Post-filling phase ichthyofaunal community and fishery potential of Chitsuwa Reservoir, a small tropical reservoir in Zimbabwe

Article *in* Lakes & Reservoirs Research & Management · March 2022

DOI: 10.1111/lre.12394

Takudzwa Comfort Madzivanzira
University of Mpumalanga

Chipo Mungenge
Zimbabwe Parks and Wildlife Management Authority

Adroit Takudzwa Chakandinakira
Zimbabwe Parks and Wildlife Management Authority

Blessing Kavhu
Zimbabwe Parks and Wildlife Management Authority

Received: 22 July 2020 | Revised: 28 September 2021 | Accepted: 22 December 2021

DOI: 10.1111/lre.12394

ORIGINAL ARTICLE

Lakes & Reservoirs: Science, Policy and Management for Sustainable Use

WILEY

Post-filling phase ichthyofaunal community and fishery potential of Chitsuwa Reservoir, a small tropical reservoir in Zimbabwe

Takudzwa C. Madzivanzira[1] | Chipo Mungenge[2,3] | Adroit T. Chakandinakira[4] | Nyasha Rugwete[5,6] | Blessing Kavhu[7]

[1]University of Zimbabwe Lake Kariba Research Station, Kariba, Zimbabwe

[2]Department of Zoology and Entomology, Rodes University, Makhanda, South Africa

[3]Lake Chivero Recreational Park, Zimbabwe Parks and Wildlife Management Authority, Harare, Zimbabwe

[4]Lake Kariba Fisheries Research Institute, Zimbabwe Parks and Wildlife Management Authority, Kariba, Zimbabwe

[5]Department of Livestock Science, University of Zimbabwe, Harare, Zimbabwe

[6]Department of Livestock Research (DR & SS), Harare Agriculture Research Centre, Harare, Zimbabwe

[7]Zimbabwe Parks and Wildlife Management Authority, Harare, Zimbabwe

Correspondence

Takudzwa C. Madzivanzira, University of Zimbabwe Lake Kariba Research Station, P.O. Box 48, Kariba, Zimbabwe.

Email: taku1945@live.com

Present address

Takudzwa C. Madzivanzira, Aquatic Systems Research Group, School of Biology and Environmental Sciences, University of Mpumalanga, Nelspruit, South Africa and DSI/NRF Research Chair in Inland Fisheries and Freshwater Ecology, South African Institute for Aquatic Biodiversity (SAIAB), Makhanda, South Africa

Funding information

ZIMPLATS

Abstract

Many small reservoirs exist throughout Southern Africa, and with adequate management have the potential to contribute significantly to food security. The fisheries and limnology of the newly created Chitsuwa Reservoir in Zimbabwe were studied with the objective of generating information to support the development, management and sustainable use of fisheries to enhance the socio-economic status of riparian communities. Based on gill nets of various mesh sizes, it was confirmed that the reservoir is presently inhabited by a fairly diverse fish community comprising ten species belonging to five families (*Clarias gariepinus*; *Coptodon rendalli*; *Labeo cylindricus*; *Marcusenius macrolepidotus*; *Micropterus salmoides*; *Momyrus longirostris*; *Oreochromis mossambicus*; *Oreochromis niloticus*; *Serranochromis microcephalus*; and *Tilapia sparrmanii*). *Oreochromis niloticus* dominated the reservoir with respect to both abundance, biomass and catch. The index of relative importance revealed *O. niloticus* and *M. macrolepidotus* were the most important species. Results from the Canonical Correspondence Analysis revealed a clear division of the fish species that followed the environmental variables. Although fisheries may benefit from the invasive *M. salmoides* and the established *O. niloticus*, their presence in the reservoir is a cause for concern for conserving native congeneric species that risk extirpation through documented mechanisms. The results of the present study suggest sound management of the reservoir is required to raise its potential of supporting the livelihoods of the surrounding communities with a predicted annual fish yield of 61.5 t/year. Management of this reservoir should involve the local communities, empowering them so that they practice sustainable non-destructive fishing methods.

KEYWORDS

dam, freshwater ecosystems, impoundment, invasive, management, *Oreochromis niloticus*

1 | INTRODUCTION

Reservoirs, lakes, canals and small seasonal floodplains less than 10 km^2 (1000 ha) in area and rivers <100-km long are considered small water bodies (Marshall & Maes, 1994). In spite of their widespread distribution, these aquatic systems have been largely neglected in hydrological and water resource research because of their small size. In Southern Africa alone, the total number of small water bodies is estimated to be between 50,000 and 100,000 (Verheust, 1998). About 86% of these water bodies (excluding South Africa) are found in Zimbabwe, including 12,000 small dams (<10 ha or 106-m^3) stretching over an area of 126,089 ha (Ersal, 1994). Most of the small dams are built across seasonal rivers that dry up during the dry season (Marshall & Maes, 1994).

While most of the reservoirs were constructed to serve one purpose, they often end up serving many other roles. Among the services offered by these impoundments are fishery resources (Jackson & Marmulla, 2001). Inland fisheries contribute over two-fifths of the world's reported finfish fisheries and aquaculture production (Lynch et al., 2016). Inland fisheries barely remain part of any high profile global fisheries assessment, however, because of the lack of reliable data (Cooke et al., 2016; Lynch et al., 2020). Moreover, the apparent low proportion of fish harvested from inland fisheries globally does not reflect the importance of inland fisheries in today's society (Bartley et al., 2015). Nevertheless, inland fisheries can be vital for food security and national economies of many African countries (Marshall & Maes, 1994; Weyl et al., 2007). The African Union has identified fisheries as a priority investment area in Africa (NEPAD, 2005). More than one-third of the continent's population consume fish as its main source of animal protein and micronutrients (NEPAD, 2014). Approximately 12.3 million people in the continent work in various sectors of fisheries which produce an estimated annual total of US$24 billion in terms of economic value (NEPAD, 2014).

Most African fisheries are exploited for food, either for sale or subsistence consumption (Marshall & Maes, 1994). For small reservoirs, subsistence consumption is given much consideration since their overall yield may be inadequate for sale. If well managed in traditional ways, and experiencing a low fishing intensity, many of these fisheries can be productive and aid the socio-economic services of local communities (Marshall & Maes, 1994). While the economic contributions of small reservoirs have not been fully established, evaluating the gross value of the estimated yield could be a good indicator (Weyl et al., 2007). In most cases, however, prior biological and fisheries data are sparse or absent, thereby limiting the direct estimation of fish production in dams (Weyl et al., 2007). Yield predictions are crucial for effective management of their fisheries, however, which can be produced using various morphoedaphic models based on chemical and physical yield covariates (Marshall & Maes, 1994; Schlesinger & Regier, 1982).

Construction of these small reservoirs interferes with river functioning and hydrological cycles producing many changes in the cycles and biodiversity of the affected rivers (Mhlanga et al., 2020; Mustapha, 2011). Impacts of damming include alterations in the natural flow regimes with subsequent changes in flow speed and volume, water temperature and oxygen concentration (Mustapha, 2011; Wetzel, 2001). A profound effect of such damming is reflected within the status of fish populations, mainly due to the creation of new micro-habitats (Mustapha, 2011). Water released downstream of a reservoir is regulated according to water inputs from the drainage basin, as well as the water uses water (Wetzel, 2001). Downstream rivers and their biological communities, including fish, are also affected by dam walls, which act as impenetrable barriers for fish movements (Bergkamp et al., 2000; Marshall, 2011). Accordingly, this disruption of fish migratory patterns may lead to species decline or speciation (Marshall, 2011).

Damming can also promote and facilitate the introduction and establishment of invasive alien species (IAS), which are major threats to biodiversity in global freshwater ecosystems (Johnson et al., 2008). Damming increases colonization opportunities for IAS, thereby enhancing their subsequent establishment success (Havel et al., 2005; Kolar & Lodge, 2000; Shea & Chesson, 2002) and subsequent opportunities to spread across landscapes (Johnson et al., 2008). Successful fish introductions could potentially transform fisheries (Marshall & Maes, 1994). In fact, the introduction of non-native fisheries to enhance fisheries has become a common practice in Southern Africa over the years (de Moor & Bruton, 1988). Examples include the introduction of common carp *Cyprinus carpio* (Linnaeus, 1758), largemouth bass *Micropterus salmoides* (Lacépède, 1802), smallmouth bass *M. dolomieu*, spotted bass *M. punctulatus* (Rafinesque, 1819), rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) brown trout *Salmo trutta* (Linnaeus, 1758), Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758), Tanganyika sardine *Limnothrissa miodon* (Boulenger, 1906) (Ellender et al., 2014) and crayfish (Madzivanzira et al., 2020, 2021). Some of these introductions, however, threaten the freshwater biota through competition, predation, habitat alteration, disease transfer and hybridization (Ellender et al., 2014).

Variations in the volume and distribution of annual rainfall in Zimbabwe, coupled with the few perennial rivers, have necessitated the impoundment of many rivers to ensure adequate water supplies. Chitsuwa Reservoir was created by Zimbabwe Platinum Mines (Private) Limited (Zimplats) by impoundment of the Munyati River in 2015, with the primary objective of providing water for its industrial operations. *Oreochromis niloticus* was introduced into the reservoir in 2015 to promote fisheries around the reservoir. Despite the overwhelming importance of small reservoirs in the development of fisheries in Zimbabwe, exploitation of these resources remains essentially unorganized, resulting in inadequate documentation of the fish yield and catch composition. Studies on fish communities in Zimbabwe have been carried out mostly on large reservoirs, including lakes Chivero and Kariba, with only a few having been conducted for smaller water bodies. As a newly impounded small reservoir, Chitsuwa Reservoir provided an opportunity to study its general fish composition and catch per unit effort (CPUE), as well as to predict the yield of the reservoir. Accordingly, the present study provides a baseline for future monitoring and tracking changes of the reservoir's natural dynamics over time and for assessing the impacts of human activities on the reservoir and its watershed.

2 | MATERIALS AND METHODS

2.1 | Study area

The present study was conducted in the Chitsuwa Reservoir (30°21′20.68″, −18°49′52.08″; 1255 m.a.s.l) located along the Munyati River, which borders three communal districts of Mhondoro-Ngezi, Kwekwe and Chirimhanzu, close to central Zimbabwe (Figure 1). Based on the ichthyological classification of regions in Zimbabwe, Chitsuwa Reservoir is located in the Middle Zambezi central region (see Marshall, 2011 for ecological classifications). It covers an area of 275 ha submerged in the water extending in communities of aforementioned districts. The reservoir has a capacity of 30,500 ML.

2.2 | Fish sampling

Fish sampling in the reservoir was carried out from 24 to 29 April 2018. The reservoir was divided into sections, and a representative site to deploy the fishing gears, with four sites chosen for this purpose (Figure 1).

Two monofilament gillnets, consisting of panels ranging from 1.5″ to 6″, with mesh intervals of 0.5″ and a 2-m height, were deployed at each sampling site. Each net panel measured 20 m in total length. The gill nets were set at 15:30 h and collected in the following morning at 07:30 h, allowing a soak time of approximately 16 h upon being collected, the fish were sorted according to mesh size, identified using the keys of Marshall (2011) and Skelton (2001), measured for standard and total length (to the nearest mm) using a fish measuring board and weighed (to the nearest g) using a scale. The gonadal status was assessed using a simplified scale of Bagenal and Braum (1968).

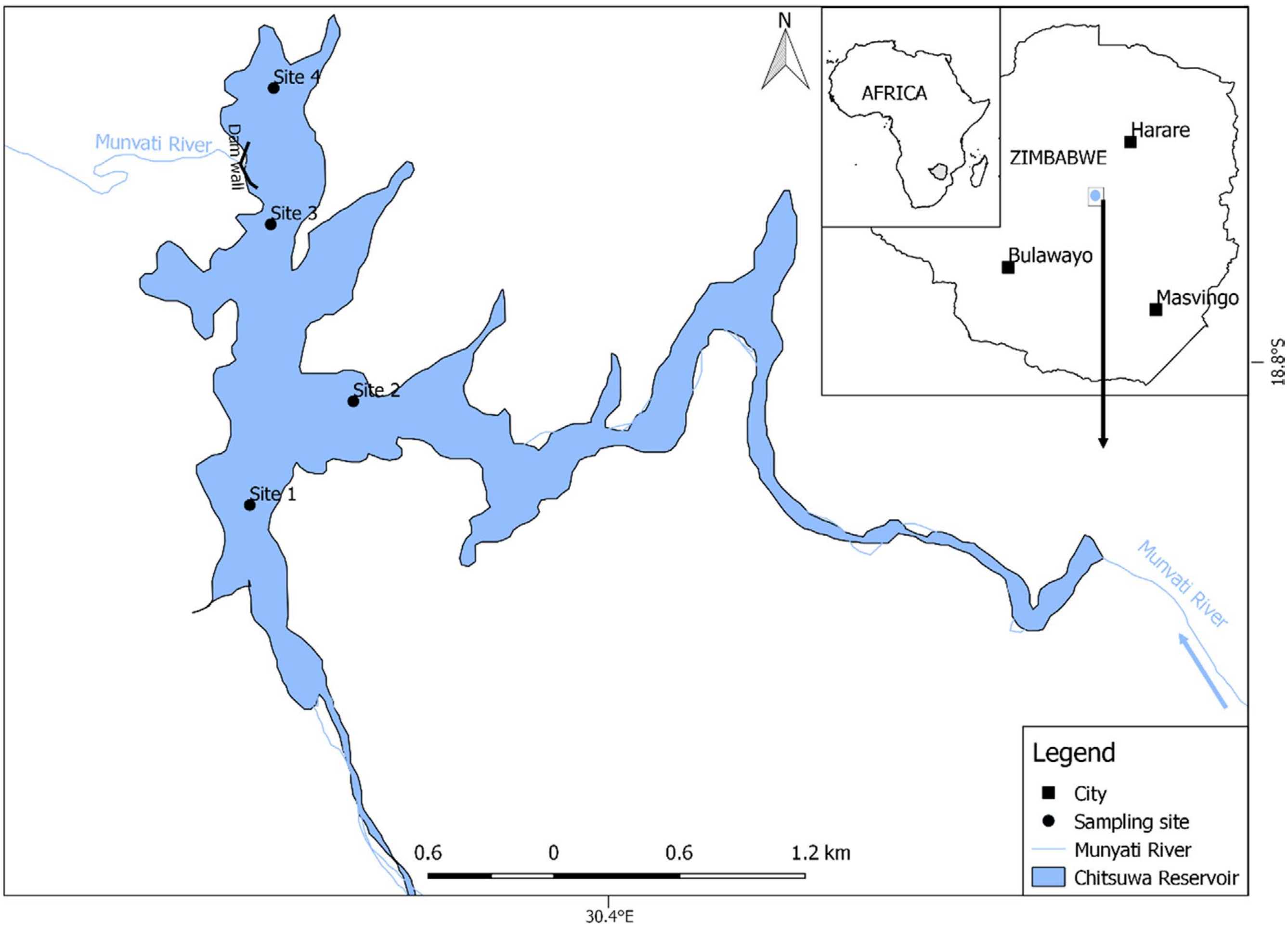


FIGURE 1 Map of Chitsuwa Reservoir showing sampling sites

2.3 | Sampling for environmental variables

Water samples were collected with a 3-L Rutner sampler at 1-m intervals from the bottom of the lake to the water surface. The samples were integrated in a 20-L bucket and temperature, pH, dissolved oxygen (DO) total dissolved solids (TDS) concentrations, electrical conductivity and turbidity (NTU) were measured using a pH, conductivity and DO metre (HACH, LDO, Germany). A Secchi disk was used to measure water transparency. A sub-sample of the integrated water was taken and placed in ice for laboratory analysis. The methods described in Bartram and Balance (1996) were used to analyse the water for nitrate, reactive phosphorus (RP), total nitrogen (TN), total phosphorus (TP), ammonia, chemical oxygen demand (COD), biological oxygen demand (BOD) and chlorophyll-a (Chl-a) concentrations.

2.4 | Data analysis

2.4.1 | Fish community composition and diversity

The Shannon–Wiener Diversity Index (Shannon & Wiener, 1949) was calculated using PAST version 3.1 (Hammer et al., 2001). The Shannon–Wiener index was calculated as follows:

$$H' = -\Sigma p_i \ln p_i \quad (1)$$

where p_i = proportion of individuals found in species i.

2.4.2 | Index of relative importance

The index of relative importance (IRI; Pinkas et al., 1971) was used to determine the most dominant species in the reservoir by number, weight and frequency of occurrence, calculated as follows:

$$\mathrm{IRI} = (\%N + \%W) \times (\%\mathrm{FO}) \quad (2)$$

where %*N* and %*W* = percentage contributions of each species by number and weight to the total catch; and %FO = overall percentage frequency of occurrence of each species.

The IRI gives a better representation of the ecologically important species than the weight, number or frequency alone. An IRI >10% suggests the species is dominant, while 1% < IRI < 10% suggests a common species (Hu et al., 2019).

2.4.3 | Catch per unit effort

Fish catch data were grouped according to mesh size and catch per unit effort (CPUE) was calculated as the quantity of fish (kg) per 200-m net per night. The Shapiro–Wilk test of normality confirmed the fish data were not normally distributed ($W = 0.097$, $p < .05$). Accordingly, a Kruskal–Wallis test was performed to assess significant differences with respect to CPUE among sampled sites.

A chi-square goodness-of-fit test was used to test whether or not the overall sex ratios for the sites sampled were significantly different from the common sex ratio of 1:1.

2.4.4 | Environmental variables

Kruskal–Wallis tests were performed to test for differences in physiochemical characteristics between sampled sites using STATISTICA Version 7 (StatSoft, 2006). A CCA was performed to explore the relationship between the physicochemical variables and the relative abundances of fish. Prior to the multivariate analysis, all physiochemical variables (except for pH, which was already logarithmic) were log-transformed to reduce skewness in the data.

2.4.5 | Fish yield prediction

First estimates of the total potential fish yield were obtained with the Marshall and Maes (1994) model, as follows:

$$\mathrm{Yield}\,(\mathrm{kg\,ha^{-1}\,year^{-1}}) = 23.281 \times (\mathrm{EC/MD})^{0.447} \quad (3)$$

where EC = mean electrical conductivity μS/m^2); and MD = mean depth of the impoundment (m). The model considers the effects of reservoir fertility and electrical conductivity, as well as the mean depth of the reservoir, in the prediction of the fish yields.

3 | RESULTS

3.1 | Fish community composition and diversity

Ten species belonging to five families (Centrarchidae [*M. salmoides* (Lacepède, 1802)]; Cichlidae [*Coptodon rendalli* (Boulenger, 1897); [*Oreochromis mossambicus* (Peters, 1852)]; [*O. niloticus* (Linnaeus, 1758)]; [*Serranochromis macrocephalus* (Boulenger, 1899)]; [*Tilapia sparrmanii* (Smith, 1840)]; Clariidae [*Clarias gariepinus* (Burchell, 1822)]; Cyprinidae [*Labeo cylindricus* (Peters, 1852)]; Momyridae [*Momyrus longirostris* and *Marcusenius macrolepidotus* (Peters, 1852)]) were observed in the Chitsuwa Reservoir (Table 1). The frequency of occurrence of *C. gariepinus*, *M. lepidotus*, *O. mossambicus*, *O. niloticus* and *T. sparrmanii* was 100%, while other species were absent at some sampled sites. The overall species diversity was 1.90, with that of all the sampled sites exceeding 1.50 (Table 1). The lengths and weights of fish caught ranged from 78-mm (*T. sparrmanii*) to 655-mm (*M. longirostris*) and 10-g (*T. sparrmanii* and *O. niloticus*) to 3435-g (*M. longirostris*), respectively (Table 2).

TABLE 1 Relative abundance, species diversity, per cent number (%*N*), per cent weight (%*W*), per cent frequency of occurrence (%FO) and the per cent index of relative importance (%IRI) of fish species sampled in Chitsuwa Reservoir, April 2018

Species	Site 1	Site 2	Site 3	Site 4	Total	%N	%W	FO	IRI	%IRI
Clarias gariepinus	2	4	2	3	11	7.01	4.45	100.00	6.09	6.09
Coptodon rendalli	2	1	0	1	4	2.55	3.21	75.00	2.29	2.29
Labeo cylindricus	3	1	3	0	7	4.46	1.68	75.00	2.45	2.45
Marcusenius macrolepidotus	14	8	12	14	48	3.18	9.28	50.00	20.50	20.50
Micropterus salmoides	1	1	0	0	2	30.57	7.99	100.00	0.39	0.39
Momyrus longirostris	1	0	0	4	5	1.27	0.19	50.00	3.31	3.31
Oreochromis mossambicus	2	3	3	4	12	7.64	5.23	100.00	6.84	6.84
Oreochromis niloticus	6	18	12	13	49	31.21	66.90	100.00	52.15	52.15
Serranochromis microcephalus	4	0	3	4	11	7.01	0.74	75.00	3.09	3.09
Tilapia sparrmanii	3	2	1	2	8	5.10	0.33	100.00	2.88	2.89
Taxa	10	8	7	8	10					
Number of individuals (*N*)	38	38	36	45	157					
Shannon Diversity Index (*H*)	1.95	1.56	1.61	1.77	1.84					

3.2 | Index of relative importance

According to the IRI, *O. niloticus* and *M. macrolepidotus* were the most important species, accounting for 52% and 21% of the total catch, respectively (Table 1). The IRI for the other species was less than 10% (Table 1).

3.3 | Catch per unit effort

Of the fishing gears used, nets of mesh sizes of 4″ to 6″ produced the overall highest contributions to the total catch (Figure 2). For all the gears, *O. niloticus* contributed 67% of the total catch, with the remaining species representing less than 10% of the catch. For a 200-m gillnet with different mesh sizes, the overall CPUE was 10.9 kg/200-m net per night. There were no significant differences in the CPUE (H (3) = 0.94; p = .82) between the sampled sites. The mean CPUE of each gillnet panel ranged from 0.7 to 1.6 kg/20 m net per night. The relative contribution of each fish species to the biomass of each net panel indicates *O. niloticus* was the most common species across the panels (Figure 3).

The female to male sex ratio between the sampled sites was not significantly different from a 1:1 ratio (χ^2 = 0.60; df = 3; p = .90). The breeding classes of each fish species in Chitsuwa Reservoir are highlighted in Figure 4. The percentage of actively breeding fish was high (69%), compared to the inactive breeding fish (21%) (Figure 4).

3.4 | Environmental variables

The mean physicochemical variables from the sites where gillnets were set are presented in Table 3. All sites were fairly uniform with respect to the physicochemical variables, displaying no significant differences (H, p > .05; Table 3).

The CCA triplot (Figure 5) was generated after extracting and integrating data from the fish community with the 16 physicochemical variables. The eigenvalues for the two first axes were 0.09 and 0.07, respectively. Axis 1, accounting for 48.92% of the variance, was positively correlated with temperature, pH and TN. Axis 2, accounting for 34.51% of the variance, was positively correlated with turbidity, RP and TP, and was negatively correlated with TDS, temperature, nitrates, TN and BOD. *Labeo cylindricus*, *S. macrocephalus*, *M. macrolepidotus*, *C. rendalii* and *T. sparrmanii* were correlated with DO, nitrogen, pH, BOD and negatively correlated with RP and TP (Figure 5). *Micropterus salmoides* were correlated with clearer water, electrical conductivity, TDS, ammonia and negatively correlated with COD and turbidity. *Oreochromis niloticus*, *O. mossambicus* and *C. gariepinus* were positively correlated with deeper waters with high phosphorus concentrations and negatively correlated with DO, TN, nitrates, pH and BOD (Figure 5).

3.5 | Yield prediction

According to the fish yield prediction formula of Marshall and Maes (1994), the estimated fish yield for Chitsuwa Reservoir is 61.5 t/year.

4 | DISCUSSION

The present study of Chitsuwa Reservoir presents a post-impoundment checklist of its ichthyofaunal composition, diversity and CPUEs. The results from this baseline study are essential to establish a point from which future mensuration and predictions

TABLE 2 Morphometric measurements (minimum, maximum and mean ± SE) and sex of fish sampled in Chitsuwa Reservoir, April 2018

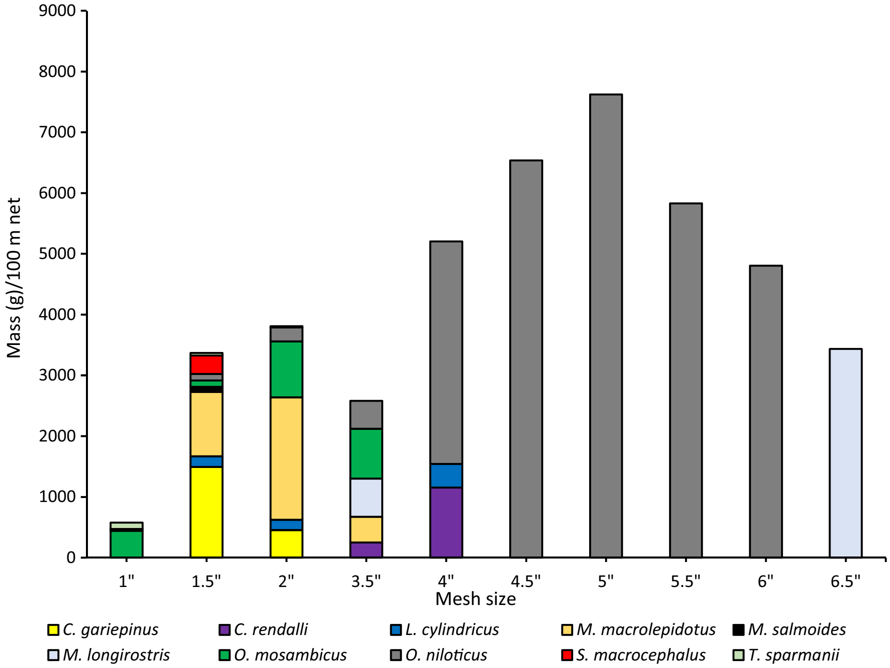
	TL (mm)			SL (mm)			Mass (g)				
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	N Female	N Male
Clarias gariepinus	98	293	238.72 ± 31.52	81	269	214.36 ± 30.12	20	273	177.09 ± 35.69	1	7
Coptodon rendalli	217	268	252.50 ± 11.95	180	203	195.75 ± 5.31	250	403	350.75 ± 35.72	3	1
Labeo cylindricus	194	205	199.75 ± 1.42	159	168	165.25 ± 1.20	84	100	91.75 ± 2.21	4	4
Marcusenius macrolepidotus	85	239	195.08 ± 4.40	68	215	174.38 ± 4.27	15	122	72.90 ± 3.42	26	22
Micropterus salmoides	160	162	161.00 ± 1.00	133	138	135.50 ± 2.50	40	44	42.00 ± 2.00	2	0
Momyrus longirostris	251	655	343.20 ± 78.14	237	590	316.00 ± 68.62	127	3435	812.20 ± 655.77	4	1
Oreochromis mossambicus	206	266	235.25 ± 6.74	175	235	202.08 ± 6.61	105	281	190.83 ± 15.36	6	6
Oreochromis niloticus	81	400	287.92 ± 9.85	63	320	226.31 ± 7.84	10	1555	597.61 ± 46.58	26	23
Serranochromis microcephalus	90	143	118.55 ± 4.96	85	128	101.27 ± 4.28	15	45	29.27 ± 3.33	3	8
Tilapia sparrmanii	78	105	90.00 ± 3.62	63	80	71.75 ± 2.34	10	26	18.13 ± 2.11	2	6

can be calculated. The present study confirmed the presence of ten species in Chitsuwa Reservoir belonging to five families. The ichthyofaunal was fairly diverse, although the species richness was low, which is a general characteristic of small reservoirs (Marshall & Maes, 1994). Similar reservoirs in Zimbabwe studied by Dalu et al. (2013) and Dube and Kamusoko (2013) where eight species were observed in both Malilangwe Reservoir and Insukamini Dam, which have a similar surface area as Chitsuwa Reservoir. A diverse aquatic community in a reservoir provides a greater probability of maintaining ecosystem conditions when it is subjected to perturbations (Yachi & Loreau, 1999).

Oreochromis niloticus dominated the fish catch with respect to both biomass and number of individuals, making it a species of relative importance. This species, which is native to the Nile Basin (Trewavas, 1983), was introduced into Zimbabwe by fish farmers in the late-1970s (Chifamba, 1998) and is presently widespread in the country (Marshall, 2011). The documented robustness traits of *O. niloticus* explain its dominance in Chitsuwa Reservoir, considering it was introduced in 2015. However, this species could have also been present in the Munyati River, which is connected to the invaded Lake Kariba, prior to the damming of the river. The introduction of *O. niloticus* into river systems in southern Africa is a cause for concern for conserving the native congeneric species that risk extirpation through hybridization and competition arising from habitat and trophic overlaps (Firmat et al., 2013; Weyl, 2008; Zengeya et al., 2015; Zengeya & Marshall, 2007). The impacts of *O. niloticus* introductions are well documented in Southern Africa, including extensive hybridization and introgression with native *O. mossambicus* in the Limpopo River system, South Africa (D'Amato et al., 2007; Firmat et al., 2013), replacing the native Kariba bream *Oreochromis mortimeri* (Trewavas, 1966) in Lake Kariba (Chifamba, 1998; Tweddle, 2010), Three-spotted tilapia *Oreochromis andersonii* (Boulenger, 1912) exist in the Kafue River, Zambia (Deines et al., 2014). It is highly likely that other native cichlids in Chitsuwa Reservoir, including *O. mossambicus*, *C. rendalli*, *S. microcephalus* and *T. sparrmanii*, are at risk of extirpation or will be localized in isolated habitats, because of the robustness of *O. niloticus*.

Despite the well documented adverse effects of *O. niloticus* to aquatic ecosystems, it remains one of the most widely cultured and propagated fish species in aquaculture and stock enhancements in the southern Africa sub-region (Zengeya et al., 2015). Managing species that possess both benefits and negative impacts (classified as conflict-generating species in Zengeya et al. (2017)), however, is complicated. *Oreochromis niloticus* is the most common fish species in Zimbabwe, constituting the dominant tilapia caught by artisanal and commercial fishermen. It is also produced intensively under aquaculture (Hamandishe et al., 2018). Decisions on the management of *O. niloticus*, therefore, should be based on the trade-offs between socio-economic benefits and potential adverse ecological effects (Zengeya et al., 2017). In most cases, the contribution to food security is considered more important than the underlying ecological impacts (Ellender et al., 2014). *Micropterus salmoides* is another non-native fish species in the reservoir, also being widespread in

FIGURE 2 Mean CPUE (bars represent minimum and maximum CPUE of fish from sites 1–4) in Chitsuwa Reservoir, April 2018



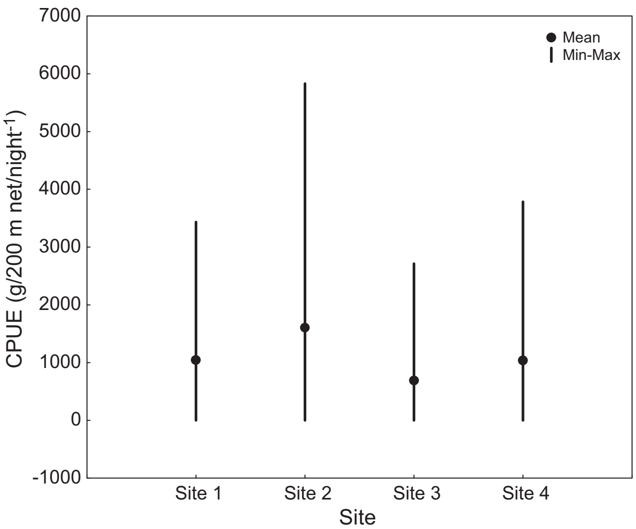


FIGURE 3 Relative contribution of each fish species to biomass of each net panel in Chitsuwa Reservoir, April 2018

Zimbabwe. This species was first introduced in Zimbabwe in 1932 and has been widely distributed by anglers, government agencies and individuals (Marshall, 2011). The ecological impacts of *M. salmoides* are also relatively well documented (e.g. Khosa et al., 2020; Takamura, 2007) and is a conflict-generating species since it is a popular angling species in Zimbabwe (Marshall, 2011).

Although they may not yield as much as larger ones, small tropical reservoirs are productive with proper management (Marshall & Maes, 1994). There is an estimated total annual yield of 60-t from the reservoir, although this estimate should only be viewed as being very preliminary and only applied with caution. The fish production in Chitsuwa Reservoir indicates that, if efficiently managed, this reservoir could produce fish that can sufficiently support the livelihoods of the local communities around the reservoir. Typical management approaches for an inland fishery include effort and gear restrictions (Sara et al., 2017). Effort restrictions include closed seasons, demarcation of fishing areas and taking turns to fish, while gear restrictions typically restrict gear dimensions (Weyl et al., 2007). The fish catch is comprised of sizes that are marketable on a commercial scale. During the survey, traders from the nearby town of Ngezi were seen buying fish from fishermen, providing evidence of how the Chitsuwa fishery is supporting local livelihoods. Demand for the resource is likely to increase, however, coupled with unemployment rates in Zimbabwe, which will collectively result in overexploitation. The local leadership, especially the traditional leaders, should be involved in managing the reservoir so that the fishery is sustainably exploited for present and future benefits. Chitsuwa Reservoir falls within the sub-tropical region in which rainfall is defined by seasonality, which affects water levels, resulting in large decreases during the long dry season (April to October) because of evaporation, use by the local community and industrial uses by ZIMPLATS. Thus, fishing should be regulated in strenuous months since the reservoir water surface area would be lower.

The fish catch composition can vary seasonally and between years, with the CPUE estimates determined during the present study only describing the fishery as it was during that time. Changes to the limnological system could result from ageing of the reservoir, which can cause a trophic upsurge attributable to the decay of inundated organic matter (van der Lingen, 1973) and, in turn, result in high fishery productivity. A trophic burst was characterized in Lake Kariba by high fish production, as well as the proliferation of the Kariba weed *Salvinia molesta* (Balon & Coche, 1974). Other changes that can be expected in the reservoir as it ages, including climate change-related impacts that could affect fishery yields as being experienced in Lake Kariba (see Magadza et al., 2020).

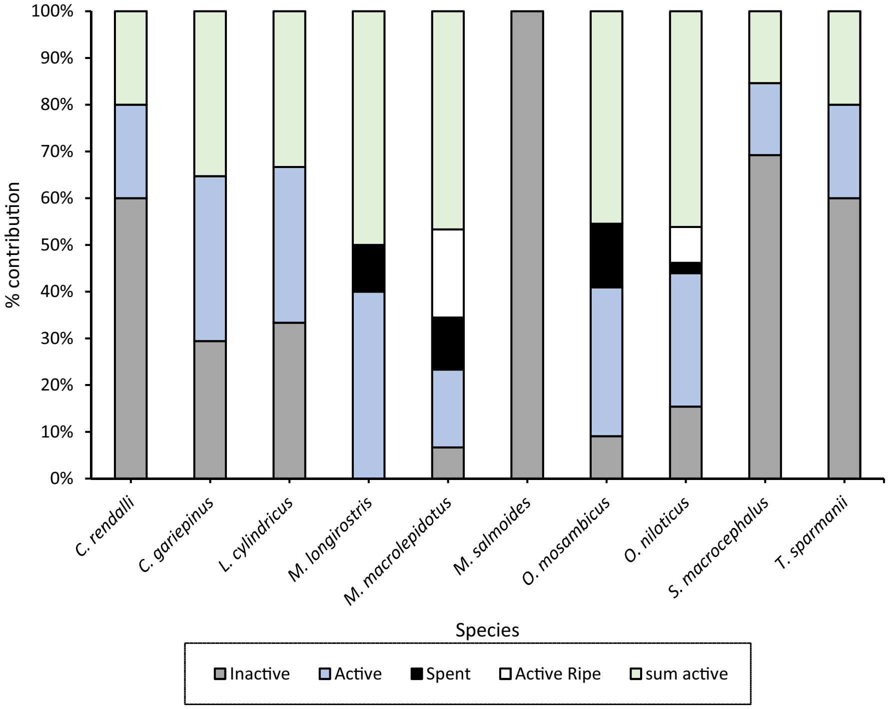


FIGURE 4 Overall breeding classes of fish from Chitsuwa Reservoir, April 2018

TABLE 3 Mean (±SE) of physiochemical variables from sampled sites in Chitsuwa Reservoir, April 2018

Variable/site	1	2	3	4	Mean	*p*
Depth	5.25 ± 0.35	13.50 ± 0.20	12.05 ± 0.15	7.10 ± 0.70	9.48 ± 1.30	.08
Temperature (°C)	21.80 ± 0.10	21.60 ± 0.10	21.75 ± 0.05	21.65 ± 0.05	21.70 ± 0.04	.32
pH	6.87 ± 0.01	6.27 ± 0.02	6.18 ± 0.00	6.25 ± 0.01	6.39 ± 0.11	.10
DO (mg/L)	5.25 ± 0.05	5.15 ± 0.05	4.95 ± 0.05	5.10 ± 0.20	5.11 ± 0.06	.37
Conductivity (μS/cm)	87.80 ± 0.00	85.35 ± 0.05	81.05 ± 0.05	80.10 ± 0.00	83.58 ± 1.19	.08
Turbidity (NTU)	15.30 ± 0.30	13.60 ± 0.60	17.05 ± 0.05	23.85 ± 0.05	17.45 ± 1.48	.08
Transparency (m)	0.68 ± 0.00	0.71 ± 0.01	0.50 ± 0.01	0.49 ± 0.01	0.59 ± 0.04	.09
Nitrate (mg/L)	0.02 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	.08
TDS	56.50 ± 0.50	55.50 ± 0.50	52.50 ± 0.51	51.00 ± 0.00	53.88 ± 0.85	.09
RP (mg/L)	0.12 ± 0.00	0.20 ± 0.00	0.08 ± 0.00	0.16 ± 0.00	0.14 ± 0.02	.08
TN (mg/L)	0.15 ± 0.00	0.09 ± 0.00	0.09 ± 0.01	0.09 ± 0.00	0.10 ± 0.01	.20
TP (mg/L)	0.17 ± 0.00	0.28 ± 0.00	0.15 ± 0.01	0.50 ± 0.02	0.28 ± 0.05	.08
Ammonia (mg/L)	0.02 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	.08
COD	10.00 ± 0.00	9.00 ± 0.00	14.00 ± 0.00	12.00 ± 0.00	11.25 ± 0.73	.07
BOD	3.50 ± 0.00	3.10 ± 0.00	4.00 ± 0.00	3.20 ± 0.00	3.45 ± 0.13	.07
Chlorophyll-*a* (mg/L)	0.004 ± 0.00	0.005 ± 0.00	0.003 ± 0.00	0.004 ± 0.00	0.004 ± 0.00	.08

Abbreviations: BOD, biochemical oxygen demand; Chlorophyll-a, chlorophyll-a concentration; COD, chemical oxygen demand; Conductivity, electrical conductivity; DO, dissolved oxygen concentration; nitrate, nitrate concentration; RP, reactive phosphorus concentration; TN, total nitrogen concentration; TP, total phosphorus concentration.

The physiological tolerance of fish prescribes the environment in which their survival and reproduction are possible (Rougier et al., 2005). The high percentage of actively breeding fish indicate good water conditions for the fish. Ordination of the fish species by CCA also demonstrated that the species variation patterns were significantly related to the environmental variables of the reservoir, which significantly explained the principal variations in the fish composition. The CCA revealed a clear division of fish species in accordance with their ecological requirements. Depending on the time of the year, therefore, a series of environmental variables in the reservoir may affect the spatial distribution of its ichthyofaunal community.

The results of the present study demonstrated that Chitsuwa Reservoir is dominated by fish species that can be exploited for

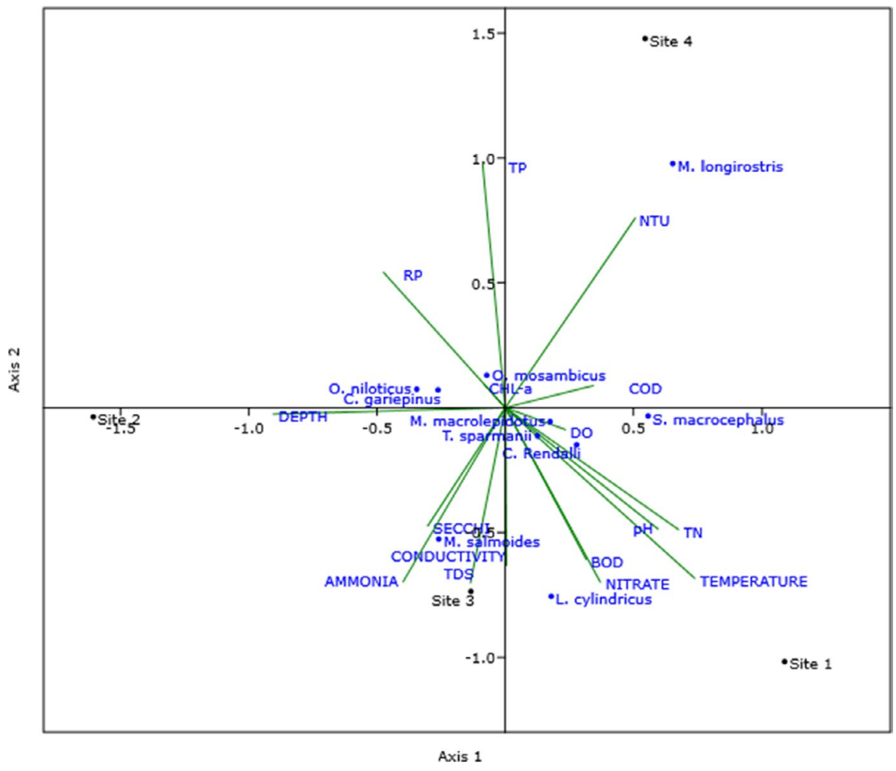


FIGURE 5 CCA triplot showing relationships between fish species and environmental variables in Chitsuwa Reservoir, April 2018

subsistence consumption, with the surplus being sold. There is a need to sustainably manage this reservoir so that it continues to provide its ecosystem services for the livelihoods of the riparian community. Because of the informal subsistence and nature of most small scale fisheries, their socio-economic contributions are often not captured in national statistics. Thus, the Zimbabwe Parks and Wildlife Management Authority (ZPWMA) should work with the local leadership in managing this resource and ensure that records of fish catches are collected so that statistics derived from these small reservoirs can determine the total yield from inland fisheries in Zimbabwe, as well as globally. Such information also has historical value for future research, as well as for the sustainable management of this reservoir.

ACKNOWLEDGEMENTS

This work was supported by funds from ZIMPLATS. Technical support from ZPWMA, University of Zimbabwe Lake Kariba Research Station (ULKRS) and the Department of Biological Sciences of the University of Zimbabwe is fully acknowledged. This research was authorized by the ZPWMA. Any opinion, finding and conclusion or recommendation expressed in this material is that of the authors. ZIMPLATS, ZPWMA and ULKRS do not accept any liability in this regard.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest. Any opinions, findings and conclusions or recommendations expressed in this manuscript are that of the authors and are not influenced by the funding organizations.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Takudzwa C. Madzivanzira https://orcid.org/0000-0001-9683-5798
Chipo Mungenge https://orcid.org/0000-0003-2949-9207
Adroit T. Chakandinakira https://orcid.org/0000-0002-8065-8114
Nyasha Rugwete https://orcid.org/0000-0003-3866-0410
Blessing Kavhu https://orcid.org/0000-0003-2065-4485

REFERENCES

Bagenal, T. B., & Braum, E. (1968). Eggs and early life history. In W. E. Ricker (Ed.), *Methods for assessment of fish production in fresh waters* (No. 3, pp. 165–201). International Biology Programme Handbook. Blackwell Scientific.

Balon, E. K., & A. G. Coche (Eds.) (1974). *Lake Kariba: A man-made tropical ecosystem in Central Africa*. Biological Monographs. Junk Publishers.

Bartley, D. M., De Graaf, G. J., Valbo-Jørgensen, J., & Marmulla, G. (2015). Inland capture fisheries: Status and data issues. *Fisheries Management and Ecology*, *22*(1), 71–77. https://doi.org/10.1111/fme.12104

Bartram, J., & Balance, R. (Eds.) (1996). *Water quality monitoring: A practical guide to the design of freshwater quality studies and monitoring programme* (pp. 383). UNDP & WHO.

Bergkamp, G., McCartney, M., Dugan, P., McNealy, J., & Acreman, M. (2000). *Dams, ecosystem functions and environmental restoration*. WCD Thematic Review Environmental Issues II. World Commission on Dams (WCD). http://www.dams.org

Chifamba, P. C. (1998). Status of *Oreochromis niloticus* in Lake Kariba, Zimbabwe, following its escape from fish farms. In I. G. Cowx (Ed.), *Stocking and introduction of fish* (pp. 267–273). Blackwell Science.

Cooke, S. J., Allison, E. H., Beard, T. D., Arlinghaus, R., Arthington, A. H., Bartley, D. M., Cowx, I. G., Fuentevilla, C., Leonard, N. J., Lorenzen, K., Lynch, A. J., Nguyen, V. M., Youn, S.-J., Taylor, W. W., & Welcomme, R. L. (2016). On the sustainability of inland fisheries: Finding a future for the forgotten. *Ambio*, *45*, 753–764. https://doi.org/10.1007/s13280-016-0787-4

D'Amato, M. E., Esterhuyse, M. M., van der Waal, B. C. W., Brink, D., & Volckaert, F. A. M. (2007). Hybridization and phylogeography of the Mozambique tilapia *Oreochromis mossambicus* in southern Africa evidenced by mitochondrial and microsatellite DNA genotyping. *Conservation Genetics*, *8*, 475–488. https://doi.org/10.1007/s10592-006-9186-x

Dalu, T., Clegg, B. W., & Nhiwatiwa, T. (2013). A study of the ichthyofauna of a small tropical reservoir, south-eastern lowveld, Zimbabwe. *African Journal of Aquatic Science*, *38*(Suppl.), 105–113. https://doi.org/10.2989/16085914.2013.768953

de Moor, I. J., & Bruton, M. N. (1988). *Atlas of alien and translocated indigenous aquatic animals in southern Africa*. South African National Scientific Programmes Report No. 144. CSIR, Pretoria.

Deines, A. M., Bbole, I., Katongo, C., Feder, J. L., & Lodge, D. M. (2014). Hybridisation between native *Oreochromis* species and introduced Nile tilapia *O. niloticus* in the Kafue River, Zambia. *African Journal of Aquatic Science*, *39*(1), 23–34. https://doi.org/10.2989/16085914.2013.864965

Dube, A., & Kamusoko, R. (2013). An investigation of fish species diversity, abundance and diets of selected predator fish in Insukamini Dam. *Zimbabwe. Journal of Animal Science Advances*, *3*(3), 121–128. https://doi.org/10.5455/jasa.20130331052157

Ellender, B. R., Woodford, D. J., Weyl, O. L. F., & Cowx, I. G. (2014). Managing conflicts arising from fisheries enhancements based on non-native fishes in southern Africa. *Journal of Fish Biology*, *85*, 1890–1906. https://doi.org/10.1111/jfb.12512

Ersal, E. (1994). Inventory of small water bodies in the SADC region. *ALCOM News*, *15*, 12–16.

Firmat, C., Alibert, P., Losseau, M., Baroiller, J.-F., & Schliewen, U. K. (2013). Successive invasion-mediated interspecific hybridizations and population structure in the endangered cichlid *Oreochromis mossambicus*. *PLoS One*, *8*, 1–12. https://doi.org/10.1371/journal.pone.0063880

Hamandishe, V. R., Saidi, P. T., Imbayarwo-Chikosi, V. E., & Nhiwatiwa, T. (2018). A comparative evaluation of carcass quality, nutritional value, and consumer preference of *Oreochromis niloticus* from two impoundments with different pollution levels in Zimbabwe. *International Journal of Food Science*, *2018*, 1–10. https://doi.org/10.1155/2018/7862971

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). PAST: Paleontological Statistics Software Package for Education and Data Analysis, Version 3.11c. Palaeontologia Electronica.

Havel, J. E., Lee, C. E., &, Vander Zanden, M. J (2005). Do Reservoirs Facilitate Invasions into Landscapes?. *BioScience*, *55*(6), 518. http://dx.doi.org/10.1641/0006-3568(2005)055[0518:drfiil]2.0.co;2

Hu, M., Wang, C., Liu, Y., Zhang, X., & Jian, S. (2019). Fish species composition, distribution and community structure in the lower reaches of Ganjiang River, Jiangxi, China. *Scientific Reports*, *9*, 10100. https://doi.org/10.1038/s41598-019-46600-2

Jackson, D., & Marmulla, G. (2001). The influence of dams on river fisheries. In G. Marmulla (Ed.), *Dams, fish and fisheries*. Opportunities, challenges and conflict resolution (No. 419). FAO Fisheries Technical Paper, Rome.

Johnson, P. T. J., Olden, J. D., & Zanden, M. J. V. (2008). Dam invaders: Impoundments facilitate biological invasions into freshwaters. *Frontiers in Ecology and the Environment*, *6*(7), 357–363. https://doi.org/10.1890/070156

Khosa, D., South, J., Cuthbert, R. N., Wasserman, R. J., & Weyl, O. L. F. (2020). Temperature regime drives differential predatory performance in Largemouth Bass and Florida Bass. *Environmental Biology of Fishes*, *103*, 67–76. https://doi.org/10.1007/s10641-019-00933-z

Kolar, C. S., & Lodge, D. M. (2000). Freshwater nonindigenous species: interactions with other global changes. In H. A. Mooney, & R. J. Hobbs (Eds.), *Invasive species in a changing world* (pp. 3–30). Island Press.

Lynch, A. J., Cooke, S. J., Deines, A. M., Bower, S. D., Bunnell, D. B., Cowx, I. G., Nguyen, V. M., Nohner, J., Phouthavong, K., Riley, B., Rogers, M. W., Taylor, W. W., Woelmer, W., Youn, S.-J., & Beard, T. D. (2016). The social, economic, and environmental importance of inland fish and fisheries. *Environmental Reviews*, *24*, 1–7. https://doi.org/10.1139/er-2015-0064

Lynch, A. J., Elliott, V., Phang, S. C., Claussen, J. E., Harrison, I., Murchie, K. J., Steel, E. A., & Stokes, G. L. (2020). Inland fish and fisheries integral to achieving the Sustainable Development Goals. *Nature Sustainability*, *3*(8), 579–587. https://doi.org/10.1038/s41893-020-0517-6

Madzivanzira, T. C., South, J., Ellender, B. R., Chalmers, R., Chisule, G., Coppinger, C. R., Khaebeb, H. F., Jacobs, F. J., Chomba, M., Musando, B., Mwale, C., Nhiwatiwa, T., Rennie, C. L., Richardson, N., & Weyl, O. L. F. (2021). Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in the Zambezi Basin. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*(11), 3156–3168. https://doi.org/10.1002/aqc.3703

Madzivanzira, T. C., South, J., Wood, L. E., Nunes, A. L., & Weyl, O. L. F. (2020). A review of freshwater crayfish introductions in continental Africa. *Reviews in Fisheries Science & Aquaculture*, *29*(2), 218–241. https://doi.org/10.1080/23308249.2020.1802405

Magadza, C. H. D., Madzivanzira, T. C., & Chifamba, P. C. (2020). Decline of zooplankton food resources of *Limnothrissa miodon* fishery in Lake Kariba: Global warming induced ecosystem disruption by *Cylindrospermopsis raciborskii*. *Lakes & Reservoirs: Science, Policy and Management for Sustainable Use*, *25*, 117–132. https://doi.org/10.1111/lre.12318

Marshall, B. (2011). *The fishes of Zimbabwe and their biology*. Smithiana Monograph 3. South African Institute for Aquatic Biodiversity.

Marshall, B. E., & Maes, M. (1994). *Small water bodies and their fisheries in southern Africa*. CIFA Technical Paper No. 29. FAO.

Mhlanga, L., Madzivanzira, T. C., Nhiwatiwa, T., Tendaupenyu, P., Barson, M., Marufu, L., & Songore, N. (2020). A survey of phytoplankton and zooplankton communities in the newly created Tugwi-Mukosi Reservoir, Zimbabwe, during the filling phase. *African Journal of Aquatic Science*, *45*(4), 466–474. https://doi.org/10.2989/16085914.2020.1733926

Mustapha, M. K. (2011). Perspectives in the limnology of shallow tropical African reservoirs in relation to their fish and fisheries. *The Journal of Transdisciplinary Environmental Studies*, *10*(1), 16–23.

NEPAD (2005). *The NEPAD action plan for the development of African fisheries and aquaculture*. NEPAD-Fish for All Summit. https://oldsite.issafrica.org/uploads/FISHPLAN.PDF

NEPAD (2014). *The NEPAD agency fisheries and aquaculture programme, 2015–2020*. nepad.org/file-download/download/public/15314

Pinkas, L., Olipham, M. S., & Iversor, I. L. K. (1971). Food habits of albacore, bluefin tuna and bonito in California waters. *Fish Bulletin*, *152*, l-105.

Rougier, C., Pourriot, R., Lam-Hoai, T., & Guiral, D. (2005). Ecological patterns of the rotifer communities in the Kaw River estuary (French Guiana). *Estuarine, Coastal and Shelf Science*, *63*(1–2), 83–91. https://doi.org/10.1016/j.ecss.2004.08.023

Sara, J. S., Weyl, O. L. F., Marr, S. M., Smit, W. J., Fouché, P. S. O., & Luus-Powell, W. J. (2017). Gill net catch composition and catch per unit effort in Flag Boshielo Dam, Limpopo Province, South Africa. *Water SA*, *43*(3), 463–469. https://doi.org/10.4314/wsa.v43i3.11

Schlesinger, D. A., & Regier, H. A. (1982). Climatic and morphoedaphic indices of fish yields from natural lakes. *Transactions of the American Fisheries Society*, *111*(2), 141–150. https://doi.org/10.1577/1548-8659(1982)111<141:CAMIOF>2.0.CO;2

Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. University of Illinois Press.

Shea, K., & Chesson, P. (2002). Community ecology theory as a framework for biological invasions. *Trends in Ecology & Evolution*, *17*, 170–176. https://doi.org/10.1016/S0169-5347(02)02495-3

Skelton, P. H. (2001). *A complete guide to the freshwater fishes of southern Africa* (pp. 395). Struik Publishers.

STATSOFT, INC. (2006). STATISTICA (data analysis software system), version 7.1.

Takamura, K. (2007). Performance as a fish predator of largemouth bass [*Micropterus salmoides* (Lacepède)] invading Japanese freshwaters: A review. *Ecological Research*, *22*, 940–946. https://doi.org/10.1007/s11284-007-0415-7

Trewavas, E. (1983). *Tilapiine fishes of the genera Sarotherodon, Oreochromis and Danakilia*. British Natural History Museum.

Tweddle, D. (2010). Overview of the Zambezi River System: Its history, fish fauna, fisheries, and conservation. *Aquatic Ecosystem Health & Management*, *13*(3), 224–240. https://doi.org/10.1080/14634988.2010.507035

van der Lingen, M. I. (1973). Lake Kariba. Early history and south shore. In W. C. Ackerman, G. E. White, & E. B. Worthington (Eds.), *Man-made lakes: Their problems and environmental effects*. (pp. 132–142). American Geophysical Union. https://doi.org/10.1029/GM017p0132

Verheust, L. (1998). Obtaining basic information for the enhancement of small water body fisheries: A regional project viewpoint. In T. Petr (Ed.). *Inland fishery enhancements* (No. 374, pp. 183–203). FAO Fisheries Technical Paper, Food and Agriculture Organization of the United Nations, Rome.

Wetzel, R. G. (2001). *Limnology: Lake and river ecosystems* (3rd ed.). Academic Press.

Weyl, O. L. F. (2008). Rapid invasion of a subtropical lake fishery in central Mozambique by Nile tilapia, *Oreochromis niloticus* (Pisces: Cichlidae). *Aquatic Conservation: Marine and Freshwater Ecosystems*, *18*, 839–851. https://doi.org/10.1002/aqc.897

Weyl, O. L. F., Potts, W., Rouhani, Q., & Britz, P. (2007). The need for inland fisheries policy in South Africa: A case study of the North West Province. *Water SA*, *33*(4), 497–504.

Yachi, S., & Loreau, M. (1999). Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. *PNAS*, *96*, 1463–1468. https://doi.org/10.1073/pnas.96.4.1463

Zengeya, T. A., Booth, A. J., & Chimimba, C. T. (2015). Broad niche overlap between invasive Nile tilapia *Oreochromis niloticus* and indigenous congenerics in southern Africa: Should we be concerned? *Entropy*, *17*, 4959–4973. https://doi.org/10.3390/e17074959

Zengeya, T., Ivey, P., Woodford, D. J., Weyl, O., Novoa, A., Shackleton, R., Shackleton, R., Richardson, D., & van Wilgen, B. (2017). Managing conflict-generating invasive species in South Africa: Challenges and trade-offs. *Bothalia*, *47*(2), a2160. https://doi.org/10.4102/abc.v47i2.2160

Zengeya, T. A., & Marshall, B. E. (2007). Trophic interrelationships amongst cichlid fishes in a tropical African reservoir (Lake Chivero, Zimbabwe). *Hydrobiologia*, *592*, 175–182. https://doi.org/10.1007/s10750-007-0790-7

How to cite this article: Madzivanzira, T. C., Mungenge, C., Chakandinakira, A. T., Rugwete, N., & Kavhu, B. (2022). Post-filling phase ichthyofaunal community and fishery potential of Chitsuwa Reservoir, a small tropical reservoir in Zimbabwe. *Lakes & Reservoirs: Research & Management*, 27, e12394. https://doi.org/10.1111/lre.12394