



Effect of a Weir and Plant Species on Leaf Litter Decomposition in River Kapingazi, Embu, Kenya

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Abstract

Leaf litter decomposition is an essential source of energy for stream food webs. However, there is limited information on weirs and plant species' Effects on leaf litter decomposition in Kenyan streams. This study's objective was to Evaluate the Effect of a weir and plant species on leaf litter (*Lantana Camara*, *Eucalyptus Grandis*, *Psidium guajava*) decomposition in River Kapingazi, Embu County, Kenya. The study adopted a longitudinal study design and involved five study sites (i.e., Further Downstream site, Further Upstream site, Weir area, Immediate Downstream site, Immediate Upstream site) Kapingazi River. The results showed differences in leaf litter decomposition rates among the three plant species at all sites and following decreasing order: *Lantana sp.* > *Eucalyptus sp.* > *Psidium sp.* The *Lantana sp.* had the highest mean leaf litter decomposition rate ($31 \pm 5\%$ A.F.D.M. gd^{-1}) 79 at the Immediate Upstream site between day 0 and day 7. The lowest mean leaf litter decomposition rate ($0.07 \pm 2\%$ A.F.D.M. gd^{-1}) was recorded for *Psidium sp.* at the Immediate Downstream site between days 7 and 14. Plant species had a significant effect ($p = 0.004$) on leaf litter decomposition during all days of incubation, while the weir only had a significant effect on leaf litter decomposition during day 7 ($p = 0.04$) and day 28 ($p = 0.004$). Shredders were lacking among the invertebrates that colonized leaf litter. However, the highest mean water velocity (0.7 ± 0.04 m/s) and dissolved oxygen (8.9 ± 0.3 mg/l) concentration were recorded at the Immediate Upstream site. In conclusion, plant species and river regulation structures such as weirs are essential factors for the leaf litter decomposition process in streams. It is recommended that future studies should evaluate other anthropogenic disturbances (e.g., wastewater effluents and mining) and the effects of leaf litter mixtures on the decomposition process.

1. Introduction

Leaf litter decomposition is one of the significant ecological mechanisms that maintain river ecosystem integrity and food webs by sustaining services such as nutrient cycling and energy transfer [1]. Decomposition refers to the process by which coarse particulate organic matter (CPOM), comprising of leaves, fruits, wood debris, barks, and other CPOM, is degraded into delicate particulate organic matter (F.P.O.M.), which is utilized as a source of energy in food webs [2]. CPOM originates from terrestrial riparian vegetation and in-stream vegetation, such as macrophytes and algae [3]. Out of all forms of CPOM, leaves appear to have a more significant contribution to nutrient cycling due to high biomass among the terrestrial litter resources [4, 5, 6]. However, anthropogenic activities continue to disturb river ecosystems through activities such as a change in flow regime [7], pollution [8], introduction of invasive species [9], and deforestation [10].

Anthropogenic disturbances, such as damming, affect leaf litter decomposition by causing notable changes in water quality, affecting macroinvertebrates and microorganisms' composition and structure. Further, damming lowers the breakdown of leaf litter by retaining fine sediment, which may be unfavorable for some detritivores by modifying the streamflow regime, which influences leaf breakdown through physical abrasion [11]. Damming affects leaf litter decomposition through a change in water quality in the upstream and downstream areas of a dam in Central Japan [12]. Changes that alter water chemistry influence the structure, diversity, and activity of biological communities that control the decomposition process [13]. For instance, Aluminum was found to increase the pH of streams affected by acidification hence inhibited litter decomposition [14].

A global assessment of the Effect of non-native riparian plant species along rivers showed that *Eucalyptus sp.* plantations led to reduced diversity, density, and biomass of macroinvertebrates such as shredders. This reduced leaf litter decomposition significantly in temperate regions [15]. Leaf litter decomposition is higher in human-disturbed sites as compared to undisturbed sites in Malaysia [16]. This observation was attributed to higher microbial activity, temperature, and abrasive action caused by sediments and garbage at the urban sites. Increased nutrient load also explained the observation by the authors. Elsewhere, organic matter breakdown was reduced by damming in a tropical savanna stream [17]. The previous observation was attributed to decreased microbial activity and macroinvertebrate activity in and downstream of the dam. The rate of organic matter breakdown depends on the climate, leaf litter quality, and the rate of consumption and colonization by microbes and shredder macroinvertebrates [18]. Species-specific breakdown depends on the stream's area where the experiment is conducted, the time of the year, the role of microorganisms, presence, the activity of macroinvertebrate shredders, and other stream-specific factors [19]. Variation in breakdown rates for species is driven by litter chemistry which entails nitrogen, lignin, and phosphorous content [20]. However, human activities may alter the dynamics of nutrient cycling by introducing invasive plant species, which may affect the dynamics of organic matter decomposition in streams. Furthermore, the increased quantity of exotic leaf litter for the breakdown in streams may alter aquatic ecosystem functionality due to macroinvertebrates' structure and composition [21].

Most studies have considered leaf litter decomposition of native abundant plant species at their study areas. In contrast, less attention has been given to the abundant exotic plant species around streams, which have been suggested to potentially change stream ecosystem functionality [22, 23, 24]. Additionally, relatively few studies have compared leaf litter decomposition between native and non-native plant species. This study aimed to Assess the Effect of a weir and plant species (*Lantana Camara*, *Eucalyptus Grandis*, *Psidium guajava*) on leaf litter decomposition rates in the Kapingazi River, Embu County, Kenya. It was hypothesized that a weir and the type of plant species from which the leaves came from would affect leaf litter decomposition by modifying Physico-chemical variables and densities of shredding invertebrates

2. Methodology

2.1 Study area and study sites

The study was conducted at River Kapingazi that drains into River Rupingazi, a tributary of River Tana, the largest river in Kenya [25]. Kapingazi River is situated at the South-Eastern slopes of Mount Kenya. It is found at the upper catchment area of River Tana, where human-induced ecosystem degradation such as deforestation, increased subsistence farming and erosion at the river banks and planting of gum trees (*Eucalyptus spp.*) are common [26]. The catchment soil is primarily made up of Eutric, Astrosols, Andosols, and Nitisols [27]. The catchment lies at an altitude ranging from 1200 to 2100m above sea

level. The river is 27km long, and the catchment area covers 61.23 square kilometers. The average rainfall ranges between 1200 and 1800 mm per year, while the atmospheric temperatures range from 21.2 °C to 27.1 °C. The catchment area has a bimodal rainfall pattern, with heavy rains between March and May and the dry period between June to September. However, the patterns have become less predictable in the past few years, presumably due to climate change.

Five study sites were selected in the upstream and downstream areas of a constructed weir (reservoir volume <50,000 m³, 27km along the Kapingazi River. The weir was the significant observable human disturbance to the river along the studied reach. Study sites included a control site located further upstream (4.53 km) (i.e., Further Upstream site) and a site located further downstream (300 m) (i.e., Further Downstream site) from the weir to evaluate differences in decomposition rates further away from the weir. Additional sites were located within the weir (i.e., Weir area), immediately downstream (6 m) from the weir (i.e., Immediate Downstream site), and immediate upstream (40 m) from the weir (i.e., Immediate Upstream site) to evaluate litter decomposition dynamics in and near the weir.

The Weir area (W.A.): a constructed weir (W.A.) (00° 29' 57.1" S – 037° 27' 41.0" E) was the defining human activity. The weir released surface water, and its size was 14 m wide and 5.5 m in height. There was a maize plantation on either side of the river. There was also a banana plantation and sedge grass (*Carex* sp.) on either side of the river. On the left bank, a student hostel was observed. In-stream, the substratum of the weir was dominated (97%) by silt. Hydro-morphologically, the site was 100% pool, and the riparian vegetation canopy cover at the area was 40%. The Immediate downstream site (I.D.S.) (00° 30' 17.8" S – 037° 27' 46.8" E) was 6 m from the weir and next to a bridge. In-stream, it was dominated (30%) by gravel and was mainly a riffle. The riparian vegetation canopy cover was 40%. The Immediate upstream site (I.U.S.) (00° 29' 57.1" S – 037° 27' 41.0" E) was 40 m from the weir wall. The left bank had a nursery for vegetables and a small-scale farm of kales (*Brassica oleracea*) and spinach (*Spinacia oleracea*). *Lantana Camara* was the most familiar plant species observed along the riverbank on this site. Guava trees (*Psidium guajava*) were less abundant than *Lantana sp.* There was a solid waste dumping site observed just next to the vegetables' farm. Throughout the study period, fetching of water and washing of clothes along the river bank was observed. The right bank was characterized by sedge grasses, *Psidium guajava* trees, and a Napier grass (*Pennisetum purpureum*) plantation.

A stand of *Croton megalocarpus* and *Grevillea robusta* trees was observed on this bank. There was a plantation of maize (*Zea mays*) and bananas (*Musa sp.*) among the trees. In-stream, the site was dominated (90%) by bedrock and was mainly a riffle/run (80%). The riparian vegetation canopy cover at the site was estimated at 30%, and the site was unimpaired by the weir. The other downstream site (F.D.S.) (00° 30' 22.2" S – 037° 27' 48.9" E) was further downstream from the weir (300 m). It was characterized by a *Eucalyptus grandis* plantation on the right bank. Other species observed included bougainvillea (*Bougainvillea sp.*) and calliandra (*Calliandra sp.*) trees. The left bank activities included a tree nursery for plants such as mangoes (*Mangifera indica*) and silky oak (*Grevillea robusta*). The site was dominated by boulders (70%) and was mainly a riffle (60%). The other upstream site (F.U.S.) (00° 30' 15.2" S – 037° 27' 42.6" E) was the farthest site from the weir area site (4.53 Km). It is located along the Nairobi to Meru highway with a bridge where the river crosses the road. The surrounding riparian vegetation did not shade the site. On both sides of the riverbank, vegetation thicket formed by *Lantana Camara* and *Psidium guajava* trees were observed. On the left bank, sedge grass was observed. People were occasionally observed to wash clothes on the river banks, but disturbances within the river bed were minimal. In-stream, the site was dominated by bedrock (40%) and is mainly a riffle (80%). The riparian vegetation canopy cover is estimated at 30%.

2.2 Physico-chemical Variables

Temperature (°C) of the water was measured using a combined T.D.S./temperature meter, Jenways model 4075 (Jenway Essex, UK) with the reading of T.D.S. corrected to 25 °C. Dissolved oxygen (mg/l), pH, and conductivity (μScm^{-1}) readings were taken using a calibrated Jenway 3405 electrochemical analyzer (Barloworld Scientific Ltd, Dunmow, Essex, UK). The various sites' average water depth was computed from measurements taken on a transect across the river channel where the litter bags were placed for observation. Current velocity was estimated by timing afloat over a distance of 5 metres [11]. A stopwatch was used to measure the time taken by the float to travel the distance. The stream velocity was estimated by dividing the distance by the interval time [28]. Five replicate trials following this method were conducted and averaged for each flow velocity estimated. During sampling of water for quality analysis, water was collected from different sites to get a composite sample. Three replicates were collected on each site. The water samples were collected by immersing a bottle pre-cleaned with distilled water and then transferred into pre-cleaned plastic sampling bottles. The samples were then preserved at 4 °C prior and transported to the Water Resources Authority (W.A.R.M.A.) laboratory for analyses. Standard spectrophotometric methods were used as described by [29].

Benthic substrates were assessed visually at each study site and categorized as “boulders” >250 mm, “gravel” >10 - 64 mm, “sand and silt” <0.06 - 2 mm [11]. Canopy cover was also estimated visually [11].

2.3 Leaf Litter Decomposition and Invertebrates

Leaves of *Lantana Camara*, *Eucalyptus Grandis*, *Psidium guajava*, the most common and abundant exotic plant species along River Kapingazi, were collected on 3 September 2018 from trees around the study sites. Mature leaves with minimal or no damage were used in the experiment. The leaves were air-dried for 5 days until they reached a constant dry mass (D.M.) and stored in a dark room. Approximately five grams (± 0.05) of the dried leaves were placed into a coarse mesh (measuring 15 by 15 cm; pore-size: 1mm) leaf litter bags, allowing medium-sized macroinvertebrates to colonize and feed on the leaves [11]. Litter bags arranged in sets of three replicates per plant species were deployed at each study site. A total of 180 litter bags were deployed in the sites. The leaf bags were deployed by securing them onto wooden poles. The bags were also secured by tying them onto rocks. The bags were anchored in shallow ends near the river bank where they would not be affected by high flows. An extra set of three litter packs was deployed and retrieved immediately to determine handling and leaching losses and correct the other bags' initial dry weight.

The incubated leaf bags were retrieved in sets of three every seven days from the stream by placing a 250-micrometer mesh dip net under the leaf packs and transferring the contents of the packs and net into labeled zip-lock plastic bags [29]. The experiment lasted for 28 days in both experimentation times (i.e., September, November/December 2018). The retrieved litter bags were transported to the laboratory in a cooler. The leaf litter from each bag was rinsed thoroughly with distilled water on a 250-micrometer sieve to remove sediments and associated macroinvertebrates. The litter was then oven-dried for 24 hours at 60 °C and weighed to determine dry leaf weight to the nearest 0.1g. Leaf litter was combusted at 500 °C for 12 h and weighed to determine ash weight. Ash-free dry weight was determined by subtracting ash weight from dry weight, and leaf litter decomposition was expressed as % ash-free dry mass grams per day (% A.F.D.M. gd^{-1}).

The collected fauna was conserved in 70 % ethanol for later analyses to determine the functional feeding and macro invertebrates' abundance [29, 30]. Abundance was expressed as the number of invertebrates present per litter bag (individuals bag^{-1}). The macroinvertebrates were observed through a dissecting

microscope, identified to the family level, and allocated to appropriate functional feeding groups according to [31].

The study site location and plant species on leaf litter degradation rates were tested using linear mixed effect models, with study site location and plant species being the fixed factors. Study site location and plant species were included as interaction terms. The relationship between physicochemical variables and leaf litter degradation rates was evaluated using Pearson's Correlation test. The Holm correction method [32] was used to adjust p-values for multiple testing and the corrected p-values are reported. Pair-wise comparisons for statistically significant models were made using Tukey contrasts. Model residuals were tested for normality and homoscedasticity following [33]. Statistical analyses were performed using the R statistical package [34].

3. Results and Discussion

3.1 Physico-chemical Variables

The highest mean ($46.2 \pm 3.6 \mu\text{scm}^{-1}$) conductivity was recorded at the weir area while the lowest mean ($41.7 \pm 1.4 \mu\text{scm}^{-1}$) conductivity value was recorded at the Immediate upstream site. The Further downstream site had the highest mean values for total dissolved solids ($41.4 \pm 25.1 \text{ mgL}^{-1}$), phosphates ($1.8 \pm 1.8 \text{ mgL}^{-1}$), and nitrates ($3.6 \pm 1.6 \text{ mgL}^{-1}$). The immediate downstream site had the highest mean values for pH (7.8 ± 0.1) and velocity ($0.7 \pm 0.04 \text{ ms}^{-1}$). The highest mean values for temperature ($21.5 \pm 0.7 \text{ }^\circ\text{C}$) and dissolved oxygen ($8.9 \pm 0.3 \text{ mgL}^{-1}$) were recorded at the weir area while the highest mean value for nitrites ($2.4 \pm 0.7 \text{ mgL}^{-1}$) was recorded at the Immediate upstream site (Table 1). Most Physico-chemical variables (e.g., temperature, velocity, pH, nitrates) were weakly correlated ($r < 0.4$) to leaf litter decomposition rates (Table 2). However, the dissolved oxygen concentration was moderately positively correlated ($r = 0.46$) to leaf litter decomposition rate after 14 days of litter incubation in the stream. Total dissolved solids was moderately negatively correlated to leaf litter decomposition rate after 14 ($r = -0.45$) and 28 days ($r = -0.53$) of litter incubation in the stream (Table 2).

3.2 Leaf Litter Decomposition

Figures 1-6 show the trend of leaf litter mass loss for the plant species with time in the studied sites. The highest mean ($31 \pm 5 \text{ \% A.F.D.M. gd}^{-1}$) leaf litter decomposition rate was recorded for the *Lantana camara* at the Immediate Upstream site (Figure 3). The lowest mean ($0.07 \pm 2 \text{ \% A.F.D.M. gd}^{-1}$) leaf litter decomposition rate was recorded for *Psidium guajava* at the Immediate Downstream site. *Eucalyptus Grandis* also had relatively low ($< 2 \text{ \% A.F.D.M. gd}^{-1}$) mean leaf litter decomposition rates when compared with *Lantana camara* (Figure 1-5). When litter decomposition data were pooled together, the highest mean leaf litter decomposition rate was recorded at the Immediate Upstream site ($9.9 \pm 2.8 \text{ \% A.F.D.M. gd}^{-1}$). In contrast, the lowest mean leaf litter decomposition rate ($5.2 \pm 2.1 \text{ \% A.F.D.M. gd}^{-1}$) was recorded at the Immediate Downstream site (Figure 6). Concerning time, leaf litter decomposed fastest between day 0 and day 7 of incubation (Figure 1-5). Study site location significantly affected leaf litter decomposition after 7 days and 28 days of incubation. The leaf species had a significant effect on leaf litter decomposition during all days of incubation (all $p < 0.05$ in the linear mixed model; Table 3). The site \times leaf species interaction term was significant during all days of leaf litter incubation (all $p < 0.05$ in linear mixed models, Table 3), apart from day 28. Tukey contrasts indicated that after 7 days of incubation, there was a significant difference in leaf litter decomposition between the immediate upstream site and other downstream site and between the immediate upstream site and immediate downstream site (all $p < 0.05$).

Table 1: Physico-chemical parameters (mean \pm S.E.) measured at the Kapingazi River sites. Tds refers to total dissolved solids. Sites ordered from downstream to upstream.

<i>Site</i>	Conductivity ($\mu\text{S}/\text{cm}$)	Temperature ($^{\circ}\text{C}$)	pH	TDS (mgL^{-1})	Velocity (ms^{-1})	Phosphates (mgL^{-1})	Nitrites (mgL^{-1})	Nitrates (mgL^{-1})	Oxygen (mgL^{-1})
Further downstream	45.1 (7.2)	19.1 (3.3)	7.7 (0.3)	41.4 (25.1)	0.5 (0.2)	1.8 (1.8)	0.8 (0.8)	3.6 (1.6)	7.8 (0.3)
Immediate downstream	43.8 (6.9)	20.1 (2.5)	7.8 (0.1)	37.6 (4.4)	0.7 (0.04)	1.3 (0.1)	0.2 (0.08)	2.3 (0.5)	8 (0.4)
Weir area	46.2 (3.6)	21.5 (0.7)	7.3 (0.2)	26.7 (2.5)	0.2 (0.02)	1.3 (0.3)	0.3 (0.09)	3.4 (0.4)	8.9 (0.3)
Immediate upstream	41.7 (1.4)	20.3 (0.8)	7.5 (0.3)	30.2 (1.8)	0.6 (0.03)	1.5 (0.3)	2.4 (0.7)	2.4 (0.3)	7.9 (0.4)
Further upstream	42.7 (3.1)	20.9 (0.6)	6.9 (0.3)	32.6 (3.6)	0.5 (0.04)	1.8 (0.5)	0.4 (0.2)	3.3 (0.3)	7 (0.6)

Table 2: Pearson's correlation coefficients (r) between leaf litter decomposition rates and Physico-chemical parameters in River Kapingazi. Dec 7-Dec 28 refers to decomposition rates between day 7 and day 28. Tds refers to total dissolved solids.

Decomposition rate	Conductivity	Temperature	pH	Oxygen	Velocity	Nitrates	Nitrites	Tds	Phosphates
Dec_7	-0.41	-0.10	0.17	0.28	0.21	-0.17	-0.11	-0.33	-0.24
Dec_14	-0.26	-0.17	0.21	0.46	0.09	-0.07	-0.22	-0.45	-0.40
Dec_21	-0.39	-0.15	0.16	0.37	-0.08	-0.08	-0.18	-0.34	-0.25
Dec_28	-0.27	-0.20	0.25	0.42	0.02	0.08	-0.09	-0.53	-0.23

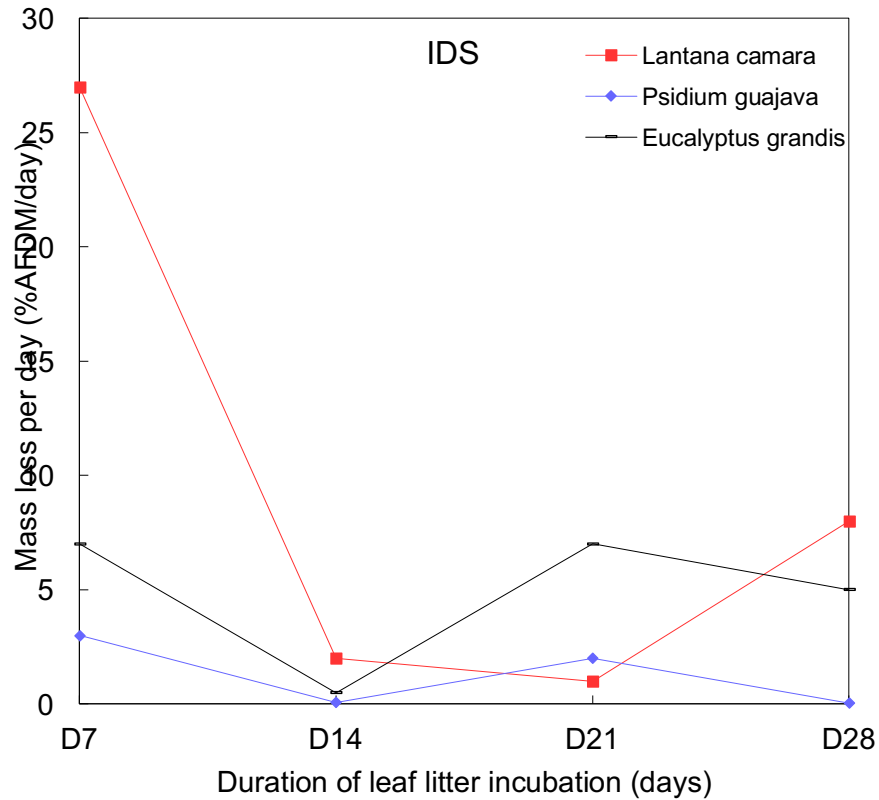


Figure 1: Leaf mass loss per day (% A.F.D.M./day) for the three-leaf species (*Lantana Camara*, *Psidium guajava*, *Eucalyptus Grandis*) during the 28 days of incubation at the immediate downstream site (I.D.S.)

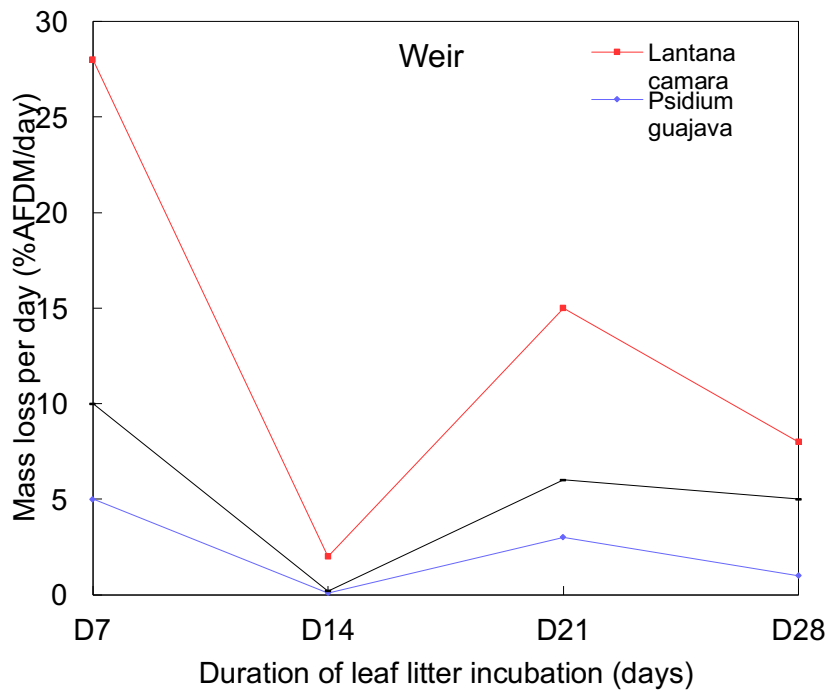


Figure 2: Leaf mass loss per day (% A.F.D.M./day) for the three-leaf species (*Lantana Camara*, *Psidium guajava*, *Eucalyptus Grandis*) during the 28 days of incubation at the weir

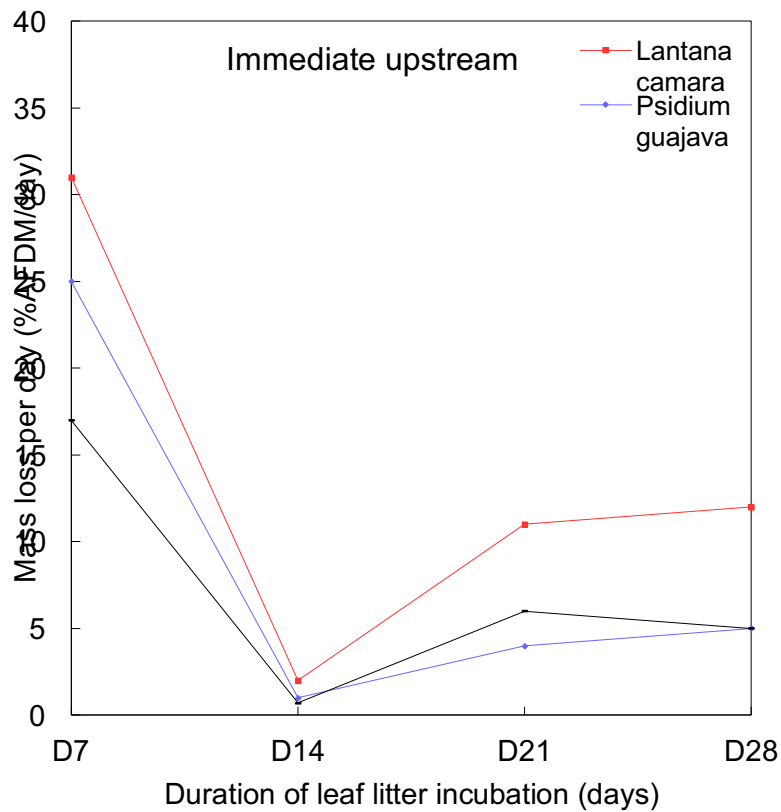


Figure 3: Leaf mass loss per day (% A.F.D.M./day) for the three-leaf species (*Lantana Camara*, *Psidium guajava*, *Eucalyptus Grandis*) during the 28 days of incubation at the immediate upstream site (I.U.S.)

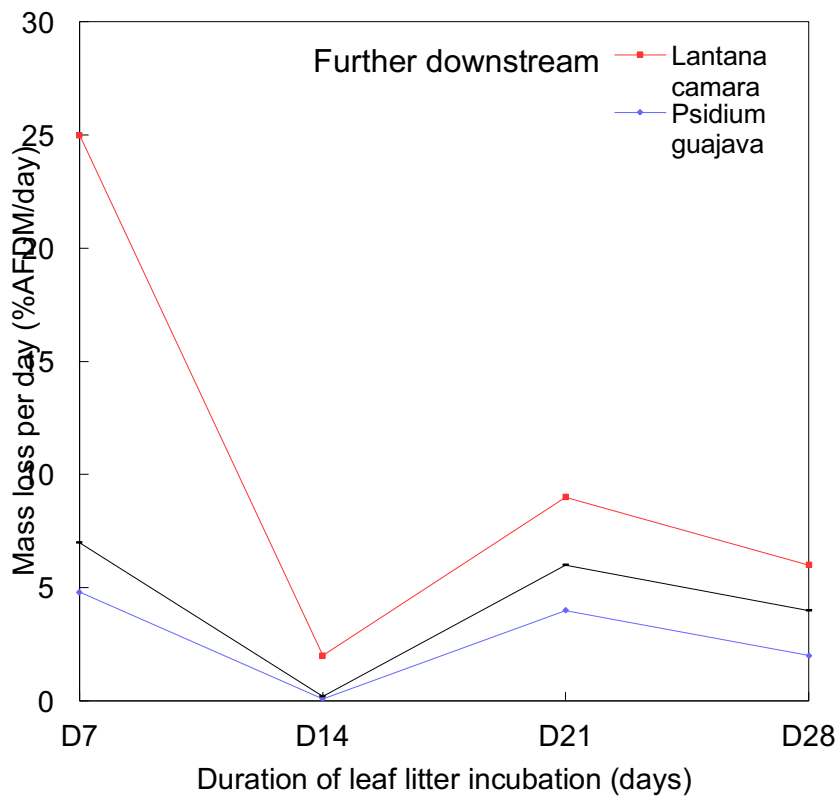


Figure 4: Leaf mass loss per day (% A.F.D.M./day) for the three-leaf species (*Lantana Camara*, *Psidium guajava*, *Eucalyptus Grandis*) during the 28 days of incubation at the further downstream site (F.D.S.)

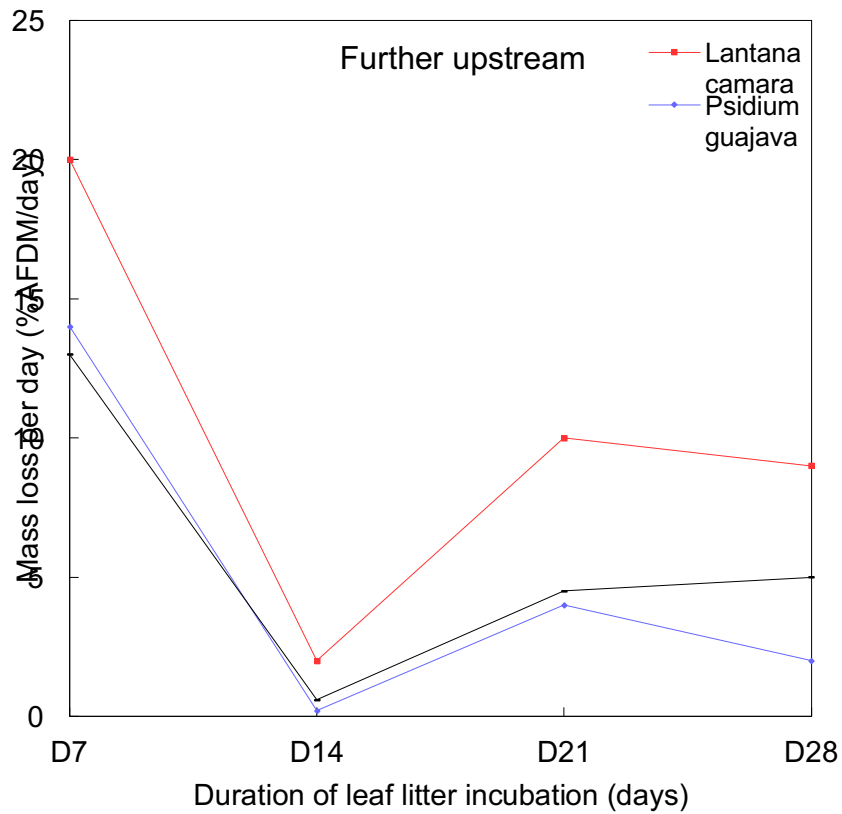


Figure 5: Leaf mass loss per day (% A.F.D.M./day) for the three-leaf species (*Lantana Camara*, *Psidium guajava*, *Eucalyptus Grandis*) during the 28 days of incubation at the Further upstream site (F.U.S.)

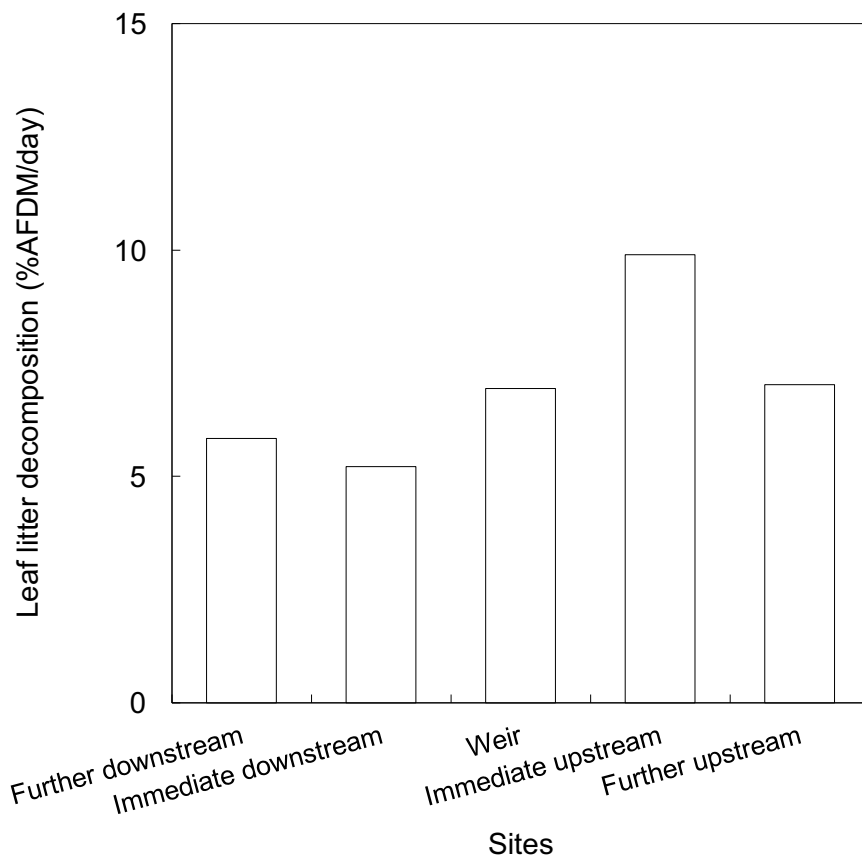


Figure 6: Mean (\pm S.E.) leaf litter decomposition rates (% A.F.D.M./day) at the study sites. Sites ordered from downstream to upstream.

Table 3: *F* and *p*-values for the mixed-effects models testing the Effect of study site location (site) and plant species on leaf litter decomposition during the time (7, 14, 21 and 28 days) of incubation in Kapingazi River. Values in bold are significant.

Day	Site		Leaf species		Site × Leaf species	
	<i>F</i> _{4,30}	<i>P</i>	<i>F</i> _{2,30}	<i>P</i>	<i>F</i> _{8,30}	<i>p</i>
7	27.7	0.04	160.9	0.004	9.0	0.04
14	2.8	0.09	228.5	0.004	2.8	0.04
21	1.9	0.12	102.6	0.004	3.4	0.02
28	6.1	0.004	79.4	0.004	1.1	0.4

3.3 Macroinvertebrates

A total of 2606 invertebrates belonging to 22 taxa were found in the 135 litter bags analyzed. Out of the total invertebrates, 1077 were associated with *Lantana Camara* leaf litter, whereas 954 and 575 invertebrates were associated with *Eucalyptus Grandis* and *Psidium guajava*, respectively (Table S1).

Table S1: Abundance of macroinvertebrates in each Functional Feeding Group in the associated leaf litters

F.F.G.	Taxa	Leaf species			Total
		<i>Lantana Camara</i>	<i>Eucalyptus Grandis</i>	<i>Psidium guajava</i>	
Gathering-collectors	Chironomidae	797	653	349	
	Canidae	46	47	52	
	Ceratopogonidae	53	48	39	
	Oligochaeta	4	3	0	
	Turbellaria	3	0	8	
	Physicodidae	2	0	1	
	Heptagenidae	1	5	3	
	Elmidae	1	19	9	
	Leptophlebiidae	0	2	2	
	Total	907	887	463	2161
Filtering-collectors	Ecnomidae	97	53	27	
	Hydropsychodidae	0	4	0	
	Total	97	57	27	183
Scrapers	Baetidae	30	55	48	
	Conizidae	1	0	0	
	Total	31	53	48	135
Predators	Perlidae	2	1	11	
	Aeshnidae	0	0	2	
	Hirudinea	34	52	15	
	Calopterygenidae	2	0	0	
	Libellulidae	0	12	1	
	Hydrophylidae	2	3	4	
	Corydalidae	2	0	0	
	Athericidae	0	6	4	
	total	40	74	37	157
	Grand Total	1077	954	575	2606

The *Lantana* sp. leaf litter was dominated (67.5 ± 42.3 individuals per bag) by Chironomidae larvae at the immediate downstream site. Other dominant invertebrate taxa associated with *Lantana* sp. leaf litter included Ceratopogonidae, Ecnomidae, Hirudinae, and Canidae. The *Eucalyptus* sp. leaf litter was also dominated by Chironomidae larvae at the weir area (54.7 ± 18.9 individuals per bag). Other major taxa associated with *Eucalyptus* sp. leaf litter included Ceratopogonidae, Baetidae, Ecnomidae, and Elmidae. The *Psidium* sp. leaf litter was also dominated (19 ± 7.62 individuals per bag) by Chironomidae larvae at the weir area. Other major taxa included Ceratopogonidae, Caenidae, Baetidae and Ecnomidae. Invertebrate functional feeding groups, shredders were absent, whereas collector-gatherers, scrapers, predators, and filtering-collectors were present (Table S1). The leaf litter was dominated by collector-gatherers and filtering collectors, whereas scrapers and predators had lower mean abundances.

4. Discussion

4.1 Environmental Factors

The high mean water conductivity recorded at the weir area, compared to the immediate upstream site, can be attributed to the reduced flow conditions at the weir area, which may have led to the accumulation of dissolved substances in the water. This finding contrasts with other studies that found small weirs to not affect water conductivity [35, 11]. The reason for this discrepancy could be due to differences in the size of the weir under investigation or the location of study sites. For example, the weirs investigated [11] were smaller in size (dam height: 1-3 m) compared to the one evaluated in the current study (dam height: 6 m). Additionally, the aforementioned study did not investigate the area located within the weir. The high-water temperature recorded at the weir area in the current study may also be attributed to reduced flow conditions. In agreement with previous studies [36, 37], the current study also found that pH, total dissolved solids, phosphates, nitrates, and nitrites were increased in the downstream sites. This can be attributed to eutrophication downstream from reservoirs associated with increased nutrient concentrations and suspended and dissolved substances in the water [38].

4.2 Leaf Litter Decomposition

The results demonstrate differences in the degradation rates of leaves of exotic and invasive (*Psidium guajava*, *Eucalyptus Grandis* and *Lantana Camara*) plant species. The generally positive correlation between water velocity and leaf litter decomposition rate shows that flow conditions positively affected the breakdown of leaf litter. Specifically, the high leaf litter breakdown rates at the Immediate Upstream site may be attributed to the high water velocity recorded at this site. This result is in accordance with other researchers who found a positive correlation between water velocity and *Ginkgo biloba* leaf litter decomposition rates at a headwater stream in Eastern Spain [39]. Dissolved Oxygen was also positively correlated to leaf litter decomposition, and differences in its concentration among the sites may explain variability in leaf litter breakdown. Oxygen encourages a myriad of organisms in the water, such as promoting microbes that aid in litter breakdown [13], and this could have been the case for this study. Further, high nutrient concentrations (e.g., nitrates and phosphates) promote microbes' growth [40, 41] and may also explain why a high mean litter breakdown rate was recorded at the Immediate Upstream, compared to the Immediate Downstream site. Further, it has been demonstrated that high macroinvertebrate shredder density is associated with faster decay of leaf litter [42, 43]. However, since no shredders were observed in this study, it is more likely that macro invertebrate-mediated litter breakdown was less important in explaining the sites' differences. The significant differences in degradation rates of the three-leaf species imply that the presence or absence of the plant species in riparian zones can affect the rate of release of nutrients into riverine ecosystems, with implications on

riverine ecosystem structure and function. Of the three studied plant species, *Lantana Camara* leaves had the highest mean leaf litter decomposition rate ($11.5 \pm 2.2\%$ A.F.D.M. gd^{-1}), while *Psidium guajava* had the lowest mean leaf litter decomposition rate ($4.0 \pm 1.3\%$ A.F.D.M. gd^{-1}). Though not evaluated in this study, factors such as lignin, cellulose, Carbon: Nitrogen ratio, Carbon: Phosphorous ratio of lignin: Nitrogen ratios were probably different across the studied plant species and most likely drove key differences in the colonization of leaf litter by organisms and decay of the litter as suggested [23]. Indeed, significant differences in degradation rates of *Lantana Camara* and *Psidium guajava* have been observed elsewhere and attributed to litter quality differences [45]. Other authors have found varied breakdown rates among leaf species and attributed it to litter quality [14, 15]. It is reported that reduced leaf toughness, lower Carbon: Nitrogen ratio, and less lignin favor higher decomposition rates [44]. Based on previously determined litter traits, *Lantana Camara* leaves are softer, have lower Carbon: Nitrogen ratio [45], and less lignin (19%, [46], causing their degradation rate to be higher [44]. On the other hand, *Psidium guajava* and *Eucalyptus grandis* leaves are relatively tougher, with high Carbon: Nitrogen ratio and are more lignified than *Lantana Camara* leaves. This justifies their slower degradation rates in this study.

Plant species had a significant effect on leaf litter decomposition during all days of incubation, while the study site only significantly affected leaf litter decomposition after incubation for 7 and 28 days. This indicates that leaf species is a crucial factor in the decomposition process in streams. Therefore, to protect key ecosystem functions in stream ecosystems, river managers should carefully choose tree species for plantation in riparian areas. In particular, exotic tree species may modify ecosystem functions in stream ecosystems and modify biodiversity. For example, an investigation on the leaf litter decomposition rates of exotic *Eucalyptus globulus* and three native tree species (i.e., *Alnus glutinosa* (alder), *Castanea sativa* (chestnut), *Quercus faginea* (oak) [47]. The study found that *Eucalyptus sp.* had one of the lowest leaf litter decomposition rates compared to natives such as alder or chestnut.

Leaf litter decomposed fastest between day 0 and day 7 compared to the other times (14, 21, 28 days) of incubation. This is likely due to the leaching of soluble compounds and non-lignified carbohydrates, as previously reported by other studies [48, 49]. The rate of degradation was relatively slowest after day 14. Nonetheless, there was progressive loss of mass observed up to the end of the study. This can be attributed to the breakdown of the more recalcitrant material of the leaves, including cellulose, lignin, and tannin [50]. In light of the preceding, the initial stage of decay for the studied leaves was between day 0 and day 14, while the advanced stage tentatively began after day 14. This observation is in line with the river continuum concept, which suggests that decomposition is composed of the liberation phase (first 14 days in this case) and the advanced stage [49]. The observation corroborates with the study that found that leaves of native (*Blepharocalyx cruckshanksii* and *Myrceugenia exsucca*) and exotic (*Pinus radiata* and *Eucalyptus globulus*) plants experienced the most significant loss of mass during the first 15 days after installation of leaf packs in the stream [51].

Conclusion

In conclusion, study site and plant species had significant effects on leaf litter decomposition. Factors such as water velocity and dissolved oxygen appear to be the main drivers of the differences in litter breakdown rates. The absence of shredders in this study perhaps implies that fungal/microbial degradation was responsible for decomposition. The effects of leaf litter quality on degradation and colonization by organisms (e.g., microbes, invertebrates) need to be studied further to expand the understanding of leaf litter decomposition in River Kapingazi. Further studies should also evaluate the decomposition of other plant species and microbes' role in leaf litter degradation.

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