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Sustainability of Fish-Hydropower Dam Interaction: A Case Study of River Nyamugasani ecosystem, Albertine Graben

Bassa Samuel[1,] *, Henry Massa[2], Shaban Bogere[3], George Owour[3], Hebert Nakiyende[1], Joseph Nyaundi[4], Anthony Taabu-Munyaho[5], Erick Ochieng Ogello[6], John Stephen Balirwa[1], Winnie Nalukenge Nkalubo[1] and Albert Getabu[7]

[1]National Fisheries Resources Research Institute, NARO, Jinja, Uganda. [2]Geotropic Consult, Kampala, Uganda. [3]Nyamughasana II Hydropower Project, Uganda. [4]Kenya Marine Research Institute, Kisumu. [5]Lake Victoria Organization, East Africa. [6]Maseno University, Kenya. [7]Kisii University, Kenya.

*Corresponding author. bassasam2018@gmail.com

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Abstract. This study examined the River Nyamugasani ecosystem in western Uganda, evaluating fish diversity status before and after construction of a hydropower dam between 2015 - 2019 and 2021 - 2022. Using both electro fisher and minnow traps as the main fishing gears at ten preselected sites within the hydropower project areas, the study sampled 1,866 fishes from twenty-four (24) species, including the endemic *Varicorhinus Ruwenzori*, Pellegrin 1909. Nyamu II PH areas registered higher diversity (Simpson index of 0.8862) potentially attributed by hydrological alterations from hydropower dams. The findings emphasize the need for hydropower management need to consider fish stock controls, restorations and conservation measures, especially for the endemic *Varicorhinus Ruwenzori* species.

Keywords: Anadromous fishes, Conservation, Endemism.

Introduction

Rivers and streams, though covering a small fraction of the Earth's land surfaces (Allan and Castillo, 2007; Naiman and Bilby, 1998) play vital role in providing natural resources, including fish and clean water. Despite their significance, human activities, especially the construction of hydropower dams, threaten the biodiversity of rivers. This study focused on the River Nyamugasani ecosystem in the Albertan Graben, exploring the structure and ecological functions of the rivers impacted by hydropower development. These rivers and streams drain a large amount of land surface water into seas and lakes. Touching all parts of the natural environment and nearly all aspects of human life culture, rivers act as integrators and centres of organization within the landscape. The roles of rivers in providing natural resources, such as fish and clean water, has been known, as are their roles in providing transportation, energy, diffusion of wastes, and recreation (Allan and Castillo, 2007; Naiman and Bilby, 1998). However, what is not well known is how such ecosystems are structured and how they function as ecological systems. People living along the riparian shores of the rivers have exploited the natural benefits provided by the running waters without understanding how these ecosystems maintain their vitality (Naiman and Bibly, 1998; Diego *et al.,* 2010).

The Nyamugasani riverine ecosystem is a resource to the riparian people for income and food. It may be considered critical to fish species for reproduction, feeding, and shelter. The critical habitats include rocky areas, sheltered bays, shallow areas, wetlands, and inflow streams into the river. It is used off-stream (withdrawn e.g., for agriculture or domestic use), in-stream (e.g. hydropower, fisheries, environment), or on-stream (e.g. transport, tourism). The fishery that is a major resource from the ecosystem has been affected by changes in the watershed (Burnside, 2006; Bassa *et al.,* 2019). A change in the ecosystem has been due to the drivers such as anthropogenic activities and the hydropower developments along the river. The parameters that have affected the fisheries resource are physical and chemical variations in the ecosystem. Habitat variables such as water temperature, turbidity, substrate, plankton community, pH, conductivity, depth, altitude and nutrient levels influence fish composition (Busulwa *et al.,* 1998; Burnside, 2006; Albinus *et al.,* 2008; Sitoki *et al.,* 2010; Li *et al.,* 2012; Bassa *et al.,* 2019). Studies from lakes and rivers indicate that activities such as land use modification greatly accelerate changes in aquatic ecosystems. The recent expansion and accelerating rate of deforestation have caused widespread concern, particularly in the tropics, where the impacts of deforestation and forest degradation on aquatic systems remain largely unknown (Chapman and Chapman, 2003; Bassa *et al.,* 2019).

In addition to that, fish is one of the commodities ranked as the second income earner in Uganda (Bassa, 2021). Uganda's per capita fish consumption is estimated at 10 kilograms per person per year. FAO recommends 25 kilograms per person per year. Comparison between the world consumption and in the country shows that Uganda consumption is low. Uganda's initiative is to developments both big and small hydropower dams both in big and small rivers is too high. That's geared at as a source of income to the country and also, industrial development and household use. This has ended up to most of the small rivers both in western and Eastern Uganda having these hydropower dams constructed. River Nyamugasani (Kasese district) is one of them that has been targeted. Rivers have rich biodiversity including fisheries which contribute to people's incomes and improved nutrition through access to cheap animal protein. However, human activities threaten the rich biodiversity by construction of hydropower dams has been proven to affect the state of biodiversity. Study focused Nyamugasani ecosystems and its fish diversity status both before & after hydropower dams' constructions. Hence this work was mainly to establish status of fish diversity, abundance. Habitat type for a period of four years (2015-2019 & 2021 to 2022). Targeting both wet and dry periods in preselected 10 sites of the hydropower project areas (Figures 1 & 2; Table 1). Internationally, the existence of regions with limited human impact is sporadic. The majority of aquatic ecosystems in the world have been disturbed or altered in some way and thus have subsequently lost their pristine characteristics (Chapman and Chapman, 2003; Meybeck, 2003; Rockstrom *et al.,* 2014; Bassa *et al.,* 2019). River Nyamugasani is one of the systems that has been facing such problems that need attention for management purposes. Since in addition to the hydropower production is also a source of food and income (Plate 2).

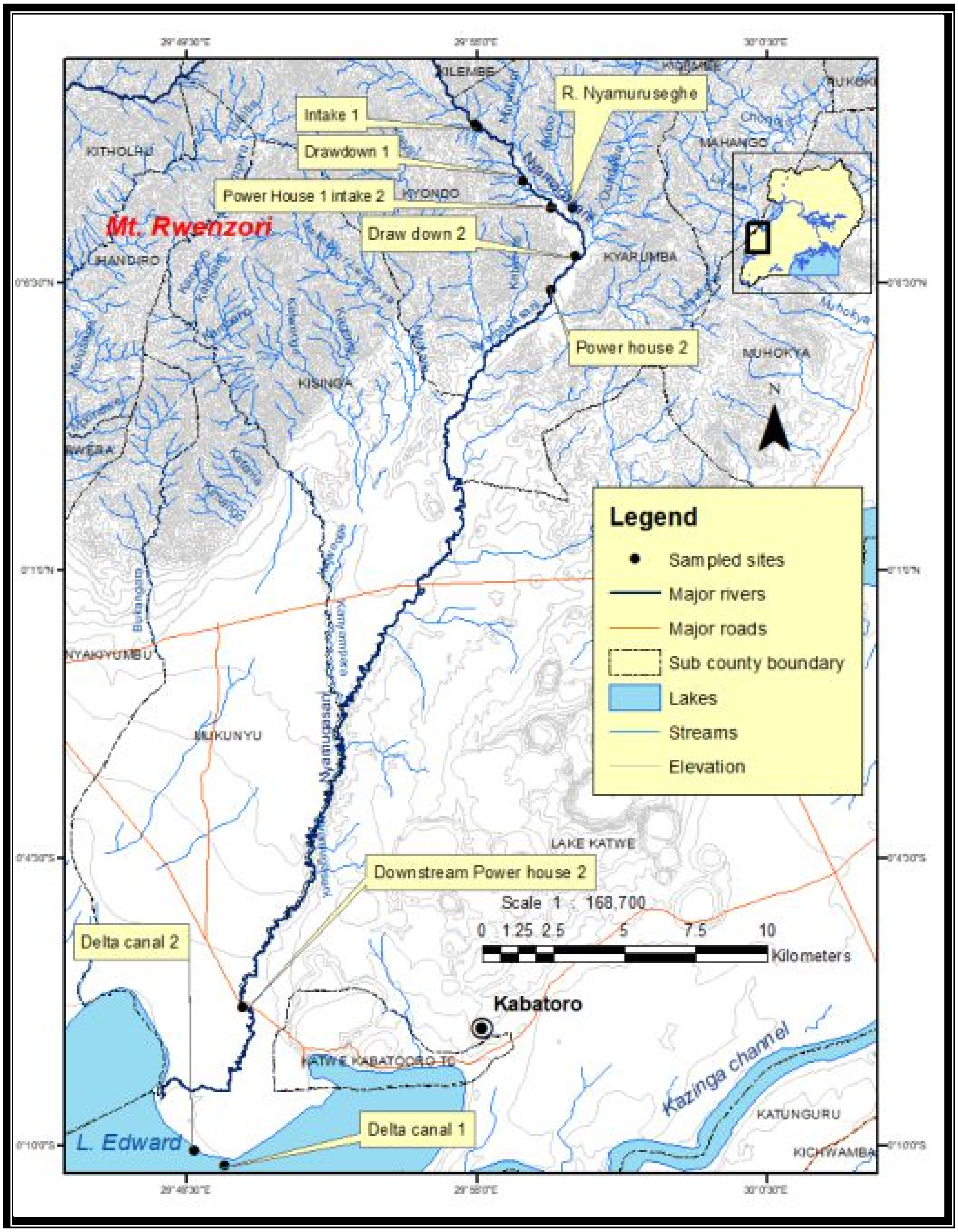


Figure 1. Map location of sampled sites on Rivers Nyamugasani and Namurusenyi, hydro power project area

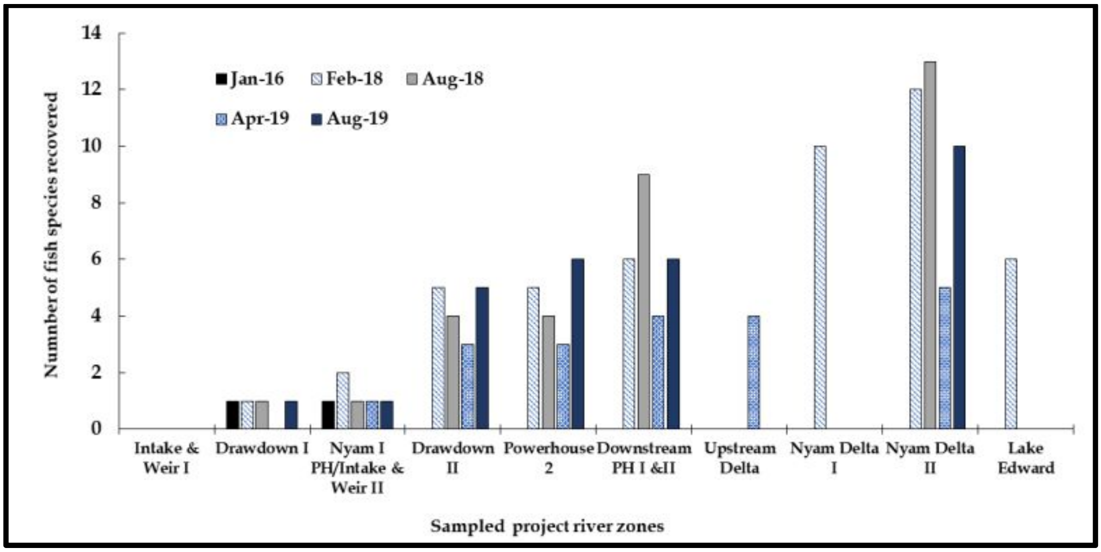


Figure 2. Fish species recovery from sampling sites of Nyamagasani 1 and Nyamagasani 2 during the baseline (January 2016) and the 1st monitoring (February 2018) and 2nd monitoring (August 2018) and 3rd monitoring (April 2019) and 4th monitoring (August 2019).

Material and Methods

Fish sampling studies were undertaken on the two hydropower dams , using the electro fisher (204-250 volts) and minnow trap methods (Twongo ,2018; Massa *et al.,* 2022) In each site and electro fisher was set for 45 minutes at the 15 minute intervals, ensuring 5 minute rest between each session to maintain system efficiency . Concurrently, minnow traps were set for 12 hours in the evenings at 6.00 pm and retrieved in the morning hours at 8.00 am at the ten preselected sites including Nyamugasani 1 (N1) Weir, Drawdown, Powerhouse, Tailrace, Nyamugasani2 (N2) Weir, Fore bay, Spillway, tailrace and Drawdown (confluence of Nyamuruseghe and Nyamugasani rivers), and River Nyamuruseghe) (Figure 1, Table 1, Plate 1).

Table 1. Sites that were sampled

Sites	Latitude (DD)	Longitude (DD)	Time of sampling	Remarks
N1_Weir	0.160400	29.913900	1300	
N1_Drawdown	0.149000	29.928100	1400	
N1_Powerhouse	0.132200	29.939300	1600	
N1_Tailrace	0.132310	29.940343	1615	Above fish passage
N2_Weir	0.132100	29.939000	1630	Above fish passage
N2_Forebay	0.121534	29.944404	945	Below fish passage
N2_Spillway	0.125300	29.946800	1020	
R. Nyamuruseghe	0.123300	29.949800	1114	
N2_Tailrace	0.104800	29.941700	1219	
N2_Drawdown	0.106200	29.943100	1258	Nyamuruseghe-Nyamugasani Confluence

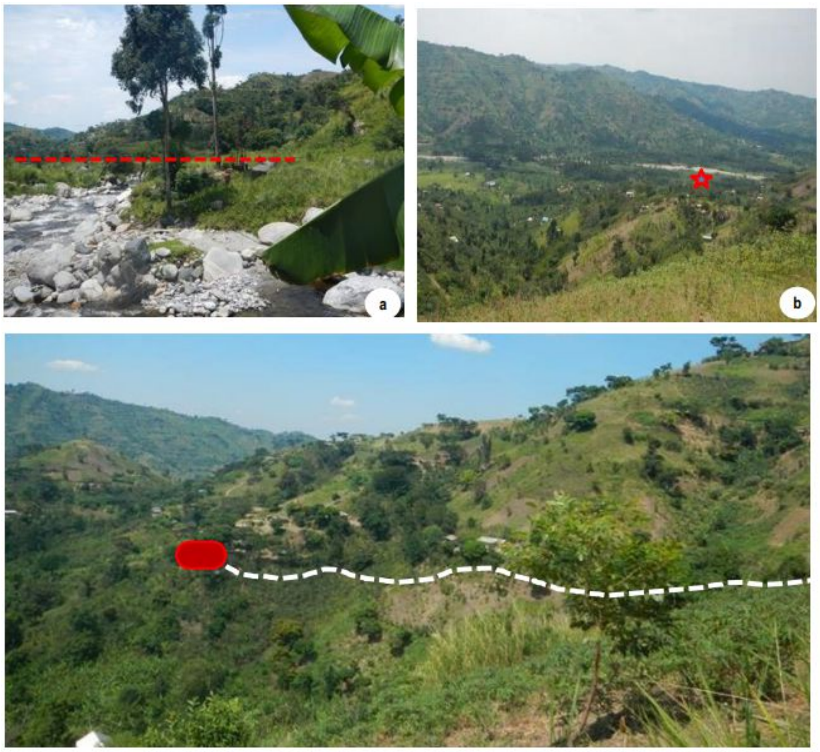


Plate 1. (a) Location of Nyamughasana-2 HPP intake weir (red line in middle ground was constructed). (b) Location where construction was done for the power house area (red star), seen from fore bay on right side of Nyamughasana River in a relatively flat area. (c) Proposed location of fore bay (red box) and approximate proposed location of canal (dotted line).

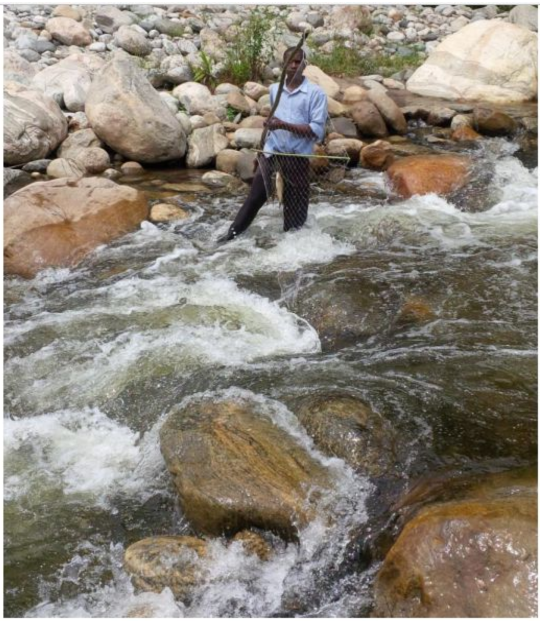


Plate 2. Local fishing gear at River Nyamugasani in Kasese, district.

The Electro fisher was preferred to other fishing gears because of the shorter fishing time, its efficiency in lotic environments and the ease of operation reducing the risk of gear loss in fast-running waters. Fish samples were immediately placed in basins for on-site species identification, with subsequent analysis conducted in the laboratory.

Fish samples were immediately placed in basins for on-site species identification, with subsequent analysis conducted in the laboratory. Fish samples that were preserved in 5% formalin for gut analysis and gonadal studies, with equipment including dissection kit, buckets, preservatives, labelling paper. The preserved fish samples were transported to the laboratory for identification using taxonomic procedures (Greenwood, 1966; Witte and Densen, 1995). Measurements included total lengths (TL), fork lengths (FL) and standard lengths (SL) using measuring board (up to 100cm), weight (g) using a digital scale of precision 0.01gram weight, ingested food, gut fullness and spawning status. Fish taxonomy in the laboratory involved comparing current and previous works (2018, 2019 and 2021). Spread sheet tools facilitated data analysis, calculating biodiversity indices such as species richness (S), Shannon-Weiner index of diversity (H'); Species evenness (J); Simpson index (D).(Flower & Cohen 1990; Krebs, 1999); Shannon-Wiener's diversity index formula;

$H = -\sum_{i=I}^{S} p_i \ln(p_i)$; Evenness index;

$$E_H = {}^{H}/_{\ln S}$$;

Simpson index of diversity; Simpson index of diversity = 1-D;

$$D = \sum_{i=I}^{s} Pi^2$$

Pi- the proportion of individuals calculated as the abundance of individual species divided by the total number of individuals in the community sampled. ln- the natural log; Σ - the sum of all calculation; S - the number of species; H – the Shannon index of diversity; D - Simpson index. Fulton's condition factor (kc)—or the coefficient of condition factor—was estimated as kc = 100*W/L3, where W is the total weight of the fish and L is its total length (Fulton, 1911). Fulton's factor is used as an approximate value, even if the allometric growth is more appropriate.

Results

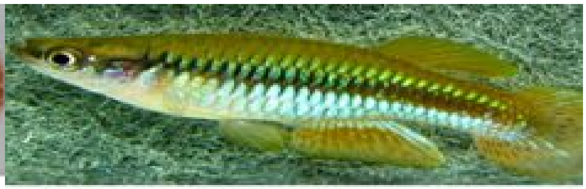
Fish species diversity in the small hydro power dam areas (diversity before and after)

A total of 1,705 fish species were sampled before commissioning the hydropower as compared to One hundred and twelve (112) in the respective years of (2015-2019) and (2021 and 2022). During the same period 29 fish species were recovered same period of time as compared to the later with only 10 species (Tables 2 and 3). Most of the fishes encountered in sampled sites were of a conservation status belonging to IUCN least concerned (LC) apart from *Varicorhinus Ruwenzori (Labeobarbus Ruwenzori)* Pellegrin, 1909 which is endemic (restricted to two small rivers flowing from the Ruwenzori mountains); (IUCN Red List, (Vreven,2006) (Plate 3 A-F).

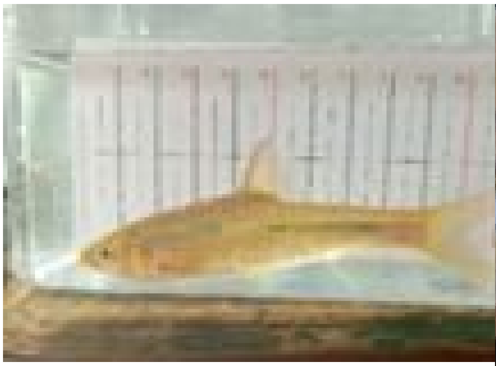
A.Baebusalluadi Photo credit: Twongo T.K.

B.Varicorhinus Rwenzori Photo credit: Twongo T.K.

C.Aplocheilichtys pumilus Photo credit Bassa S.



D.Lucustricola pumilus Phot credit Twongo T. K.



E.Enteromius jacksonii Photo credit Bassa S.

F.Clarias liocephalus Photo credit Bassa S.

Plate 3. Some of the fish species (A-F) sampled from River Nyamugasani

Relative abundance, Size structure, fecundity and food and feeding of the fish species

The study recorded fish species recorded in the areas of Nyamugasani hydro power dam the size structure of the fish species before commission ranged as follows;; *Labeobarbus Ruwenzori; (*8.6±4.2 to 11.5±2.5) *Amphilius jacksonii; (*8.7±3.8 to 9.4±1.8); *Clarias carsonii; (*13.1±4.1 to 14.4±4.7); *Clarias gariepinus (*19.3±7.5 to 13.1±3.5); *Labeobarbus altianalis, (*4.9±0.7)*; Barbus jacksonii (*19.1±1.5 to 9.2-19.0); *Barbus kersternii (*16.3±4.5) in cm TL as compared to period after commission as *Varicorhinus Ruwenzori (*5.3-8.9 to 3.5-3.5); *Amphilius jacksonii (*2.9-12.3 to 11-11.5); *Clarias carsonii (*15-15) *Labeobarbus altianalis (*19.5-2.1 to 30-20.6) and *Barbus kersternii (*5.7-9.4). In addition to that it also varied in terms of relative indices as observed in (Tables 2, 3 4, and 5 and figures 3, 4, and 5). The food and feeding varied based on the fish species and these were mainly; Insect remains, High plant materials, Chironomids and Chaoborids Ephemeropteran & Detritus; Ephemerocropterans; Insect remains; and algae. The food contents did not change much in the two period of samplings (Tables 4, 5, 6 and 7).

Table 2. Sites specific sampled during the fisheries biodiversity indices for Nyamugasani hydropower region before commissioning (2016-2019)

Family	Species	Nyam 1 DD	Nyam 1 PH / Nyam 2 Intake	Nyam 2 DD	Nyam 2 PH	Downstream PH 1&2	Upstream Delta1	Delta 2	Total
Protopteridae	*Protopterus aethipicus*							1	1
Mormyridae	*Pollymyrus nigricans*					1	5	3	9
	Marcusenius nigricans						273	2	275
Cyprinidae	*Labeobarbus kersternii*				17	18	2		37
	Labeobarbus altianalis			5	1	249	7	85	347
	Labeobarbus jacksonii			30	21	39		2	92
	Labeobarbusradiastus/pala					24			24
	Labeobarbus perince		2		2	10		10	24
	Barbus sp.				8	166	131		305
	Labeobarbus ruwenzorii	71	84	33	27	15	15		245
Bagridae	*Bagrus docmac*							1	1
Clariidae	*Clarias carsonii*			11	7				18
	Clarias gariepinus						14		14
	Clarias alluaudi				16	5			21
Amphiliidae	*Amphilius jacksonii*			18	14		3		35
Cyprinodontidae	*Aplocheilichtys pumilus*			7	9	4	5	2	27
	Aplocheilichtys eduardiana			51	28		1		80
	Aplocheilichtys sp			2	7				9
Cichlidae	*Oreoahromis niloticus*					5	3		8
	Oreoahromis leucostictus				1	2	1		4
	Astatochromis aullaudi					4	6		10
	Astatotilapia aeneocolor					1	5	3	9
	Astatotilapia schubotzellius			1			8		9
	Enterochromis nigripinnis					7	47		54
	Harpagochromis squamipinnis						5	5	10
	Labrochromis taurinus						2	1	3
	Psammochromis schubotzi					2	3	1	6
	Haplochromis					3	5	16	24
Anabantidae	*Ctenopoma murie*							4	4

Total	71	86	158	158	555	536	135	1705
Number of individuals (N):	71	86	158	158	555	230	135	1705
Species Richness (S)	1	2	9	13	17	13	14	29
Shannon-Weiner -Index of Diversity (H'):	0.000	0.0454	0.7951	0.8821	0.7017	0.9323	0.5863	0.872
Species Evenness (H')/In(S))	0.000	0.1105	1.7752	2.2731	1.4910	1.0532	1.3995	2.430
Simpson	-	0.1594	0.8079	0.8862	0.5263	0.4106	0.5303	0.722

Table 3. Sites specific sampled during the fisheries biodiversity indices for Nyamugasani hydropower region after commissioning (2021 and 2022)

Family	Species	Nyam 1 Intake	Nyam 1 DD	Nyam 1 PH / Nyam 2 Intake	Nyam 2 DD	Nyam 2 PH	Downstream PH 1&2	Total
Cyprinidae	*Labeobarbus kersternii*			5			1	
	Labeobarbus altianalis				6		2	8
	Labeobarbus jacksonii	20				1	16	37
	Labeobarbus perince		1	11	14	4	5	35
	Enteromius paludinosus	2	1		3	1		
	Barbus sp.					9		9
	Labeobarbus ruwenzorii					3	2	5
Bagridae	*Bagrus docmac*		2					2
Clariidae	*Clarias carsonii*			1			1	2
Amphiliidae	*Amphilius jacksonii*	4	2	3			5	14
	Total	26	6	20	23	18	32	112
	Number of individuals (N):	3	4	20	23	18	32	112
	Species Richness (S)	3	4	4	3	3	7	8
	Shannon-Weiner -Index of Diversity (H'):	0.3787	0.750	0.610	0.54442	0.6667	0.6914	0.736356
	Species Evenness (H')/In(S)):	0.6871	1.241	1.110	0.91840	1.3006	1.4898	1.592800
	Simpson	0.6254	0.8949	0.8005	0.8360	1.1838	0.7656	0.7660

Table 4. Biological parameters of the dominant fish species at river zones of Nyam 1 & Nyam 2 hydropower plants along River Nyamagasani during the monitoring surveys of February 2018, August 2018, April 2019 and August 2019.

Fish species	Selected parameters	February 2018	August 2018	April 2019	August 2019
Labeobarbus	Size range Mean length (cm TL)	5.0-16.1 (8.6±4.2)	4.8-15.8 (9.3±2.8)	4.8-15.8 (11.5±2.5)	3.4-19.4 (10.0±3.6)
Ruwenzori	Sex ratio (M:F)	4.5:1	4:1	5.4:1	6:1
	Maturity (%)	68.2	58.0	70.0	66.8
	Main food type (Increasing importance)	Detritus	Ephemeropteran & Detritus	Detritus	Ephemoropterans & Detritus
	Relative condition factor (Kn)	0.64-1.37 (1.01±0.03)	0.67-2.01 (1.01±0.19)	0.65±1.35 (1.02±0.05)	0.58-1.23 (1.01±0.13)
	Sample size (n)	94	(61)>100	(16)>24	(48)>52
Amphilius	Size range Mean length (cm TL)	2.9-12.3 (8.7±3.8)	5.1-13.0 (9.1±2.4	3.8-11.8 (9.2±2.7)	6.5-12.6 (9.4±1.8)
jacksonii	Sex ratio (M:F)	1:4	1:5	1:1	1.1:1
	Maturity (%)	50	88	100	82.6
	Main food type (Increasing importance)	Ephemerocropterans; Insect remains	Ephemeropterans	Ephemecropteran; Detritus	Ephemerocropterans; Insect remains
	Relative condition factor (Kn)	0.87-1.31 (1.01±0.04)	0.82-1.84 (1.28±0.21)	0.91-1.33 (1.12±0.01)	0.77-0.31 (1.00±0.1)
	Sample size (n)	90	20	21	33
Clarias	Size range Mean length (cm TL)	6.1-22.8 (13.1±4.1)	-	12.1-21.0 (14.4±4.7)	9.6-21.2 (14.4±3.9)
carsonii	Sex ratio (M:F)	1:1.3	-	1:2	1.1:1
	Maturity (%)	71.4	-	33	81.8
	Main food type (Increasing importance)	Ephemerocropterans; Insect remains	-	Insect remains	Insect remains; Detritus
	Relative condition factor (Kn)	0.82-1.13 (1:00±0.04)	-		0.81-1.20 (1.00±0.12)
	Sample size (n)	19	-	0.66-1.45 (1.2±0.01)	11
Clarias	Size range Mean length (cm TL)	9.5-58.0 (19.3±7.5)	-	-	-
gariepinus	Sex ratio (M:F)	1:1	-	-	-
	Maturity (%)	15.6	-	-	-
	Main food type (Increasing importance)	Insect remains; Detritus; Fish remains	-	-	-
	Relative condition factor (Kn)	0.86-1.17 (1.01±0.08)	-	-	-
	Sample size (n)	15	-	-	-
	Size range Mean length (cm TL)	-	30-20.6 (13.1±3.5)	-	-

Labeobarbus altianalis	Sex ratio (M:F)	-	3:1	-	-
	Maturity (%)	-	66.7	-	-
	Main food type (Increasing importance)	-	Detritus and Insect remains	-	-
	Relative condition factor (Kn)	-	0.89-1.27 (1.01±0.13)	-	-
	Sample size (n)	-	15	-	-
Barbus jacksonii	Size range Mean length (cm TL)	-	-	-	3.2-5.7 (4.9±0.7)
	Sex ratio (M:F)	-	-	-	3:1
	Maturity (%)	-	-	-	38.3
	Main food type (Increasing importance)	-	-	-	Detritus
	Relative condition factor (Kn)	-	-	-	0.59-1.9 (1.08±0.5)
	Sample size (n)	-	-	-	36
Barbus kersternii	Size range Mean length (cm TL)	-	-	-	3.24.7 (4.1±0.5)
	Sex ratio (M:F)	-	-	-	3.2:1
	Maturity (%)	-	-	-	51.7
	Main food type (Increasing importance)	-	-	-	Detritus
	Relative condition factor (Kn)	-	-	-	0.58-1.43 (1.01±0.2)
	Sample size (n)	-	-	-	17
Oreochromis niloticus	Size range Mean length (cm TL)	-	18.5-20.4 (19.1±1.5)	-	9.2-19.0
	Sex ratio (M:F)	-	1:1.5	-	
	Maturity (%)	-	100	-	
	Main food type (Increasing importance)	-	Detritus and algae	-	
	Relative condition factor (Kn)	-	4.4-19.5 (16.3±4.5)	-	
	Sample size (n)	-	10	-	1
Oreochromis leucostictus	Size range Mean length (cm TL)	-	4.4-19.5 (16.3±4.5)	-	-
	Sex ratio (M:F)	-	1:1.3	-	-
	Maturity (%)	-	67	-	-

Main food type (Increasing importance)	-	Detritus and algae	-	-
Relative condition factor (Kn)	-	0.94-1.03 (0.99±0.03)	-	-
Sample size (n)	-	6	-	-

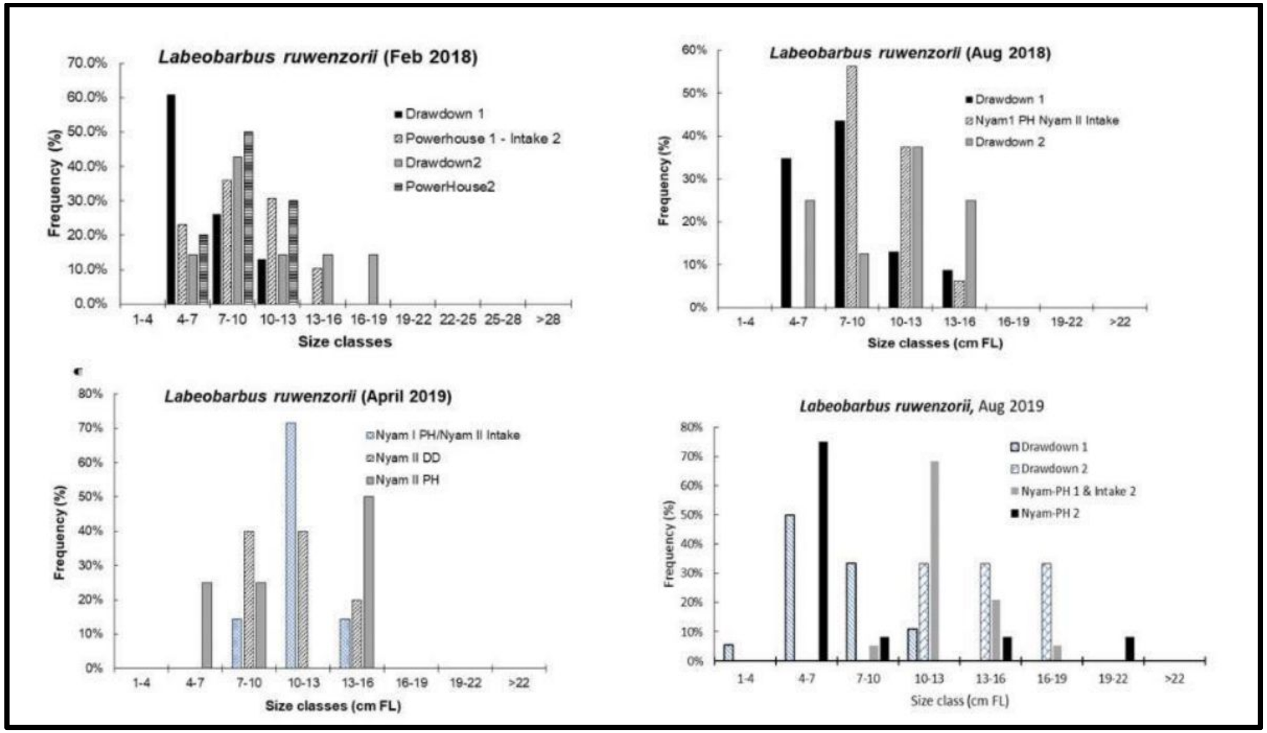


Figure 3. First, second, third, and fourth monitoring length-frequency distribution of Labeobarbus ruwenzorii caught from selected locations in Nyam 1 & Nyam 2 hydropower plants

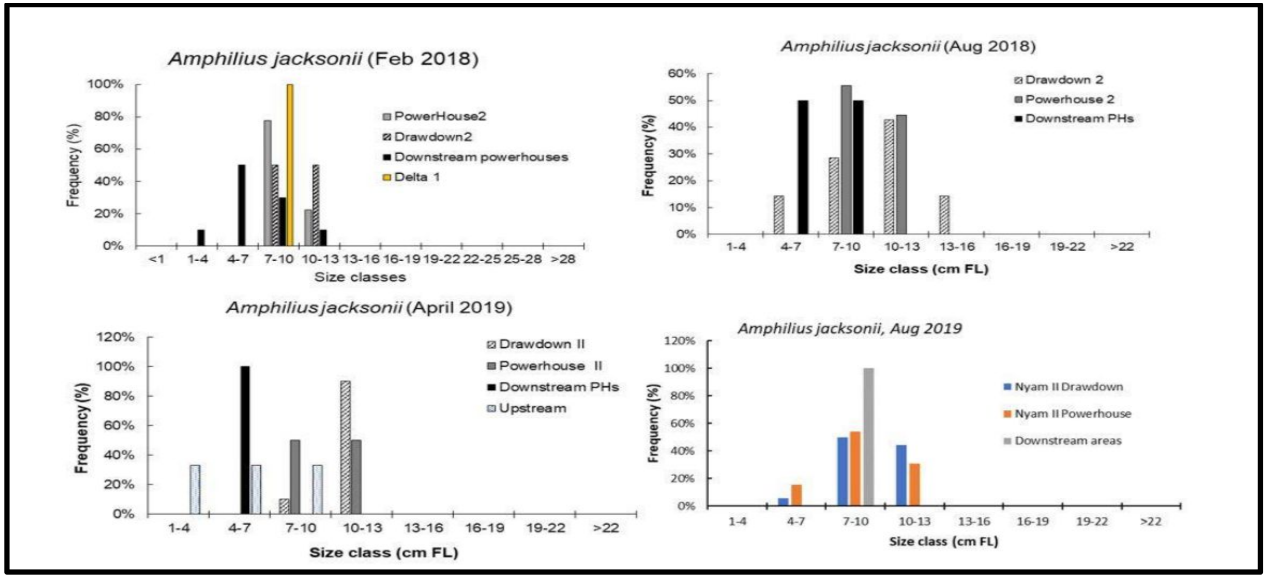


Figure 4. First, second, third, and fourth monitoring length-frequency distribution of the marbled mountain catfish Amphilius jacksonii caught from the selected river locations Nyamagasani 1 and Nyamagasani 2 hydropower plants along River Nyamagasani

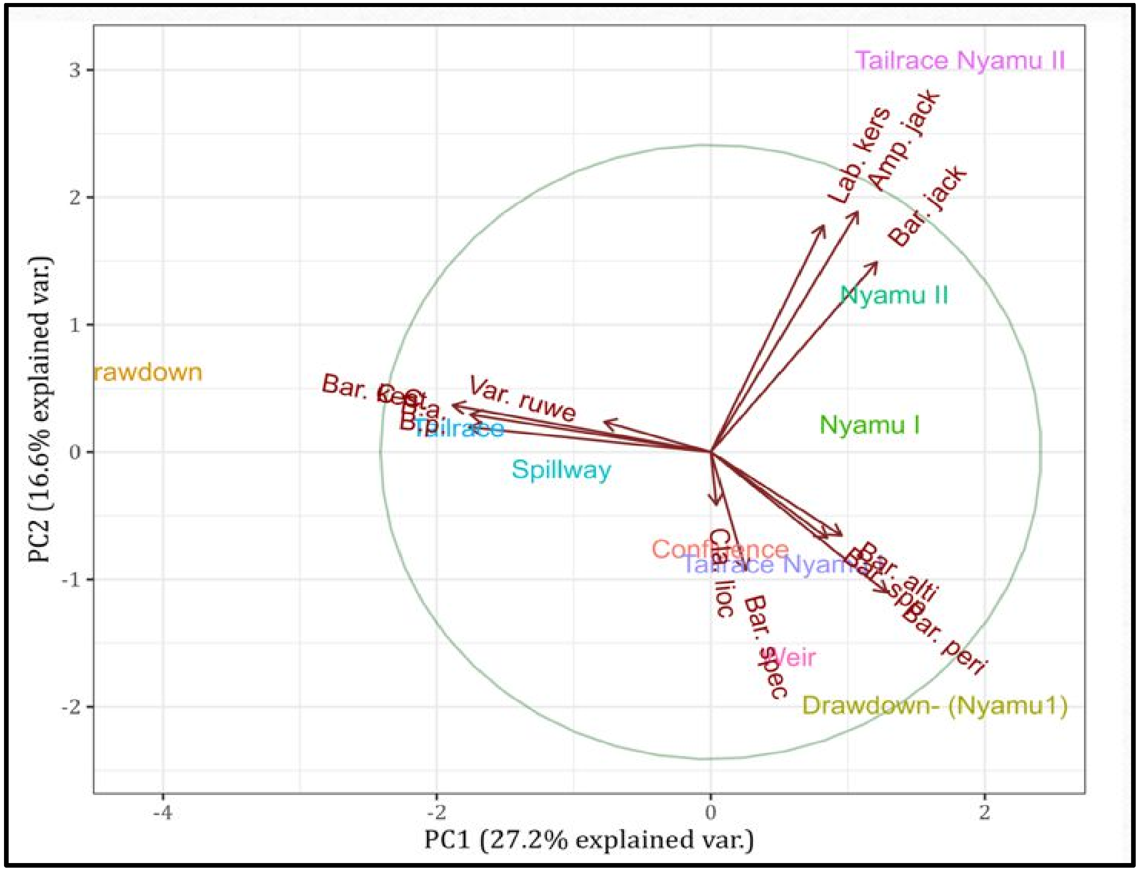


Figure 5. Fish species diversity from River Nyamugasani (2021 and 2022)

Table 5. Fish species recorded in February 2022, from the sampled sites of Nyamugasani project area with conservation status (LC = Least Concern, NT = Near Threatened, EN = Endangered, VU- vulnerable; DD = Data Deficient, NE = Not Evaluated and Endemic; IR- Insect remains).

Site	Fish species	IUCN	CPUE (g/gear/day)	Size (TL)	Sex ratio (M:F)	Gut content
Before power hse Nyamu II	*Amphillus jacksonii* (Boulenger 1912)	LC	17.42±0.86	11-11.5	1:1	Chironomids, Chaoborids larvae
	Enteromius jacksonii (Gunther 1889)	LC	9.79±1.05	7.5-10.3	1:1	Insect remains
	Enteromius perince (Ruppel 1837)	LC	3.49±1.06	4.2-7.5	1:2	Insect remains
	Enteromius paludinosus (Peters, 1852)	LC	23.49±0.00	10.9	-	Insect remains
Confluence (Nyamu 1 & Nyamugaseri)	*Enteromius paludinosus* (Peters, 1852)	LC	10.42±0.00	9.5	1:1	Empty
	Clarias liocephalus (Boulenger 1889)	LC	70.63±4.48	19.5-21	1:1	High plant materials
Drawdown- (Nyamu1)	*Labebarbus altinalias* (Boulenger 1900)	LC	183.83±14.79	20.7-22.7	1:1.1	Chironomids, Insect remains
	Enteromius perince (Ruppel 1837)	LC	17.5±0.65	10.3-12	1:1	Insect remains
	Enteromius paludinosus (Peters, 1852)		20.33±2.60	10.3-11.9	-	Chironomids & Insect remains
Nyamu I below the fish ladder	*Enteromius jacksonii* (Gunther 1889)	LC	14.92±0.00	9	-	Empty
	Enteromius perince (Ruppel 1837)	LC	9.08±0.00	9	1:1	Insect remains
	Enteromius paludinosus (Peters, 1852)	LC	10.74±0.00	8.5	-	Empty
Tailrace Nyamu I	*Enteromius paludinosus* (Peters, 1852)	LC	56.57±0.00	16	-	Insect remains
Tailrace Nyamu II	*Amphillus jacksonii* (Boulenger 1912)	LC	18.29±4.02	7.3-12.3	1:1	Insect remains
	Labeobarbus kerstenii (Peters 1868)	LC	0.32±0.00	3.2	-	Empty
	Labeobarbus altinalias (Boulenger 1900)	LC	50.21±30.69	12-15.9	1:1	Insect remains
	Enteromius jacksonii (Gunther 1889)	LC	10.41±1.28	3.5-8.0	1.1:1.2	Insect remains
	Enteromius perince (Ruppel 1837)	LC	2.54±0.89	3.9-7.9	1:1	Insect remains
	Clarias liocephalus (Boulenger 1889)	LC	0.91±0.00	4.9	-	Insect remains
	Varicorhinus Ruwenzori (Pellegrin, 1909)	VU	0.60±0.00	3.5	-	Empty

Table 6. The Fish species recorded in October 2021, from the sampled sites of Nyamugasani project area with conservation status (LC = Least Concern, NT = Near Threatened, EN = Endangered, DD = Data Deficient, NE = Not Evaluated and Endemic; IR- Insect remains).

Sites	Recorded Species	IUCN	CPUE (g/hr/gear)	Size range(cm)	Sex ratio Male: Female	Gut content
N2_Drawdown	*Amphillus Jacksonii (Boulenger 1912)*	LC	9.41±3.55	8-10.5	!:1	Insect remains
	Barbus perince (Ruppell 1837)	LC	6.94±0.62	6.6-8.5	1.2:1.3	Insect remains
	Barbus kestern	LC	10.74±2.44	5.7-9.4	1:1	Insect remains
	Clarias liocephalus Boulenger 1898	LC	31.39±0.00	15	-	Insect remains
N2_Spillway						
	Barbus perince (Ruppel 1837)	LC	8.51±0.58	7.3-8.5	1.2:1	Insect remains
N2_Tailrace	*Barbus perince (Ruppell 1837)*	LC	1.00±0.00	4.5	-	Insect remains
	Varicorhinus Ruwenzori	Endemic	8.52±3.28	5.3-8.9	1.1:1	Insect remains
	Amphillus Jacksonii (Boulenger 1912)		16.09±2.84	9-911	-	Insect remains
N2_Weir (below fish pathway)	*Barbus perince (Ruppell 1837)*	LC	9.61±1.63	8.1-8.8	1.1:1.1	Insect remains
	Barbus species		14.07±1.63	7.9-10.8	1.1:1.1	Insect remains

Fish species richness and occurrences from the sampled sites

During the years between 2016 to 2019 the fish species diversity varied in all the sites sampled and the overall was; Number of individuals (N):1705; Species Richness (S), 29; Shannon-Weiner -Index of Diversity (H'):0.872; Species Evenness (H')/In(S)):2.430; Simpson index: 0.722. Where as in 2021 and 2022 the overall diversity showed; Number of individuals (N):112; Species Richness; (S); 8, Shannon-Weiner -Index of Diversity (H'): 0.73636; Species Evenness (H')/In(S)): 1.5928 and Simpson index was 0.7660 for all species in the whole period of sampling. In addition to that the fish species occurrences for all the years sampled showed more in Nyamu Power house and Nyamu drawdown sites (Tables 4, 5, 6 and 7).

Overall, the findings in in the species abundance among the habitats, with Drawdown significantly contributing to PC2 in a principal component analysis. The occurrences and distributions of species varied across different sites, with Drawdown PH and Nyamu2 Drawdown showing the highest occurrences compared to other sites (Table 5). In general, Barbus spp. were most distributed in Drawdown Nyamu 1.

The study provides essential awareness into fish-hydropower dam sustainability within the River Nyamugasani ecosystem, highlighting the importance of continued monitoring and conservation efforts.

Discussions

The fisheries in River Nyamugasani and their implications

The period of before and after the commissioning were done and comparison were observed and recorded in the two hydropower station project areas of River Nyamugasani including the confluence of River Nyamuruseghe that showed that potamodromous fishes dominated the catches as compared to any other types (Massa *et al.,* 2021; Greenwood, 1966; Worthington, 1929, Witte & Densen, 1995). The total catches recorded showed an increase in total weight, number and species diversity were high before the commissioning of the hydro power dam as you descend downstream to Nyamu II areas of the river as after the commission. Despite that in all the samplings low catches upstream were recorded that could have been attributed to hydropower developments thus affected the resident areas for these fishes and also where they could use as breeding sites. Thus the hydro power modification could have attributed the fish species diversity. The potamodromous fishes such as the Barbus species migrates upstream for spawning before they migrate to the lake for growth and feeding interactions (Massa *et al.,* 2021; Bassa *et al.,* 2018; Kibara, 1985).

Changes in sampling sites from previous years (Twongo *et al.,* 2018), to current sites and the ongoing construction of fish ladder may have contributed to variations in recorded fishes or sample sizes. The N2_Drawdown site consistently showed higher fish presence, potentially attributed to hydrological alterations caused by hydro-power dams constructed along the river, affecting fish passage and distribution. At the time of samplings, the fish ladder was under construction providing hope for more even distribution of fisheries biodiversity once completed.

Hydropower activities, altering habitat biodiversity, emerge as a key factor limiting fish distribution and abundance. Environmental factors such as, conductivity, dissolved oxygen, phytoplankton and micro-invertebrates, crucial for fish distribution, not included in these samplings. Macro invertebrates, as fish food (Massa *et al.,* 2021; Busulwa, 1989; Bassa *et al.,* 2019; Sekiranda *et al.,* 2004), may contribute to fish distribution along the Nyamugasani stretch.

Varicorhinus Ruwenzori, found bellow the Tailrace of Nyamu II, is categorized as vulnerable (VU) under the IUCN, emphasizing the need for environmental operating procedures alongside dam operationalization to ensure species conservation.

Conclusions

Successful hydropower management require a balance between power production and fisheries biodiversity conservations. Implementing mechanisms such as fish passages for the upstream fish movements and ensuring the conservation of species such as *Varicorhinus Ruwenzori* are essential. Constant monitoring and compliance by the hydropower managers is crucial for sustainability and conserving the Nyamugansani riverine fishery. In addition to that Nyamugasani hydropower dam like Isimba (Mukwanason *et al*, 2022), the gradual increase of permitted discharges is like to increases the risk of overtopping that could lead to dam failures and therefore the operation of the reservoir is further strained in order to safely accommodate the incoming flood. This requires the hydropower management to have mitigation measures for such instances.

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