and the demand for timber and fire wood (Olowolafe, 2008).

In fact, the only fish taxa described from the greater Jos Plateau are the nothobranchiid killifish *Fundulopanchax gardneri nigerianus* Clausen, 1963 and the labeonin cyprinid *Garra trewavasae* Monod, 1950. Moreover, extremely few ichthyological records are available in museum collections as reflected in global databases, such as Fishbase (Froese & Pauly, 2019). However, Reid & Sydenham (1979) surveyed part of the Jos Plateau in their study of the fishes of the Lower Benue. Other studies on the fishes from the Plateau are unpublished theses (Ekeanyanwu (1980), cited in (Antony, Eneriene, & Ufodike 1986); Oguzie (1982)). However, these studies either only refer to commercially important fish species, some of which have been introduced (*Oreochromis niloticus* Linnaeus, 1758, *Poecilia reticulata* Peters, 1859, *Cyprinus carpio* Linnaeus, 1758), while there is little information on smaller fish species. Further, these studies were not designed to provide faunistic baseline data and lack up-to-date systematic ichthyological expertise. As recent studies have shown; some water bodies on the Jos Plateau have been degraded, and its undocumented fish species are potentially at risk (Ademola, 2008; Akpan & Anadu, 1991; Anadu & Ejike, 1981).

This study provides first comprehensive information on the ichthyological diversity of the Jos Plateau based on DNA barcodes and morphological identification of voucher specimens.

Materials and Methods

Fieldwork, study sites and species identification

Sampling was carried out on several field trips to the Jos Plateau during the dry season (December 2013, and January - April 2014). Fishes were collected at 37 strategically selected sampling locations in 17 major rivers on the Jos Plateau (supplmentary table 1 provides detailed locality information; Figures 1 & 2). Fishes were captured using different methods (cast net, gill net, frame net, fish traps) depending on the size and habitat of the site. Freshly caught specimens were euthanized with an overdose of anaesthetic (Benzocaine, MS-222). Specimens representative of all taxa from each collection at each sampling site were individually tagged and pectoral fin clip sampled. The whole specimens are photographed after-which they are fixed in 5% formalin and eventually preserved in 70% ethanol after being treated in changes of water followed by different concentrations (20%, 40% and 60%) of ethanol according to Neumann (2010). Tissues were placed immediately into individually labelled tubes filled with 96%

ethanol. Specimens were exported on the 17th of September, 2014 and subsequently deposited in the fish collection of SNSB-ZSM (Germany). We followed all applicable international and national guidelines of animal use and ethical standards for the collection of samples. The permit to survey in the fishes of the Jos area was obtained from the GWOM SOPP palace, Riyom, Plateau State.

After a preliminary identification of specimens in the field to a genus level, preserved specimens were subsequently assigned to a species using standard identification keys (Paugy, Leveque & Teugels, 2003; Stiassny, Teugel, & Hopkins, 2007). When required, additional literature (i.e. original descriptions) were consulted allowing species identification and the clear identification of diagnostic characteristics, this was. This was especially necessary for the identification of the candidate species belonging to the genera *Enteromius* and *Clarias* and their comparison to potentially similar species. If morphometric measurements were required, we measured those following protocols in the identification keys using a manual calliper. Important meristic traits were examined using a stereomicroscope (Leica MZ6) as well as with a digital X-ray using a Faxitron Ultrafocus LLC X-ray unit. However, some of the collected specimens could not be assigned to any described species known from West Africa (please see further below for a comprehensive overview of the newly discovered candidate species).

Notes on collection sites (see Figure 2)

Most of the collection sites were situated in perennial or annual headwaters of major rivers in Nigeria. Generally, they originate as small streams before they flow over long stretches of fine-grained alluvial soils with few rocks. After a substantial increase in stream size, they reach the margin of the high plateau before descending, often in rapids and cascades, to the lowland plains below. On the plateau, water flow is usually moderate, whereas in rapids and waterfalls it may be torrential. Vegetation along the river banks provides partial shading and is best characterized as a savanna-forest mosaic. None of the sampled locations was pristine; all were impacted by farming, domestic waste deposition, industrial discharges or by mining.

Water chemistry (supplementary table 3)

The physico-chemical characteristics of the Assop, N'gell, Rukuba, and Tahoss rivers were assessed following standard procedures. The water temperature was measured *in situ* using mercury-in-glass bulb thermometer with calibration range (-10^0 C – 110^0 C). Samples for the analysis of physico-chemical parameters were collected in clean 2 litre plastic bottles. However, dark reagent bottles were used for Biochemical Oxygen Demand (BOD_5) sample collections and kept in a dark cupboard for five days for subsequent analysis. The pH, conductivity, and total dissolved solids (TDS) of each sample were determined using a PCE-PHD1 multi-parameter meter. The analytical determinations of the physico-chemical water quality parameters were carried out within the holding time of each parameter (Ademoroti, 1996; APHA, 1995; Golterman, Clymo, & Ohnstadt, 1978). The BOD_5 was determined by iodiometric titration

(Golterman, Clymo, & Ohnstadt, 1978). Colour was investigated using a colourimeter (Jenway 6051 model) standardized with a set of potassium chloroplatinate-cobalt solutions as Pt-Co standards, while turbidity was assessed using a turbidimeter (Ademoroti, 1996). Sulphate (SO_4^{2-}) and nitrate (NO_3^-) were determined by spectrophotometric methods (Ademoroti, 1996). Magnesium (Mg^{2+}) was determined by the complexio-metric titration method using Na_2EDTA (Golterman, Clymo, & Ohnstadt, 1978). All recommended quality control (QC) and quality assurance (QA) measures were taken for each determination.

Laboratory protocols

For DNA extraction, we subsampled the ethanol-preserved fin clips and transferred them to 96-well plates. These plates were sent to the Canadian Center for DNA Barcoding (CCDB, Guelph, Canada) for DNA extraction, PCR amplification, and Sanger sequencing (all protocols are available online: ccdb.ca/resources/). PCR amplification of all samples employed the fish primer pair C_FishF1t1/C_FishR1t1 (Ivanova *et al.*, 2007) for the CO1 (mitochondrial cytochrome *c* oxidase subunit 1) barcode fragment. The same primer were used for subsequent bidirectional Sanger sequencing reactions. The resulting sequence data and trace files were uploaded to BOLD (Ratnasingham & Hebert, 2007) as well as all corresponding metadata voucher information (i.e. locality data, altitude, taxonomic classification, habitat images, primer information etc.) and are publicly accessible in the "NGAJO" dataset in BOLD. DNA barcodes were also subsequently uploaded to GenBank (accession numbers available after manuscript review).

Molecular data anaylsis

We used the "Sequence Analysis" toolbox on BOLD and restricted analysis to sequences >500 bp. MUSCLE (Edgar, 2004) was employed to align the sequences while the sequence divergences (i.e. mean and maximum intraspecific variation as well as the minimum genetic distance to the nearest-neighbour species) were calculated using the 'Barcode Gap Analysis' tool on BOLD. This analysis employs the Kimura-2-Parameter (K2P) distance metric (Puillandre *et al.*, 2012). As well a neighbour-joining (NJ) tree was constructed to graphically represent the BIN clusters. Within BOLD, closely similar COI barcode sequences are assigned a globally unique identifier, termed a "Barcode Index Number" or BIN (Ratnasingham & Hebert, 2013). The ''BIN Discordance'' report on BOLD was used to reveal cases where BINs were shared between species clusters or restricted to certain species clusters (BIN Discordance and BIN Sharing). In addition, we obtained for each BIN recovered on the Jos Plateau the nearest BIN available on BOLD (which includes data deposited on GenBank) along with corresponding divergence information directly from the individual BIN records (see Table X).

This was done by screening the BOLD database for all available CO1 sequences for each genus (with a minimum length of 500bp) using the "Record Search" tool, including public records mined from GenBank.

In addition, we created additional and more comprehensive CO1 DNA barcode sequence datasets for all genera for which putatively undescribed species (see below) appeared to be present on the Jos Plateau region. This was done by screening the BOLD database for all available CO1 sequences for each genus (with a minimum length of 500bp) using the "Record Search" tool. Subsequently, we constructed a NJ tree for each genus as indicated above.

Results

Nearly 800 specimens were collected during the three surveys and, based on morphological keys, they were assigned to 23 species (8 families, 17 genera), some of which appeared to represent undescribed species (see below for further information). Potentially new species fell into four genera - *Clarias* Scopoli, 1777, *Enteromius* (Cope, 1867), *Labeo* Cuvier, 1816 and *Labeobarbus* Rüppell, 1835. Further, two species were observed to have different phenotypes (morphs) - *Coptodon zillii* (Gervais, 1848) and *Enteromius perince* (Rüppell, 1835). *Poecilia reticulata* Peters, 1859 was the only non-native species found on the Jos Plateau. The order and family with the highest species diversity was the Cypriniformes (family Cyprinidae) with 10 of 23 species so it represented nearly half of all recorded species. It was followed by the Siluriformes (Mochokidae, Clariidae) with five species and by Cichliformes (Cichlidae) with three species. The Osteoglossiformes (Mormyridae) and Cyprinodontiformes (Nothobranchiidae, Poecilidae) were each represented by two species while there was a single species of Characiformes (Alestidae). Representative specimens of all species and morphs found on the Jos Plateau are depicted in Supplementary Figures 1-4. The distribution of the species according to sampling sites are noted in supplementary table 2.

DNA barcode library

In total, 176 CO1 DNA barcode sequences were generated with lengths >635 bp (1 shorter barcode (444 bp) was excluded from further sequence analysis). These sequences represented 20 of the 23 fish species collected on the Jos Plateau. Three species lacked barcode coverage because of suboptimal tissue preservation and low sample size: *Chiloglanis* cf. *benuensis* Daget & Stauch 1963, *Clarias* cf. *gariepinu*s Burchell, 1822 and *Marcusenius mento* Boulenger, 1890. Only a single barcode was obtained for five species (*Heterobranchus longifillis, Labeo sp.* Assop, *Labeobarbus bynni, Synodontis violaceus*, and *Poecilia reticulata*) whereas the other species all had two or more sequences. Overall, CO1 amplification was successful for 92% of the 190 submitted specimens. The sequence divergence values for the CO1 barcode region (supplementary table 4) show that most species of the Jos Plateau possessed very low intraspecific genetic distance values.

A NJ tree (Figure 3) showed that barcodes reliably discriminated most species as all conspecific specimens were recovered as monophyletic lineages assigned to a single BIN (19 BINs in total). *Oreochromis niloticus* and *Sarotherodon galilaeus* shared a BIN, but formed two different haplotype clusters with a low sequence divergence (see Figure 3). These results are similar to those in an earlier barcoding study on the freshwater fishes of south-eastern Nigeria (Nwani *et al.*, 2011) which found very low genetic divergence between *O. niloticus* and *Sarotherodon galilaeus boulengeri*. While another barcoding study on the ichthyological fauna of the Nile recovered a low genetic divergence between *Oreochromis aureus* (Steindachner 1864) and *S. galilaues* (Ali *et al.*, 2020). The clustering of *S. galilaeus* within *Oreochromis* might either point to regular miss-identification of this species, which however appears rather unlikely, or a taxonomic misassignment of *S. galilaeus* in the genus *Oreochromis*. However, recent nuclear based studies support the monophyly of the genus *Oreochromis* while *Sarotherodon* clearly appears to be polyphyletic (Dunz & Schliewen, 2013; Ford *et al.*, 2019) Overall, the afore-mentioned studies in combination with our results alternatively suggest a cytonuclear discordance in respect of the phylogenetic position of *S. galilaeus,* which might be the result of past hybridization events. Indeed, hybridization between *Oreochromis* and *Sarotherodon* has been previously suggested to have taken place (see i.e.(Ford *et al.*, 2019; Nagl *et al.*, 2001). Further, it is known that both genera in captivity (Otubusin, 1988) and are commonly farmed in aquaculture facilities throughout Nigeria (Ayinla, 2007). In any case, the biological reason for the BIN sharing between the *O. niloticus* and *S. galilaeus* on the Jos Plateau and elsewhere remain uncertain and would need to be critically tested with appropriate genomic datasets.

Notes on new candidate species from the Jos Plateau

The morphological investigation of the collected specimens as well as the subsequent COI analyses suggest the presence of at least five candidate species [following the terminology regarding potentially undescribed species of (Padial *et al.*, 2010; Vieites *et al.*, 2009)]; four Cyprinidae, and one Clariidae.

Among the potentially new cyprinid species, two belong to the genus *Enteromius* (Cope, 1867). This genus was recently revalidated by (Yang *et al.*, 2015) for the small diploid African barbs formerly placed in the genus *Barbus* (Daudin, 1805), but is known to be polyphyletic (Yang *et al.*, 2015). Although a comprehensive taxonomic re-evaluation of the diploid African barbs is needed, this interim generic assignment is currently generally accepted (Englmaier, Tesfaye, & Bogutskaya 2020; Hayes & Armbruster, 2017; Martin & Chakona, 2019; Skelton, 2016).

The first species, herein referred to as *Enteromius* sp. Silver (see supplementary Figure 2, was widespread on the Jos Plateau, being present at most collection sites. It is phenotypically similar to *Enteromius callipterus* (Boulenger 1907), a widely disturbed West African barb originally described from Cameroon but differs by its possession of a faint greyish longitudinal band (vs. no lateral colour pattern for *E. callipterus*). In addition, the dorsal spot in the dorsal fin is less pronounced, i.e. irregular and not deep black but rather greyish with translucent orange (background colour of the dorsal fin), as compared with *E. callipterus* (Leveque, 2003). In a NJ tree based on all available CO1 sequences of *Enteromius* on BOLD (see supplementary Figure 5) *Enteromius* sp. Silver was a distinct mitochondrial lineage not clustering with *E. callipterus.* Instead, it was sister group to a cluster including different Enteromius species occurring in the Congo drainage [i.e. *Enteromius brazzai* (Pellegrin 1901)] and the Zambezi drainage [i.e. *Enteromius radiatus* (Peters 1854).

The second candidate species, referred herein as *Enteromius* sp. Gold (see supplementary Figure 2), was collected from four rivers (N'gell, Delimi, Shen Fusa, Rukuba). It is a comparatively small species easily recognized by its yellowish to golden body coloration and small irregular blackish spots forming a more or less confluent longitudinal band on the sides which terminates before the base of the caudal fin in a slightly larger blackish spot. Morphologically, *Enteromius* sp. Gold could not be assigned to any *Enteromius* species known from West Africa or Lower Guinea based on standard keys (Leveque, 2003; De Weirdt *et al.*, 2007). Interestingly, a NJ tree based on all CO1 sequences for *Enteromius* on BOLD (see supplementary Figure 5) revealed that *Enteromius* sp. Gold was a sister taxon to *Enteromius cf. macrotaenia* (Worthington 1933)**,** a species known from south-eastern Africa. The sister group of this clade included *Enteromius lukusiensis* (David & Poll, 1937), *Enteromius greenwoodi* (Poll, 1967), and the goldie barb *Enteromius pallidus* (Smith, 1841)*,* which is endemic to the eastern Cape Fold Ecoregion of South Africa (Martin & Chakona, 2019). These results suggest the closest relatives of *Enteromius* sp. Gold are found in the southern parts of Africa, raising interesting questions on its biogeographic history (i.e., when and how it colonized the Jos Plateau area).

The third potentially new cyprinid species, referred herein as *Labeo* sp. Assop*,* was only collected from the Assop River (see supplementary Figure 2). It shows affinities with *Labeo parvus* Boulenger 1902 which is widespread on the Jos Plateau. A NJ tree including all available CO1 sequences for *Labeo* on BOLD (see supplementary Figure 6) revealed that *Labeo* sp. Assop was a sister taxon to a clade including *Labeo lukululae* Boulenger, 1902 *Labeo quadribarbis* Poll & Gosse, 1963, and *Labeo* sp. aff. *rectipinnis* Tshibwabwa, 1997. Interestingly, and similar to the case of *Enteromius* sp. Gold, all three species forming the sister group to Labeo sp. Assop are neither present in the Niger/Benue drainage system nor in the Chad system but are restricted to the Congo drainage system.

The fourth potentially new cyprinid species, referred herein as *Labeobarbus* sp. Assop, is the second candidate species collected only from the Assop River (see supplementary Figure 3 A). It could not be assigned to any known *Labeobarbus* species found in western Africa based on morphological data and following the key in Leveque (2003). The collected specimens were recovered as sister to *Labeobarbus brevispinis* Holly, 1927 in a NJ tree based on all available CO1 sequences on bold (see supplementary Figure 6).

The last candidate species, referred herein to as *Clarias* sp. White dots (see supplementary Figure 4), was found in four rivers (N'gell, Gurum, Kassa, Rukuba). It could not unambiguously be assigned to any described *Clarias* species known from Western Africa based in standard morphological keys (Teugels, 2003; Teugels *et al.*, 2007). Nevertheless, it is phenotypically similar to *Clarias agboyienesis* Sydenham 1980**,** a species known from West African coastal basins including the lower course of the Niger. The latter species is, however, characterized by a very light coloration with yellowish brown flanks and a light grey belly whereas the body ground coloration of *Clarias sp.* White dots is dark with larger specimens having small whitish to yellowish spots on the flanks and on unpaired fins. Interestingly, the sequenced specimens of *Clarias sp.* White dots clustered with sequences of *Clarias gabonensis* Günther, 1867 in the NJ tree based on all CO1 sequences for *Clarias* on BOLD (see supplementary Figure 7). The coloration of *C. gabonensis* is either uniform brownish yellow or marbled with small yellowish spots (Hanssens, 2007; Teugels *et al.*, 2007) which shows some correspondence to the coloration pattern of *Clarias* sp. White dots, but it has a distinctively shorter head. Furthermore, *C. gabonensis* occurs in the Congo basin and different drainage systems of Lower Guinea, e.g. the Ogowe, Noya, Kouilou and Chilango rivers (Hanssens, 2007; Teugels *et al.*, 2007), and it was only recently recorded from Nigeria (Nwani *et al.*, 2011). However, the taxonomic assignment of the Nigerian specimens of *Clarias gabonensis* might be incorrect and it should be carefully investigated, since the identification of Clarias species is often challenging. Indeed, *C. gabonensis* was revealed to be polyphyletic in our NJ tree (see supplementary Figure 7), indicating probable misidentifications or cryptic species. Our sequences of *Clarias* sp. White dots group with some Nigerian *C. gabonensis* in one of the larger clades identified as *C. gabonensis.* Taken together it would be premature to assign our specimens of *Clarias* sp. White dots to *Clarias gabonensis* until more thorough morphological and genetic investigations are made within this species complex.

A thorough taxonomic investigation and the formal description of these candidate species is in progress and will be presented in a follow up study.

In addition to these five putatively new species, we observed substantial phenotypic variation in two species. First, in the cichlid, *Coptodon zillii*, which is widespread on the Jos Plateau and occurs in two color morphs, morp 1 and morph 2. Both morphs occurred sympatrically at one single location (Delimi River). Although differences between these morphs is modest, the flank coloration of one morph is predominantly yellowish (Morph 1) whereas in the other morph is whitish (Morph 1) (see supplementary Figure 1). Furthermore, morph 1 has a pale green upper lip and and a whitish lower lip while morph 2 has greenish to brownish upper lips and blueish lower lips. Members of the two morphs formed two distinct mitochondrial lineages with low genetic divergence (see Figure 3).

Specimens of *Enteromius perince* (Rüppell, 1835) also showed clear intraspecific variation. Most specimens showed the colouration typical of this species (i.e., silver body ground coloration with three spots aligned along the mid-lateral line, but a few specimens had additional spots. These individuals resemble the so-called "*lepidus* form" (Leveque, 2003), but no CO1 barcodes were recovered from them so their divergence from the nominate form is uncertain.

Discussion

By providing the first DNA barcode library for the ichthyofauna of the Jos Plateau, this study represents important progress in the taxonomic study of Nigerian fishes as few earlier investigations have employed DNA barcoding (Falade, Opene, & Benson, 2016; Iyiola *et al.*, 2018; Nneji *et al.*, 2020; Nwakanma, Ude & Unachukwu, 2015; Nwani *et al.*, 2011; Sogbesan *et al.*, 2017; Ude *et al.*, 2020). Aside from providing barcode records for known species, the results suggest the presence of at least five species new to science. As well, the new DNA barcode records constitute an important contribution to the growing reference library for Nigerian freshwater fishes, especially because most of the species are shared with the Niger, Benue, and Chad River drainages, the major river systems in Nigeria.

Most rivers on the Jos Plateau flow into the lower Benue River drainage and hence a part of the wider Nilo-Sudan Ichthylogical Province (Roberts, 1975). Among the site of fish collections by Reid & Sydenham, (1979) in their study of fishes from the lower Benue river basin, two sites were on the Jos Plateau. The authors reported eight species from these two sites. The species reported were *B. nigeriensis* (now known as *E. nigeriensis*), *B. spurelli* (now known as *E. ablabes*), *B* cf. *holasi* (now known as *Labeobarbus* cf. *wurtzi*), *Fundulopanchax gardneri* and a species the authors provisionally identified as *G. waterloti*. The authors also reported two other Garra species which they were not certain about their taxonomic identity. One of the Garra species was reportedly thought to be either *Garra waterloti* or G. *ornata*, while the other was supposed to be either *Garra trewavasae* or *G. waterloti.* However, they could not identify the original collection site for *G. trewavaseae* described by (Monod, 1950) as 'a small tributary of the Gongola River, South West of the Bargesh district'.

Just two of the species (*G. trewavasae*, *F. gardneri*) reported by Reid & Sydenham (1979) were found during our study, perhaps because we did not resample their sites (see Figure 1). Therefore, the species count for the Jos Plateau area based on this study might be expanded to include four more species (*E. nigeriensis*, *E. ablabes*, *Labeobarbus* cf. *wurtzi*, *G. waterloti*). Alternatively, some species reported earlier may reflect misidentifications. This might be the case for specimens assigned to "*Barbus spurelli*", a species described by Boulenger, (1913) from Ghana that was later synonymized with *Barbus ablabes* (now *E. ablabes*) by Leveque, (1983) as he was unable to find any differences between these two taxa apart from differences in the coloration; these are the presence of a longitudinal stripe on the middle of the sides in *E. ablabes*, which should be absent in "*Barbus spurelli*". *Enteromius* sp. Silver has only a very faint longitudinal stripe and matches with some aspects of the description of "*Barbus spurelli*"; it has, e. g., dark-edged scales which are darker at the base, indicating that our specimens of *E.* sp. Silver might be conspecific with the specimens identified as "*Barbus spurelli*" by Reid & Sydenham (1979). In fact, *E.* sp. Silver is readily distinguished from *E. ablabes* by its possession of longer barbels and more than 3.5 scales between the origin of the dorsal fin and the lateral line (Paugy, Leveque & Teugels, 2003) However, without careful re-examination of fish specimens collected by Reid & Sydenham, (1979) this remains speculative. It is clear that the sampling locations visited by Reid & Sydenham, (1979) should be resampled to help resolve the identity of the species at these two localities

The overall number of fish species (23) recorded from the Jos Plateau is low in comparison with other river basins in Nigeria such as the Imo (142 species) and Ogun (119 species). As well, more than half (12) of the fish species on the Jos Plateau are also found in the Benue, Chad, and Niger drainages (*F. gardneri, M. hasselquisti*, *B. nurse*, *E. perince*, *L. parvus*, *R. nigeriensis*, *R. senegalensis*, *H. longifillis*, *S. violaceous*, *O. niloticus*, *S. galilaeus, T. zillii*). The only described fish species endemic to the area is *G. trewavasae* and the subspecies *Fundulopanchax gardneri nigerianus* rendering a low regional endemism, and *M. mento* is found in both the Upper Niger and Lower Benue basin but not in the Chad basin. However, if the potentially new species detected in this study are considered, the level of endemicity would reach ~ 30 % (7 out 23 recorded species), a result emphasizing the need for further taxonomic and biogeographic research.

The closest relative of *Enteromius* sp. Gold seems to be found in Southern Africa which underscores the important gap in knowledge of the biogeography of the small African *Enteromius*. This lack in knowledge is largely due to the limited understanding of phylogenetic interrelationships within the group despite past studies (Howes, 1991; Rainboth, 1991). However, the recent study of Yang *et al.*, (2015) has shed more light on the biogeographical distribution of the cyprinine fishes. Their study suggests that the distribution of the cyprinids could not have been influenced by Gondwanaland separation as the dispersal events of the cyprinids are much more recent than the separation between 50-80 mya. Their findings suggest several independent dispersal events for cyprinids. Among the Smiliogastrini (diploid barbs), two hypothetical dispersal events were identified; those involving the small-sized African barbs and allies and another involving the small-sized Asian *Puntius* and allies. However, there is inadequate information to explain the factors that might have shaped the odd distribution of the newly found *Enteromius* sp. Gold between western and southern Africa, if the preliminary DNA barcode based association is maintained.

The Jos Plateau is dotted with waterfalls along its main rivers (Farin Ruwa, Kwall, Assop, Kura) at the southern, western, and eastern margins respectively. Waterfalls are ordinarily viewed as a major dispersal barrier to fishes (Torrente-Vilara *et al.*, 2011), but the impact of those on the Jos Plateau appear to be limited since upstream and downstream populations of fishes did not show sequence divergence at CO1. Furthermore, not all rivers that originate on the Jos plateau feature a waterfall because the north-eastern part of the Plateau slopes gradually towards the lowlands (Payne & Firefinch, 1998). *Garra trewavasae* has apparently not dispersed beyond the Jos Plateau area because of the lack of comparatively cold streams in the lowlands.

The sampling program for this study occurred during the dry season when most water bodies were nearly dry, being fragmented into remnant pools along the river course. Only a few were flowing. This situation suggests that rivers on the Jos Plateau are already heavily impacted by climate change that has reduced rainfall in the area by more than 5% (Fasona & Omojola, 2005). On the positive side, most water quality parameters were within ranges tolerated by fishes except the high turbidity and colour of many water bodies, especially on the N'gell River (supplementary table 3). The fact that all assessed water bodies were turbid underscores widespread anthropogenic impacts across the plateau, indicating the need for urgent management steps to safeguard fish communities from intensified impacts in the future. Some of the key activities leading to this high turbidity are domestic washing, small-scale mining, making building blocks, and the release of industrial waste (Figure 2).

Conclusion

In conclusion, this study provides a valuable COI barcode dataset which will serve as reference for further studies on the ichthylogical diverstiy of western Africa. It indicates the need for further taxonomic studies on Nigerian fishes with an obvious need to evaluate the taxonomic status of the five potentially new species found on the Jos Plateau.

Acknowledgements

We thank Dr. Tinuke Olaleye and Dr. Pam Luka, who worked hand-in-hand to provide logistics support, information about the local geography and the security situation which were invaluable for the success of our field work. Mr Samuel Popoola helped to design the map of the Jos Plateau. Emmanuel Ikpe collected the water samples while he and Dr. Adedeji Aduwo helped with the water quality analysis. We thank Lawrence Kent for his kind support and encoragement to build an ichthyological collection at Obafemi Awolowo University. Our appreciation also goes to Jérôme Morinière (AIM, Advanced Identification methods, Leipzig) for his support and useful advice for handling the BOLD database. We are grateful for the kind support of the CBG team (Guelph, Canada) in processing the samples and providing results on the BOLD database. Dirk Neumann (SSNB-ZSM) is kindly acknowledged for his help with collection mangement, accessioning, and cataloging the Jos Plateau at SSNB-ZSM.

Author contributions

M.O.P. and U.K.S designed the study while M.O.P organized and conducted the sampling. Specimen identification was done by F.D.B.S, U.K.S and M.O.P. Subsequent analysis and corresponding figures and tables were prepared by F.D.B.S. and M.O.P. F.D.B.S. and M.O.P wrote togehter the first draft of the manuscript and U.K.S. and P.D.N.H. provided edits and comments. All authors read and approved the final manuscript.

Ademola, J. A. (2008). Exposure to high background radiation level in the tin mining area of Jos Plateau, Nigeria. *Journal of Radiological Protection*, *28*, 93–99.

Ademoroti, C. M. O. (1996). *Standard methods for water and effluents analysis*, 3rd ed. Foludex Press Ltd., Ibadan.

Akpan, A. W., & Anadu, D. I. (1991). Dissolved particulate organic matter loading and transport in Delimi River in Jos, Nigeria. *Journal of Aquatic Sciences*, 23–30.

Ali, F. S., Ismail, M., & Aly, W. (2020). DNA barcoding to characterize biodiversity of freshwater fishes of Egypt. *Molecular Phylogenetics and Evolution*, *47*, 5865–5877.

Anadu, D. I., & Ejike, C. (1981). Distribution of some fish and macro-invertebrate fauna in Delimi River in relation to point discharge of mine washings. *Bulletin of the Science Association of Nigeria*, 202–210.

Antony, A. D., Eneriene, G., & Ufodike, E. B. C. (1986). Studies on the icthyofauna of Ouree reservoir Plateau State of Nigeria. *Nigerian Journal of Applied Fisheries and Hydrobiology*, *1*, 15–16.

APHA. (1995). *Standard Methods for the Examination of Water and Wastewater*, 19th ed. American Public Health Association Inc., New York.

Boulenger, G. A. (1890). Description of a new species of Mormyrus. *Annals and Magazine of Natural History*, *6*, 193.

Boulenger, G. A. (1902). Additions à la faune ichthyologique de bassin du Congo. Matériaux pour la faune du Congo. *Annales du Musee du Congo*, *2*, 15–57.

Boulenger, G. A. (1907). Descriptions of three new freshwater fishes discovered by Mr. G. L. Bates in South Cameroon. *Annals and Magazine of Natural History*, *20*, 485–487.

Boulenger, G. A. (1913). Descriptions of three new fishes discovered in the Gold Coast by Dr. H. G. F. Spurrell, M. A., F.Z.S. *Proceedings of the Zoological Society of London*, *1*, 51–53.

Buchanan, K. M., & Pugh, J. C. (1955). *Land and People in Nigeria*. University of London Press, London.

Burchell, W. J. (1822). *Travels in the interior of southern Africa. 2 vols. London. v. 1: i-xi + 1-582 + 1-4, 1 Map.; v. 2: 1-648. [Fishes in v. 1: 280, 284, 425, 445.].*

Clausen, H. S. (1963). Description of three new species of Aphyosemion Myers from Nigeria and Cameroun. *Videnskabelige Meddelelser fra Dansk Naturhistorisk Forening*, *125*, 197–205.

Cope, E. D. (1867a). Supplement on some new species of American and African fishes. Transactions of the American Philosophical Society (New Series) v. 13 (pt 3) (art. 13): 400-407.

Cope, E. D. (1867b). Supplement on some new species of American and African fishes. *Transactions of the American Philosophical Society (New Series)*, *13*, 400–407.

Cuvier, G. (1816). *Le Règne Animal distribué d'après son organisation pour servir de base à* *l'histoire naturelle des animaux et d'introduction à l'anatomie comparée. Les reptiles, les poissons, les mollusques et les annélides. v. 2: i-xviii + 1-532, [Pls. 9-10, i*, 1st ed.

Daget, J., & Stauch, A. (1963). Poissons de la partie camerounaise du Bassin de la Bénoué. *Mémoires de l'Institut français d'Afrique Noire*, 85–107.

Daudin, F. M. (1805). Barbus. *Dictionnaire des sciences naturelles. BAN--BLU. Tome quatrième. Paris (Levrault, Schoell & Cie.) [Série 1] v. 4: 1-483. Dictionnaire des sciences Naturelles [Série 1] v. 4. [Year also given as 'An XIII' of the French revolutionary calendar.]* (p. 58).

David, L., & Poll, M. (1937). Contribution à la faune ichthyologique du Congo Belge: Collections du Dr. H. Schouteden (1924-1926) et d'autres récolteurs. *Annales du Musée du Congo Belge*, *3*, 189–294.

Dunz, A. R., & Schliewen, U. K. (2013). Molecular phylogeny and revised classification of the haplotilapiine cichlid fishes formerly referred to as "Tilapia". *Molecular Phylogenetics and Evolution*, *68*, 64–80.

Edgar, R. C. (2004). MUSCLE: Multiple sequence alignment with high accuracy and high throughput. *Nucleic Acids Research*, *32*, 1792–1797.

Englmaier, G. K., Tesfaye, G., & Bogutskaya, N. G. (2020). A new species of Enteromius (Actinopterygii, cyprinidae, smiliogastrinae) from the awash river, Ethiopia, and the re-establishment of e. akakianus. *ZooKeys*, *2020*, 107–150.

Falade, M. O., Opene, A. J., & Benson, O. (2016). DNA barcoding of Clarias gariepinus, Coptodon zillii and Sarotherodon melanotheron from Southwestern Nigeria. *F1000Research*, *5*.

Fasona, M. . . &, & Omojola, A. S. (2005). Climate change, Human security and Communal clashes in Nigeria: Paper at international Workshop on human Fjord Hotel. *Oslo*, 25–48.

Ford, A. G. P., Bullen, T. R., Pang, L., Genner, M. J. R., Bills, T., Flouri, B. P., … Day, J. J. (2019). Molecular phylogeny of Oreochromis (Cichlidae: Oreochromini) reveals mito-nuclear discordance and multiple colonisation of adverse aquatic environments. *Molecular Phylogenetics and Evolution*, *136*, 215–226.

Froese, R., & Pauly, D. (2019). FishBase. World Wide Web electronic publication. www.fishbase.org.

Gervais, F. L. P. (1848). Sur les animaux vertébrés de l'Algérie, envisagés sous le double rapport de la géographie zoologique et de la domestication. *Annales des Sciences Naturelles, Paris (Zoologie)*, *10*, 202–208.

Golterman, H. L., Clymo, R. S., & Ohnstadt, M. A. M. (1978). *Methods for Physical and Chemical Analysis of Freshwaters*, 2nd ed. Blackwell Scientific Publications.

Günther, A. (1867). New fishes from the Gaboon and Gold Coast. *Annals and Magazine of Natural History*, *20*, 110–117.

Hanssens, M. (2007). A review of the Clarias species (Pisces ; Siluriformes) from the Lower

Congo and the Pool Malebo. *J. Afrotrop. Zool.*, *5*, 27-40.

Hayes, M. M., & Armbruster, J. W. (2017). The Taxonomy and Relationships of the African Small Barbs (Cypriniformes: Cyprinidae). *Copeia*, *105*, 348–362.

Holly, M. (1927). *Mormyriden, Characiniden und Cypriniden aus Kamerun. Sitzungsberichte, Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Klasse v. 136 (Abt. 1) (nos 3-4): 115-150.*

Howes, G. J. (1991). *Systematics and biogeography: an overview*. I. J. Winfield & J. S. Nelson (Eds.).

Ivanova, N. V., Zemlak, T. S., Hanner, R. H., & Hebert, P. D. N. (2007). Universal primer cocktails for fish DNA barcoding. *Molecular Ecology Notes*, *7*, 544–548.

Iyiola, O. A., Nneji, L. M., Mustapha, M. K., Nzeh, C. G., Oladipo, S. O., Nneji, I. C., … Adeola, A. C. (2018). DNA barcoding of economically important freshwater fish species from north-central Nigeria uncovers cryptic diversity. *Ecology and Evolution*, *8*, 6932–6951.

Lee, V. H. (1972). Ecological aspects of the Jos Plateau, Nigeria. *Bulletin of the World Health Organization*, *46*, 641–644.

Leveque, C. (1983). Le genre Barbus (Pisces , Cyprinidae) et Cote d'Ivoire. *Cybium*, *7*, 61–86.

Leveque, C. (1997). *Biodiversity dynamics and conservation: the freshwater fish of tropical Africa*. Cambridge University Press, The Edinburgh Building, Cambridge CB2 2RU, UK.

Leveque, C. (2003). Cyprrinidae. In D. Paugy, C. Leveque, & G. G. Teugels (Eds.), *The Fresh and Brackish water fishes of West Africa* (p. 457).

Linnaeus, C. (1758). *Systema Naturae, Ed. X. (Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Tomus I. Editio decima, reformata.) Holmiae. v. 1: i-ii + 1-824 [Nantes and Pisces in Tom. 1, p*.

Martin, M. B., & Chakona, A. (2019). Designation of a neotype for Enteromius pallidus (Smith, 1841), an endemic cyprinid minnow from the Cape Fold Ecoregion, South Africa. *ZooKeys*, *2019*, 103–118.

Monod, T. (1950). Sur deux Garra d' Afrique occidentale. *Bulletin de l'Institute Francais d' Afrique Noire.*, *12*, 976–983.

Nagl, S., Tichy, H., Mayer, W. E. ., Samonte, Irene E.; McAndrew, B. J., & Klein, J. (2001). Classification and Phylogenetic Relationships of African Tilapiine Fishes Inferred from Mitochondrial DNA Sequences. *Molecular Phylogenetics and Evolution*, *20*, 361–374.

Nneji, L. M., Adeola, A. C., Mustapha, M. K., Oladipo, S. O., Djagoun, C. A. M. S., Nneji, I. C., … Nwani, C. D. (2020). DNA Barcoding Silver Butter Catfish (Schilbe intermedius) Reveals Patterns of Mitochondrial Genetic Diversity Across African River Systems. *Scientific Reports*, *10*, 1–9.

Nwakanma, C., Ude, G., & Unachukwu, M. N. (2015). The Use of DNA Barcoding in

Identification of Genetic Diversity of Fish in Ugwu-Omu Nike River in Enugu. *Nig J. Biotech*, *29*, 27–33.

Nwani, C. D., Becker, S., Braid, H. E., Ude, E. F., Okogwu, O. I., & Hanner, R. (2011). DNA barcoding discriminates freshwater fishes from southeastern Nigeria and provides river system-level phylogeographic resolution within some species. *Mitochondrial DNA*, *22*, 43–51.

Olowolafe, A. E. (2008). Land use effects on the properties of an Alfisol on the Jos Plateau, Nigeria. *GeoJournal*, *71*, 83–91.

Paugy, D., Leveque, C., & Teugels, G. G. (2003). *The Fresh and Brackish Water Fishes of West Africa*, IRD Editio. Publications scientifiques du Museum, MRAC.

Payne, R. B., & Firefinch, R. (1998). A new species of firefinch Lagonosticta from northern Nigeria and its association with the Jos Plateau Indigobird Vidua maryae. *Ibis*, *140*, 368–381.

Peters, W. (C. H. . (1859). *Eine neue vom Herrn Jagor im atlantischen Meere gefangene Art der Gattung Leptocephalus, und über einige andere neue Fische des Zoologischen Museums. Monatsberichte der Königlichen Preussischen Akademie der Wissenschaften zu Berlin*. 411–413 pp.

Poll, M. (1967). *Contribution à la faune ichthyologique de l'Angola. Publicações Culturais, Companhia de Diamantes de Angola (DIAMANG), Lisboa No. 75: 1-381, Pls. 1-20.*

Poll, M., & Gosse, J.-P. (1963). *Contribution à l'étude systématique de la faune ichthyologique du Congo Central. Annales, Musée Royal de l'Afrique Centrale, Tervuren, Série in 8o, Sciences Zoologiques No. 116: 43-101, Pls. 1-4.*

Puillandre, N., Lambert, A., Brouillet, S., & Achaz, G. (2012). ABGD, Automatic Barcode Gap Discovery for primary species delimitation. *Molecular Ecology*, *21*, 1864–1877.

Rainboth, W. J. (1991). Cyprinid fishes of Southeast Asia. In I. J. Winfield & J. S. Nelson (Eds.), *Cyprinid Fishes: Systematics, Biology and Exploitation* (pp. 156–192).

Ratnasingham, S., & Hebert, P. D. N. (2007). BOLD: The Barcode of Life Data System: Barcoding. *Molecular Ecology Notes*, *7*, 355–364.

Ratnasingham, S., & Hebert, P. D. N. (2013). A DNA-Based Registry for All Animal Species: The Barcode Index Number (BIN) System. *PLoS ONE*, *8*.

Reid, G. M., & Sydenham, H. (1979). A checklist of lower benue river fishes and an ichthyogeographical review of the benue river (West africa). *Journal of Natural History*, *13*, 41–67.

Roberts, T. R. (1975). Geographical distribution of African freshwater fishes. *Zoological Journal of the Linnean Society*, *147*, 239–317.

Rüppell, W. P. E. S. (1835). *Neuer Nachtrag von Beschreibungen und Abbildungen neuer Fische, im Nil entdeckt. Museum Senckenbergianum: Abhandlungen aus dem Gebiete der beschreibenden Naturgeschichte, von Mitgliedern der Senckenbergischen Naturforschenden*

Gesellschaft in Frankfurt am .

Scopoli, J. A. (1777). Introductio ad historiam naturalem, sistens genera lapidum, plantarum et animalium hactenus detecta, caracteribus essentialibus donata, in tribus divisa, subinde ad leges naturae. *Prague*, *i–x*, 1–506.

Skelton, P. H. (2016). Name changes and additions to the southern African freshwater fish fauna. *African Journal of Aquatic Science*, *41*, 345–351.

Smith, A. (1841). Pisces. *Illustrations of the zoology of South Africa; consisting chiefly of figures and descriptions of the objects of natural history collected during an expedi¬tion into the interior of South Africa in 1834–36. v. 4: 77 unnumb. pp, accompanying Pls. 1–31. .*

Sogbesan, O. A., Sanda, M. K., Jaafar, N. J., & Adedeji, H. A. (2017). DNA Barcoding of Tilapia Species (Pisces: Cichlidae) from North-Eastern Nigeria. *Journal of Biotechnology & Biomaterials*, *07*, DOI: 10.4172/2155-952x.1000277.

Stiassny, M. L. J., Teugel, G. G., & Hopkins, C. D. (2007). *The Fresh and Brackish Water Fishes of the Lower Guinea West Central Africa*.

Sydenham, D. H. J. (1980). New species of Clarias from West Africa (Pisces, Clariidae). *Revue de Zoologie Africaine*, *94*, 659–677.

Teugels, G. G. (2003). Clariidae. In D. Paugy, C. Leveque, & G. G. Teugels (Eds.), *The Fresh and Brackish water fishes of West Africa* (pp. 145–173).

Teugels, G. G., Adriaens, D., Devaere, S., & Musschoot, T. (2007). Clariidae. In M. L. J. Stiassny, G. G. Teugels, & C. D. Hopkins (Eds.), *The Fresh and Brackish water fishes of Lower Guinea and West-Central Africa* (pp. 658–691).

Torrente-Vilara, G., Zuanon, J., Leprieur, F., Oberdorff, T., & Tedesco, P. A. (2011). Effects of natural rapids and waterfalls on fish assemblage structure in the Madeira River (Amazon Basin). *Ecology of Freshwater Fish*, *20*, 588–597.

Tshibwabwa, S. M. (1997). *Systématique des espèces Africaines du genre Labeo (Teleostei, Cyprinidae) dans les régions ichthyogéographiques de Basse-Guinée et du Congo. I. Presses Universitaires de Namur. v. 2: 303-530, Pls. 1-5.*

Ude, G. N., Igwe, D. O., Brown, C., Jackson, M., Bangura, A., Ozokonkwo-Alor, O., … Das, A. (2020). DNA barcoding for identification of fish species from freshwater in Enugu and Anambra States of Nigeria. *Conservation Genetics Resources*, *12*, 643–658.

De Weirdt, D., Getahun, A., Tshibwabwa, S., & Teugels, G. G. (2007). Cyprinidae. In M. L. J. Stiassny, G. G. Teugel, & C. D. Hopkins (Eds.), *The Fresh and Brackish water fishes of Lower Guinea and West-Central Africa* (pp. 466–572).

Worthington, E. B. (1933). The fishes of Lake Nyasa (other than Cichlidae). *Proceedings of the Zoological Society of London* (pp. 285–316).

Wright, D., & Jones, P. (2005). Population densities and habitat associations of the range-restricted Rock Firefinch Lagonosticta sanguinodorsalis on the Jos Plateau, Nigeria. *Bird Conservation International*, *15*, 287–295.

Yang, L., Sado, T., Vincent Hirt, M., Pasco-Viel, E., Arunachalam, M., Li, J., … Mayden, R. L. (2015). Phylogeny and polyploidy: Resolving the classification of cyprinine fishes (Teleostei: Cypriniformes). *Molecular Phylogenetics and Evolution*, *85*, 97–116.

Figure 1

Map of the Jos Plateau area showing the sampling locations (green) examined in this study and the sampling point (red) examined by Reid & Sydenham (1979).

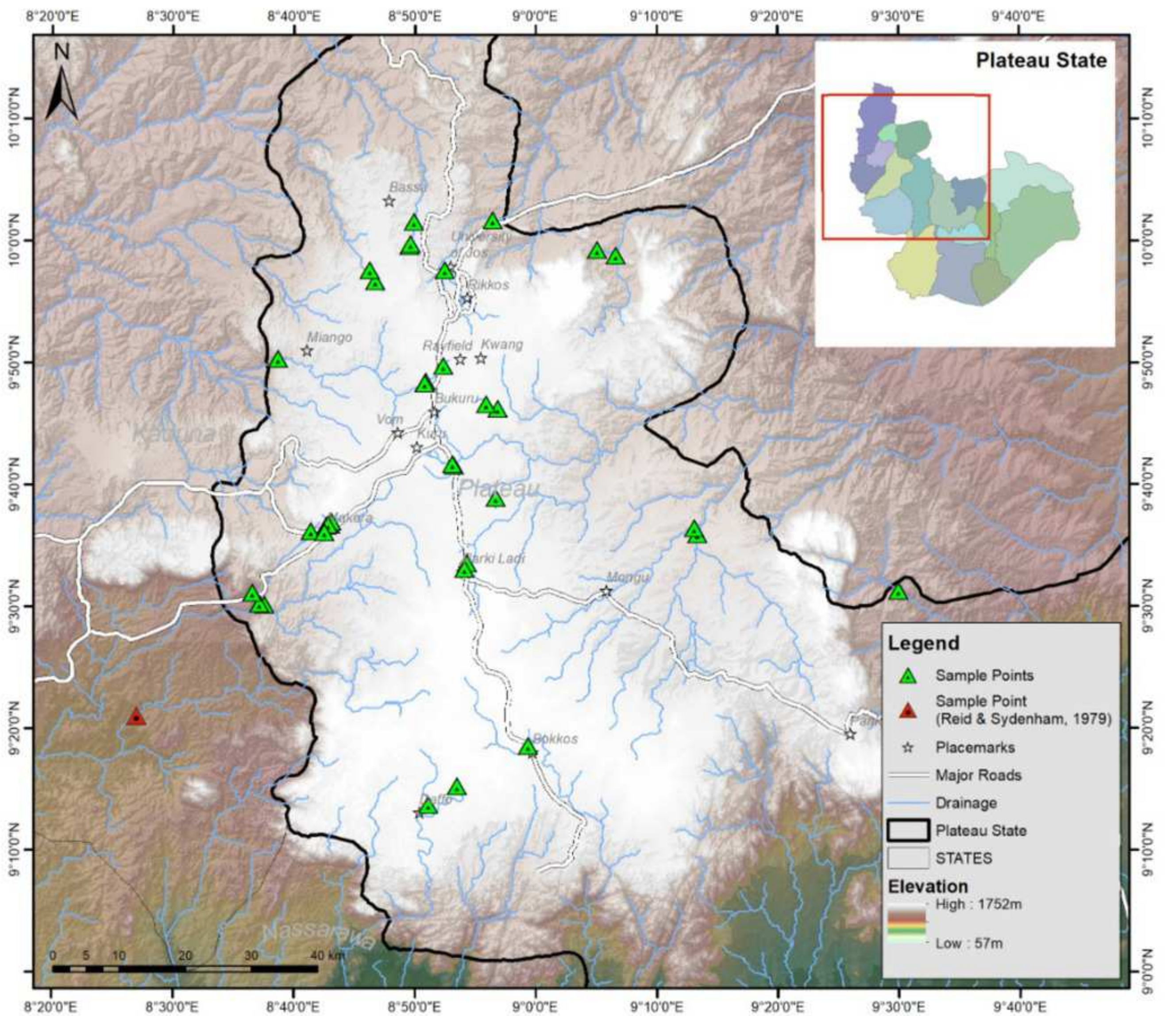

Figure 2

Overview of sampling sites. Corresponding sampling sites number as in table 1 are indicated alongside A) Magurji River (2) B) Delimi River (28, 29) C) Assop River (4) D) Gindiri River (26, 27) E) Shen Fusa River (18, 19) F) Rukuba River (22, 23) G) Artisa

Figure 3

Map of the Jos Plateau area showing the sampling locations (green) examined in this study and the sampling point (red) examined by Reid & Sydenham (1979).

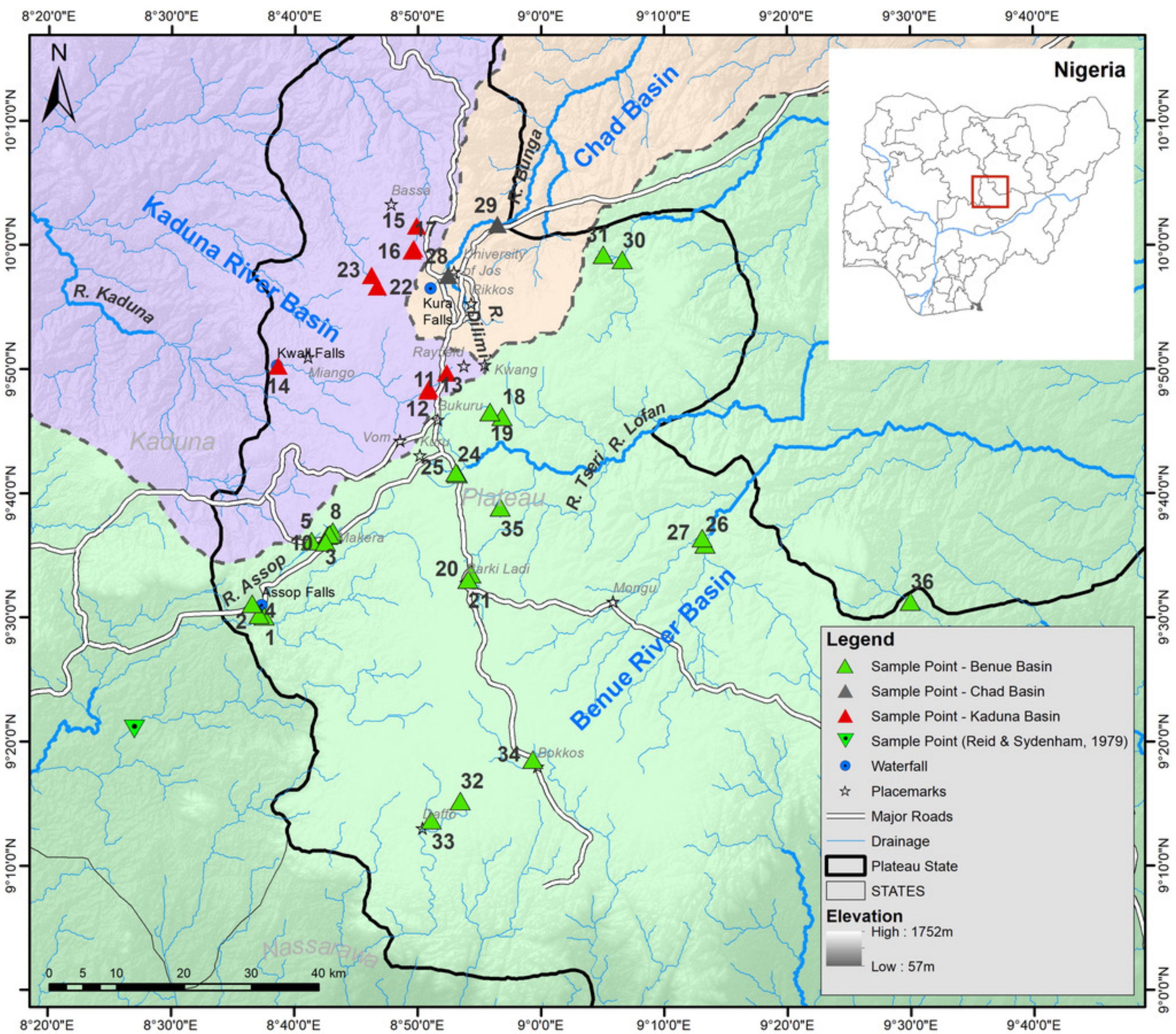

Figure 4

Neighbour-Joining tree based on 176 CO1 barcode sequences of fish species occurring in the Jos Plateau, created in BOLD using "Taxon ID tree" tool. The circularized NJ tree was created using FigTree v1.4.4 (http://tree.bio.ed.ac.uk/software/figtre/)