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Community Diversity and Dynamics of Fish Assemblages in Lake Kanyaboli, Western Kenya

Benjamin N. Kondowe[1,2] | Frank O. Masese[1] | Phillip O. Raburu[1] | Wales Singini[2] | Augustine Sitati[1,3] | Riziki Jacques Walumona[1,4]

[1]Department of Fisheries and Aquatic Sciences, University of Eldoret, Eldoret, Kenya | [2]Department of Fisheries and Aquatic Sciences, Mzuzu University, Luwinga, Malawi | [3]Department of Biological Sciences, University of Alabama, Tuscaloosa, Alabama, USA | [4]Département of Chemistry and Physics, Institut Supérieur Pédagogique de Bukavu (ISP/Bukavu), Bukavu, Congo

Correspondence: Benjamin N. Kondowe (benjy85@gmail.com)

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ABSTRACT

Although Lake Kanyaboli provides a sanctuary for fish species that are considered extinct (e.g., *Oreochromis esculentus*, *Oreochromis variabilis* and *Haplochromis* spp.) in Lake Victoria, comprehensive data on species diversity and abundance are lacking. This study, conducted over a year (February 2020 to February 2021), addressed this gap by assessing the temporal variation in fish diversity, abundance and catch (biomass) in Lake Kanyaboli. The primary fish data collected in the lake were supplemented with secondary data, and physico-chemical variables were used to correlate with fish assemblages. Fish catches decreased over time from 1981 to 2020, with the highest catch observed in 1981 (250 mt). Fish species composition data showed heterogeneity over the years, ranging from 9 to 15 species. *O. esculentus*, haplochromines, *Oreochromis niloticus*, *Protopterus aethiopicus* and *Clarias* sp. were present in all the reviewed years (from 1981 to 2020), whereas *Coptodon zillii* was non-existent post-1981 results. The February 2020 to February 2021 survey recorded 14 species dominated by Cichlidae (10 species), whereas Protopteridae and Anabantidae recorded one taxon each. Interestingly, *Bagrus* sp. was recorded in the current study, suggesting fish movement from the Yala River to the lake. The annual fish catch in the lake comprised tilapias (50%, *O. esculentus*, *O. variabilis*, *O. niloticus* and *Oreochromis leucostictus*), *Clarias* sp. (23%), *P. aethiopicus* (20%), haplochromines (7%), Cyprinids (0.03%) and Anabantidae (0.01%). There were no significant monthly differences in fish abundance and fish catches. The decline in fish catch in Lake Kanyaboli over the years is consistent with most tropical lakes and reservoirs in developing countries due to overexploitation. This study highlights the need for biomonitoring in Lake Kanyaboli to protect its fish population, including the endangered *O. esculentus* and *O. variabilis*, and ensure the long-term sustainability of the ecosystem.

1 | Introduction

Fish are diverse and widespread among aquatic organisms, contributing to the economy of many countries worldwide (Lévêque et al. 2008). The Fish Base, an online fish species repository (Froese and Pauly 2018), has at least 33,000 species described, representing more than the combined total of all other vertebrate species on Earth. However, rapid environmental changes and human activities have altered the spatial and temporal structuring of biological diversity and associated ecosystem services globally (Rodríguez and Lewis 1997; Tejerina-Garro, Fortin, and Rodrı´guez 1998; Saint-Paul et al. 2000; Su'arez, Petrere, and Catella 2001; Galactos, Barriga-Salazar, and Stewart 2004; Mao et al. 2021). Furthermore, aquatic trophic structures are driven by ecosystem size, productivity and disturbance (Jia et al. 2021). The ecosystem size driver theory suggests that the abundance of fish species tends to increase with an increase in lake size due to abundant habitat availability and diversity (Post, Pace, and Hairston 2000; Jia et al. 2021). In contrast, the productivity driver entails limits on species richness caused by the rate at which energy enters a system, affecting food web complexity (Wright 1983; Currie et al. 2004). The ecosystem disturbance driver leads to shorter food chains in highly variable environments (Pimm and Lawton 1977). Thus, fish diversity, abundance and distribution offer insights into the status and integrity of the ecosystem (Thompson, Davies, and Gonzalez 2015).

Water level fluctuations and anthropogenic activities also influence fish diversity, abundance and biomass (Dudgeon et al. 2006; Hastings and Wysham 2010; Wang et al. 2015; Amoutchi et al. 2021; Yongo et al. 2021; Walumona et al. 2022; Morara et al. 2022). Likewise, fish recruitment is affected by strong winds and waves due to high egg and larval mortality (Clady 1976; Aalto and Newsome 1993; MacKenzie 2000; Weber and Brown 2013). Windy conditions in shallow lakes alter visibility due to increased turbidity, making foraging difficult (Weber and Brown 2013). In addition, macrophytes also influence the fishermen's access to fish stocks, the use of fishing gear and boat access possibilities (Petr 2000). Likewise, macrophytes support fish species composition and production associated with diverse plankton communities providing forage for fish (Gasith and Hoyer 1998; dos Santos et al. 2020). Thus, fish serve as biological indicators of ecosystem health due to their long lifespan and responses to changes in water and habitat quality (Karr et al. 1986; Zainudin 2005; Dudgeon et al. 2006; Hamzah 2007; López-López and Sedeño-Díaz 2015; Achieng et al. 2021).

Nevertheless, literature indicates that small water bodies in the tropics, such as lakes and reservoirs bordered by rich wetlands, face biodiversity threats due to anthropogenic activities (Moyle and Leidy 1992; Aloo 2003; DeFries, Foley, and Asner 2004; Dahlberg and Burlando 2009; Darwall et al. 2018; Yu et al. 2018; Tickner et al. 2020). This has led to studies on fish occurrence, distribution, abundance and population dynamics (Tolonen et al. 2005; Haddad et al. 2015; Bryan-Brown et al. 2020). In the Lake Victoria basin, many wetlands, satellite lakes and river mouths have been lost, degraded or converted for grazing, farming and human settlement (Kairu 2001; Aloo 2003; Thenya et al. 2006; Mwanja et al. 2007; Masese, Raburu, and Kwena 2012; Okeyo-Owuor et al. 2012; Rongoei et al. 2013).

Lake Kanyaboli, a small satellite lake of Lake Victoria found in Yala Wetland, Western Kenya, is a sanctuary for threatened fish species like *Oreochromis esculentus* and *Oreochromis variabilis* (Abila 2005). Other fish species reported in the lake include six *Haplochromine* spp., *Coptodon zillii*, *Clarias gariepinus*, *Protopterus aethiopicus* and *Xenoclarias* spp. (Aloo 2003; Gichuki, Maithya, and Masai 2005). However, a significant part of Yala Wetland was reclaimed for agricultural activities. This has a negative impact on the ecosystem integrity of the wetland and the three satellite lakes—Lakes Kanyaboli, Sare and Namboyo (Wilfred et al. 2005; Abila and Othina 2005). Lake Kanyaboli is the largest of the three lakes and is more prone to disturbances because it is directly affected by the reclamation of the Yala Wetland (Aloo 2003; Abila 2005; Angienda et al. 2011; Kondowe et al. 2022a). However, studies on Lake Kanyaboli are infrequent and limited, with most data predating the major developments and reclamation efforts in Yala Wetland (Okemwa 1981; Mavuti 1989; Aloo 2003; Kondowe et al. 2022a). Previous fish-related studies focused on the occurrence of various species (Maithya 1998; Aloo 2003; Masai, Ojuok, and Ojwang 2005) with limited biomass and fish production estimation. This study addressed these gaps by providing a comprehensive overview of fish species diversity, composition, abundance, catch and the factors driving their temporal variations in the lake. We hypothesised that fishing pressure and human activities in the catchment areas contribute to fish diversity and abundance changes in Lake Kanyaboli and similar small water bodies in the tropics. These findings are important for understanding the factors influencing small tropical lakes and their response to threats. The findings are also important for informing biomonitoring, management and conservation efforts of threatened fish species and fisheries.

2 | Materials and Methods

2.1 | Description of the Study Area

This study was done in Lake Kanyaboli (Figure 1), one of the satellite lakes on the northern shores of Lake Victoria found in Yala Wetland. The wetland also contains two other satellite lakes, namely, Lake Sare (5 km^2) and Lake Namboyo (0.01 km^2), but Lake Kanyaboli (10.5 km^2) is the largest. The lake lies between latitudes 0°05S′N and 0°02′N and longitudes 34°09′E and 34°11′E, with an average depth of 3 m (Opiyo and Dadzie 1994; Abila et al. 2008). The climate around Lake Kanyaboli is characterised by two dry and wet seasons annually. The long dry season is from July to September, whereas January to February is shorter. Likewise, March to June is a long wet season, whereas October to December is a shorter wet season.

Lake Kanyaboli is ecologically important because it provides refuge for threatened fishes such as *O. esculentus* and *O. variabilis* that have been lost from Lake Victoria (Aloo 2003; Abila 2005). Lake Kanyaboli provides riparian communities with a livelihood through fisheries, irrigated agriculture and the handicraft industry. Fish is the most critical wetland product, and 98%–100% of the residents depend on fishing for subsistence or sale (Abila 2005). Nevertheless, Lake Kanyaboli has been impacted by anthropogenic activities such as the reclamation of part of Yala Wetland. It is estimated that 2300 ha of the Yala Wetland was reclaimed for agricultural purposes between 1965 and 1970 (Owiyo, Kiprono, and Sutter 2012). The lake has previously experienced poor water quality due to a lack of inflow after the blockage of the feeder canal constructed during the reclamation to replenish lake water (Aloo 2003).

2.2 | Sample Collection

The study follows the tenets of the Declaration of Helsinki. Fish samples were collected monthly for 1 year, from February

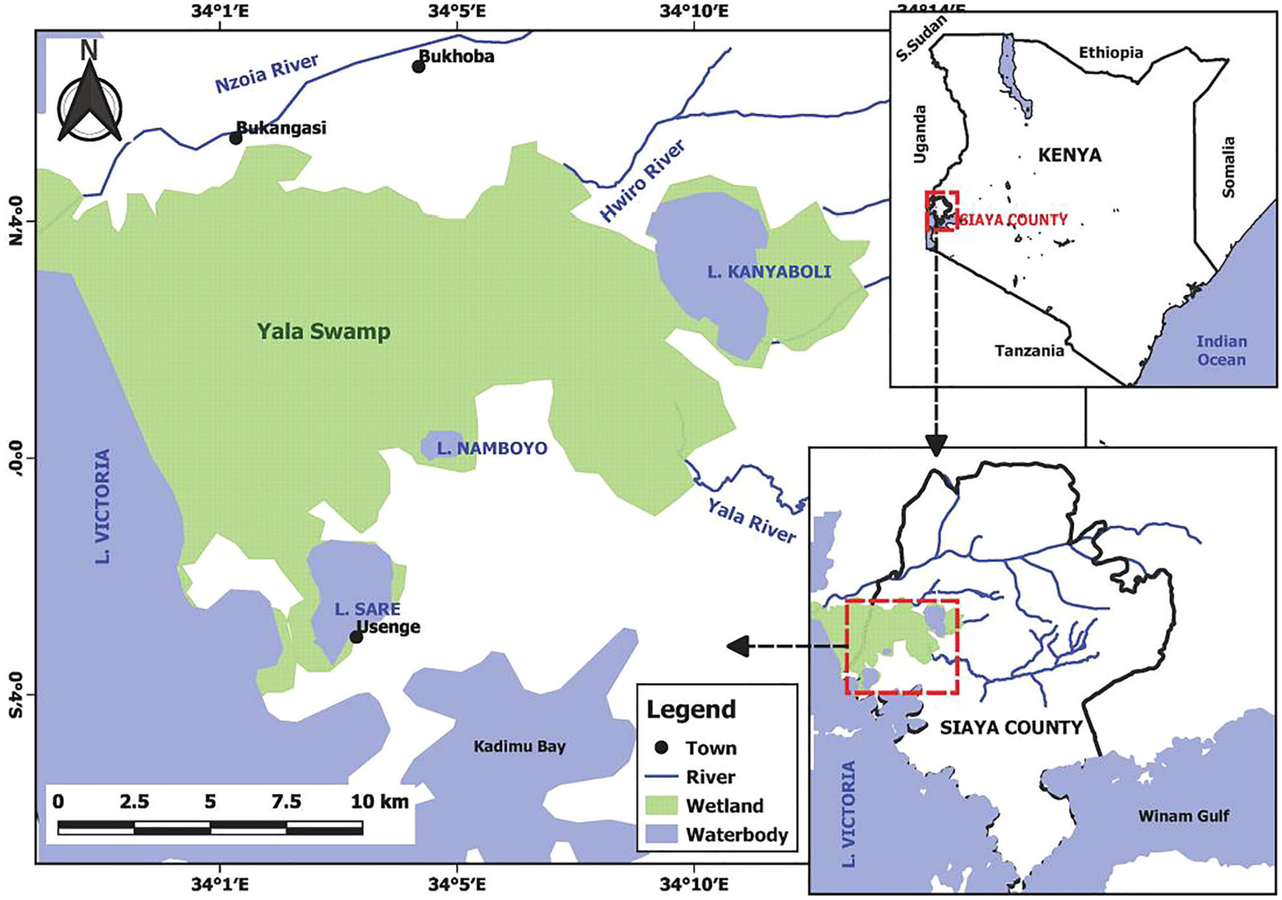

FIGURE 1 | Yala Swamp map showing Lake Kanyaboli, Sare and Namboyo.

2020 to February 2021, around Lake Kanyaboli. Samples for tilapia, haplochromine and cyprinids were collected from fishers operating gillnets and fish traps, whereas *Clarias* sp. and *P. aethiopicus* samples were collected from fishers operating gillnets and longlines. The lake was considered one unit for data analysis purposes because it is not zoned into different fishing grounds due to its smaller size. Data on fish catches were supplemented with secondary data from published and grey literature from 1981 to 2015. However, the historical data were limited, infrequent and inconsistent, with only 4 years (1981, 2013, 2014 and 2015) having usable data. But these data were only collected for short periods, <1 year. Furthermore, abundance data for different fish species were scarce; hence, the secondary data were only used to estimate total (all species) biomass or catches and species occurrence.

Fish samples collected during the present study were identified to species level where possible using several keys and guides, such as Trewavas (1983), Witte and Densen (1995), Seegers, de Vos, and Okeyo (2003) and FishBase (Froese and Pauly 2018). Fish identification utilised colour patterns, morphometric and meristic (dorsal spines, dorsal soft rays, anal spines, anal soft rays etc.) characteristics. Fish species composition data were collected for 7 days each month. On the other hand, monthly fish biomass was estimated using the daily mean catch calculated from 7 days of catch data for each month for the entire study period.

In addition to fish data, the February 2020 to February 2021 survey also used 10 key informants, comprising 2 individuals from each designated landing site, to collect data on the number of fishers, fishing crafts, type and number of fishing gears and fishing time. The data were used to estimate fishing efforts in Lake Kanyaboli. This helped track the temporal changes in fishing pressure and catches in the lake.

In addition, physico-chemical data on pH, electrical conductivity (EC), dissolved oxygen (DO) concentration, temperature, Secchi depth (SD), nitrates (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), soluble reactive phosphorus (SRP), total nitrogen (TN) and total phosphorus (TP) from Kondowe et al. (2022a) were used. The data were used to assess the relationship between water quality and fish abundance and catch in the lake.

2.3 | Data Analysis

Descriptive statistics were used to summarise fishery characteristic data from the February 2020 to February 2021 survey and compare annual fish catch data with historical data. Further statistical analyses were performed on data collected during the present study (February 2020 to February 2021). Some diversity indices were used to compare the composition of fish data among months and seasons. The indices used included species richness (S), Shannon's diversity index (H'), Simpson's evenness index (E), Fisher's alpha index, Berger–Parker index and individual numbers (abundance).

The Kruskal–Wallis test compared fish abundance and catch/biomass among months. One-way analysis of similarities (ANOSIM) was also used to compare average rank similarities of fish composition and biomass between the wet and dry seasons for February 2020 to February 2021 survey data, followed by permutational multivariate analysis of variance (PERMANOVA) to check for significant differences. ANOSIM calculates a test statistic, the *R*-statistic, which varies between 0 and 1; higher values indicate greater differences among factors. For statistically significant ANOSIM, similarity percentages analysis (SIMPER) is used to determine fish taxa responsible for potential differences among seasons. The percentage contribution of each taxon to the overall dissimilarity per season was quantified. SIMPER is a strictly pairwise analysis between two-factor levels (Clarke and Warwick 2001), and in this case, comparisons were made between dry and wet seasons. Seasonal data were also compared using paired *t*-test. Canonical correspondence analysis (CCA) investigated the relationship between fish data (abundance and catch) and environmental variables visualised using triplots.

Statistical analyses were performed with Minitab version 17.1 for Kruskal–Wallis and *t*-test, whereas PAST version 2.17 (Hammer, Harper, and Ryan 2001) was used for diversity indices, SIMPER and ANOSIM. On the other hand, CCA was analysed using R (ver. 3.3.3, R Foundation for Statistical Computing, Vienna, Austria; see http://www.R-project.org/). Furthermore, Microsoft Office Excel (2016) was used to generate graphs and summarise results.

3 | Results

3.1 | Characteristics of the Fishery

Although the lake was considered a single unit because there were no boundaries on fishing grounds, the data on characteristics of the fishery were disintegrated based on landing sites (Table 1). Lake Kanyaboli fishery is predominantly artisanal, targeting tilapia species, haplochromines, small-sized cyprinids, catfish and mudfish. Data from the current study in Lake Kanyaboli between February 2020 and February 2021 show that 390 fishers were using 148 fishing crafts (Table 1). Gangu landing site had the highest number of fishers (230) and fishing crafts (58). On the other hand, Hawinga site had the lowest number of fishers (21) and fishing crafts (12). The results further showed that of 148 fishing crafts, 126 used gillnets, whereas 12 used fish traps (Table 1). The gillnet mesh sizes range from 1/2 in (targeting haplochromines) to 4 in, used to target large-sized fish such as *Oreochromis niloticus* and *Clarias* sp. The intermediate mesh sizes are used for other cichlid species, such as *O. esculentus* and *O. variabilis*. The fishing gears were left overnight, and the average soak time for all the fishing gears was 10 h.

TABLE 1 | Summary of characteristics of the fisheries and fishing crafts of Lake Kanyaboli.

Fishery characteristics	Kadenge	Gangu	Kombo	Hawinga	Swila	Total
Number of fishers	63	230	50	21	26	390
Number of crafts	27	58	37	12	14	148
Number of boats using traps	2	—	10	—	—	12
Number of boats using gillnets for haplochromine and Tilapia fisheries	20	55	25	12	14	126
Number of boats using hooks (all fisheries)	5	3	12	—	—	20
Number of traps per boat (all fisheries)	20	—	10	—	—	30
Number of gillnets per boat for haplochromine fishery	20	30	18	45	45	158
Number of hooks per boat (all fisheries)	200	400	250	—	—	850

Note: The data were obtained from February 2020 and February 2021.

3.2 | Historical Trends in the Fish Catches of Lake Kanyaboli

The summary of annual fish catches or biomass between 1981 and 2020 from literature and 2020 survey data in Lake Kanyaboli showed variations in the total catch (Table 2). The highest fish catch was recorded in 1981 (250 mt), whereas the year 2020 had the lowest landed fish catch (93 mt). The historical data showed

TABLE 2 | Changes in annual fish catches in tons over the years from 1981 to 2020 in Lake Kanyaboli (Okemwa 1981, Kimani, Okemwa, and Aura 2018 and present study).

Year	Catch (mt)	References
1981	250	Okemwa (1981)
2013	194	Kimani, Okemwa, and Aura (2018)
2014	134	Kimani, Okemwa, and Aura (2018)
2015	100	Kimani, Okemwa, and Aura (2018)
2020	93	Present study

that fish catches decreased by 22.4% between 1981 (250 mt) and 2013 (194 mt), whereas there was a similar amount of decrease (25.4%) between 2014 (134 mt) and 2015 (100 mt). On the other hand, the fish catch in 2020 (93 mt) indicated a 7.00% decrease compared to the amount recorded in 2015.

Historically, the main species in the catches include Tilapia (*O. esculentus*, *O. variabilis*, *Oreochromis leucostictus* and *O. niloticus*) (54.5%), *Clarias* (19.3%), *Protopterus* (18.5%) and *Haplochromis* (7.7%) landed using fishing effort comprised of about 188 fishers operating 99 fishing crafts for the period 2013–2015 (Kimani, Okemwa, and Aura 2018). The combined proportion of tilapia shows a general decline in tilapia catches as *O. esculentus* composed about 64% of the lake's fisheries in the 1980s (Okemwa 1981), while Aloo (2003) reported that *O. esculentus* and *O. niloticus* contributed 50% and 40% towards total catch (250 mt) respectively. Contrarily, the number of fishers increased from 130 in 2003, with a corresponding increase in fishing crafts (Lihanda, Aseto, and Atera 2003). Among the tilapia species landed, *O. esculentus* occurs in substantial quantities compared to Lake Sare, where Nile Perch (*Lates niloticus*) has been blamed for the low landing of the species (Abila and Othina 2005).

The fish species composition of Lake Kanyaboli has shown great variability over the years, recording between 9 and 15 taxa (Table 3). The temporal comparison from 1981 to 2020 indicated *O. esculentus*, Haplochromines (particularly *Pseudocranilabrus multicolor victoriae*, *Haplochromis maxillaris*, *Astatoreochromis alluaudi*, *Haplochromis* (*Astatotilapia*) *nubilus* and *Haplochromis phytophagus*), *O. niloticus*, *P. aethiopicus* and *Clarias* sp. fish species were present in all the years considered. The fish species, including *Enteromius paludinosus*, *Enteromius kerstenii* and *Enteromius apleurogramma*, were only reported in 2005, whereas *C. zillii* was only in 1981 (Table 3). Four recorded fish species are critically endangered, including *O. esculentus*, *Haplochromis martini*, *O. variabilis* and *Xenoclarias* sp. (Table 3).

3.3 | Monthly and Seasonal Variations in Fish Composition

The fish species recorded between February 2020 and February 2021 showed that March 2020 had a high number of individuals (30,577), whereas January 2021 had the lowest number of individuals (12,770) (Table 4). Eight months (from February 2020 to September 2020 and February 2021) had 14 taxa, whereas a lower number of taxa were recorded in January 2021 (12).

The summary of diversity indices (Table 5) showed that Shannon diversity (*H′*) had higher diversity in November 2020 (2.09), whereas April 2020 had a lower index (1.93). The Simpson diversity index ranged between 0.81 in April 2020 (lowest) and 0.84 (highest), recorded in 6 months. Likewise, dominance was high in April 2020 (0.19), whereas February 2020, March 2020, July 2020, August 2020, November 2020 and January 2021 had the lowest (0.16). In contrast, evenness was high in January 2021 (0.67), whereas April 2020 had the least evenness (0.49) (Table 5). Fisher's alpha diversity index was lower in January 2021 (1.27) and higher in September 2020 (1.44). The Berger–Parker index ranged between 0.21 and 0.34 in March 2020 and September 2020, respectively. Overall, the dry and wet seasons recorded the same

TABLE 3 | Comparison of fish species composition from 1981 to 2020 in Lake Kanyaboli.

Family	Fish species	Okemwa (1981)	Maithya (1998)	Aloo (2003)	Masai, Ojuok, and Ojwang (2005)	Present study	IUCN Red List status
Cichlidae	*Oreochromis esculentus*	+	+	+	+	+	CE
	Pseudocranilabrus multicolor victoriae	*	–	+	+	+	DD
	Haplochromis maxillaris	*	+	+	+	+	V
	Astatoreochromis alluaudi	*	+	+	+	+	LC
	Haplochromis (Astatotilapia) nubilus	*	–	+	+	+	V
	Astatotilapia sp. bigeye	*	–	+	–	+	–
	Haplochromis phytophagus	*	+	+	+	+	DD
	Haplochromis martini	*	+	–	–	–	CE
	Oreochromis variabilis	+	–	+	–	+	CE
	Oreochromis niloticus	+	+	+	+	+	NE
	Oreochromis leucostictus	+	–	+	–	+	LC
	Coptodon zillii	+	+	–	–	–	LC
Protopteridae	*Protopterus aethiopicus*	+	+	+	+	+	LC
Clariidae	*Clarias* sp.	+	+	+	+	+	LC
	Xenoclarias sp.	+	–	+	–	–	CE
Schilbeidae	*Schilbe* sp.	–	–	+	–	–	LC
Bagridae	*Bagrus* sp.	–	–	–	–	+	LC
Anabantidae	*Ctenopoma muriei*	–	–	–	+	+	LC
Poeciliidae	*Aplocheilichthys pumilus*	–	+	+	–	–	LC
Cyprinidae	*Enteromius paludinosus*	–	–	–	–	*	CE
	Enteromius kerstenii	–	–	–	+	*	NE
	Enteromius apleurogramma	–	–	–	+	*	NE

Note: '+' means recorded during the study year; '–' means not recorded during the study year. '*' **means** several haprochromines and *Enteromius* sp. (formerly Barbus, FishBase (Froese and Pauly 2018) lumped together.
Abbreviations: CE = critically endangered; DD = data deficient; LC = least concern; NE = not evaluated; V = vulnerable.

TABLE 4 | Species-wise monthly fish abundance caught in Lake Kanyaboli from February 2020 to February 2021.

Family	Fish species	Feb 2020	Mar 2020	Apr 2020	Jun 2020	Jul 2020	Aug 2020	Sep 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021	Feb 2021
Cichlidae	*Astatotilapia sp. bigeye*	724	1224	836	612	612	2180	836	1732	1284	1508	1060	948
	Pseudocranilabrus multicolor victoriae	109	137	53	22	24	17	71	33	42	60	112	98
	Haplochromis phytophagus	4192	6483	8509	5489	3565	5920	4778	4527	3542	5151	4158	4473
	Haplochromis maxillaris	1948	6243	3324	2532	1894	2271	1370	1824	924	1432	1455	1516
	Astatoreochromis alluaudi	4558	3148	3294	3102	1684	1324	985	1093	739	969	908	839
	Haplochromis (Astatotilapia) nubilus	631	616	531	554	462	662	631	631	569	708	623	689
	Oreochromis esculentus	5983	6027	4795	4889	4204	3996	1925	2818	1486	1724	1447	2148
	Oreochromis variabilis	56	112	32	41	55	30	0	13	66	0	28	64
	Oreochromis niloticus	3526	4208	3067	2331	1679	2498	1864	2231	2634	2589	2468	2740
	Oreochromis leucostictus	405	689	284	244	325	696	255	260	213	509	505	429
Protopteridae	*Protopterus aethiopicus*	693	861	924	553	616	427	413	119	616	567	490	182
Clariidae	*Clarias* sp.	1771	770	616	693	693	693	770	154	616	616	770	539
Anabantidae	*Ctenopoma muriei*	21	24	31	22	63	35	56	21	0	0	0	14
Cyprinidae	*Enteromius* sp.	77	35	35	70	84	140	70	91	35	70	56	84

TABLE 5 | Temporal changes in diversity indices and the number of fish taxa in Lake Kanyaboli from February 2020 to February 2021.

	Feb 2020	Mar 2020	Apr 2020	Jun 2020	Jul 2020	Aug 2020	Sep 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021	Feb 2021
Number of taxa	14	14	14	14	14	14	14	13	13	13	12	14
Number of individuals	24,694	30,577	26,331	21,154	15,960	20,889	14,052	15,534	13,995	15,969	12,770	14,763
Dominance index	0.16	0.16	0.19	0.17	0.16	0.16	0.18	0.17	0.16	0.17	0.16	0.17
Simpson diversity index	0.84	0.84	0.81	0.83	0.84	0.84	0.82	0.83	0.84	0.83	0.84	0.83
Shannon diversity index	2.05	2.03	1.93	1.97	2.06	2.05	2.05	1.96	2.09	2.07	2.08	2.04
Evenness index	0.56	0.54	0.49	0.51	0.56	0.56	0.56	0.55	0.62	0.61	0.66	0.55
Fisher's alpha index	1.44	1.40	1.43	1.46	1.51	1.46	1.54	1.40	1.41	1.39	1.31	1.53
Berger–Parker index	0.24	0.21	0.32	0.26	0.26	0.28	0.34	0.29	0.30	0.32	0.28	0.30

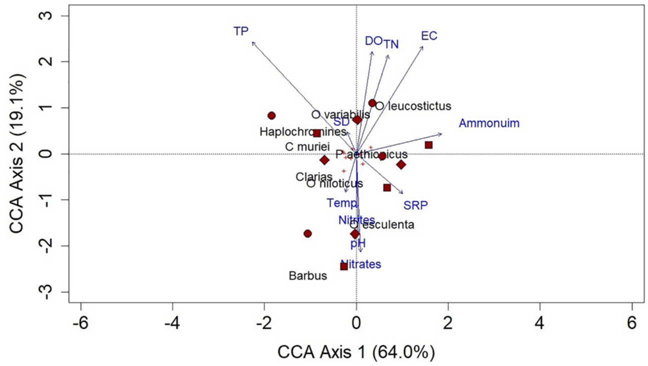

FIGURE 2 | Canonical correspondence analysis of the relationship between fish abundance and physico-chemical variables in Lake Kanyaboli from February 2020 to February 2021. DO = dissolved oxygen, TP = total phosphorous, NO_3^- = nitrate, NO_2^- = nitrite and SRP = soluble reactive phosphorus.

number of species (14). However, all diversity indices (Simpson diversity index, evenness indices, Fisher-alpha index and Berger–Parker index) were high in the dry season except for dominance and Shannon diversity index (Table 5).

A total of 226,686 individuals belonging to 15 taxa (including *Bagrus* sp.) were recorded in the lake during the year-long study (February 2020 to February 2021). Interestingly, only one individual of *Bagrus* sp. was recorded throughout the study period and hence not included in the summary tables for abundance (Table 5) and catch (biomass) (Table 7). Family Cichlidae had more species (10), whereas Protopteridae and Anabantidae had one species each. *H. phytophagus* was abundant in the samples (26.31%), whereas *Ctenopoma muriei* contributed the least number of individuals (0.13%). Overall, more fish samples were recorded during the wet season (122,275 ± 10,186) compared to the dry season (104,410 ± 8211) (Table 6). However, *Clarias* sp., *Enteromius* sp., *C. muriei*, *O. leucostictus* and two *Haplochromis* spp. (*H.* (*Astatotilapia*) *nubilus* and *P. multicolor victoriae*) were dominant during the dry season, whereas the rest of the fish species (*O. esculentus*, *O. variabilis*, *O. niloticus*, *Astatotilapia* sp. 'bigeye', *A. alluaudi*, *H. maxillaris*, *H. phytophagus* and *P. aethiopicus*) were dominant during the wet season (Table 6). Nevertheless, all 14 fish species (excluding *Bagrus* sp.) were recorded during dry and wet seasons. Kruskal–Wallis test and *t*-test showed that fish abundance did not vary significantly between months ($H_{(11)} = 2.80$, $p = 0.993$) and seasons ($t_{(136)} = -1.11$, $p = 0.276$), respectively. Likewise, ANOSIM showed no significant differences between wet and dry seasons (*R*-statistic = 0.06, $p = 0.2518$). PERMANOVA also did not show significant differences among the seasons ($F = 1.492$, $p = 0.2176$).

3.4 | Relationships Between Water Quality and Fish Abundance

CCA based on Axis 1, which accounted for 64.00%, and Axis 2, accounting for 19.10%, showed associations among water quality variables and fish species based on abundance data (Figure 2). The results showed that *C. muriei*, *O. variabilis* and haplochromines were positively correlated with SD and high concentrations of TP, whereas *O. leucostictus* were positively

TABLE 6 | Relative abundance (percentage, %) of each fish species to the total annual abundance of all fishes caught in Lake Kanyaboli from February 2020 to February 2021.

Family	Fish species	Dry	Wet	Contribution (%)
Cichlidae	*Astatotilapia sp. bigeye*	6360 ± 571	7196 ± 416	5.99
	Pseudocranilabrus multicolor victoriae	431 ± 47	314 ± 34	0.14
	Haplochromis phytophagus	27,086 ± 979	33,701 ± 1723	26.87
	Haplochromis maxillaris	10,454 ± 351	16,279 ± 1923	11.82
	Astatoreochromis alluaudi	10,298 ± 1427	12,345 ± 1238	10.01
	Haplochromis (Astatotilapia) nubilus	3698 ± 80	3609 ± 64	3.23
	Oreochromis esculentus	19,703 ± 1741	21,739 ± 1875	18.32
	Oreochromis variabilis	233 ± 24	264 ± 43	0.21
	Oreochromis niloticus	14,775 ± 661	17,060 ± 729	14.07
	Oreochromis leucostictus	2615 ± 154	2199 ± 190	2.13
Protopteridae	*Protopterus aethiopicus*	2821 ± 179	3640 ± 286	2.86
Clariidae	*Clarias* sp.	5236 ± 448	3465 ± 216	3.85
Anabantidae	*Ctenopoma muriei*	189 ± 25	98 ± 13	0.13
Cyprinidae	*Enteromius* sp.	511 ± 29	366 ± 24	0.37
Total		104,410	122,275	**100.00**

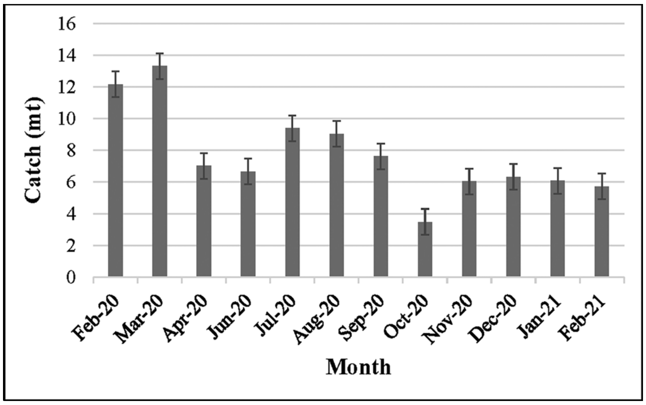

FIGURE 3 | Monthly fish landings (mt) in Lake Kanyaboli from February 2020 to February 2021.

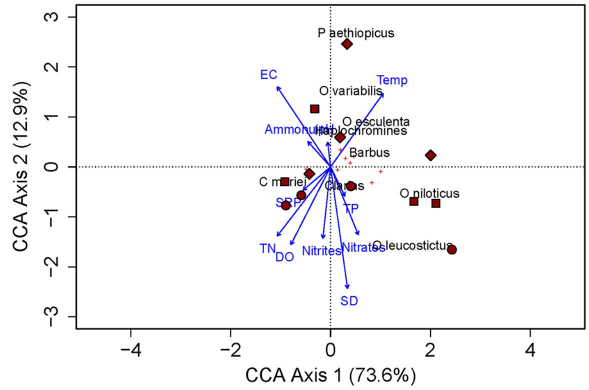

FIGURE 4 | Canonical correspondence analysis of the relationship between fish catch and water physico-chemical variables in Lake Kanyaboli from February 2020 to February 2021. DO = dissolved oxygen, TP = total phosphorous, NO_3^- = nitrate, NO_2^- = nitrite and SRP = soluble reactive phosphorus.

correlated with TN, DO, EC and NH_4^+. On the other hand, *Enteromius* sp. (*Barbus* sp.), *Clarias* sp. and *O. niloticus* were negatively correlated with temperature.

3.5 | Monthly and Seasonal Variations in Fish Catch

The summary of species-wise fish catch/biomass in 2020 between February 2020 and February 2021 indicated that *O. niloticus* contributed more towards total catch (29.85%), whereas *C. muriei* contributed the least (<1%) (Table 7). The pulled group data revealed that the main species in catches were tilapia (50%) followed by *Clarias* sp. (22.45%), *P. aethiopicus* (19.86%) and Haplochromines (7%) (Table 7), but other species comprising *C. muriei* and *Enteromius* sp. (<1%) were also present.

Analysis of monthly fish catch between February 2020 and February 2021 showed that March 2020 had higher catch (13.41 mt), whereas October 2020 had lower fish catch (3.49 mt) (Figure 3). Although fish catch was relatively higher in the dry season (49.82 ± 3.59 mt) than wet season (42.92 ± 2.37 mt), Kruskal–Wallis showed no significant differences in inter-monthly fish catches ($H_{(11)} = 2.17$, $p = 0.998$). Similarly, one-way ANOSIM confirmed no significant seasonal differences (R-statistic = 0.04, $p = 0.259$). Likewise, PERMANOVA did not yield significant seasonal differences ($F = 0.50$, $p = 0.642$).

3.6 | Relationship Between Water Quality and Fish Catch

The CCA analysis of the relationships between water quality variables and fish catches from February 2020 to February 2021 showed that Axis 1 accounted for 73.60% of the total variation, whereas Axis 2 accounted for 12.90% (Figure 4). The CCA indicated that *O. variabilis*, *O. esculentus*, *P. aethiopicus*, *O. niloticus*, *Enteromius* sp. (*Barbus* sp.) and haplochromines were positively correlated with water temperature, whereas *C. muriei* was negatively correlated with TN, SRP and NO_2^-. On the other hand, *O. niloticus*, *O. leucostictus* and *Clarias* sp. were correlated with SD, TP and NO_3^-.

4 | Discussion

The present study investigated ichthyofauna composition and abundance in Lake Kanyaboli, a small and shallow Afrotropical lake. It also quantified the importance of environmental conditions in influencing fish abundance and catch. Declining annual fish composition and catch (biomass) from 1981 to 2020 were observed. The 1-year data (February 2020 to February 2021) showed no significant seasonality in fish assemblage. In addition, the family Cichlidae dominated fish species diversity and abundance, whereas Protopteridae, Clariidae, Anabantidae and Cyprinidae had lower species diversity and abundance for the 2020–2021 survey. The variations over the years confirmed the hypotheses that fish diversity, composition and catch vary over time, and environmental variables influence these parameters. This is consistent with previous studies on tropical lakes (Tejerina-Garro, Fortin, and Rodrı´guez 1998.; Amarasinghe and Welcomme 2002; Cheng et al. 2010). In addition, *O. niloticus*, an introduced species, has established itself in the lake, whereas native species, such as *O. esculentus* and *O. variabilis*, are proportionally reducing in the catches.

4.1 | Historical Trends in Fish Composition and Landings

The present study revealed that species considered virtually extinct in Lake Victoria, such as *O. esculentus* and *O. variabilis*, occur in relatively high numbers in Lake Kanyaboli. Yet, studies on fish abundance, diversity and distribution, as well as the anthropogenic effects on aquatic resources, have mainly focused on Lake Victoria (Okaronon 1994; Bundy and Pitcher 1995; Kitchell et al. 1997; Naigaga et al. 2011; Witte et al. 2013; Outa and Yongo 2017). Thus, ongoing fishing, Yala Wetland conversion and agricultural intensification threaten the lake. Furthermore, this study showed that *O. esculentus* occurs in substantial quantities compared to *O. variabilis*, despite both being ‘critically endangered’ (Table 3) (IUCN 2019). However, its contribution to the total catch is reducing. The findings possibly indicate replication of competition from *O. niloticus* that they (*O. esculentus* and *O. variabilis*) faced in Lake Victoria (Njiru, Mkumbo, and van der

TABLE 7 | Percentage contribution of each fish species to the total annual biomass from Lake Kanyaboli between February 2020 and February 2021.

Family	Fish species	Biomass (mt)	Percentage Contribution (%)
Cichlidae	*Astatotilapia sp. bigeye*	0.46	0.49
	Pseudocranilabrus multicolor victoriae	0.03	0.03
	Haplochromis phytophagus	3.19	3.44
	Haplochromis maxillaris	1.66	1.80
	Astatoreochromis alluaudi	1.13	1.22
	Haplochromis (Astatotilapia) nubilus	0.25	0.27
	Oreochromis esculentus	17.75	19.14
	Oreochromis variabilis	0.13	0.14
	Oreochromis niloticus	27.68	29.85
	Oreochromis leucostictus	1.17	1.27
Protopteridae	*Protopterus aethiopicus*	18.42	19.86
Clariidae	*Clarias* sp.	20.82	22.45
Anabantidae	*Ctenopoma muriei*	0.01	0.01
Cyprinidae	*Enteromius* sp.	0.03	0.03
Total		**92.74**	**100.00**

Knaap 2010). Likewise, *O. niloticus* poses a threat to the existence of native tilapiine species through potential hybridisation with *O. esculentus* and *O. leucostictus* (Nyingi and Agnèse 2007; Angienda et al. 2011; Ndiwa, Nyingi, and Agnese 2014). On the other hand, *Schilbe* sp. and *C. muriei* are categorised as 'least concern' despite being scarce, possibly signalling overexploitation (Table 3).

The fish landings from Lake Kanyaboli decreased over time. At the same time, the contribution of tilapia species to total fish catch has reduced by over 40% since the 1980s (Okemwa 1981). This probably indicates reducing biomass due to increasing fishing pressure and the use of illegal fishing gear (Abila and Othina 2005). Fishing crafts in the lake increased from 99 in 2018 (Kimani, Okemwa, and Aura 2018) to 148 in 2020 (personal observation), corresponding to 188 fishers in 2018 to 390 in 2020. The declining trend in fish catches in Lake Kanyaboli is consistent with other small lakes in developing countries, such as Lake Chapala (Moncayo-Estrada et al. 2012), Kyoga Lake system (Ogutu-Ohwayo et al. 2013) and Lake Naivasha (Yongo et al. 2021). This is linked to the increasing fishing activity in lakes and reservoirs in resource-poor communities because they lack alternative livelihoods and rely on agriculture or fisheries (Balirwa et al., 2003; Ogutu-Ohwayo et al. 2013). Fishers at Lake Kanyaboli use gillnets with smaller mesh sizes (1/2″), either to catch haplochromines or as a way to increase their catch. However, this practice likely leads to growth overfishing of larger tilapia species, concurring with results from Yongo et al. (2021) in Lake Victoria and Ahmed, Hambrey, and Rahman (2001) in India's Kaptai reservoir. In addition, the practice poses a threat of recruitment overfishing in larger tilapia species like *O. niloticus* as noted by Abobi et al. (2019) in Ghana's Tono reservoir.

4.2 | Fish Assemblage Variations From February 2020 to February 2021

Haplochromines were more diverse, followed by tilapia species in catch composition disintegrated data. Although fish abundance and catch did not show seasonality, the wet season recorded higher abundance, whereas the dry season had higher fish biomass. Our study found that the high abundance of fish during the wet season was likely linked to the short-lived increased food supply at the beginning and end of the wet season. Fish catch reportedly peaks during flood months (wet season) due to increased productivity and availability of more habitat (Madsen and Shine 2000; Soyinka, Kuton, and Ayo-Olalusi 2010; Jin et al. 2019). Rainfall is associated with nutrient loading into the lake, resulting in high primary production at the base of the food web, favouring higher trophic levels (Mulimbwa, Raeymaekers, and Sarvala 2014). However, relatively high biomass in the dry season could be linked to harvesting heavier fish that encountered more food due to the increased photic zone in the dry season. The lake has previously recorded high plankton production in the dry season (Kondowe et al. 2022b).

Nevertheless, the lake faces threats like nutrient input from the catchment, which can result in eutrophication and the proliferation of toxic cyanobacteria (Yongo et al. 2021). According to Sitoki, Kurmayer, and Rott (2012), the replacement of *Aulacoseira* and diatoms by blue–green algae caused the decline in *O. esculentus* and *O. variabilis* in Lake Victoria. Additionally, Lake Kanyaboli is threatened by the open-access regime despite the existence of the Beach Management Unit (BMU). The reliance on BMU to perform all management activities weakens the management system because the committees are dominated by interested parties (e.g., fishers and fish traders). Similar observations, coupled with the corruption of fisheries officers, have led to the overexploitation of some species in Lake Victoria (Njiru et al. 2008). Operating at open access also disadvantages fish conservation, leading to the collapse of fish stocks and dissipation of economic rent (Kasulo and Perrings 2006; Arthur 2020).

4.3 | Relationship Between Water Physico-Chemical and Fish Assemblage

Fish abundance and catch (biomass) showed correlation with physico-chemical variables, such as TP, TN, DO, EC, NH_4^+, NO_3^-, EC and SD (Figures 2 and 4). Previous studies have shown that fish diversity, biomass and communities are structured differently among various water bodies, with different factors influencing their structure (Rahel 1984; Tejerina-Garro, Fortin, and Rodrı´guez 1998.; Amarasinghe and Welcomme 2002; Petry, Bayley, and Markle 2003; Cheng et al. 2010).

The positive correlation between nutrients and fish assemblage in Lake Kanyaboli may be due to organic effluents supporting primary production to sustain the fishery (Cheng et al. 2010). However, eutrophication negatively impacts fish communities by causing algal blooms, which deplete DO when algal matter dies en masse (Öğlü et al. 2020). The positive relationship between fish biomass and temperature means that feeding increases during increasing temperatures, leading to improved growth and biomass as well as reproduction and development (Fukushima et al. 1999; Roubeix et al. 2017). Favourable temperatures also promote phytoplankton growth, creating a complex food web (Woodworth-Jefcoats et al. 2013). These dynamics highlight the importance of monitoring wetlands, which support up to 20% of the world's species despite accounting for 1% of the Earth's surface (Dugan 1993).

4.4 | Management and Conservation Implication of Fish Production and Composition Study

The fish species of Lake Kanyaboli before the reclamation of part of Yala Wetland are not well documented because no detailed study of the lake's ichthyofauna exists. As a result, there are concerns about the unnoticed disappearance of fish species from the lake (Aloo 2003). Nonetheless, comparing the 2020 species diversity survey with previous studies showed that *C. zillii*, once part of the 1981 catch (Okemwa 1981), is now non-existent. Furthermore, fish species, such as *O. variabilis*, *Enteromius* sp., *Xenoclarias* sp. and *C. muriei*, that were once abundant are hardly encountered in the catches. A single individual of *Bagrus* sp. was recorded during the 2020 survey, but this species was not previously reported in the lake. The introduction of *Bagrus sp.* to Lake Kanyaboli may have occurred through the feeder canal that directly connects the lake and Yala River, where it has been reported by Masese et al. (2020). Besides, *Bagrus* sp. is migratory (Masese et al. 2020), further supporting our occurrence through the introduction hypothesis due to the interconnectedness between the river (where it occurs) and the lake. Previous studies have documented the effects of anthropogenic activities in various lake drainage basins on the existence of fish biodiversity both in Kenya (Aloo 2003; Kiage and Liu 2009; Yongo et al. 2021), regional (Jamu et al. 2011; Amoutchi et al. 2021) and elsewhere (Moiseenko et al. 2009; Debjit, Anilava, and Subrata 2010; Sharip and Jusoh 2010; Wang et al. 2015).

Lake Kanyaboli should be safeguarded from introductions considering the substantial biomass of *O. esculentus* and *O. variabilis* that once formed part of the catch in Lake Victoria (Njiru, Mkumbo, and van der Knaap 2010). In addition there are six haplochromine species (*H. maxillaris*, *H.* (*Astatotilapia*) *nubilus*, *Astatotilapia* sp. 'big eye', *P. multicolor victoriae*, *H. phytophagus* and *A. alluaudi*) (. The invasion of alien fish species has already affected the Lake Victoria basin. For example, the Nile Perch (*L. niloticus*) has impacted Lake Sare in Yala Wetland, and various cyprinids that have established themselves in the catchment threaten Lake Kanyaboli.

5 | Conclusions

The findings of this study have indicated the importance of long-term evaluation of species composition and biomass of small tropical lakes and reservoirs. The study has demonstrated the ecological significance of Lake Kanyaboli in conserving threatened fish species that once formed a significant part of Lake Victoria's fish populations and fishery. However, the lake's biodiversity is threatened by unregulated fishing, anthropogenic activities in the catchment area and potential accidental introductions that may outcompete native species. Similarly, the lake's fish stocks are likely experiencing overexploitation, as suggested by declining catches and the disappearance of some species against the rising number of fishers and fishing crafts. There are perhaps multiple stressors acting on the fishery of Lake Kanyaboli, but a lack of strong management structures, such as an effective BMU to enforce fishing rules and regulations, exacerbates the problem. Therefore, there is a need for improved enforcement to curb illegal fishing gears and regulate the number of fishers to ease fishing pressure. Furthermore, monitoring fish biodiversity in the lake and its catchment (Yala River and Yala Wetland) is vital to ensure timely remedies.

Author Contributions

Benjamin N. Kondowe: Conceptualisation, investigation; methodology, original draft preparation, data curation, formal analysis. **Frank O. Masese**: Funding acquisition, resources, conceptualisation, supervision, visualisation, validation, writing–review and editing. **Phillip O. Raburu** and **Wales Singini**: Funding acquisition, supervision, writing–review and editing. **Augustine Sitati** and **Riziki Jacques Walumona**: Investigation; formal analysis, writing–review and editing.

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Conflicts of interest

The authors declare no conflicts of interest.

Data Availability Statement

Data is available from the corresponding author on request.

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