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Influence of In-stream Ecosystem Restoration Techniques on the Fish Ecology of the River Nabongo in Eastern Uganda

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ABSTRACT The study was the first in Uganda to assess the responses of fish community assemblages to introduced woody debris structures in a tropical river in Eastern Uganda. For comparison purposes, two different woody debris structures (simple and complex) were introduced in river Nabongo, and their effect on fish assemblage and feeding was established based on experiments conducted in two heterogeneous stream environments (a pool and a riffle). Results showed that sampling plots treated with restoration structures registered higher fish species richness, diversity, and abundance than sampling plots without restoration structures (control plots) at each site. The study (experiment) applied a stratified sampling design which used purposive identification of a pool and a riffle in River Nabongo Catchment. Fish were captured using a drift net, an electro-fishing gear, and a hand net. Data were analysed using a one-way ANOVA generated from STATA version 14. At the pool site, total fish density varied significantly from plot to plot ($P<0.05$) but was highest in the complex structures with 64 ± 1.08 fishes/m^2 and lowest with 24 ± 0.82 fishes/m^2 in untreated plots. K-factor did not vary significantly in untreated plots at the pool site but significantly differed from treated plots at $P<0.05$. The relative abundance of fish species at the pool site was highest in the complex structures with $40.7\pm0.66\%$ and $21.5\pm0.42\%$ before structures but was least in the control plot, varying significantly from plot to plot at $P<0.05$. It was concluded that woody debris restoration is an effective stream restoration technique. Fish individuals, trophic groups, and taxa more densely colonised sampling plots that had structures than those that did not have structures.

Keywords: Feeding group; fish metrics; K-factor; sampling plots; taxonomic composition

INTRODUCTION

Successful ecosystem restoration is pivotal in increasing the stability and diversity of species and recovery of biotic features. It is essential to assess and monitor ecosystem restoration practices and processes since ecosystems follow a cyclic pattern. Therefore, ecologists should monitor pre- and post-restoration activities to ensure stream ecological sustainability and stability (Leal *et al.*, 2012; Turyahabwe *et al.*, 2021).

Ecological stream restoration returns a stream ecosystem's structure and function to a more meditative state of its pre-disturbance form. Regardless of the method applied, the goal of ecological stream restoration is to restore the stream ecosystem's physical, chemical, and biological composition as close as possible to the native state, given the permanent watershed alterations (Roni *et al.*, 2002; Aazami *et al.*, 2015).

Researchers have come up with a wide range of restoration techniques to improve lotic ecosystems, including but not limited to; dam removal to restore longitudinal connectivity, levee breaching to restore lateral connectivity, vegetative methods to control stream bank erosion, riparian road improvements, and physical in-stream restoration (Roni *et al.*, 2002; Shields *et al.*, 2003). Restoration structures are expensive to establish, and if not carefully located in a stream, they alter flow rate, which may induce flooding, increase turbidity and conductivity, and negatively impact the health of fish and other aquatic living organisms. In-stream restoration improves water quality, aesthetic value, lotic habitat and floodplain function and generally uplifts the lotic ecosystem health of rivers (Winemiller *et al.*, 2010; Philemon *et al.*, 2015). This study concentrated on an in-stream restoration technique that focuses on creating immediately usable habitat, i.e. adding large woody debris in a stream.

Even though ecologists in different parts of the world for many centuries have agitated for removing woody debris from rivers to avoid channel clogging, there has been an increasing knowledge about the ecological importance of woody debris in the rivers (Brooks *et al.*, 2004). This is why European settlers in Australia had concentrated on removing woody debris from rivers. However, after realising their ecological importance as habitat enhancement for macroinvertebrates and fish, they embarked on the re-introduction of woody debris back to the Australian rivers with the hope that these could optimise pools and riffles, which in turn would enhance fish and macroinvertebrate diversity (Gerhard *et al.*, 2000). TEEB (2013) observed that despite river ecosystems being associated with disservices like flood risks, river ecosystems translate into several benefits to communities. These include but are not limited to the provision of water for domestic consumption and commercial production in irrigation and industrial activities, habitat for aquatic biota, which sometimes are a tourist attraction, and enhanced artisanal fisheries, which are sources of food for humans. River ecosystems support the continued flow of water that sustains hydropower generation for economic purposes. In this regard, Brooks *et al*. (2004) tested the effectiveness of re-introducing woody debris to improve channel stability and recreate habitat diversity for fish and macroinvertebrates. Findings indicated that woody debris was a pivotal component of the physical habitat for fish and macroinvertebrates in rivers.

Benke *et al*. (2003) had earlier observed that re-introducing woody debris in rivers was becoming an essential management and restoration strategy in the contemporary world to improve both refuge and biodiversity of both fish and macroinvertebrates in rivers. For example, Willis *et al*. (2005) observed that the fish species diversity and density in a tropical river's littoral flood plain habitat were positively correlated with the habitat complexity of woody debris at a patch scale. Additionally, Hrodey *et al*. (2008) & Winemiller *et al*. (2010) explained this by indicating that woody debris provides a rigid substrate for colonisation by algae and micro-organisms on which fish and macroinvertebrates feed.

Brook *et al*. (2004) defined woody debris as wood materials as big as >3cm diameter usually found in forested regions that slowly decompose when subjected to freshwaters. Bilby *et al*. (2003) stated that large woody debris that falls in streams forms a solid habitat for aquatic organisms and can last for decades. Gurnell *et al*. (2002) observed that once woody debris falls in running water, it enhances the variability of aquatic ecosystem microhabitats like riffles, runs, and pools, thereby increasing the diversity, abundance, and richness of aquatic organisms like fish.

Submerged woody debris is ecologically crucial in streams and rivers as they alter streamflow and riverbed morphology and profile (Mathooko & Otieno, 2004; Brook et al., 2004). Woody debris submerged in streams provides spawning grounds for stream fish and enhances macroinvertebrate habitat, which increases the diversity and richness of fish taxa, especially in low-flowing rivers (Benk *et al*., 1984).

However, Hynes & Philemon *et al*. (2015) noted that knowledge about the importance of woody debris in stream ecology is as young as 70 years old worldwide, receiving increased attention in the last 33 years. This is why it has not yet been adopted in most parts of the world, like tropical Africa, especially East Africa, while Uganda lacks literature. The literature on how woody debris has influenced fish community structures in streams has concentrated mainly on the temperate world (Brooks *et al*., 2004). The results from the previous studies are more temperate-specific and do not address the east African region-specific lotic environment, given different geographical differences.

In east Africa, river channel rehabilitation using riparian vegetation and woody debris would be essential and integral in watershed management strategies (NEMA, 2008), but there is limited research in this region. Apart from Mathooko *et al*. (2004), other researchers in East Africa have hardly examined the impact of woody debris on the restoration of fish assemblage. Yet, east African environmental managers need this region-specific information to develop policies that can guide sustainable freshwater resource conservation.

Therefore, it is against this background that, in the current study, we experimented with assessing the responses of fish community assemblages to the introduced woody debris structures in the tropical river River Nabongo in Eastern Uganda. Two objectives; 1, guided the current study. To assess the influence of woody debris restoration structures on fish assemblage and feeding habits, and 2. To analyse the influence of woody debris restoration on fish assemblage metrics in river Nabongo catchment. The study considered both riffle and pool environments intending to base on results to advise ecologists on which wood restoration technique/ structure can work best in the two environments of the same river and or rivers in similar environments.

MATERIALS AND METHODS

Study area

River Nabongo drains the eastern slopes of Mount Elgon and is located in Eastern Uganda, stretching between 33.5°-36°E and 2°-5°N, as shown in Figure 1. It flows into the Muyembe, part of the larger River Sironko, which flows into the Lake Kyoga basin. The river flows over a distance of approximately 14Km, with its headwaters originating from the slopes of the northern part of the Mount Elgon range (approximately 1870 m a.s.l). The most significant part of the relief is mountainous, with interceptions of gentle slopes westwards. River Nabongo traverses a natural tropical forest reserve in its headwaters in the uppermost reaches and cultivated steep slopes where perennial and annual crops are grown. It crosses perennial and some annual crop farms, and residential areas in the middle, while annual crop farms dominate the lower reaches. River Nabongo crosses a vital trading centre at a town board level called Nabongo-Muyembe town board. The river catchment comprises a variety of climatologically and ecologically different regions. This ranges from a year-round wet climate in the source area of the steep Elgon Mountain (2000-3000 mm annual rainfall) to a wet climate with two short dry seasons per year (1400 mm annual rainfall) in the mid-range regions of the system, to the drier downstream region (1000 mm annual rainfall) with pronounced dry and wet seasons. The mean temperature from the source to the confluence areas varies from 20°C to over 24°C (Turyahabwe *et al*., 2020).

The coordinates for the two sampling points in were; N1°20'13.2864 E34°18'11.2536 (1303M ASL) for the riffle site, while the pool site was N1°20'10.5396 E34°17'52.2528 (1080M ASL). The experimental sites of the pool and riffle were lying within a stretch of 800 m of the stream (Figure 1). These locations had the characteristics indicated in the theoretical background (Winemiller, 2010). The velocity at the pool site ranged between 0.4±0.1 to 0.5±0.1 m/s, while at the riffle site, it ranged between 0.9±0.2 m/s to 1.3±0.3 m/s. The width of the wetted channel at the pool site was between 6.7± 0.1 m to 7.3±0.4 m but was narrower at the riffle site

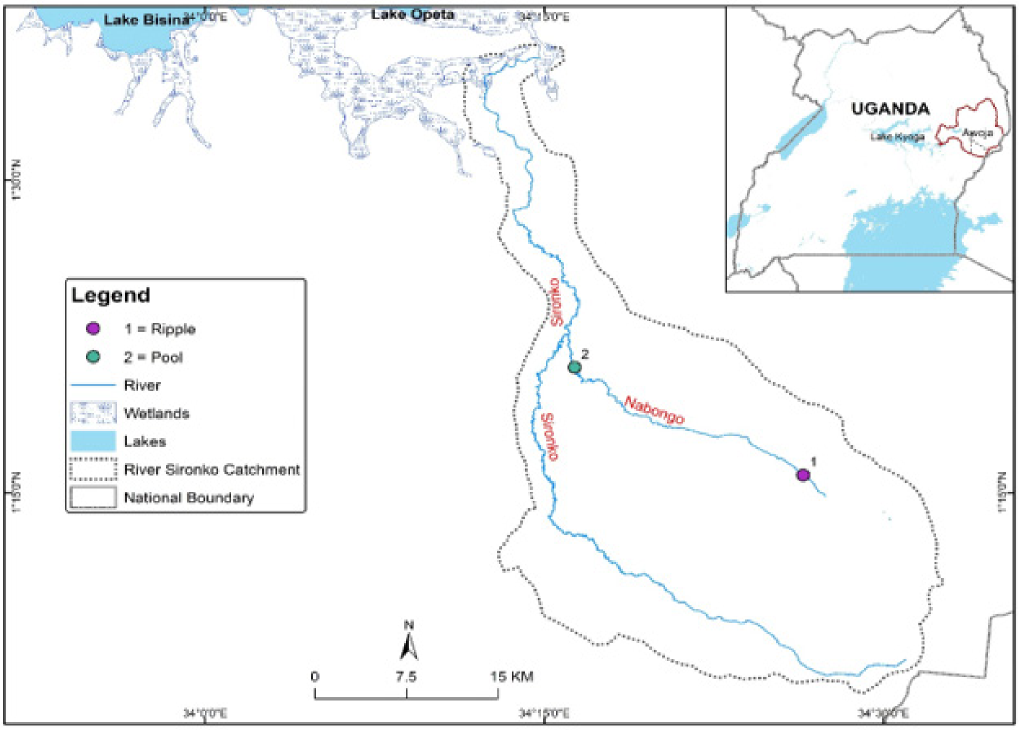

Figure 1. Location of sampling sites on River Nabongo.

ranging between 5.6±0.5 m to 6.1±0.6 m. The wet channel depth ranged between 79.2±0.2 cm to 89.2± 18.2 cm at the riffle site but was more profound at the pool site ranging between 107.0±13.4 cm to 141.0±0.6 cm. The temperature was most excellent at the riffle site with a minimum of 20.7±0.9°C but warmer at the pool with 24.2±1.1°C. Dissolved oxygen at the pool site was as low as 7.7±0.7 ppm but highest at the riffle site, up to 10.6±0.2 ppm. pH at both the riffle and pool site ranged between 6.7±0.4 to 8.2±0.4. The natural substrate of the pool site was composed of sand, gravel, mud, and cobles, while the riffle site was composed of sand, cobbles, silt, pebbles, and bedrock.

River Nabongo in Uganda is one of the significant streams that sustain Lake Kyoga, the second largest lake in Uganda. It is a spawning ground for many rare fish species in Lake Kyoga. Various land uses such as urban. Arable farming land uses are traversed by the river, some of which degrade its biota. If restoration attempts are not put in place, fish stocks in the lake may decline, and the number of rare fish species such as *Clarias leocephalus* and, *Clarias carsonii*, *Amphillius lujani*, among others, may become extinct in both the river and the Lake Kyoga (Muyodi *et al*., 2011). Mitigation measures for this condition start with trying out several restoration techniques to maintain and improve the fish diversity, richness, density, and K-factor.

Restoration structure make up

We sampled woody debris naturally occurring in the river to find the dominant wood type submerged in the river. This was to help us know which wood species we needed to use in our experiment. However, tiny grooved and very few, fairly rotten eucalyptus species (*Eucalyptus saligna* Sm) dominated the submerged woody debris in the study area (river Nabongo). Based on this finding, we cut 200 dry grooved eucalyptus blocks of wood of species *Eucalyptus saligna* Sm with a diameter ranging between 3-5 cm and 60 cm long, each with their barks intact. These were kept in the river water near the shoreline for 1 week to condition them as submerged woody debris. On retrieval, they were bundled in 10 s using a high tensile stainless steel wire, making them 20 bundles (10 bundles were to be installed in a pool site while the other 10 were installed in the riffle site). Each bundle was made in an inverted funnel (tee-pee), and all the bundles had gaps between sticks/woods of up to 13 cm to allow fish to enter the constructed structure. This is what we call the complex structure (Figure 2).

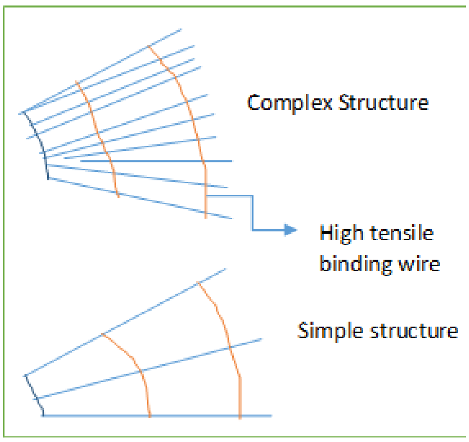

Figure 2. Arrangement of individual structures

We also cut 60 grooved eucalyptus wood with diameters ranging from 6-8 cm, 60 cm long each. These were kept in the river water for one week to condition them as submerged woody debris. On retrieval, we arranged and bundled them into groups of three kids of wood, making them 20 bundles (10 bundles were to be installed in a pool site while the other 10 were to be installed in the riffle site). This is what we call simple structures (Figure

2). Each of these 20 bundles was bound with a high tensile stainless-steel wire with gaps between woods of approximately 13 cm to allow fish to enter and colonise. The diameter of the woods in each case was measured using a digital flat edge model Vanier calliper with ±0.1 mm accuracy, while the length was measured using a tape measure.

Site treatment

At the pool site, a stretch of 20 m was measured; the average stream width was 6.8 m. The 20 m stretch was divided into 4 sections as described by Winemiller *et al*. (2010), where the first 5 m upstream were reserved as a control treatment (no wood was introduced), and the second 5 m was used to install 5 simple structures on the left bank and 5 simple structures on the opposite right bank. A gap of five metres below the simple structures was skipped to separate complex structures from simple structures. Below this gap, in the remaining 5 m, we installed 5 complex structures on the left bank and the other 5 on the opposite right bank facing each other.

At the riffle site, a similar arrangement of structures was made as at the pool site, only that the wet channel width was smaller (5.3 m). Each structure was installed in the stream, slanting at an angle of >45° to break the water velocity. The distance between one structure in each set and another on the same bank side was 20 cm, while that between structures on opposite sides of the banks at each site varied between 0.9-1.8 m depending on the channel's morphology.

Both simple and complex structures were stuck in the river by driving three unwashed conditioned sticks through the structures and through the substrate on the river's bed vertically in the form of a wedge up to a depth of approximately 1.5 ft to avoid washing of structures away by stream water. This design of structure installation in the riffle site was replicated in the pool site (Figure 3). Fish were sampled pre and post-structure installation. All the sites were monitored for 30 days, as indicated by O'Connor (1991), before retrieval/sampling of the structures for each sampling campaign.

Fish sampling

Fish sampling was done before establishing structures at the riffle and pool sites to compare pre and post-experiment results. Later sampling campaigns were launched in treated plots after every 30 days of introducing woody debris structures into the stream. The wood was retrieved after 30 days of treatment. Both the treated sites of the pool and riffle were first blocked off from up and downstream of each treatment structure type with block nets mesh size 1mm to avoid escaping fish from one treatment or control zone to another during the sampling of fish from structures. Sampling fish in structures started downstream of each treatment at each site where a drift net mesh size 0.3 mm, 1 m diameter (at the entrance) was used. A whole wood structure with its contents (fish and its detritus) while still inside the river water was carefully lifted and driven inside the drift net and then retrieved/lifted out of the water, ensuring that chances of losing fish were minimised as described by (O'Connor, 1992; Phillips & Kilambi, 1994; Turyahabwe et al., 2021). The fish from the same structure or

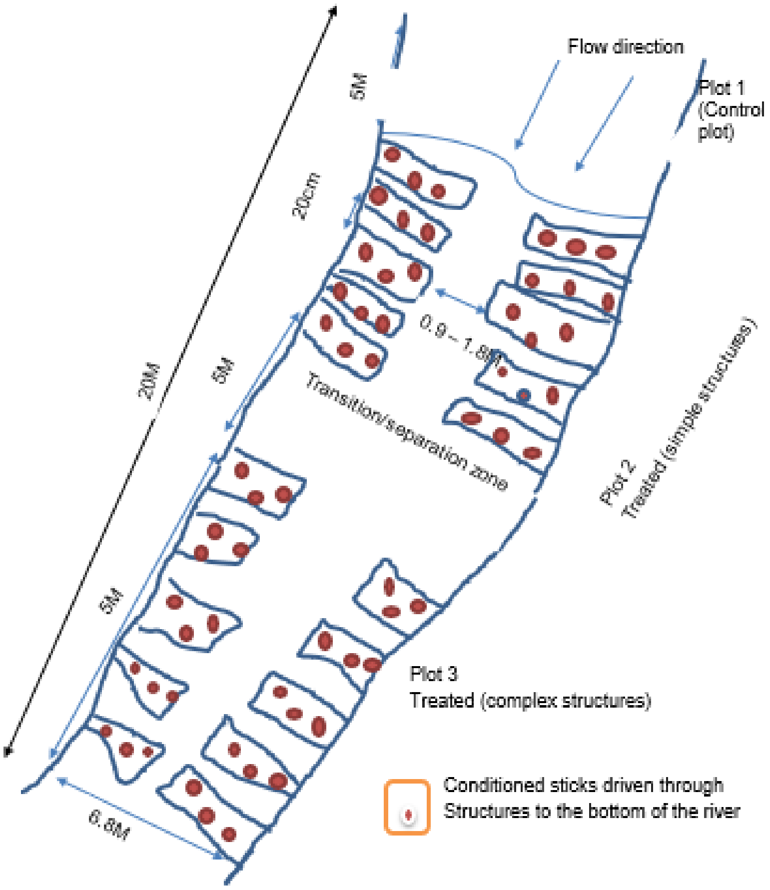

Figure 3. A schematic representation of site treatment on each of the two sampling sites.

treatment for each site were pooled together in a bucket containing water, where they were kept awaiting addition from electro-fishing results. Electrofishing was permitted and carried out by experts from the national fisheries regulatory body called National Fisheries Resources Research Institute (NaFiRRI)- Uganda.

Immediately after all structures were removed from a site, electro-fishing was carried out for each treatment section using a Battery-powered Smith-Root LR-24 backpack electro-fisher (output 300 W) set at 300 V and a hand net. Electrofishing was also used to sample the fast swimming and shy fish species that would have been missed by retrieving or sampling woody debris structures, but also the gear increases the number of individuals caught (Amy *et al.*, 2017).

Each section was sampled for 10 minutes in two slow downstream zigzag passes. The fish samples from electro-fishing were added to those obtained directly from the respective woody structures (treatment) to make one sample, put in a bucket, 10% formalin added, sealed, labelled, and taken to the laboratory for further processing. While in the laboratory, the fish were first blotted with a cloth to reduce the amount of moisture on the outer body. This was weighed using a 3 - digital Dial- O gram beam balance, length measured using a measuring board to get the fish condition from the anterior-most extremity of the mouth closed at a stopper up to the tailfin end, taxonomically identified based on external morphology characteristics (Greenwood, 1966) and counted. Fish sampling was conducted twice during the rainy season between October and January and twice during the dry season between July and September for comparison and enough time scope. The fish condition (K) factor was calculated based on Fulton's condition factor taking into account the isometric and allometric growth pattern of fish based on the formula denoted by;

$$K = \frac{W}{L3} \times 100$$

Where; K is the fish condition factor, W is the weight of individual fish (g), and L is the individual fish total/fork length (mm) as described by Froese (2006) and Ricker (1975).

Supporting site characteristics such as dissolved oxygen, temperature, and pH for each site were determined in 'situ' using a multi-parameter analyser model Consort C3010/C3030 dual channel. We measured the velocity, depth, and width of the wetted channel on each site before and after the introduction of woody debris. Velocity was measured using buoyant dry sticks and a stopped clock over 5 m. The channel width and depth were measured using a tape and wading rod.

Species diversity and richness of fish were determined at each site using Shannon Weaver's Diversity Index (Shannon & Weaver, 1949) to compare fish diversity between various habitats associated with different wood treatments as follows:

$$H = \sum_{i=1}^{n} \left(\frac{ni}{N} [\log 2] \left(\frac{ni}{N}\right)\right)$$

Where,
H= Shannon Wiener index of diversity,
ni= Total No. of individuals of a species,
N= Total No. of individuals of all species.

Species relative abundance was calculated from the formula denoted by (A);

Species density was calculated from the formula according to Froese (2006) (B),

Fish biomass was calculated from the formula according to Froese (2006 (C);

$$\text{(A)} \quad \text{Relative abundance} = \frac{\text{number of individuals of one taxon x 100.}}{\text{Total number of individuals on a site}}$$

$$\text{(B)} \quad \text{Fish species density} = \frac{\text{Total number of fish individuals caught per sampling plot site}}{\text{Size of the area sampled } (m^2).}.$$

$$\text{(C)} \quad \text{Fish Biomass} = \frac{\text{Total weight of all the fish harvested from a sampling plot (g)}}{\text{Size of the area sampled } (m^2)}$$

Data analysis

To compare the differences in fish assemblage metrics in different sampling plots, a parametric (ANOVA) approach was used. Before the comparison, a normality test using Shapiro-Wilk was applied to fish assemblage metrics. After all the data had passed the normality test, one-way ANOVA was performed to assess the differences between means of dependent variables (assemblage metrics) from the different sampling plots. For those models found to be significant under ANOVA, a post hoc test using Turkey's Honestly Significant Difference (HSD) test was generated from STATA version 14.

RESULTS AND DISCUSSION

Influence of woody debris restoration technique on fish assemblage and feeding

Data about the influence of woody debris restoration technique on fish ecology was categorised into two, i.e., Fish taxonomic composition (assemblage) and fish assemblage metrics. Summarised in Table1 are the results of fish assemblage in experimental sites on river Nabongo.

From Table 1, it is evident that we harvested 2.648 fish individuals represented by 13 species categorised into four feeding groups: herbivorous, insectivorous, predators, and filter feeders. The categorisation of the feeding groups was based on what we found in the fish's gut content (stomach remains). The five insectivorous species dominated the feeding groups, accounting for 38% of all the groups. The feeding group was composed of *Amphillius lujanii*, *Tilapia rendalii*, *Tilapia sparmanii*, *Leptoglanis rotundiceps*, and *Barbus altianalis*. The herbivorous feeding group accounts for 30% of the total number of feeding groups. The insectivorous catch was represented by four species: *Labeo victorianus*, *Clarias leocephalus*, *Clarias carsonii*, and *Cyprinus carpio*. Both predators and filter feeders were represented by two species accounting for 15% of each of the total feeding groups (Table 1). Predators comprised *Serranochromis robustus* and Micropterus salmoides, while filter feeders were represented by *Barbus palludinosus* and *Barbus jacksonii*. It should be noted that *Barbus altianalis* was observed crossing from one feeding group to another. i.e., in the wet season, the gut content was mainly full of insect remains while it was dominated by plant remains in the wet season.

Before woody debris restoration structures were introduced in the stream, the pool site was dominated by insectivorous species having 128 individuals accounting for 45.4%, with the highest number being contributed by *Tilapia rendalii*. Filter feeders had 127 individuals accounting for 45%, with the highest number of individuals representing *Barbus palludinosus* species. The predator fish species were represented by 13 individuals representing only (4.6%) and the smallest feeding group. At the same time, the herbivorous species registered only 14 individuals accounting for 4.9% of the total site catch. Before introducing restoration structures at the pool site, widespread species were dominated by *Barbus palludinosus* with 84 individuals. The rarest was *Clarias carsonii*, with only two individuals, even found in the stream only during the wet season.

The introduction of complex structures at the pool site increased the number of individuals of insectivorous species from 128 to 197 individuals even though the relative abundance reduced from 45% to 36.8% but remained the dominant feeding group on site. The number of individual predator fishes increased from 13 to 165, twelve times higher. Specifically, *Serranochromis robustus* (predator) increased from seven to 112 individuals and emerged as the most dominant fish species in this treatment on this pool site. The number of other individual fish species generally increased save for filter feeders that maintained their numbers from pre-treatment to complex treatment. The herbivorous were the fewest, with only 46 individuals accounting for 8.6%, with the rarest species in the treatment being *Labeo victorianus* with only 5 individuals. The number of fish individuals increased from 282 in pre-treatment to 535 in complex treatment.

On the other hand, the introduction of simple structure treatment in the pool site generally registered a lower number (252) of individuals than the complex treatment (535) and pre-treatment (282). The complex treatment attracted most of the fish, so the fish struggling with the flowing current found a better refuge in the complex than simple structures could provide. The most abundant in this treatment was the filter-feeding species accounting for 38.5%, while the most dominant specie in the treatment was *Barbus palludinosus* with 51 individuals, while the rarest was *Barbus altianalis* was also a filter feeder. The minor feeding group was predator fishes, with only 16 fish individuals. The predators did not prey on filter feeders but rather insectivorous and herbivorous since the number of these two groups remained the same as that of pre-treatment but increased in the simple structure treatment and the control plot. Predators were fewer in the simple structure treatment than in complex structure treatment, and their prey had accumulated in the complex treatment with limited prey in simple structures. Compared with the complex treatment, simple structures generally had fewer individuals than those harvested from the control plot. The control plot generally had fewer individuals than pre and post-treatment. There were more predators in the control plot than in simple structures.

Before structures were introduced in the stream at the riffle site, only 4 predator fish individuals accounted for 1.4% of the total site catch. The dominant feeding group was insectivorous, with 203 individuals accounting for 73% of the site's total catch. The most dominant specie was *Leptoglanisrotundiceps* (insectivorous), with 76 individuals, while the most diminutive species was *serranochromisrobustus*, with only one individual. In response to the complex structure's introduction in the stream, the total number of fish individuals increased from 278 in pre-treatment to 471. The number of predator fish individuals increased from 4 pre-treatment to 15 in complex treated plots, insectivorous increased from 203 to 241, herbivorous from 30 to 61, and filter feeders increased from 41-to 160. The most dominant specie was *Barbuspalludinosus*, with 94 individuals, while the rarest was *Micropterussalmoides*, with only four individuals.

Even though they were fewer than those found in the complex structures, apart from insectivorous and herbivorous, other fish feeding groups increased in number in response to the simple structure's introduction. Predators dominated the simple structures at the riffle site, with 113 individuals accounting for 33% of the treatment catch, while herbivorous were the rarest, with only 47 individuals accounting for 13.7% of the treatment catch. The most abundant specie was *Barbus palludinosus*, with 78 individuals.

Compared to the complex plot, *Amphillius lujanii* and *Barbus altianalis* did not appear in the control plot. Barbus altianalis at the riffle site only appeared in the simple structures. Leptoglanis rotundiceps dominated the control plot here with 76 individuals. Only 7 filters and 8 predator fish individuals were available in the control plot at the riffle site. Generally, simple structures had fewer taxa (species) and individuals at the pool site than complex treatment. This was the opposite at the riffle site, with simple structures having more taxa than complex structures.

The number of individuals in control plots was more minor than in pre and post-treatment. The overall riffle treatment (excluding the control plot) yielded 813 fish, while the total pre-treatment at this site yielded 278 fish individuals. Taking the difference between these two indicates that the overall treatment caused an increase of 535 fish individuals. Based on the individual treatments at the riffle site, the control plot yielded 244 individuals for all the four sampling campaigns, the complex treatment yielded 471, and the superficial treatment yielded 342 individuals. It is indicative that complex structures at the riffle site were associated with a more significant positive impact on fish ecology (increment of

Table 1. Influence of woody debris on fish assemblage in experimental sites on river Nabongo.

		Pool site				Riffle site			
		Before structures	After complex structure	After simple structure	Control plot in pool site	Before structures	After complex structure	After simple structure	Control plot
Fish species	Feeding group (Greewood,1966)	Total	Total	Total	Total	Total	Total	Total	Total
Amphilliuslujanii	insectivorous	47	54	45	17	27	61	34	-
Coptodonrendalli	insectivorous	48	43	12	20	45	68	15	45
Tilapia sparrmanii	insectivorous	15	34	16	16	55	69	6	55
Zaireichthysrotundiceps	insectivorous	10	19	7	16	76	43	11	76
Labeobarbusaltianalis	insectivorous	8	47	-	14	-	-	6	-
Total for this feeding group		128	197	80	83	203	241	72	176
The percentage for this group		45.4	36.8	31.7	34.0	73.0	51.2	21.1	72.1
Labeovictorianus	Herbivorous	4	5	12	6	8	10	12	8
Clariasleocephalus	Herbivorous	3	12	22	3	6	12	8	6
Clariascarsonii	Herbivorous	2	13	12	3	11	31	21	11
Cyprinuscarpio	Herbivorous	5	16	13	10	5	8	6	5
Total for this feeding group		14	46	59	22	30	61	47	30
The percentage for this group		5.0	8.6	23.4	9.0	10.8	13.0	13.7	12.3
Micropterussalmoides	Predator	6	53	6	11	3	4	62	3
Serranochromisrobustus	Predator	7	112	10	9	1	11	51	1
Total for this feeding group		13	165	16	20	4	15	113	4
The percentage for this group		4.6	30.8	6.3	8.2	1.4	3.2	33.0	1.6
Enteromiuspaludinosus	filter feeder	84	84	51	82	16	94	78	4
Barbusjacksonii	filter feeder	43	43	46	43	25	66	32	3
Total for this feeding group		127	127	97	125	41	160	110	7
The percentage for this group		45.0	23.7	38.5	51.2	14.7	34.0	32.2	2.9
Total		282	535	252	244	278	471	342	244

Note. Total= Means the total number of individuals per fish species at each site.

227 individuals) than simple structures (increment of 98 individuals). The overall treatments yielded 787 individuals at the pool site while pre-treatment sampling yielded 282. Taking the difference between the two shows that treatment at the pool site caused an increase in the number of fish individuals by 505. Comparing the overall treatments, complex treatment attracted more taxa, diversity, richness, and general fish assemblage than simple structures, while riffle treatment had more total fish individuals than pool site. This was associated with site characteristics like higher DO, neutral pH, and lower temperature at the riffle site.

Influence of woody debris restoration technique on fish assemblage metrics from river Nabongo experimental plots

The means of data about fish metrics obtained from the experimentation plots for all the four sampling campaigns were summarised in Table 2. A one-way ANOVA was used to explain the distribution of the fish assemblage metrics, as summarised in Table 2.

From Table 2, at the pool site, the highest mean wet weight of fish was associated with complex structures at the pool site with 17.5±0.27 g, followed by simple structures with 13.3±0.15 g. The lightest average wet weight was registered at the pool site before structures were introduced in the stream with 8.2±0.89 g. Generally, the average wet weight distribution varied significantly from plot to plot at $P<0.05$. The mean fish biomass followed the same order of effect by structures, with complex structures having the highest standing crop with 864.65±248.65 g/m^2, followed by simple structures with 459.28±0.75 g/m^2. One-way ANOVA results indicated that there was no significant difference in biomass among the study sites ($P>0.05$) apart from complex structures ($P<0.05$). Unlike the pool site, at the riffle site, the heaviest mean wet weight was recorded in the simple structures and control plot with 21.6±0.26 g and 12.1± 0.32 g, respectively, while the lightest was recorded at the site before structures were introduced in the stream system with 11.4±0.29 g. This means that the simple structures increased the mean wet weight of fish by 10.2 g. Apart from simple structures that differed significantly from the rest of the sampling plots at $P<0.05$, the distribution of wet weight was similar in other sampling plots at $P>0.05$. The mean fish biomass was highest in the complex structures with 667±262 g/m^2 but lowest in simple structures with 46.8±0.01 g/m^2, while before structures were introduced in the stream, the biomass stood at 264.4±0.18 g/m^2. Complex structures increased the standing crop by 403 g/m^2. The distribution of mean biomass varied significantly from plot to plot at $P<0.05$.

At the pool site, the total fish density varied significantly from plot to plot ($P<0.05$) but was highest in the complex structures with 64±1.08 fishes/m^2 and lowest with 24±0.82 idv m^{-2} before the introduction of restoration structures. At the riffle site, apart from simple structures, there was no significant difference in the distribution of fish density at all the sampling plots ($P>0.05$). The fish density was highest in complex and simple structures with

Table 2. Influence of woody debris restoration technique on fish assemblage metrics from river Nabongo experimental plots.

Sampling plots	No. Of fish	Mean wet weight (g)	Mean Fish density (Number/m^2)	Mean fish biomass(g/m^2)	Mean K-factor	Mean Diversity	Mean Richness	Mean Relative Abundance
				Pool site				
Control plot	244	9.9±0.41^a	29±1.47^a	287±0.10^a	2.1±0.18^a	1.31±0.01^a	9±0.41^a	18.6±0.26^c
Before structures	282	8.2±0.89^d	24±0.82^d	192.65±0.26^a	1.9±0.07^a	0.63±0.01^c	6±1.08^b	21.5±0.42^b
After simple structure	252	13.3±0.15^b	35±1.08^b	459.28±0.75^a	2.9±0.14^b	0.58±0.01^c	10±1.08^a	19.2±0.16^c
After complex structure	535	17.5±0.27^c	64±±1.08^c	864.65±248.65^b	3.2±0.04^b	0.97±0.03^b	11±0.41^a	40.7±0.66^a
				Riffle site				
Control plot	244	12.1±0.32^a	29±0.82^a	352.33±0.55^a	2.2±0.04^a	1.32±0.01^c	5±0.82^c	18.3±0.01^d
Before structures	278	11.4±0.29^a	23±0.01^a	264.4±0.18^c	2.4±0.04^a	1.20±0.01^d	7±0.41^b	20.8±0.37^c
After simple structure	342	21.6±0.26^b	47±0.82^b	46.8±0.01^d	4.6±0.18^b	1.58±0.05^a	9±0.41^a	25.85±0.25^b
After complex structure	471	11.9±0.46^a	56±1.47^a	667±262^b	2.5±008^a	1.49±0.01^b	9.75±0.63^a	35.3±0.08^a

*Different sampling plots with different letters (a, b, c and d) in the same column per site indicate significant differences at a 5% level.

56±1.47 fishes/m^2 and 47±0.82 idv/m^{-2}, respectively, but lowest at the site before the introduction of structures with 23±0.01 fishes/m^2. This means that while complex structures increased the density by 33 idv/m^{-2}, simple structures increased it by 24 idv/m^{-2}. Simple structures significantly differed from the rest of the sampling plots at P<0.05.

ANOVA results indicate that K-factor did not vary significantly in untreated plots (before structures and control plot)at the pool site but was significantly different from that in treated (complex and simple structures) plots at P<0.05. Generally, all the fish were healthy since their K-factor exceeded one but were healthiest in complex treatment with 3.2±0.04 than simple structures and untreated plots like 1.9±0.07 before structures. At the riffle site, the healthiest fish were associated with the simple structures at an average K-factor of 4.6±0.18, while the rest of the sampling plots registered K- factor values ranging between 2.2±0.04 at the control plot to 2.5±008 at the complex structures. Compared with before the introduction of structures where k- factor was 2.4±0.04 indicates that complex restoration structures increased the fish well-being by 0.1 while simple structures increased fish well-being by 2.2 (twofold). The mean K-factor did not vary significantly from one sampling plot to another (P>0.05) apart from the simple structures.

Fish species diversity at the pool site was highest in the control plot with 1.31±0.01 and lowest in simple structures with 0.58±0.01. This varied significantly from site to site, while species diversity varied significantly from sampling plot to sampling plot at P<0.05 at the riffle site but was highest in simple and complex structures with 1.58±0.05 and 1.49±0.01 respectively but was lowest at the site before structures were introduced at 1.20±0.01.

The distribution of fish species richness at the pool site did not vary significantly from plot to plot (P<0.05) apart from before structures but was highest in complex structures with 11±0.41 and lowest in before structures with 6±1.08. On the other hand, species richness at the riffle site was highest in the complex structures with 9.75±0.63 but lowest in the control plot with 5±0.82. Richness distribution did not vary in the treated plot (P> 0.05) but varied significantly during control and before structure introduction at P<0.05.

The relative abundance of fish species at the pool site was highest in the complex structures with 40.7±0.66% and 21.5±0.42% before structures but was least in the control plot. It varied significantly from plot to plot at P<0.05. Complex and straightforward structures registered the highest relative abundance of fish species with 35.3±0.08% and 25.85±0.25percent, respectively, while the lowest abundance was registered in the control plot with 18.3±0.01percent. The relative abundance varied significantly from one sampling plot to another at P<0.05.

Discussion

Influence of woody debris restoration technique on fish assemblage and feeding

The overall number of fish individuals increased from 282 in pre-treatment to 535 in complex treatment, more than untreated plots at the pool site. This is because most fish found refuge against flow velocity in woody debris than in bare plots. This is similar to what Cederholm *et al*. (1997) noted when they indicated that introducing woody debris in a stream channel potentially causes changes in fish assemblages, especially species abundance and composition.

There were more predators in the control plot than in simple structures. This is because most predator fish species were more prominent than their prey. The prey fishes manoeuvred in structures, and their predators could not manoeuvre in the smaller spaces where these small prey fishes could hide. Minello & Zimmerman (1983) explained that complex structures protect prey fishes from predators.

The total number of individuals in control plots was less than in the pre and post-treatment. Complex structures at the riffle site caused an enormous positive impact on fish ecology (increment of 227 individuals) than simple structures (increment of 98 individuals). This is because complex structures broke the flow velocity more than the superficial ones. Hence complex structures were spawning grounds for fish since they were least affected by flow current. The fingerings evidenced this, and spawning eggs were observed at the poolside in the complex structures. DeVore & White (1978) noted a similar finding and found that adding plywood boards increased the number of brown trout that used the boards as velocity refugees by 1.4 times. The plywood provided a tactile stimulus that was attractive to the fish.

At the riffle site, the total number of fish harvested before the woody debris was 203, while that in the superficial structures was 72. This is because predators increased from four before the establishment of structures to 113 after the establishment of structures in this plot, so they preyed on many fishes, thereby reducing their numbers. This does not mean that structures do not work, but predator fishes must be regulated at sites like this. Kristal *et al*. (2008) found a similar scenario, who found that, in the river channel, the average species richness of fishes captured from reference plots lacking structure was more than fivefold more incredible than the average number captured from patches with structures. It further noted that the average abundance of fish captured from reference plots lacking structure was significantly more significant than the average abundance from patches with woody debris.

Influence of woody debris restoration technique on fish assemblage metrics

The fish density was highest in complex and simple structures with 56±1.47 fish idv/m^{-2} and 47±0.82 idv/m^{-2}, respectively but lowest at the site before the structures with 23±0.01 idv/m-2. This is because Woody debris introduced in the stream reduced the flow velocity and increased the refuge of fish from predators, increasing their numbers and population density. This is similar to what Crook *et al*. (1999) had observed in North America, where woody debris decreased predation risk by reducing the contact and interactions between fish (prey) and their predators in complex structures.

The fish diversity at the riffle site was highest in simple and complex structures with 1.58±0.05 and 1.49±0.01, respectively but was lowest in the plots before the introduction of structures with 1.20±0.01. This is probably due to the high velocity that was accelerated in the wet season that caused high mortality of juvenile fishes and due to lack of refugee positions; they were highly exposed to their predator counterparts, which could have reduced their diversity in untreated plots. This is in line with the observation made by Cederholm *et al*. (1997) that the metabolic rates of fish decline under high-velocity currents, leading to a decrease in their ability to avoid predators, which reduces their population.

The relative abundance of fish species was highest in the complex structures with 40.7±0.66% and 35.3± 0.08% at pool and riffle sites, respectively but was least in the control plots with 18.6±0.26 and 18.3±0.01% at the pool and riffle sites respectively. This is in line with Beechie & Bolton (1999), who had earlier noted that woody debris is known to influence fish microhabitat, which in turn influences the distribution and abundance of stream fish.

An experiment carried out in the River Mississippi in central North America about the importance of woody debris introduction in streams as compared to untreated plots indicated that fish biomass was higher in treated (among woody debris) than in untreated plots (Angermeier & Karr, 1984; Lehtinen *et al*., 1997). This is in agreement with our experiment where the introduction of complex structures influenced the highest standing crop (biomass) with 864.65±248.65g /m^2, followed by simple structures with 459.28±0.75 g/m^2 at the pool site. At the riffle site, complex structures increased the standing crop by 403 g/m^2. This is because organic matter stored by woody debris and fine particle accumulations colonised by algae and biofilm provides valuable food resources for many fish species and macroinvertebrates that different fishes feed on. Hence the fishes found in woody structures had their stomachs full most of the time, accounting for the heavyweight that increased their biomasses.

Generally, fish at all sampling plots were healthy since their K-factor exceeded one, a standard indicated by Barnham *et al*. (1998) and Froese (2006), but fish were healthiest in complex treatment with 3.2±0.04 than untreated plots with 1.9±0.07 at the pool site. This is because in woody structures, fish spend less energy swimming to look for food, and more still, the food is readily available as minerals and macroinvertebrates as well as organic matter on the wood crevices all entrapped on the wood structures leading to luxuriant growth of the fish. This finding is not different from the one of Sundbaum & Näslund (1998), who examined the effects of woody debris on the growth and behaviour of brown trout in experimental stream channels and found that fish held in channels with woody debris maintained better condition than fish held in channels without any instream cover.

Species richness was highest in complex structures with 11±0.41 and 9.75±0.63 at pool and riffle sites and lowest in untreated plots with before structures at pool site having 6±1.08 and the control plot at riffle with 5± 0.82. This might be because we used complex structures of woody debris with grooves and crevices (interstices) that provided suitable refuge sites for fish of different sizes and types, given their different sizes. Hence, the predatory fishes found it hard to manoeuvre and reach their small-sized prey in complex structures, meaning that the dense and complex structures protected prey fishes from their predators hence encouraging a higher richness of fish taxa in complex structures than in bare plots (Minello & Zimmerman, 1983).

CONCLUSIONS

Most fish used the wood structures as spawning and or refuge points from the current flow of the river water. Sampling plots that had structures were more densely colonised by fish individuals, trophic groups, and taxa than those that did not have structures, an indicator that woody debris restoration is an effective restoration method that should not only be encouraged but should also be adopted by east African ecologists for sustainable river ecosystem Biomonitoring. This is because they were seen to increase biomass, fish condition, density, and diversity. Other researchers should study the influence of other in-stream ecosystems restoration techniques such as floating islands, constructed wetlands, and D-deflectors, a comparison of which with restored woody debris will enable ecologists to choose the most suitable technique to apply at different stream points.

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AUTHOR'S CONTRIBUTIONS

RT is doing research and conceptualisation, and AJ is data analysis and writing, NMW is writing, funding and editing, and A.M is data collection and research.

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