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Impact of Weirs on Decomposition Rates of *Dombeya goetzenii* (K. Schum) Leaf Litter in the River Njoro, Kenya

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ABSTRACT

Water storage impoundments have deleterious effects on the structure and functioning of running water ecosystems. Many studies have been undertaken on the impacts of large impoundments on river ecosystems. However, comparatively few researches have determined the impact of small weirs on the functioning and structure of running water ecosystems. The main objective of the current study was to determine the impact of weirs on the decomposition rates of *Dombeya goetzenii* leaf litter in the Njoro River. The study was undertaken at five study sites located along the middle reaches of the Njoro River, near Egerton University, between November 2021 and January 2022. Four study sites were situated at upstream and downstream areas (i.e., approximately 10 m) of two weirs (i.e., Treetops and Canning weirs). A reference site was situated approximately 100 m upstream from the impoundment of the first weir. Physico-chemical factors such as temperature, conductivity and nutrients (e.g., nitrates, ammonium) were determined at each study site. Additionally, decomposition rates of one of the most common tree species (i.e., *Dombeya goetzenii*) found growing along the Njoro River were determined. Leaf litter decomposition was determined using fine (100 µm) and coarse (500 µm) mesh litter bags and the negative exponential decay model was used to estimate decomposition rates (-k per day). The mean leaf litter decomposition rate was highest at the reference site (-k/day = 0.04) and lowest (-k/day = 0.02) at the upstream side of the first weir (i.e., Treetops weir). Leaf litter decomposition rates differed significantly ($p = 0.002$) between the aforementioned sites. Weirs had a significant local effect on the decomposition rates of *Dombeya goetzenii* leaf litter. The study provides crucial information to managers of riverine ecosystems about the impact of water storage weirs on an ecosystem function. The concerned government agencies should take action to prevent negative effects of weirs on riverine ecosystems.

Keywords: Damming, Litter, Decomposition, Ecology, Tropical

INTRODUCTION

Weirs are structures constructed across open water ways, such as rivers. They are constructed using a variety of materials, such as rocks, wood and concrete, and allow water to spill over to the downstream areas (Garcia de Leaniz, 2008). Weirs act as river barriers which raise the water level at the upstream areas of running water ecosystems. They are constructed for purposes such as trapping organic and inorganic debris, water storage, mitigating flooding and maintenance of surface flows for navigation and fishing (Garcia de Leaniz, 2008). Despite the various advantages of weirs, they may have detrimental effects on the ecology of running waters, such as trapping sediments, habitat modification and restricting fish movement (Poulet, 2007; Garcia de Leaniz, 2008).

Introduction of weirs along streams and rivers is considered a major setback to aquatic ecosystems functioning and biodiversity (Agoston *et al.,* 2016; Arantes *et al.,* 2022). Important theoretical concepts of riverine ecosystems such as the river continuum concept and the serial discontinuity concept consider running water ecosystems as uninterrupted ecosystems (Stanford & Ward, 2001). Moreover, the flowing water ecosystems, according to the river continuum concept, are described as a series of biotic and abiotic factors, continuously integrated from the headwaters to the river mouth (Mergou *et al.,* 2012; Schiller *et al.,* 2016).

Introduction of weirs along running water ecosystems creates a discontinuity of physico-chemical factors (e.g., temperature and nutrients) and biological communities in the river continuum, a concept referred to as the serial discontinuity concept (Stanford & Ward, 2001). Additionally, weirs tend to cause discontinuities in nutrient cycling due to sudden changes in nutrient retention at the upstream and downstream areas of weirs (Cisowska & Hutchins, 2016; Teran-Velasquez *et al.,* 2022). Introduction of weirs along running water ecosystems, thus, creates lentic and lotic systems leading to modification of abiotic factors from upstream to downstream areas (Schiller *et al.,* 2016; Jung *et al.,* 2022).

Furthermore, weirs can alter the hydraulic components, changing habitat quality and structure of lotic ecosystem communities (Martínez *et al.,* 2013; Jo *et al.,* 2022). Mueller *et al.* (2011) found a severe reduction in macroinvertebrate diversity below a dam located along a small river. The author further found that water temperature change resulting from weirs can affect the growth and development of certain families of stoneflies below the dams.

Physico-chemical factors such as stream water temperature are crucial to lotic ecosystems and faunal organisms. However, stream modifications such as weirs may alter the thermal regime of water (Chandesris *et al.,* 2019; Marteau *et al.,* 2022). Besides, the presence of weirs and small dams along streams and rivers create lentic ecosystems, affecting both the physico-chemical and biological variables (Jung *et al.,* 2022; Jo *et al.,* 2022; Marteau *et al.,* 2022). For example, Zaidel *et al.* (2021) showed that small dams warmed downstream waters, by 0.20-5.25 °C, compared to the upstream waters. According to Zaidel *et al.* (2021) the warmest temperatures were recorded near the small dams. Additionally, water temperature in dammed rivers can be influenced by their geographical location. For instance, weirs located in forested watersheds cool quickly compared to those in the open watershed (Rice & Jastram, 2015; Marteau *et al.,* 2022).

Although dissolved oxygen (DO) concentrations fluctuate naturally due to underwater photosynthesis, wind effects, and organisms' respiration, small dams and weirs may cause a sudden and steep change in DO levels (Jo *et al.,* 2022). Weirs create pools whose DO levels are inherently below or above the normal range of a naturally free flowing stream (Allan *et al.,* 2020). If the water is rich in nutrients, a massive growth of algae may occur in the pools, leading to supersaturation of DO levels. However, in the absence of photosynthetic algal production, DO concentrations can reduce below the desired levels because dams accumulate waste materials compared to free-flowing reaches of the same stream (Allan *et al.,* 2020).

One contributing factor for DO reduction in weirs is the slow physical re-aeration in the pools than in a free-flowing reach of the same stream. Re-aeration is directly linked to stream water velocity and inversely to depth (Maurice *et al.,* 2017). Since pools reduce water velocity and increase water depth, natural physical aeration may dramatically reduce (Castillo *et al.,* 2017). One of the problems of low aeration in weirs is that more oxygen is used due to lower velocities (Chandesris *et al.,* 2019). Consequently, organisms suspended in the water column and at the benthic zone of weirs utilize more dissolved oxygen to satisfy their respiratory needs, lowering DO levels (Wu *et al.,* 2019). Weir-induced alterations of physico-chemical factors, habitat and fauna can lead to modification of ecosystem functions (e.g., leaf litter decomposition) in affected river ecosystems. Given that small dams and weirs are one of the most common disturbances affecting riverine ecosystems worldwide, information on the effects of weirs on rivers and streams will guide future conservation and restoration efforts directed towards the affected ecosystems.

River Njoro is faced with unprecedented anthropogenic challenges that affect water quality, abundance and species richness of aquatic invertebrates (e.g., Mokaya *et al.,* 2004). Some of the anthropogenic activities in river Njoro include the introduction of weirs along its longitudinal gradient. Most of the previous studies focusing on the Njoro River have mainly assessed the riparian plants, effect of human-related disturbances (e.g., land use) on physico-chemical factors, organic carbon and fauna (e.g., Magana, 2001; Kibichii *et al.,* 2007; Ngari, 2010). There is still a paucity of information on how weirs affect the leaf litter decomposition process in the river Njoro ecosystem, despite the river being an important source of water for the local people and habitat for organisms. The specific objectives of the current study are: (i) to determine the effect of weirs on physico-chemical factors and litter-associated macroinvertebrates, and (ii) to determine the effect of weirs on decomposition rates of *Dombeya goetzenii* leaf litter in the river Njoro.

MATERIALS AND METHODS

Study area and sites

The Njoro River is a second order river originating from Olokurto Division, Entiyani Location, Eastern Mau, Narok County. The drainage basin of the river is about 250 km^2 and the river lies between latitude 1°14'S, 0°23'S and longitude 35°50'E, 36°4'E (Fig 1). The river drains into Lake Nakuru, having transversed through Logoman forest, agricultural farms and urban centres. Much of the rain in the drainage basin falls between April and November. However, there is a period characterized by short rains between December and March.

Three study sites (Fig. 1) were selected for study along the Njoro River base on presence of weirs along the river. The first study site was situated (0°23'S, 35°38.4'E) at an area where there were no weirs and the mean width and length of the site was 5.5 m and 30 m, respectively. The site was located about 100 m upstream of the Treetops weir along the mid reach of the river. There was a farm along the right bank while the left bank bordered Egerton University. Vegetation at the site was mainly composed of shrubs on both banks and canopy cover intensity was about 12%. The substrates were mainly composed of bedrock (70%). The second study site was located (0°23'S, 35°40.0'E) at the Treetops weir. The Ahero shopping centre is located on the right bank while Egerton University staff residential houses are located on the left bank. The weir was about 1.5 m and 15 m in height and width, respectively. The weir was constructed in 1984 by the Erithia flower farm for irrigation purposes and released surface water. There were *Syzygium cordatum* trees along the right bank. The third study site was situated (0°21'S, 35°57'E) at the downstream side of Njoro canning factory and approximately 500 m from the first weir at the Treetops area. At the upstream side of the weir there was discharge of treated waste water effluents by the Egerton University waste water treatment ponds. Abstraction of water by the local community from the weir was observed. At the Treetops and Njoro caning weir, leaf litter decomposition study was conducted 10 m above and 10 m below the weirs (Fig. 2). The objective of selecting the first study site was to act as the reference (i.e., control) site (Stoddard *et al.,* 2006). On the other hand, selection of study sites 10 m above and 10 m below the weirs was aimed at evaluating the immediate effects of weirs on water quality and leaf litter decomposition rates. Details of river bottom substrates, riparian vegetation canopy cover and slope are provided in Table 1.

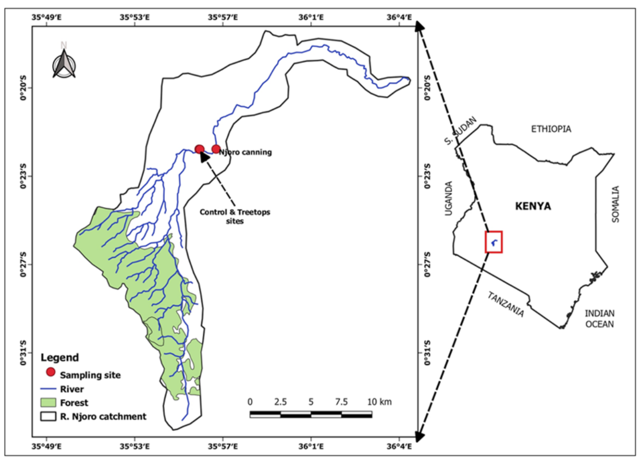

Figure 1: A map of the river Njoro drainage basin showing the sampling sites.

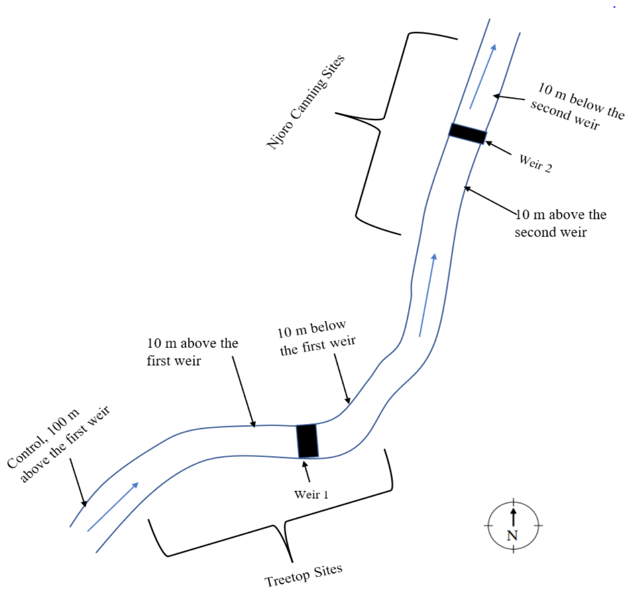

Figure 2: A diagram showing location of study sites and weirs along the Njoro River. The arrow indicates the direction of river flow.

Table 1: Details of substrate composition at the study sites.

Parameters	R	ATW	BTW	ANCW	BNCW
Substrate composition (%)					
Bedrock	70	35	80	20	25
Boulders	20	5	7	5	3
Cobbles	4	2	4	5	10
Pebbles	5	3	4	5	30
Sand, Gravel, Mud	1	55	5	65	32
Canopy cover (%)	12	50	60	41	64
Left bank slope (°)	20	60	45	25	50
Right bank slope (°)	35	50	35	40	80

R, ATW, BTW, ANCW, BNCW refers to reference, above Treetop weir, below Treetop weir, above Njoro canning weir and below Njoro canning weir.

Measurement of physico-chemical factors

Physical factors such as width, depth and length were determined on the first sampling occasion while current velocity, discharge and other factors were measured every time sampling was done. The dissolved oxygen concentration and total dissolved solids were assessed using a HACH HQ 30d meter. pH, electrical conductivity and water temperature were determined using a HACH HQ 40d meter. River width was assessed using a tape measure at 5 transects along each study site. The depth of the river was assessed using a 1-m ruler at 5 points across the river (Masese *et al.,* 2014). Current velocity was determined at 60% of the total water depth using a flow meter (OTT MF pro) and the mechanical Vale port flow meter (model 0012/B) computed the water discharge from current velocity, width and depth values.

Four water samples were obtained from each site using acid-washed water bottles for nutrients analysis. The bottles were rinsed using stream water and filled up with the same water. The water samples were placed in cool boxes and transported to the laboratory for analysis of nutrients. In the laboratory, 500 ml of the water samples were filtered using Whatman GF/C filter papers (0.45μm). 25 ml of the filtered water was used to determine nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), soluble reactive phosphorus (SRP), and ammonium-nitrogen ($NH4^+$). On the other hand, unfiltered water samples were utilized to assess the concentrations of total phosphorous (TP) and total nitrogen (TN). Ammonium was measured using the salicylate method and the concentration determined at 665 nm using a spectrophotometer (GENESYS ™ 10S UV-V). Nitrates were measured using the sodium salicylate method and the concentration determined at a wavelength of 420 nm. Nitrites were measured using the colorimetric method utilizing N-(1 naphthyl) ethylenediamine dihydrochloride solution and sulfanilic acid as the dyes. Nitrites concentration was determined at 565 nm using a spectrophotometer. Total nitrogen and total phosphorous were measured utilizing the persulphate digestion method and soluble reactive phosphorous was determined using the molybdenum blue method using 25 ml of filtered water sample. The methods of analysing chemical factors are described by APHA (2005).

Leaf Litter decomposition

The leaves of one of the most abundant riparian plant species (i.e., *Dombeya goetzenii*) found growing along the Njoro River were obtained from trees during the abscission period. The leaves were air-dried at room temperature for a period of two weeks. Five grams of the leaves were placed in coarse (500 μm) and fine mesh (100 μm) litter bags and clearly labelled. The coarse mesh litter bags were used to evaluate macroinvertebrate-mediated decomposition and the fine mesh bags were used to evaluate microbial decomposition of leaf litter (Riedl *et al.,* 2013). A total of two hundred and forty fine and coarse mesh litter bags were placed in the five study sites. The litter bags were tightened onto rocks and wooden pegs using nylon threads at about 0.3 m from each other.

Six litter bags were retrieved from each of the study sites during eight sampling occasions. The litter bags were obtained from the study sites after 2, 3, 7, 14, 21, 28, 35 and 42 days to assess litter decomposition rates with time. During retrieval of litter bags, a fine meshed net (100 µm) was positioned behind the litter bags to prevent loss of macroinvertebrates and leaf materials. After retrieval, each litter bag was placed in plastic bags, preserved using formaldehyde solution and placed in a cool box before transportation to the laboratory. The leaves were removed from each bag and rinsed using distilled water to remove sediments and other substrate. The samples were sieved using a 250 µm mesh sieve to segregate macroinvertebrates from the leaf litter. The leaves were put in khaki bags and dried at 60 °C for 48 hours in an oven to obtain dry weight. Subsequently, the oven dried leaves were placed in a muffle furnace for 4 hours at 550 °C, cooled in a desiccator and weighed suing a weighing balance to assess the ash-free dry mass. Leaf litter decomposition rates were determined using the negative exponential model:

$$W_t = W_o e^{-kt}$$

Where, W_t = remaining AFDM at time t, t = time (retrieval days), W_o = initial AFDM and k = leaf litter decomposition rate (Alvarez-Sanchez & Enriquez, 1996).

Aquatic macroinvertebrates samples were placed into a tray and identified up to family and order levels. The invertebrates were identified using a dissecting microscope. Subsequently, the samples were placed in sample bottles and preserved using 70% ethanol solution. The macroinvertebrates were categorized into functional feeding groups following Cummins *et al.* (2005). The macroinvertebrates were placed into functional feeding groups such as scrapers, predators, shredders and collectors (Tachet *et al.*, 2006).

Data analysis

Differences in physico-chemical factors, nutrients and macroinvertebrates abundance among the study sites were tested using Kruskal-Walli's test (Kruskal & Wallis, 1952). Differences in leaf litter decomposition rates among the study sites was evaluated using analysis of variance (ANOVA). Pairwise comparisons for significant models were performed using Tukey contrasts (Hothorn *et al.,* 2008). Normality of the data was evaluated using the Shapiro-wilk test and data that was not normal was tested using non-parametric test. Data was analyzed using the R statistical software (R Development Core Team, 2014).

RESULTS

Physico-chemical factors

The mean dissolved oxygen (DO) concentration was highest at the reference site (7.18 ± 0.03 mg/L) and at the site situated below the Treetops weir (7.05 ± 0.07 mg/L) (Table 2). On the other hand, the lowest mean DO concentrations were recorded at the study sites located above the Njoro Canning weir (6.64 ± 0.05 mg/L) and above the Treetops weir (6.83 ± 0.02 mg/L). The highest mean water temperature was recorded at the study site situated below the Njoro canning weir (17.18 ± 0.06 °C) and at the study site situated above the Njoro canning weir (16.89 ± 0.21 °C). The lowest mean water temperature was recorded at the reference site (15.53 ± 0.13 °C). However, the reference site had higher mean pH values (7.71 ± 0.08) than the study sites located near the weirs. The study sites located above and below the Njoro canning weir had the highest mean electrical conductivity (EC) values (> 63 *µs*/cm) while the reference site had the lowest (56.95 ± 1.68 *µs*/cm) mean electrical conductivity value. With regard to water velocity and discharge, the study site located below the Treetops weir had the highest mean values while the study sites located above the two weirs had the lowest mean velocity and discharge values (Table 2). The Kruskal-Walli's test indicated that the physico-chemical factors differed significantly among the study sites (all $p < 0.05$, Table 2).

The study sites located above (4.15 ± 0.08 mg/L) and below (2.66 ± 0.07 mg/L) the Njoro Canning weir had the highest mean nitrate values while the reference site (1.19 ± 0.01 mg/L) had the lowest mean nitrates value (Table 3). Similarly, nitrites, total nitrogen, total phosphorous and soluble reactive phosphorous had the highest mean values at the study sites located above and below the Njoro canning weir while the reference site had the lowest mean values for the aforementioned nutrients (Table 3). The Kruskal-wallis test indicated that the nutrients concentration differed significantly among the study sites (all $p < 0.05$, Table 3).

Macroinvertebrates

The mean macroinvertebrate density was highest (100.24 ± 29.58 individuals/litter bag) at the reference site and lowest at the above Njoro Canning weir site (5.4 ± 2.21 individuals/litter bag) and below the Njoro Canning weir site (10.04 ± 3.77 individuals/litter bag). Species richness was highest at the reference site (22) and lowest at the above Njoro Canning weir site (8) and above the Treetops weir site (9). With regard to macroinvertebrate functional feeding groups, scrapers had the highest mean density at the reference site (150.78 ± 70.71 individuals/ litter bag) and lowest mean densities at the above the Njoro Canning weir site (2.67 ± 2.02 individuals/litter bag) and below the Njoro Canning weir site (8.11 ± 6.52 individuals/litter bag). A similar trend was observed for predators where the highest mean density was recorded at the reference site (63.5 ± 24.10 individuals/litter bag) and the lowest mean density was recorded at the above the Njoro canning weir site (10.7 ± 4.89 individuals/ litter bag) and below the Njoro canning weir site (10 ± 2.68 individuals/litter bag). Shredders were only recorded at the reference site and below the Treetop weir site. Kruskal-wallis test indicated that macroinvertebrate density differed significantly among the study sites (H = 12.32, d.f. = 4, p <0.05). Kruskal-wallis test also indicated that collectors (H=7.23, d.f. = 4, p < 0.05), predators (H = 5.38, d.f. = 4, p < 0.05) and scrapers (H=8.72, d.f. = 4, p < 0.05) differed significantly among the study sites.

Leaf litter decomposition rates

The highest mean leaf litter decomposition rate was recorded at the reference site and at the study site located below the Treetops weir (Table 4, Figure 3). On the other hand, the lowest mean leaf litter decomposition rates were recorded at the study sites located above the Njoro canning weir and below the Njoro canning weir (Table 4). With regard to the litter bags mesh size, the fine mesh litter bags (-k/day = 0.01 – 0.04) had relatively lower mean leaf litter decomposition rates than the coarse mesh litter bags (-k/day = 0.02-0.08) (Table 4). Analysis of variance indicated that leaf litter decomposition rates differed significantly among the study sites (ANOVA, $F_{(1,200)}$ = 60.19, p = 0.0004). Tukey contrasts indicated that leaf litter decomposition rates differed significantly between the reference site and above the Treetops weir (p = 0.002). Tukey contrasts also indicated that leaf litter decomposition rates differed significantly between the reference site and the site located above the Njoro canning weir and between the reference site and the site located below the Njoro Canning weir (all p<0.05). However, Tukey contrasts indicated that leaf litter decomposition rates did not differ significantly (p = 0.98) between the control site and the study site located at the downstream side of the Treetop weir.

Table 2: Mean (±SE) values for physico-chemical factors at the sampling sites.

Parameters	R	ATW	BTW	ANCW	BNCW	H-value	*p*-value
DO (mg/L)	7.18 ± 0.03	6.83 ± 0.02	7.05 ± 0.07	6.64 ± 0.05	6.92 ± 0.02	54.71	0.002
Temperature (°C)	15.53 ± 0.13	15.90 ± 0.13	15.81 ± 0.06	16.89 ± 0.21	17.18 ± 0.06	25.1	0.002
pH	7.71 ± 0.08	5.89 ± 0.18	7.67 ± 0.04	6.07 ± 0.20	7.45 ± 0.02	70.42	0.004
EC (µs/cm)	56.95 ± 1.68	62.52 ± 1.50	59.57 ± 1.49	66.64 ± 1.70	64.60 ± 2.12	18.78	0.003
Velocity (m/s)	0.07 ± 0.03	0.01 ± 0.00	0.09 ± 0.04	0.01 ± 0.00	0.06 ± 0.02	91.84	0.001
Discharge (m^3/s)	0.03 ± 0.01	0.02 ± 0.01	0.05 ± 0.03	0.02 ± 0.01	0.04 ± 0.02	94.86	0.003

R, ATW, BTW, ANCW, BNCW refers to reference, above Treetop weir, below Treetop weir, above Njoro canning weir and below Njoro canning weir.

Table 3: Mean (±SE) nutrients concentration at the study sites.

Nutrients	R	ATW	BTW	ANCW	BNCW	H-value	*p*-value
Nitrates (mg/L)	1.19 ± 0.01	1.30 ± 0.01	1.21 ± 0.01	4.15 ± 0.08	2.66 ± 0.07	95.51	0.003
Nitrites (µg/L)	13.09 ± 0.33	27.70 ± 0.68	22.72 ± 0.40	34.68 ± 0.45	31.06 ± 0.63	90.99	0.001
Total Nitrogen (mg/L)	6.50 ± 0.31	16.57 ± 0.68	11.72 ± 0.48	22.62 ± 0.47	17.93 ± 0.39	89.26	0.003
Total Phosphorous (µg/L)	33.95 ± 0.58	51.66 ± 1.33	36.29 ± 0.44	72.38 ± 1.04	66.67 ± 0.86	89.26	0.001
Soluble Reactive Phosphorous (µg/L)	22.55 ± 0.72	44.89 ± 0.64	34.99 ± 0.66	85.27 ± 0.97	78.97 ± 0.86	97.44	0.002

R, ATW, BTW, ANCW, BNCW refers to reference, above Treetop weir, below Treetop weir, above Njoro canning weir and below Njoro canning weir.

Table 4: Mean leaf litter decomposition rates (-k/day) in fine and coarse-mesh litter bags and time (days) for 50%, 80% and 90% for the *Dombeya goetzenii* leaves to be decomposed.

Sites	Mesh-size	-k/day	50%	80%	90%
R	Fine	0.04	22	52	75
	Coarse	0.08	15	38	55
ATW	Fine	0.02	35	77	109
	Coarse	0.04	25	57	80
BTW	Fine	0.03	25	58	84
	Coarse	0.07	20	50	72
ANCW	Fine	0.01	39	84	119
	Coarse	0.02	37	83	118
BNCW	Fine	0.01	38	84	119
	Coarse	0.04	35	81	116

R, ATW, BTW, ANCW, BNCW refers to reference, above Treetop weir, below Treetop weir, above Njoro canning weir and below Njoro canning weir.

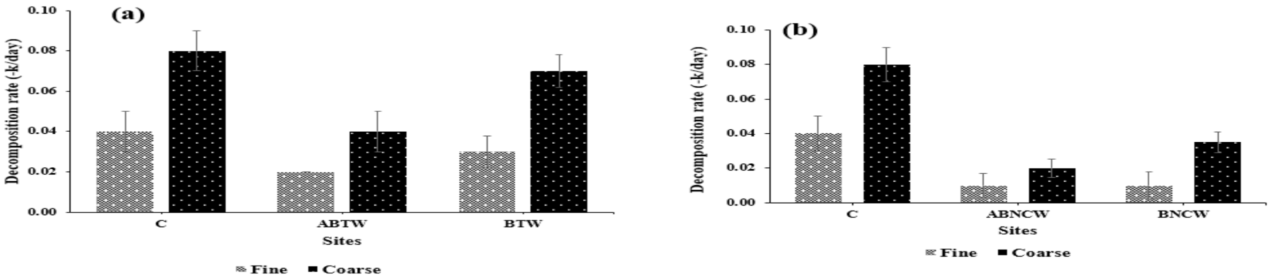

Figure 3: Leaf litter decomposition rates in fine and coarse mesh litter bags at the study sites. Figure 3 a compares the reference site (C) with study sites (ABTW, BTW) located at the Treetops weir and Figure 3 b compares the reference site with study sites (ABNCW, BNCW) located at the Njoro canning weir.

DISCUSSION

The highest leaf litter decomposition rate was recorded at the reference site while the lowest leaf litter decomposition rates were recorded above and below the Njoro canning weirs. The high leaf litter decomposition rates at the reference site could be due to the absence of major human-related disturbances which could affect stream water physico-chemical factors (e.g., velocity) and leaf litter decomposition rates.

Weirs convert stream ecosystems into lentic ecosystems where the flow of the river is inhibited by the dam. This reduces leaf litter breakdown by physical abrasion due to reduced water velocity. Water velocity is a major driving force for the decomposition of organic materials such as leaves and twigs in aquatic ecosystems through physical abrasion effects (Abril *et al.,* 2021). The low leaf litter decomposition rates at the study sites located above the weirs could be due to reduced water velocity and discharge. On the other hand, high water velocity and discharge below the weirs could have resulted in higher leaf litter decomposition rates through increase in physical abrasion effects.

Weirs and dams have an effect on nutrient concentrations in river water and this may affect leaf litter decomposition process through stimulation of organisms such as microbes (e.g., fungi) and invertebrates (Gessner *et al.,* 1999; Pascoal and Cássio, 2004). For example, Menéndez *et al.* (2012) evaluated the effect of small impoundments on leaf litter decomposition in streams and found that the presence of dam affected leaf litter decomposition depending on water release mechanism of reservoirs. In impoundments with surface release mechanism, decomposition rates were slower at the downstream areas of the dam whereas for those with hypolimnetic release mechanism it was faster at the downstream areas. The high leaf litter decomposition rates at the downstream areas of impoundments with hypolimnetic release was associated with high concentrations of nutrients (e.g., dissolved inorganic nitrogen) and temperature, and high densities of invertebrate shredders.

Although high concentrations of nutrients in rivers may lead to high microbial-mediated litter decomposition rates, high nutrient concentrations at the upstream areas of the weirs in the current study did not result in higher leaf litter decomposition rates. The possible reason for this is that the weirs possibly accumulated other toxicants (e.g., heavy metals) which had a negative effect on organisms (e.g., invertebrates) and leaf litter decomposition process. For example, Colas *et al.* (2013) evaluated the effect of dams on leaf litter decomposition in streams and found that presence of toxicants (e.g., heavy metals) in impoundments led to modification of invertebrate assemblages (e.g., shredders) and reduction of leaf litter decomposition rates.
Weirs can also affect the leaf litter dec
omposition process by modifying physico-chemical factors such as fine sediment and dissolved oxygen content. At the study sites located above the Treetop and Njoro canning weirs, low dissolved oxygen concentrations were recorded when compared to the study sites located at the downstream areas of the weirs and this could have led to the low leaf litter decomposition rates. Low dissolved oxygen content can have negative effects on organisms involved in leaf litter decomposition, such as invertebrate shredders, and cause a reduction in leaf litter decomposition rates. The reason for lower dissolved oxygen concentrations at the upstream areas of weirs is that weirs are likely to retain sedimentary organic materials and microbes may use extra oxygen for respiratory purposes during organic matter decomposition. This finding is supported by Mueller *et al.* (2011) whose findings revealed low oxygen concentrations at the upstream areas of weirs due to biological oxygen demand by microbial organisms.

Reduced water turbulence and mixing at the upstream areas of weirs can also lead to reduced oxygen concentrations. Weirs may also lead to increased accumulation of fine sediment in rivers and interfere with leaf shredding invertebrates' habitats. This may probably be another reason why leaf litter decomposition rates were lower at the study sites located above the weirs when compared to the reference site. According to Muehlbauer *et al.* (2008), weirs increase the sedimentation effect, causing insufficient oxygen for macroinvertebrates and microbial activities. Increase in the amount of deposited sediment also reduces accessibility and fragmentation of leaf litter by macroinvertebrates through burial of organic materials (Carter & Marks, 2007; Muehlbauer *et al.*, 2008).

Other studies conducted in other regions of the world also found that impoundments created by small dams had an effect on leaf litter decomposition rates in rivers. For example, Pinna *et al.* (2003) found that leaf litter decomposition rates above a weir were low while higher decomposition rates were recorded below the weir. Mendoza-Lera *et al.* (2012) evaluated the effect of small impoundments on leaf litter decomposition rates in Spain and found that leaf litter decomposition rates were significantly lower below the dams. Low leaf litter decomposition rates below the dams were mainly associated with reduction in density of shredder invertebrates. However, there were no significant variations in physico-chemical factors between the study sites. Another study conducted in Germany evaluated the effect of small impoundments on leaf litter decomposition rates and found that the impoundments did not have a significant effect on most physico-chemical factors. However, the density of invertebrate shredders and leaf litter decomposition rates were lowest at the study sites located immediately above the impoundments (Mbaka & Shäfer, 2016).

CONCLUSION

The weirs decreased leaf litter decomposition rates at the study sites located above the weirs. Weirs also caused an increase in physico-chemical factors such as nitrites, nitrates, total phosphorous at the study sites located above the weirs. However, some factors such as water velocity, pH, discharge and invertebrates density decreased at the study sites located above the weirs. Therefore, weirs can have an effect on physico-chemical factors, invertebrates and leaf litter decomposition rates in study sites located close to the weirs. Future studies should evaluate the effect of weirs on other ecosystem functions such as metabolism.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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