

**EFFECTS OF STREAM SIZE AND FOREST TYPE ON LEAF LITTER
DECOMPOSITION AND MACROINVERTEBRATE DIVERSITY IN KAMWETI
AREA, KENYA**

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the Award of Master of Science Degree in Limnology of Egerton University**

EGERTON UNIVERSITY

MAY, 2016

DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not been submitted or presented for examination in any institution.

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DEDICATION

To the loving memory of my Dad, the late Joseph J. Oduma who did all he could to establish the foundation of my education.

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ABSTRACT

Streams draining the Southern part of Mt. Kenya are currently heavily impacted by human encroachment and large patches of riparian forests have been converted from indigenous to plantation forests. Modification of riparian vegetation was hypothesized to have influence on streams. This study aimed at investigating the effect of forest type and stream size on leaf litter decomposition, macroinvertebrate diversity and water quality in streams draining Mt. Kenya catchment. Riparian tree species were identified along both banks of the studied streams. About 2.5g dry leaves of *Syzygium cordatum* were incubated in streams for 56 days to estimate leaf-processing rates. In total, 150 litter-bags measuring 11 x 11cm, mesh size 5 x 5 mm were prepared and exposed on 1st February 2015 in six studied streams. Five bags were retrieved after 0, 7, 14, 28, 42, and 56 days of exposure per stream. Macroinvertebrates were separated from the leaves, counted, enumerated and identified up to the family level before assigning them to the major functional feeding groups. Plants were more diverse along the streams draining native tree dominated forests ($H' = 2.9$) than in exotic tree dominated forests ($H' = 1.9$). The most dominant riparian species were *Tabernaemontania stapfiana*, *Neubotonia macrocalyx*, and *Syzygium guineense* in native tree dominated forests while *Eucalyptus* species dominated the riparian riverbanks of the streams draining exotic tree dominated forests. Decomposition of *S. cordatum* leaves was slower in streams draining exotic tree dominated forests ($-k = 0.0172$) than in streams draining native tree dominated forests ($-k = 0.0213$). Processing rates were significantly lower in small streams ($-k = 0.0174$) in comparison to big ($-k = 0.021$). There was a significant difference in mean decomposition rates between small and big streams (Two-way ANOVA $df = 1$, $F = 5.026$; $P < 0.05$) while no significant difference was evident in mean decomposition rates between streams in native and exotic tree dominated forests. Macroinvertebrate abundance and diversity associated with decomposing litter were lower in streams draining exotic tree dominated forests than in streams draining native tree dominated forests and in small streams than in big streams while no significant differences of macroinvertebrate abundance were found between forest types (Two-way ANOVA $d. f = 1$, $F = 2.423$; $P > 0.05$). The study concluded that depletion and modification of native riparian vegetation through successive land use activities and replacement with exotic tree species has negative impacts in altering stream ecosystem functioning and small streams are more impacted than big streams.

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LIST OF ABBREVIATIONS AND ACRONYMNS

AFDW	Ash Free Dry Weight
ANOVA	Analysis of Variance
APHA	American Public Health Association
CPOM	Coarse Particulate Organic Matter
DM	Dry Matter
DO	Dissolved Oxygen
FFGs	Functional Feeding Groups
FPOM	Fine Particulate Organic Matter
RDM	Remaining Dry Mass
RDW	Remaining Dry Weight
SRP	Soluble Reactive Phosphorous

CHAPTER ONE

INTRODUCTION

1.1 Background information

Riparian vegetation is important in acting as the source of energy for aquatic ecosystems through the input of organic matter, which undergoes decomposition process. The water quality level in streams, rivers, lakes and along shorelines is maintained by riparian vegetation. The riparian environment forms a transition zone between the open stream and the adjacent uplands (Wayne and Amanda, 2007). Much of the organic matter in a stream may originate from the surrounding terrestrial environment or from the riparian zone and is transported to the stream by wind, water, gravity, or direct deposition. Regeneration capacity and growth of any riparian vegetation depend on the type of their uses. Fine balance between the vegetation use and its regeneration capacity is vital in maintaining the vegetated buffer strips. Riparian vegetation is important in supporting the food web within the stream ecosystems (Wayne and Amanda, 2007). This is due to input of organic matter from leaves, fruits, flowers, wood and twigs. Shaded stream channels heavily depend on allochthonous organic matter for their energy sources (Vannote *et al.*, 1980). In such streams, the leaves from the riparian areas form the bulk of the organic matter input.

For these organic matter fragments to be useful in streams, they ought to undergo decomposition. Decomposition process begins once fallen leaves enter the stream. Leaf litter decomposition generally occurs through a system of sequential processes: passive leaching of soluble compounds, microbial colonization or conditioning (Gessner and Chauvet, 1994), fragmentation by invertebrate shredders and physical abrasion (Graca *et al.*, 2005). There is evidence of a paucity of shredders in the tropics (Dobson *et al.*, 2003). However, some crustaceans and caddis fly larvae (*Phylloicus* sp.) are important shredding organisms in the tropics (Crowl *et al.*, 2001). Paucity of shredding activities in the tropics therefore leaves the microbes to control decomposition process in tropical streams. The fungi group known as aquatic hyphomycetes produce enzymes capable of causing leaf maceration. After 2 to 3 weeks, up to 15 % of the decomposing leaf biomass corresponds to fungal activity (Manuel and Canhoto, 2006).

Decomposition of leaf litter is an important process since litter breakdown rate provides a good estimate of detritus quality and can be an indirect measure of biological activity (Vannote *et al.*,

1980). Litter breakdown can therefore measure the potential of litter quality as a food resource for aquatic organisms. On the other hand, riparian vegetation has proved to be the most important source of energy especially in forested streams and also serving a number of hydrological functions that sustain the environmental integrity of catchments and their streams, such as buffering and filtering agricultural nutrients and pollutants, and controlling sedimentation and erosion (Osborne and Kovacic, 1993).

A qualitative and quantitative change in the riparian forest affects the litter input to streams and thus can modify completely the structure of the biotic community (Afonso *et al.*, 2000; Mas, 2001). Streams in Mt. Kenya region experience small-scale anthropogenic disturbances on daily basis that includes water abstraction, linen washing, bathing, swimming, domestic animals drinking water among others. Another common disturbance to these streams is the replacement of riparian native forests by exotic tree species. It was envisaged that these changes had influence on streams that drained both native and exotic forests. It is therefore important to study the influence of forest type and stream size on the leaf litter processing rates and macroinvertebrate diversity in streams experiencing such characteristics.

The scope of this study focused on six first order streams draining the southern Mt. Kenya region. All the six streams are located within close proximity being tributaries of River Thiba draining southern Mt. Kenya and easily accessible by roads. The study had limitations such as assigning the functional feeding groups to family level since required information on morphology and behavior needed to assign FFG is particularly scarce for aquatic insects in tropical regions (Alonso and Pablo, 2014). Funds and study time-frame also are some factors that limited this study.

1.2 Statement of the Problem

Increased human encroachment and settlements coupled with modification of riparian vegetation by replacing native riparian tree species with exotic ones is thought to have influence on streams of Mount Kenya region. Native vegetation in Kamweti region has been completely cleared for cultivation and replaced with exotic tree species. The natural vegetation is restricted only to the Mt. Kenya national park. There is scanty information on whether forest type (native versus exotic) and size of the stream has any significant influence on the type of macroinvertebrates and leaf litter processing in streams. The results and quantitative data obtained from this study will therefore help

link forest type, macroinvertebrate responses and stream functioning in terms of litter processing rates within Mount Kenya streams and related catchments.

1.3 Objectives

1.3.1 General Objective

To establish leaf litter processing rates and macroinvertebrate participation in six streams of various sizes draining native and exotic tree dominated forests in Mt. Kenya region.

1.3.2 Specific Objectives

1. To determine physico-chemical variables in three small and three big streams draining native and exotic tree dominated forests in Mt. Kenya region
2. To determine riparian plant diversities associated with streams draining native & exotic forests in Mt. Kenya region.
3. To determine leaf litter processing rates and macroinvertebrate diversity in three small and three big streams draining native and exotic tree dominated forests

1.4 Hypotheses

1. There is no significant difference in physico-chemical variables in three small and three big streams draining native and exotic tree dominated forests in Mt. Kenya region
2. Riparian plant diversity is the same along streams draining native and exotic forests in Mt. Kenya region.
3. Leaf litter processing rates and macroinvertebrate diversity is not statistically different in three small and three big streams draining native and exotic tree dominated forests

1.5 Justification

Due to human encroachment and impacts from different land uses, native forests in Kenya have been destroyed and there is a gradual replacement by exotic tree species such as *Eucalyptus* and *Grevillea* species especially in Mt. Kenya region. These exotic tree species are given preference over the native ones due to their fast growth rates and high economic value. Replacement of the indigenous tree species coupled with other anthropogenic activities interfere with the normal functioning of streams by directly influencing the quality and quantity of litter inputs as well as aquatic insects that depend on these leaves as their food. This in turn affects the overall litter

processing, functioning of tropical streams and hence the stream water quality. For continuous power generation from Masinga, irrigation at Mwea rice scheme hence meeting the targets of Kenyan vision 2030, sustainable development goals and requirements of chapter five of Kenyan constitution 2010, the streams in Southern Mt. Kenya region must be in good condition since they form tributaries of River Thiba which drains into River Tana, Kamburu and Masinga dams.

In addition, for ecological services provision and ecosystem support, there is need for continuous research and preparation of an inventory of riparian plant species composition and distribution and their contribution to litter biomass into the streams. This study therefore address the question whether the stream size and type of riparian forest (native or exotic trees dominated) has any impact on ecosystem functioning by affecting litter processing rates and macroinvertebrate diversity. The outcome of this research is crucial for management and restoration of degraded riparian buffer strips as well as native forests in future by conservationist.

CHAPTER TWO

LITERATURE REVIEW

2.1 Allochthonous litter input in streams

Organic matter derived from many sources is important in providing a basis of stream food webs. The most intensively studied source of organic matter in streams is plant litter, which is of high likelihood to enter into streams from the forest canopy (Weigelhofer and Waringer, 1994) especially low order streams which are relatively shaded. In terms of weight, leaves from the surrounding land constitute the largest allochthonous source of energy for stream consumers, but other items, including fruits, flowers, wood and twigs, and terrestrial insects, are important (Wantzen, *et al.*, 2008).

In addition, inputs of allochthonous material vary depending on the dominant vegetation type, season, hydrologic conditions and position in the river network (Maseh and McClain, 2012). For instance, in the tropics, leaf fall is a response to hydric stress, and the loss of leaves is a strategy to reduce water loss through transpiration during the driest period of the year (Franc *et al.*, 2009). These inputs include those transported from upstream, direct (or vertical) inputs (also called fall-in), and lateral inputs of material deposited on the forest floor and mobilized by wind or some other agent (Manuel *et al.*, 2005).

Shaded stream channels are heavily dependent upon detritus derived from the adjacent terrestrial environment for their energy resources (Dobson, *et al.*, 2002). The allochthonous Organic Matter (OM) connects the terrestrial and aquatic ecosystems, and contributes importantly to the secondary productivity of streams (Odum and Barrett, 2005), and this has been studied by investigating the breakdown of coarse particulate organic matter (CPOM). In several studies, ways have been sought to sample continuously a portion of the flowing water, or to build grid-like structures to retain all litter transported during extended periods (Likens and Bormann, 1995). However, sampling using these approaches require large effort and is often feasible. Therefore, a less accurate but more readily applicable method for non-woody litter inputs to small streams is always preferred (Manuel *et al.*, 2005).

2.2 Leaf litter decomposition in streams

Decomposition and the sequestration of organic carbon in soils and sediments stand out as central components of ecosystem functioning. It refers to all biological processes contributing to organic matter mass loss and transformation, and not including physical losses caused by abrasion, fragmentation or leaching (Mark *et al.*, 2010). Decomposition of organic matter in streams is controlled by interacting processes like chemical leaching of the soluble compounds, aerobic degradation by microbial organisms, physical abrasion and physical fragmentation by leaf shredding macroinvertebrates (shredders) (Webster and Benfield, 1986).

In the water, litter decomposition starts immediately and usually proceeds in three overlapping phases. The first phase involves leaching of soluble compounds, which can lead to the loss of up to 42% of the initial leaf mass (Verónica, 2006). Once fallen leaves enter the stream, osmotic breakage of dead cell walls, penetration by fungal hyphae, and softening of the structural elements by microbial enzymes combined with feeding by invertebrate shredders enhance leaching (Wantzen *et al.*, 2008).

The second process involves microbial decomposition, which can be responsible for the loss of about 27% of leaf mass and lastly biotic and physical fragmentation occurs. Biotic fragmentation occurs because of the feeding activities of invertebrates, mainly shredders, which can result in up to 64% of mass loss (Hieber and Gessner, 2002). The fungi group known as aquatic hyphomycetes is capable of producing enzymes capable of causing leaf maceration, and by 2 to 3 weeks, up to 15 % of the decomposing leaf biomass corresponds to fungi (Manuel and Canhoto, 2006). In some studies, leaching rates occurred for a period of 24–48 hours after immersion of leaves in water even though some leaching processes continue for weeks (Strauss and Lamberti, 2002).

Shredder invertebrates are also biological agents involved in litter breakdown (Manuel and Canhoto, 2006). A study in a Kenyan stream indicated that freshwater crabs comminute large amounts of leaf litter within a period of a few days (Moss, 2007). However, many reports show an evidenced conspicuous lack of shredders in tropical streams in Africa, Asia, and the Neotropics systems (Irons *et al.*, 1994; Rosemond, *et al.*, 1998; Dudgeon, 2000; Dobson *et al.*, 2002; Mathuriau and Chauvet, 2002; Rueda-Delgado *et al.*, 2006; Wantzen and Wagner, 2006). Some literature also syndicate that information on tropical stream food webs and the feeding ecology of tropical stream invertebrates is still incipient (Boyero *et al.*, 2009).

Physical and chemical factors influence decomposition rates in streams. Temperature is an important driver of fungal mediated litter decomposition. Goncalves *et al.*, (2013) determined that the effect of temperature was more pronounced in oak leaves than alder leaves. However, decomposition efficiency measured as the ratio of decay rate to fungal biomass was greater at higher temperatures in both cases. Discharge is also a key factor that determines leaf litter decomposition. For instance, breakdown in high-velocity microhabitats, such as riffles, is faster than in pools (Stout and Coburn, 1989). Wantzen *et al.* (2008) also explains that physical abrasion and fragmentation are some of the main factors that determine decay rates in rivers and streams.

Dissolved nitrate is also taken as an important factor controlling litter decomposition. A study in a subtropical stream found that leaf litter decomposition was affected by dissolved nitrate concentration in the water (Tonin and Hepp, 2011). The study determined that decomposition of particulate and dissolved organic carbon was faster in nitrate enriched treatment under high dissolved oxygen condition. In contrast, a decomposition experiment using *Eucalyptus* leaves found that nutrient addition did not increase microbial and invertebrate colonization, which accelerate breakdown rates (Abelho *et al.*, 2010).

The breakdown of leaf litter in streams is also influenced by leaf quality since there is variability in decomposition among different species of leaves (Todd and Wayne, 2001). Early studies attributed these differences to N contents in the leaves and their palatability by shredding macroinvertebrates (Kaushik and Hynes, 1971; Peterson and Cummins, 1974). A study in a French stream by Gessner and Chauvet (1994) found that percentage lignin was the most important leaf characteristic controlling the decay of seven types of leaves.

2.3 Riparian vegetation and forest types along the streams and Rivers

The riparian zone is considered an important interface between aquatic and terrestrial ecosystems (Naiman *et al.*, 2005). It forms a transition zone between the open stream and the adjacent uplands. The stream/riparian interface may be a sharp boundary (edge) or a gradual transition (ecotone) between the two (Wayne and Amanda, 2007). Riparian zone therefore performs a number of hydrological functions that sustain the environmental integrity of catchments and their streams, such as buffering and filtering agricultural nutrients and pollutants, and controlling sedimentation

and erosion (Verhoeven *et al.*, 2006). In addition, its vegetation supplies and accumulates organic matter, stabilizes stream banks, and increases the heterogeneity of the riverbed. All these result in different current speeds and sediments, and a variety of habitats for biological communities (Naiman *et al.*, 2005) Riparian vegetation also constitutes an important corridor for animal migration, and thus contributes to the maintenance of faunal diversity (Becker *et al.*, 2010).

Trees from the riparian zone are important since they produce leaves and other organic materials acting as allochthonous material, which is the major energy source in low order streams running through forests (Vannote *et al.*, 1980). They also have important influences on stream ecology by affecting bed substrate composition and modifying local flow conditions (Richard and Gary, 2007). Riparian habitats are especially important as refuges during periods of environmental stress, such as annual drought or rapid shifts in climate, because of the ameliorated climates they provide along river valleys (Gregory *et al.*, 1991).

The principal biotic components of riparian habitats are comparable to those of the open water in streams. However, the primary producers are predominantly woody terrestrial plants (especially shrubs), sedges, and grasses instead of algae and flaccid vascular plants, and the vertebrate consumers are mainly birds and mammals, in place of fish (Wayne and Amanda, 2007). According to Gregory *et al.*, (1991), the size and distinctiveness of the riparian border and whether it is viewed as a distinct boundary or an ecotone depend on the harshness of the environmental conditions encountered between open water and uplands. A number of factors including climate, topography, landform, and geological control (constraint) attributes to the sharpness of the environmental gradient. The removal of riparian vegetation along low-order streams has also had the effect of increasing primary production by both macrophytes and phytoplankton while at the same time reducing inputs of coarse particulate organic matter (Masese and McClain, 2012). However, this increase is insignificant and unsustainable for ecosystem functioning and energy flow.

Tropical riparian vegetation contributing high CPOM is responsible for high macroinvertebrate density (Mbaka, *et al.*, 2014). This shows that macroinvertebrate density increases with increase in total CPOM content, which is associated with high canopy cover. It is therefore very important to conserve the riparian vegetation due to their important role as a source of CPOM to streams.

2.4 Riparian plant composition

Riparian vegetation is mainly composed of macrophytes, which are literally “large plants” (Richard and Gary, 2007). White and Hendricks, (2000) interpret macrophytes to include large filamentous algae (e.g., *Batrachospermum* spp. and the Characeae), bryophytes, and liverworts, as well as higher plants. However, macrophytes are vascular plants in which specialized cells (tracheids) transport water and minerals from true roots (Richard and Gary, 2007). Therefore, freshwater macrophytes are often classified based on their life form: emergent plants, floating-leaved plants, submerged plants, and free-floating plants, which is not very applicable to stream plant species.

Goncalves and Callisto, (2013) working on a headwater tropical stream in Brazil identified 1258 individual riparian plants to belong to 192 species, in 90 genera and 52 families. The families with the largest numbers of species were Myrtaceae (29 species), Lauraceae (21), Leguminosae - Caesalpinioideae (8), and Euphorbiaceae (8). The other families comprised less than 5% of the total species. They later recommended that future studies should concentrate on understanding the importance of each plant species to the functioning of the riparian zone, in particular species that contribute small quantities of allochthonous CPOM overall, but are relatively important during periods of low input, as observed in their study. Mathooko and Kariuki, (2000) investigating on disturbance and distribution of riparian vegetation of a Rift Valley stream identified Montane *Juniperus procera*-*Olea europaea* spp. *africana* and submontane *Acacia abyssinica* forests as the main riparian vegetation groups.

2.5 Impact of land use and anthropogenic activities to riparian vegetation and ecosystem functioning

Disturbance at different scales is important in maintaining species diversity in an ecosystem. However, conversion of forestlands and human settlement on riparian areas, including the growth of towns, is changing the quality and influx of both particulate and dissolved fractions of organic matter in streams (Masese and McClain, 2012).

A qualitative and quantitative change in the riparian forest affects the litter input to streams and thus can modify completely the structure of the biotic community (Afonso et al., 2000; Mas, 2001). More so, removal of riparian vegetation can result in increases of water temperature and,

consequently, alterations in levels of dissolved oxygen, invertebrates, and fish (Wayne and Amanda, 2007). In many countries, the degradation of riparian vegetation results from the disordered expansion of agricultural borders which, in turn contributes to the formation of immense open areas, often characterized by grassy and herbaceous vegetation (Carvalho and Uieda, 2010).

A study in a tropical Rift Valley stream found out that disturbances on the riparian vegetation zone are broadly classified as those induced by man, livestock and wildlife. Comprehensive effects of disturbance included loss of vegetation vertical strata, increase/decrease of species diversity, introduction of alien plant species, and reduction of plant sizes and vegetation hectarage (Mathooko and Kariuki, 2000).

2.6 Summary of literature review

In summary, past studies have reviewed anthropogenic threats to rivers (Mathooko and Kariuki, 2000, Dudgeon *et al.* 2006, Masese and McClain, 2012). Many causes are due to the conflicting demands on freshwater, changing land use, and many unsustainable practices that characterize growing populations and expanding economies throughout the world. According to FAO Forest Resource Assessment (2008) most human activities that harm the river ecosystems showed an upward trend throughout the 20th century, and although some aspects of pollution have been ameliorated in recent years. Other pressures, including species invasions and climate change, are expected to worsen.

Due to encroachment, exotic plant species are replacing native riparian vegetation along streams worldwide. The exotic forests have the potential of altering stream ecosystem functioning and invertebrate assemblages through the input of foreign allochthonous leaf litter to the stream (Lecerf *et al.*, 2005). Empirical evidence on the effects of exotic vegetation on leaf-litter breakdown and shredder assemblages is variable. Some investigators have found reduced shredder-mediated breakdown rates of exotic litter compared to native litter (Albarino and Balseiro, 2002; Clapcott and Bunn, 2003; Larranaga *et al.*, 2006; Davies and Boulton, 2009). Other studies have found the opposite as shown in the Japanese knotweed in France (Lecerf *et al.*, 2007) and Norway maple in USA (Reinhart and Vandervoort, 2006). However, other studies have found no differences as

demonstrated in *Eucalyptus* forests in Brazil (Goncalves *et al.*, 2007) and some areas in USA (Lacan *et al.* 2010).

Streams in Mt. Kenya region like other tropical regions experience small-scale anthropogenic disturbances on daily basis that include water abstraction, linen washing, bathing, swimming, domestic animals drinking water among others. Another common disturbance to these streams is the replacement of riparian native forests by exotic tree species. There is little information on how these anthropogenic disturbances at different sites of these rivers affects stream functioning for instance, decomposition rates and macroinvertebrate densities. Thus, there is a gap that needs to be addressed to answer the question whether these activities have any influence on decomposition rates, physicochemical variables and macroinvertebrate densities.

The extents of the effects of these changes have not been investigated while considering stream size. It is on this basis that this study was undertaken to investigate the extent of influence of these changes on stream functioning in terms of decomposition rates, macroinvertebrate abundance and diversity as well as functional feeding groups within Mt Kenyan streams. This was achieved by assessing six streams of different sizes draining native tree forests and other three draining eucalyptus tree forests.

CHAPTER THREE

MATERIALS AND METHODS

2.2 Study Area and the study sites

2.2.1 Study Area

The study was carried out in six selected stream reaches within the six streams draining Southern Mt. Kenya catchment (Figure 1).

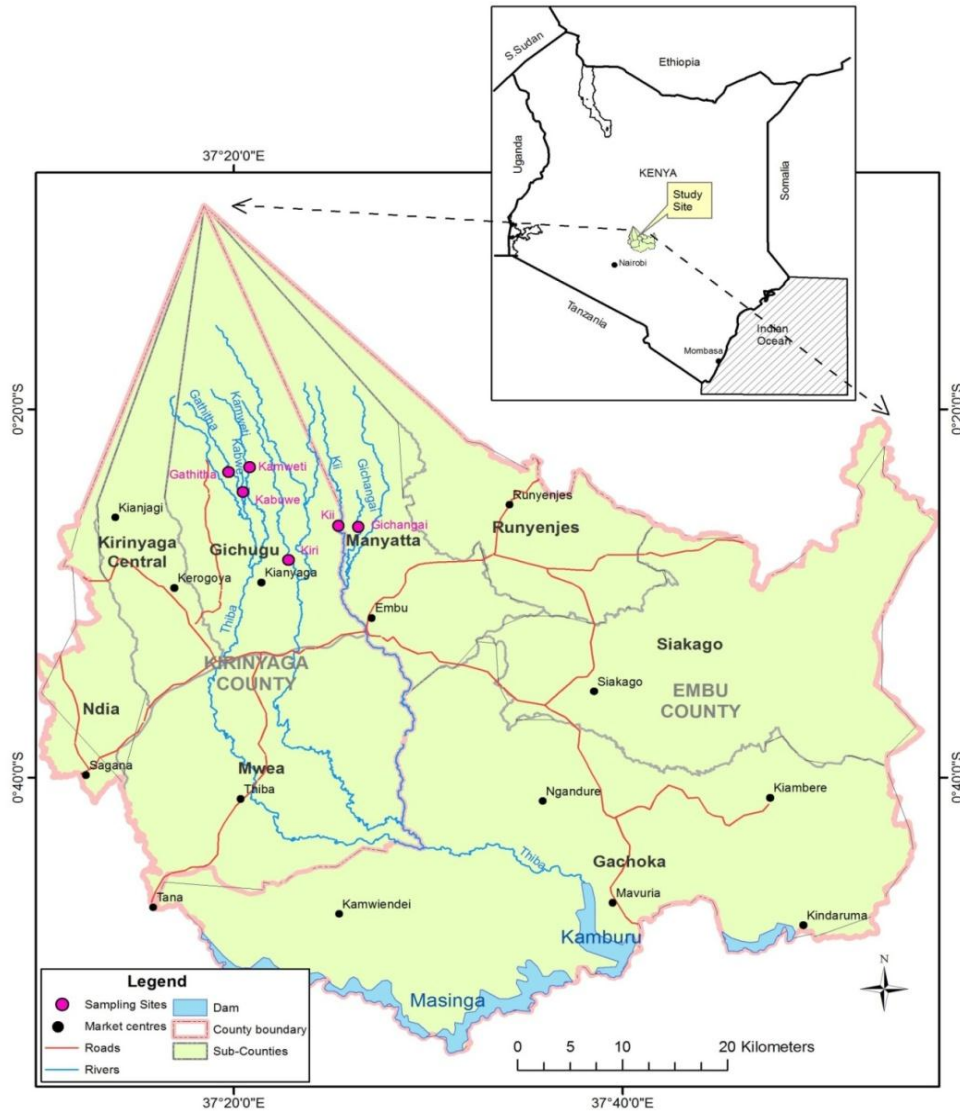


Figure 1: Map of Kenya showing the study sites and streams (Source: Topographical map of Kenya, 2014)

The study was done in Kamwet area located on the southern slopes of Mount Kenya. The region is dissected by several rivers and streams the main ones being Kamwet River and Gathitha all of which are tributaries of Thiba River which drains into river Tana. These permanent rivers are important since they supply for domestic use and form the main source of irrigation water in Mwea Rice Irrigation Scheme.

Geologically the area consists of tertiary recent volcanic rocks with generally Ando-like soils. Most native vegetation in Kamwet region has been cleared for cultivation and the natural

vegetation is restricted only to the forests within Mt. Kenya national park. The forests consist of both natural and exotic species, which were established through ‘Taungya’ system (Kariuki, 2004). The exotic tree species in this area mainly consist of *Eucalyptus* species, *Cupressus lusitunica* and *Grevillia robusta*. Indigenous species dominating this area include *Olea europea var.africana*, *Neuboutonia macrocalyx*, *Ekerbergia capensis*, and *Ehretia cymosa*.

The area has high potential for forestry, tea and coffee and the land is densely populated with approximately 250 people per km² (Kariuki, 2004). The crops grown within the area include coffee and tea as cash crops while maize, beans and bananas are the main subsistence crops. The residents also grow other minor food crops like potatoes, cabbages, kales, yams, citrus fruits, tomatoes, etc. Zero grazing for both cattle and goats is the main pastoral production system.

2.2.2 Description of study sites

Three of the studied streams; Kabwe (small), Kamweti (big) and Gathitha (big) drain native trees dominated forests (plate 1) and are therefore considered as semipristine due to absence of anthropogenic disturbances whilst the other three; Kiri (small), Kii (big) and Gichangai (small) streams drain *Eucalyptus* tree dominated plantations (plate 2). In this study, small streams refer to a stream whose average width was < 3m and not less than 1m while big stream implied those with > 3m stream width and less than 10m in width. All the six streams are of first order and located within close proximity being tributaries of River Thiba draining southern Mt. Kenya and easily accessible by roads.





Plate 1: Sites within native forested streams, a = Kamweti (B), b = Kabwe (S), c = Gathitha (B), B stands for big and S = small, (Source: photograph by the Author 01/02/2015).



Plate 2: Sites within Eucalyptus forested streams a = Kii (B), b = Kiri (S), c = Gichangai (S); B = big and S = small, (Source: Author 01/02/2015)

Streams like Kamweti, Kabwe and Gathitha were located in the Mt. Kenya National Park, a well-preserved landscape consisting of rocky afro-montane forests at higher elevations and highly diverse riverine forests in the valleys. The riparian corridor at the study sites were more than 12 m wide in streams draining native tree dominated forests, shading most of the stream bed, and is mainly composed of *Tabernaemontania stapfiana* (Apocynaceae family), *Syzygium guineense* (Myrtaceae family) and *Neubotonia macrocalyx* (Euphorbiaceae family). The other three sites in Kiri, Kii and Kabwe streams were located in exotic dominated forests with a very thin riparian corridor composing of *Eucalyptus sp.* as the most dominant tree along the banks as shown in plates above. Details of geographic positioning (GPS) and biotopes of each stream are presented in Table 1.

Table 1: Summary of the geographic positioning (GPS), and biotopes of each stream's study sites, B = big, S = small

River	Latitude	Longitude	Elevation	Width (m)	Canopy cover (%)
Native Forests					
Kamweti (B)	S 00°24'39"	E 37°20'48"	1765 m.a.s.l	8.65 ± 0.48	96%
Kabwe (S)	S 00°24'43"	E 37°20'28"	1765 m.a.s.l	2.07 ± 0.23	90%
Gathitha (B)	S 00°24'38"	E 37°20'18"	1760 m.a.s.l	5.62 ± 0.60	94%
Eucalyptus Forests					
Kii (B)	S 00°26'24.5"	E 37°25'28"	1656 m.a.s.l	3.45 ± 0.16	87%
Kiri (S)	S 00°27'59"	E 37°22'51"	1553 m.a.s.l	3.3 ± 0.16	80%
Gichangai (S)	S 00°26'27"	E 37°26'18"	1637 m.a.s.l	1.24 ± 0.06	75%

3.2 Study design

3.2.1 Sampling of water and measurement of physico-chemical parameters

At each sampling site, percentage in-stream canopy cover, stream width, water depth, velocity, and discharge were measured over a 100 m reach. Stream width was measured with a measuring

tape on 10 transects at midpoints of 10 m intervals along the reach. On each transect, water depth was measured with a 1-m ruler at a minimum of 5 points (Masese *et al.*, 2014b).

Stream conductivity was measured at every sampling site with a HACH conductivity meter. Three readings of dissolved oxygen and percentage saturation were determined using a HACH oxygen meter whereas pH and water temperature was determined in triplicates using a combined HACH meter. Mean water velocity was measured at 60 % of the total water depth with a General Oceanic flow meter model 2030R (Richard and Gary, 2007). Triplicate water samples were collected from each sampling site using clean plastic bottles from which nutrients were analyzed later in the laboratory. After collection, the samples were transported in a cooler box to the laboratory at Egerton University where further physico-chemical variables were analyzed.

3.2.2 Litter bag preparation and placement in the stream

One dominant native tree species (*Syzygium cordatum*) was used for this study. The choice of the tree species was considered since it has been used in other related studies and it majorly dominates most riparian zones of tropical streams. In addition, *Syzygium cordatum* species belongs to the same family with *Eucalyptus* species, which majorly replaces the native species as a riparian tree, therefore it could help in a comparison. Senescent leaves were collected from this tree and oven-dried at 60°C for 24 hours (Benfield, 1996), after which they were weighed into 2.5 g packs each, wetted, and then enclosed separately in (11.0 x 11.0 cm) nylon litter bags of 5 x 5 mm mesh size which were later coded as indicated in plate 3 a. The bags were then transported to the streams and placed in a 100 m stretch of stream on day 0 after recording their initial dry weights. In total 25 bags were set in each of the study streams. Each string was secured in the stream channel by tying to tree roots and steel poles hammered into the stream bed. Poles were randomly placed 0.5m from each other to avoid bags from different strings encountering each other. Codes were then given to poles corresponding to the respective bags for easier retrieval during sampling. Some leaves were left in the laboratory for determination of weight loss on handling (Benfield, 1996).

3.2.3 Litter bag retrieval and sample processing

Five litter bags were retrieved randomly during each sampling occasion from each stream (see plate 3 b). This was done for the six streams i.e. during 0, 7, 14, 28, 42, and 56 days of exposure, therefore 30 litter bags in total were retrieved on each sampling day (see Table 2). The litter bags

collected on day 0 were used for estimating weight loss on handling. Macroinvertebrates from litter bags were sorted, fixed in 70% alcohol and identified to family level. This study assigned functional feeding group at family level using available information after a review done by Alonso and Pablo, (2014).

Table 2: Sampling dates during 0, 7, 14, 28, 42 and 56 days of exposure within the six streams. B = big and S = small streams respectively.

Stream	SAMPLING DATES					
	Day 0	Day 7	Day 14	Day 28	Day 42	Day 56
Native Forests						
Kamweti (B)	1/2/2015	8/2/2015	15/2/2015	1/3/2015	15/3/2015	29/3/2015
Kabwe (S)	1/2/2015	8/2/2015	15/2/2015	1/3/2015	15/3/2015	29/3/2015
Gathitha (B)	1/2/2015	8/2/2015	15/2/2015	1/3/2015	15/3/2015	29/3/2015
Exotic Forests						
Kii (B)	1/2/2015	8/2/2015	15/2/2015	1/3/2015	15/3/2015	29/3/2015
Kiri (S)	1/2/2015	8/2/2015	15/2/2015	1/3/2015	15/3/2015	29/3/2015
Gichangai (S)	1/2/2015	8/2/2015	15/2/2015	1/3/2015	15/3/2015	29/3/2015

After retrieval, the leaves from the litter bags were rinsed with water through a 100 µm sieve to remove the accumulated sediments, attached debris and macroinvertebrates. Macroinvertebrates were then sorted both visually (see plate 4 below) and under stereomicroscope at 40 x 10 total magnification, identified, and stored in 70% ethanol. Identification was carried out under the same light microscope, generally to family level using available identification keys (Gerber and Gabriel, 2002). Shannon Wiener diversity index (H') was used to determine the macroinvertebrate diversity associated with decomposing litter. The remnants of the leaves were then oven-dried at 60°C for 24 hours and weighed to obtain dry mass (DM). The processing coefficient ($-k$) of the leaves were determined by fitting the data to the exponential model: $DM_t = DM_0 e^{-kt}$, where DM_t = dry mass (g) remaining at time t (days), DM_0 = initial dry mass (g). This was done after natural log transformations of the dry mass (DM) at the beginning and at the end of each exposure duration as follows: $-k = (\ln DM_0 - \ln DM_t) / t$, according to the procedure by Graca *et al.*, (2005). The data used for generating the k -values was fitted to a linear model that provided the time required for 25, 50, 75, and 90% of the leaves to be processed in the six streams.

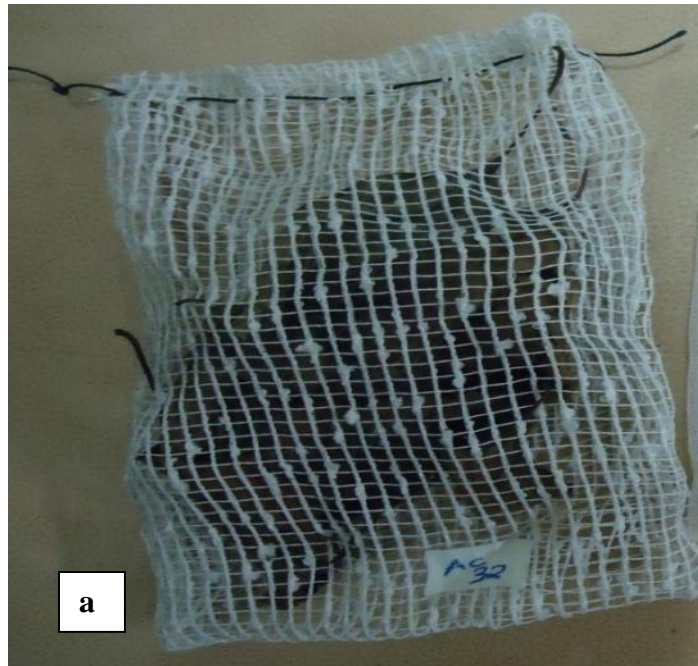


Plate 3: Sample litter bag packed with leaf litter (a) and retrieval of litter bags from the stream (b),
Source: Author 01/02/2015.



Plate 4: Sorting of macroinvertebrates washed from litter bags, Source: Photograph of the Author 01/03/2015

3.2.4 Determination of riparian tree species (abundance, composition and diversity)

One plot, which is visually homogenous (50 x 100 m), was established along both banks in each stream. This measurement was taken because it is representative. Within each plot, three transects at 0, 50 and 100m were made and all tree species were recorded at every one metre interval for both banks (Kent and Paddy, 1992). In calculating diversity of plants, Shannon Wiener diversity index (H') was used, (H') = $-\sum (p_i \ln p_i)$. From the equation, p_i = the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), \ln is the natural log, Σ is the sum of the calculations along the transects, community diversity samples were taken at 1 m intervals.

3.2.5 Determination of nutrients in stream water

Triplicate water samples were collected from each sampling site using clean plastic bottles from which nutrients were analyzed later in the laboratory. After collection, the samples were

transported in a cooler box to the laboratory in Egerton University where further physical and chemical variables were analyzed.

In the laboratory, water nutrient analyses were undertaken using standard methods provided by the American Public Health Association (APHA, 2005). The soluble nutrients, including SRP, $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NH}_4\text{-N}$ were analysed from filtered water samples, while unfiltered water samples were used for TP analysis after persulfate digestion to SRP. The SRP was analyzed using the ascorbic acid method with absorbance read at a wavelength of 885 nm. Nitrate - nitrogen ($\text{NO}_3\text{-N}$) was analysed using the salicylate method with the spectrophotometric absorbance read at a wavelength of 420 nm. Nitrite-nitrogen ($\text{NO}_2\text{-N}$) concentration was determined based on the chemical reaction between sulfanilamide and N-naphthyl-(1)-ethylendiamin-dihydrochloride to develop a pink colour. The intensity of colour formed was read at 543 nm. Ammonium-nitrogen ($\text{NH}_4\text{-N}$) was analyzed through the reaction between sodium salicylate and hypochloride solutions and the spectrophotometric absorbance of the green colour was read at a wavelength of 655 nm. The absorbance values read were used to work out the concentration using equations generated from the standard calibration curves made for each of the nutrient species.

3.3 Data analysis

Statistical tests and data analysis were done using SIGMA Plot 11 statistical software. Significant differences in physicochemical variables among the six studied streams were tested using one-way ANOVA. Significant differences in physicochemical variables between streams in native and exotic tree dominated forests and between big and small streams were tested using Student's t-test. Influence of forest type and stream size on decomposition rates and macroinvertebrate diversity within streams of different sizes in native and exotic tree dominated forests were tested using two-way ANOVA where forest type \times stream size were the interaction terms. Significance differences in $-k$ values among streams in both native and Exotic forests and among small and big streams were tested using one-way ANOVA. The differences in $-k$ values were tested using Tukeys (a post hoc test). Data on physico-chemical parameters (water temperature, Dissolved Oxygen (DO), current velocity, Ammonium nitrogen ($\text{NH}_4\text{-N}$), Nitrates Nitrogen ($\text{NO}_3\text{-N}$), Nitrite Nitrogen ($\text{NO}_2\text{-N}$) and soluble reactive phosphorus (SRP) were computed to find their mean values over time or in time space of the experiment.

CHAPTER FOUR

RESULTS

4.1 Physico-chemical parameters of the studied streams

Statistical parameters of the measured variables within the six streams of southern Mt. Kenya catchment are shown in Table 3. The data is presented as means \pm standard errors except for pH which is given as ranges. Small streams (pooled data) recorded significantly higher values of temperature compared to the big streams which had significantly lower values ($t = -3.420$, $d.f = 22$, $P < 0.05$). There was no significant differences in the values (pooled data) of temperature between the streams draining native tree dominated forests (17.36 ± 1.38 °C) and *Eucalyptus* (17.58 ± 1.09 °C) tree dominated forests ($t = -0.345$, $d.f = 22$, $P > 0.05$). The values of conductivity showed no significant difference between the streams draining native tree dominated forests and *Eucalyptus* tree dominated forests ($t = -1.234$, $d.f = 22$, $p > 0.05$), the same test showed no significant difference in conductivity values between small and big streams ($t = 0.840$, $d.f = 22$, $P > 0.05$). However, the lowest value of conductivity was recorded in Kamweti stream; big draining native tree dominated forest (32.55 ± 0.54 $\mu\text{S}/\text{cm}$) and the highest value was recorded at Kii stream; big draining exotic tree dominated forest (Table 3).

In terms of pH, there was no significant difference in pH values among the six streams irrespective of forest type and stream size (One-Way ANOVA; $P > 0.05$). The pH values ranged from 6.92 in Gichangai (small draining *Eucalyptus* forests) to 8.96 at Gathitha (Big draining native forests). The values of DO showed no significant differences between streams in native tree dominated forests (7.74 ± 0.15 mg/L) and exotic (7.42 ± 0.14 mg/L) tree dominated forests ($t = 1.542$, $d.f = 22$, $P > 0.05$). However, small streams had significantly lower levels of DO compared to big streams which significantly recorded higher values of DO ($t = 7.333$, $d.f = 22$, $P < 0.001$). There was significant difference (pooled data) in mean NO_2^- values between streams draining native and exotic tree dominated forests ($t = -2.387$, $d.f = 22$, $P < 0.05$) while NH_4^+ concentrations showed no significant differences between the streams in native forests (42.18 ± 3.15 $\mu\text{g}/\text{L}$) and those in exotic tree (44.81 ± 3.20 $\mu\text{g}/\text{L}$) dominated forests ($t = -0.587$ $d.f = 22$, $P > 0.050$). Significant difference in SRP concentrations was observed between streams

draining native forests ($21.83 \pm 2.02 \mu\text{g/L}$) and the ones draining exotic tree dominated forests ($5.51 \pm 0.64 \mu\text{g/L}$); ($t = 7.675$, $d.f = 22$, $P < 0.001$).

Table 3: Temperature, EC, pH, DO, Nitrogen and Phosphorus for the big streams (Kamweti, Gathitha & Kii) and for the small streams (Kabwe, Kiri & Gichangai) (values are means \pm standard deviations except for pH which is given as ranges)

Parameter	NATIVE	FORESTS	STREAMS	EXOTIC	FOREST	STREMS
	Kamweti	Kabwe	Gathitha	Kiri	Kii	Gichangai
Discharge ($\text{m}^3 \text{s}^{-1}$)	0.95 ± 0.53	0.02 ± 0.01	0.97 ± 0.51	0.24 ± 0.12	0.59 ± 0.29	0.17 ± 0.06
Temperature ($^{\circ}\text{C}$)	16.68 ± 1.53	18.95 ± 2.09	16.45 ± 0.70	17.43 ± 1.28	16.58 ± 0.24	18.75 ± 1.24
Conductivity ($\mu\text{S/cm}$)	32.55 ± 0.54	36.40 ± 0.88	$41.25 \pm 0.1.56$	41.53 ± 5.10	42.90 ± 6.11	33.45 ± 1.61
pH:	7.71 ± 0.97	7.69 ± 0.92	8.02 ± 0.94	7.75 ± 0.92	7.90 ± 0.80	7.46 ± 0.54
Dissolved oxygen (mg/L)	8.03 ± 0.40	7.18 ± 0.40	8.00 ± 0.10	7.42 ± 0.19	7.98 ± 0.06	6.87 ± 0.12
NO_3^- ($\mu\text{g/L}$)	38.30 ± 40.48	15.97 ± 17.43	9.94 ± 14.31	46.42 ± 48.68	25.49 ± 19.20	23.72 ± 24.51
NO_2^- ($\mu\text{g/L}$)	3.90 ± 0.98	3.78 ± 1.12	3.43 ± 1.26	$4.95 \pm 0.1.24$	$3.74 \pm 0.1.68$	6.44 ± 0.83
NH_4^+ ($\mu\text{g/L}$)	44.77 ± 11.15	42.47 ± 15.30	39.29 ± 7.65	34.69 ± 4.17	40.69 ± 13.24	55.87 ± 2.72
SRP ($\mu\text{g/L}$)	18.18 ± 3.19	17.68 ± 5.61	29.63 ± 4.04	5.10 ± 2.45	6.47 ± 2.82	5.10 ± 1.49

4.2 Riparian plants

4.2.1 Riparian plant composition

Summary of tree species identified from riparian zones of streams draining native and exotic tree dominated forests are presented in Appendix 2. Trees and shrubs composed the major forms of riparian vegetation along the studied streams as shown in Table 4. It is worth noting the lowest number of climbers and grasses within the riparian zones of the studied streams. Vegetation structure did not depict a definite pattern of variation from the stream banks along the transects at 0, 50 and 100 m reach in both banks within the native forests. However, Submontane *Syzygium guineense*, *Tabernaemontania stapfiana*, *Piper capense*, forest occurred as a dense belt with many different species of trees and shrubs within the native forests along transects made from the riverbanks. In streams draining exotic tree dominated forests, there was a clear pattern of *Eucalyptus* forest that occurred in patches directly to the riverbanks with species of *Grevillea robusta* and *Pennisetum purpureum* bordering sharply with plantations. Both banks of the streams within the native tree dominated forests were well vegetated contrary to the banks of streams within Exotic tree dominated forests which had patches of riparian vegetation along the streams. Table 5 shows the percentage composition of vegetation forms in both banks of streams draining native and exotic tree dominated forests, trees and shrubs recorded the highest percentage in composition.

Table 4: Summary of the individual tree species of various forms of riparian vegetation species within the studied streams both in native and exotic tree dominated forests

Form	Native forest streams	Exotic forest streams
Tree	155	82
shrub	94	10
Herb	6	7
Forb	18	2
Grass	6	9
climber	8	1
TOTAL	278	111

Table 5: Summary of the vegetation forms (percentage) for Right and Left bank of the studied streams both in native and exotic tree dominated forests

		% composition					
Type of forest		Tree	shrub	Herb	Forb	Grass	climber
Native	Right bank	52%	37%	1%	10%	0%	0%
	Left bank	64%	30%	4%	2%	0%	0%
Exotic	Right bank	74%	6%	8%	2%	10%	0%
	Left bank	73%	13%	4%	2%	6%	2%

4.2.2 Plant abundance and diversity

The study identified 394 individuals belonging to 75 species, in 31 families. The families with the largest numbers of species within the native forests were Rutaceae (4), Asteraceae (4), Euphorbiaceae (2), Boraginaceae (2) and Rubiaceae (2), while Myrtaceae (4), Poaceae (2) and Rubiaceae (2) dominated streams draining exotic forests. *Eucalyptus globulus* and *E. grandis* species dominated the riparian riverbanks of the streams draining exotic tree dominated forests forming 74 and 73% on right and left banks respectively (Table 5). The most dominant families in native tree dominated forests were Myrtaceae, Rutaceae, Eurphobiaceae, Piperaceae, Rubiaceae and Apocynaceae with the most dominant riparian species being *Tabernaemontania stapfiana*, *Neubotonia macrocalyx*, and *Syzygium guineense*. Proteaceae, Tilliaceae, Theaceae, Tiliaceae and Zingiberaceae families were only found in riparian zones of the streams draining exotic tree dominated forests. Details of the plant species and abundance can be obtained in appendix 1 and 2.

From Shannon Weiner diversity index, streams draining native tree dominated forests recorded the highest values of H' (2.89585) with abundance of 71 individual riparian plant species compared to streams draining exotic tree dominated forests with H' value of 1.8981 and 34 individual riparian

plant species. All the streams within the native tree dominated forests had the highest diversity of vegetation at the right bank (Table 6) while in streams draining exotic forests Kii had the highest diversity of riparian vegetation on the left bank contrary to its counterpart Kiri.

Table 6: Summary of Shannon Weiner macroinvertebrate diversity indices (H) for the studied streams (* shows data not collected)

Stream	NATIVE FOREST			EXOTIC FOREST		
	Kamweti	Kabwe	Gathitha	Kiri	Kii	Gichangai
Right bank	2.86871	2.87212	*	1.8522902	1.487816	*
Left bank	2.78707	2.63133	*	1.8002948	3.592988	*

4.3 Leaf decomposition

4.3.1 Decomposition trends

Except for Gichangai stream where leaves decomposed slowly, breakdown of *Syzygium cordatum* leaves for the other five streams followed the same general pattern of classical negative exponential decay trend whereby the leaves lost weight from day 0 of the exposure time to day 56 as shown in Figures 2 and 3 below. In streams draining native tree dominated forests, leaves decomposed faster in Kamweti stream followed by Kabwe and Gathitha (Figure 2a). In streams draining exotic forests, *S. cordatum* leaves were processed faster in Kii stream followed by Kiri and Gichangai (Figure 2b). In terms of stream size, decomposition of syzygium leaves was faster for Kamweti followed by Kii and lastly Gathitha (Figure 3a). Decomposition was faster in Kabwe stream followed by Kiri and lastly Gichangai.

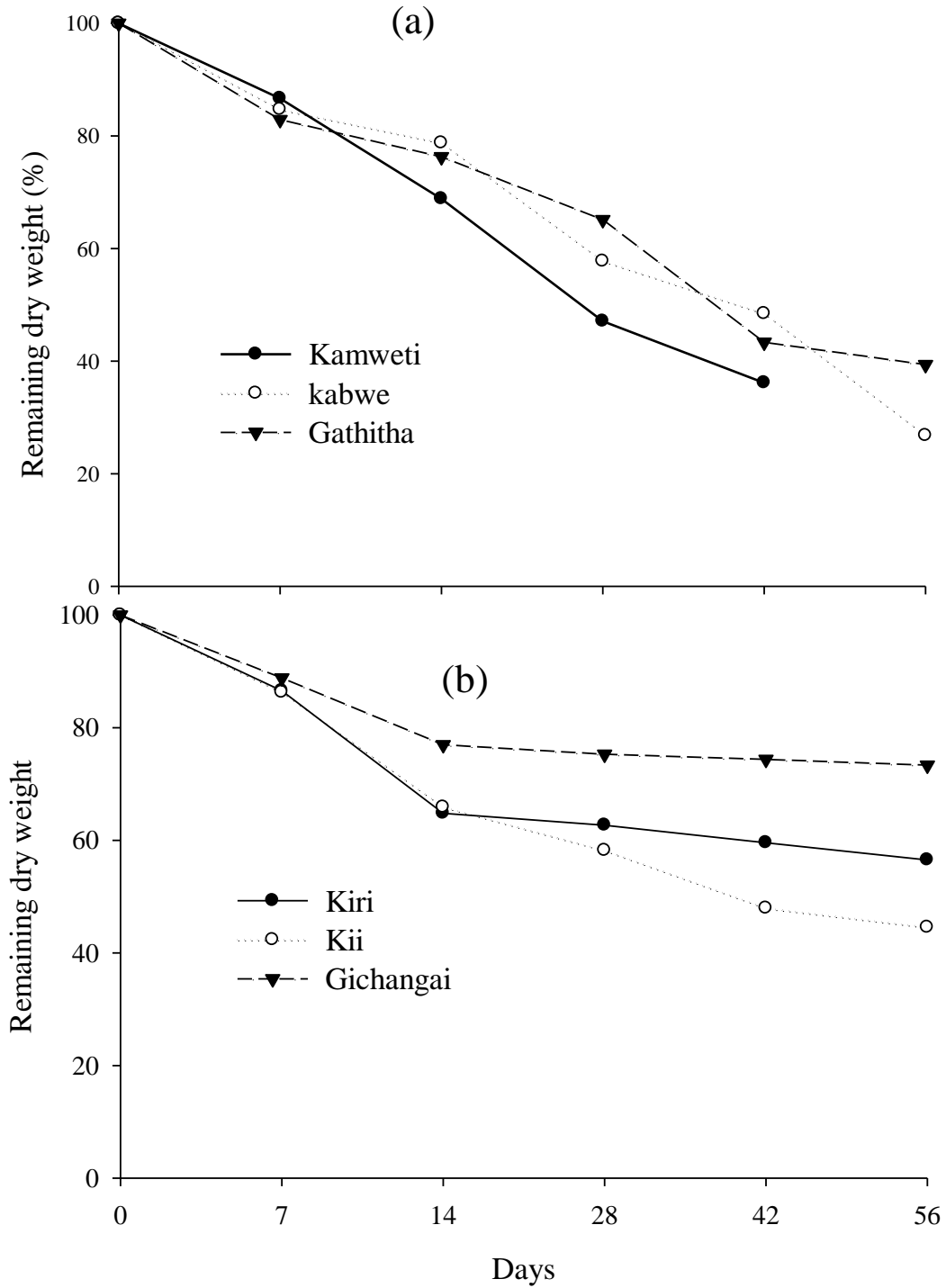


Figure 2: Remaining dry mass (percentage) for the *Syzygium cordatum* leaves for the streams draining native (a) and exotic (b) forests after incubation timing

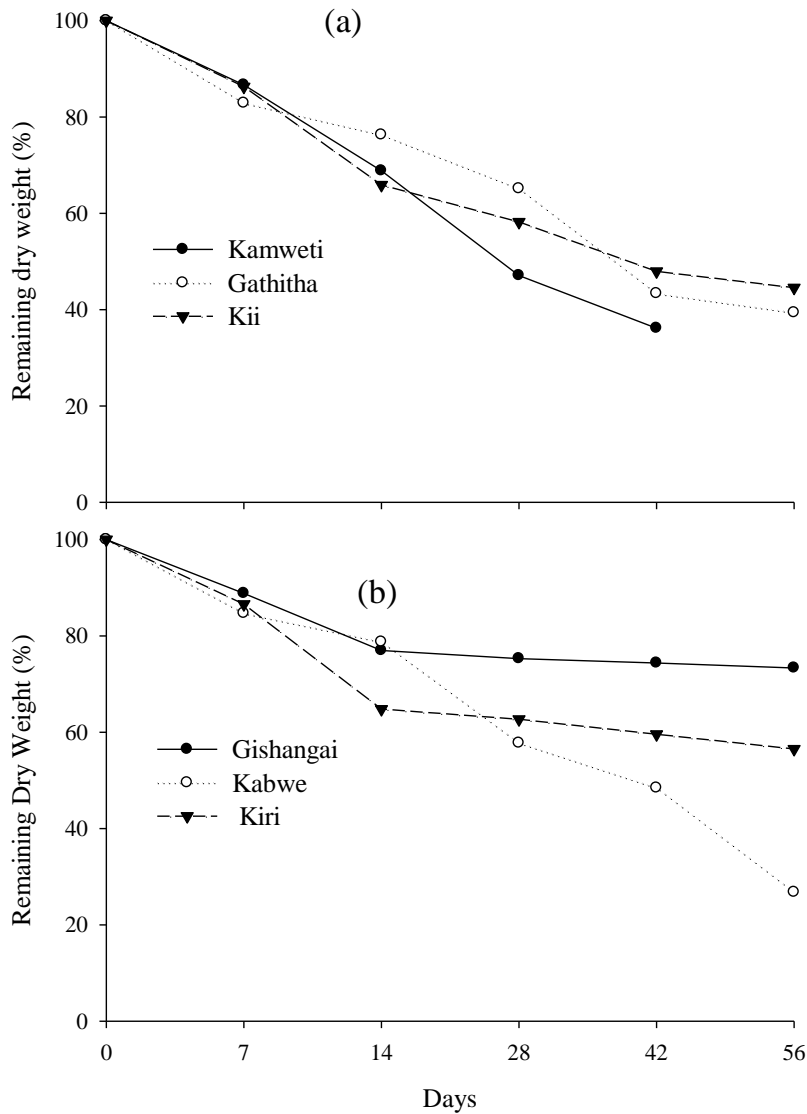


Figure 3: Remaining dry mass (Percentage) for the *Syzygium cordatum* leaves for the big streams (a) and for small streams (b) after incubation timing

4.3.2 Litter processing rates

The rates of mass loss (k-values) for *Syzygium cordatum* leaves in six streams studied are presented in Table 7. In general, leaf litter decomposition was slower in streams draining exotic tree dominated forests than in streams draining native tree dominated forests, in small than in big streams, while no significant differences were found between streams in native and exotic forests (Figure 4, Two-way ANOVA $df = 1$, $F = 2.915$; $P > 0.05$). Significant differences in mean

decomposition rates were recorded between small and big streams (Figure 4, Two-way ANOVA $d.f = 1, F = 5.026; P < 0.05$). The big streams recorded significantly higher values of decomposition rates of 0.0217 ($-k$ values per day and 41.9 % of dry mass remaining at the end of the experiment) compared to $-k = 0.0178$ and 52.2% of dry mass remaining at the end of the experiment in small streams. Streams within native forests recorded higher mean values of decomposition rates; ($-k = 0.0213$ with 33.1% of dry mass remaining) compared to streams draining exotic tree dominated forests ($-k = 0.0183$ with 58.1% of dry mass remaining at the end of the experiment). The results showed no significant interaction between the forest type and the stream size (Two-way ANOVA $df = 1, F = 2.618; P > 0.05$). All the litterbags got lost in Kamweti stream on day 56 due to human and animal interferences.

Table 7: $-k$ values of *S. cordatum* species calculated from exponential decay equations for streams draining native and exotic tree dominated forests (B = big Streams and S = small streams. * means data missing).

Forest type	STREAM	DAY 7	DAY 14	DAY 28	DAY 42	DAY 56	MEAN
Native tree dominated	Kamweti (B)	0.021	0.027	0.028	0.025	*	0.025
	Kabwe (S)	0.024	0.017	0.022	0.018	0.025	0.021
	Gathitha (B)	0.028	0.02	0.016	0.016	0.011	0.018
Exotic tree dominated	Kiri (S)	0.021	0.025	0.018	0.012	0.01	0.017
	Kii (B)	0.022	0.03	0.02	0.02	0.015	0.021
	Gichangai (S)	0.017	0.019	0.011	0.007	0.006	0.012

Leaves of *S. cordatum* would take the longest time to be processed in streams draining exotic tree dominated forests than in native tree dominated forests. On average, it took twice more time for 50% and 90% of the leaves of *S. cordatum* to be processed in streams draining exotic tree dominated forests than in streams draining native tree dominated forests. Similarly, it took double the amount of time for similar amount of organic matter to be processed in smaller streams than bigger streams (Table 8). In addition, the leaves took longer time to be processed in small streams compared to big streams. It took 35, 28 and 42 days to decompose 50 % of the leaves of *S. cordatum* in Kabwe, Kamweti and Gathitha streams respectively, which drain native forests. On

the other hand, it took 63, 36 and 149 days to decompose 50% of the same leaves in Kiri, Kii, and Gichangai streams respectively, which drain the exotic forests.

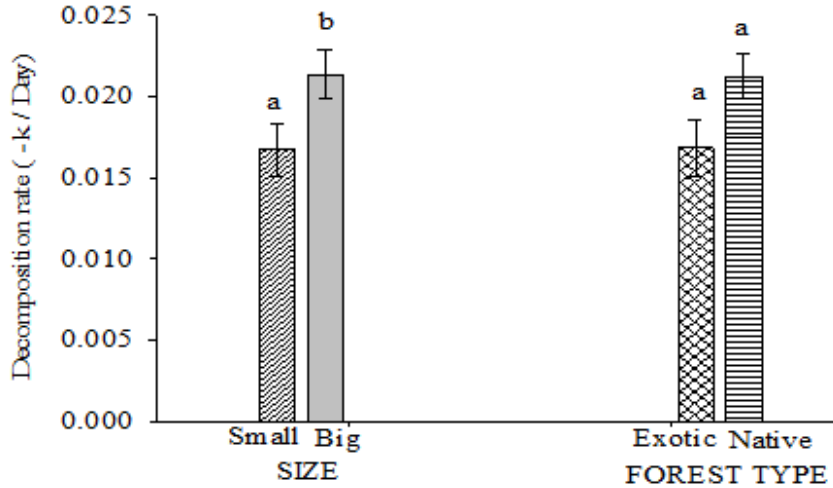


Figure 4: Mean (\pm SE) - k rates for streams of different sizes and streams draining Native and Exotic tree dominated forests (different letters on the bars indicate significant differences among streams for each factor; size of the stream and the forest type).

Table 8: Time in days required for 25%, 50%, 75% and 90% of the *S. cordatum* leaves to decompose in streams of different sizes draining native and exotic tree dominated forests.

Type of Streams	25%	50%	75%	90%
In Native forests	14.28	34.57	69.26	115.11
In Exotic forests	26.50	82.81	179.08	306.34
Big streams	13.76	35.12	71.64	119.92
Small streams	27.02	82.26	176.70	301.53

Big streamss draining the native forests recorded mean value of $-k$ as 0.0218 with Kamweti having the highest value of $-k$; (0.025) and Gathitha recording the least value of 0.018 (Fig. 5 a). On the other hand, small streams had mean value of 0.0178 for $-k$ with Kiri and Gichangai, which drain Exotic forests recording mean value of 0.0149 for $-k$. Within the small streams, Kabwe had the highest value of $-k$ as 0.0207 (Figure 5b). There was no significant difference in $-k$ values for

streams draining native forests (One-Way ANOVA; $P > 0.05$). In contrary, Kii and Gichangai differed significantly in terms of decomposition rates for streams draining exotic tree dominated forests (One-Way ANOVA; $P < 0.05$).

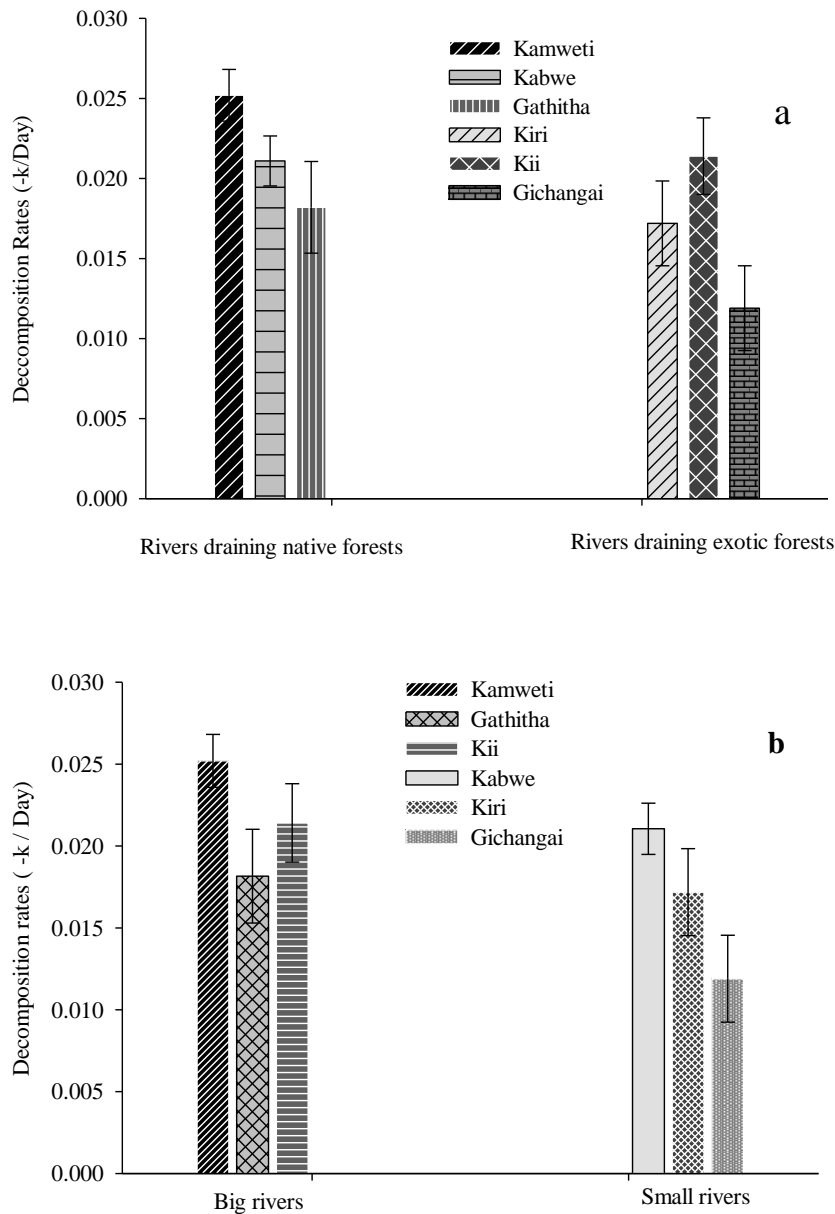


Figure 5: Mean (\pm SE) - k rates for six streams draining native and exotic tree dominated forests (a) and for small and big streams (b)

There was no significant differences in decomposition rates within big streams (One-Way ANOVA; $P > 0.05$) while Kabwe and Gichangai differed significantly in terms of $-k$ values for small streams (One-Way ANOVA; $P < 0.05$).

4.4 Macroinvertebrates taxon richness and diversity

In this study, 1108 individual macroinvertebrates belonging to 23 families and 9 orders were found across the six streams studied; all the orders were represented in all the streams draining native and exotic forests except for Kii and Gichangai streams where Lepidoptera and Decapoda orders were not represented (Table 9).

Table 9: Presence or absence of various macroinvertebrate taxa within the six studied streams draining native and exotic tree dominated forests (+ means present and – means absent)

TAXA	Streams in Native forests			Streams in Ecalyptus		
	Kamweti	Kabwe	Gathitha	Kiri	Kii	Gichangai
(a) Ephemeroptera						
Baetidae	+	+	+	+	+	+
Caenidae	+	+	+	+	+	-
Heptagenidae	+	-	+	+	+	+
(b) Trichoptera						
Hydropsychidae	+	+	+	+	+	+
Hydroptilidae	+	+	-	-	-	-
Leptociridae	+	+	+	+	+	+
(c) Coleoptera						
Dytiscidae	+	-	+	-	-	-
Elmidae	+	+	+	-	+	+
Gyrinidae	-	-	-	+	-	-
Helodidae	+	+	+	+	+	+
Hydraenidae	-	-	+	+	-	-
(d) Hemiptera						
Veliidae	+	+	+	+	+	+
(e) Odonata						
Libellulidae	+	+	+	-	+	-
Aeshnidae	+	+	-	-	-	-
(f) Diptera						
Ceratopogonidae	+	+	+	+	+	+
Chironomidae	+	+	+	+	+	+

Culicidae	+	+	+	+	+	+
Dixidae	-	+	+	+	+	-
Simulidae	+	+	+	+	+	+
Tipulidae	+	+	+	+	+	+
(g) Plecoptera						
Perlidae	+	+	+	-	-	-
(h) Lepidoptera						
Pyralidae	+	+	-	-	-	-
(i) Decapoda						
Potamonautidae	+	+	-	+	-	-

In general, macroinvertebrate abundance and diversity associated with decomposing litter were lower in exotic streams than in native streams and in small streams than in big streams while no significant differences of macroinvertebrate abundance were found between forest types (Fig. 6, Two-way ANOVA d.f = 1, F = 2.423; P > 0.05).

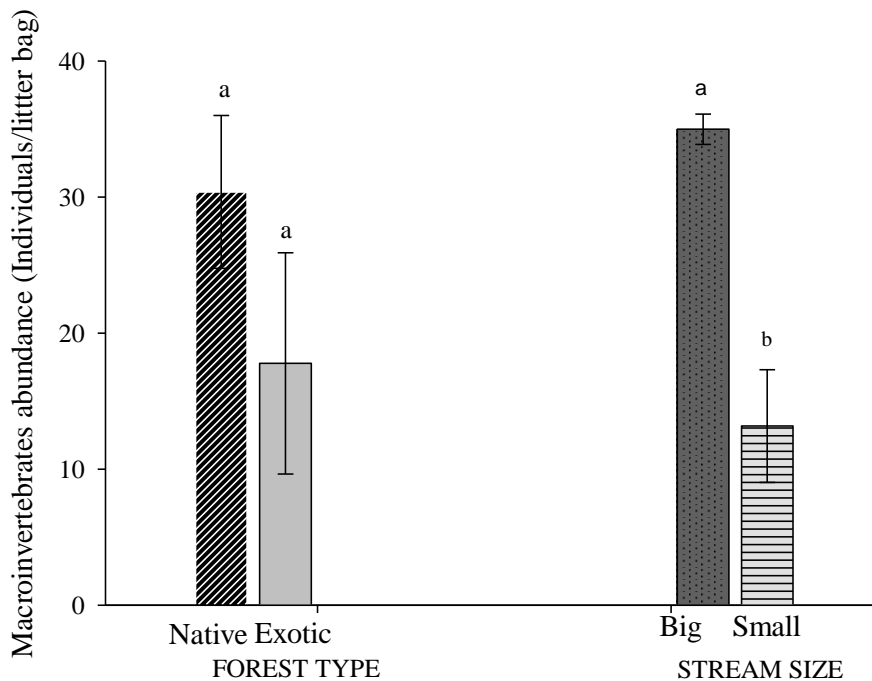


Figure 6: Mean (\pm SE) for macroinvertebrates abundance (individuals per bag) for streams of different sizes draining Native and Exotic forests (different letters on the bars indicate significant differences among streams for each factor; size of the stream and the forest type).

Stream size significantly influenced the total macroinvertebrate abundance whereby big streams had significantly higher number of macroinvertebrates (Two-way ANOVA $df = 1$, $F = 27.535$; $P < 0.05$). Twenty taxa were found in native forests, 21 in exotic forests, 23 in big streams while 21 taxa occurred in small streams. There was significant interaction between forest type and stream size in influencing macroinvertebrate diversity within the six studied streams (Table 10) while there was no significant difference in macroinvertebrate diversity among streams of various sizes (Table 10, Figure 7).

Big streams within the native forests (Kamweti and Gathitha) had a higher mean diversity (1.626 ± 0.0573) compared to Kii (1.588 ± 0.0774), which was the only big stream draining exotic forests. Small streams draining exotic forests on the other hand had the lowest mean of macroinvertebrate diversity (1.312 ± 0.0536) compared to Kabwe (1.767 ± 0.0774) which was the only small stream draining native forests (Figure 7).

Table 10: Summary of Two-way ANOVA performed on Shannon Weiner macroinvertebrate diversity (H) for small and big streams; factor Size and in streams draining native and exotic forests; Forest type factor. * There is a significant difference (* = $P < 0.05$, ** = $P < 0.01$).

Source of Variation	DF	SS	MS	F	P
Size	1	0.14	0.14	1.017	0.315
Forest type	1	1.873	1.873	13.577	0.001**
Size x Forest type	1	1.347	1.347	9.767	0.002**
Residual	133	18.349	0.138		
Total	136	22.397	0.165		

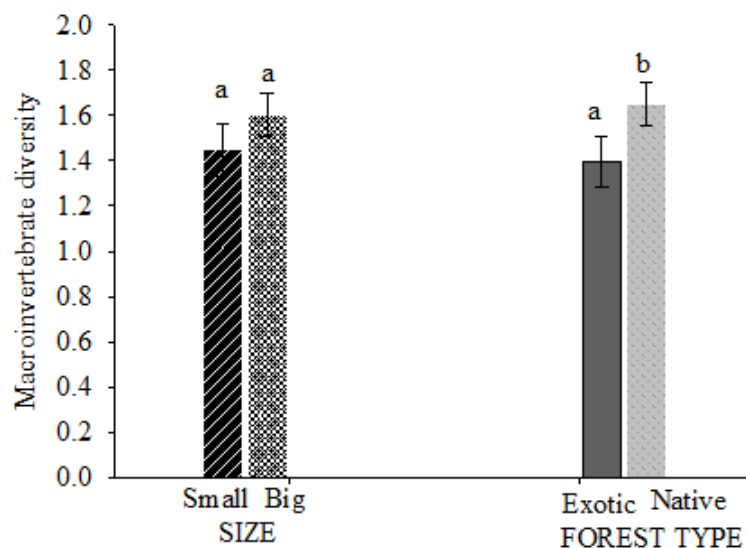


Figure 7: Mean (\pm SE) of macroinvertebrates diversity (Shannon Weiner diversity index; H) for streams of different sizes draining Native and Exotic forests (different letters on the bars indicates significant differences among streams for each factor; size of the stream and the forest type).

Table 11: Summary of four dominant macroinvertebrate taxa in both native and exotic tree dominated forests values are numbers of individual macroinvertebrates per litter bag.

TAXA				
Streams in native forests				
	Chironomidae	Leptoceridae	Baetidae	Helodidae
Kamweti	65	21	15	3
Kabwe	22	23	11	19
Gathitha	66	25	42	21
Streams in exotic forests				
	Chironomidae	Simulidae	Baetidae	Helodidae
Kiri	44	2	8	2
Kii	31	0	29	41
Gichangai	10	1	4	2

More information on macroinvertebrate diversity values is shown in the appendix 1. The same test showed significant differences in macroinvertebrate diversity between native and exotic forests with native forests recording significantly higher value of diversity (Table 10, Figure 7). Chironomidae dominated in most streams draining native tree dominated forests and exotic tree

dominated forests followed by Leptoceridae in streams draining native tree dominated forests (Table 11).

4.4.1 Functional Feeding Groups

The distribution and abundance of FFGs among six streams of different sizes draining native and exotic forests are presented in Table 12. A total of 5 shredders, 6 collectors, 2 scrapers and 5 predator groups were identified within the six streams. All the shredder taxa were found both in streams draining native and exotic forests except for Potamonautidae taxa, which was restricted to streams within the native forests. During the study period, total number of shredder taxa were higher in streams draining native forests than streams within exotic tree dominated forests. Baetidae and Leptoceridae were the most abundant shredder taxa in streams draining native forests although there was distribution of shredder taxa within all the six streams. Considering stream size, all FFGs and shredder abundance was higher in big streams draining the native forests. About an average of 54% of the insects colonizing the *Syzygium* leaves in native streams were Collectors, 37 % were Shredders, 5% scrapers, and 4% predators.

A similar trend was recorded for streams draining exotic tree dominated forests, which had 55% collectors, 27 % shredders, 11% scrapers, and 7% predators. It is clear that collectors and shredders dominated the *Syzygium* leaves within the six streams in this study, a trend that was seen both in small and big streams.

Table 12: Summary of percentage composition of Macroinvertebrate Functional Feeding Groups (FFG) in the studied streams

Percentage composition of FFGs				
Type of stream	Collectors	Predators	Scrapers	Shredders
Native	54%	4%	5%	37%
Exotic	55%	7%	11%	27%
Small	48%	6%	11%	34%
Big	57%	6%	5%	32%

4.4.2 Number of macroinvertebrates per litter bag over time

Macroinvertebrate numbers changed with time for the six streams used in the study as shown in Figures 8 and 9. The highest abundance of macroinvertebrates was on day 28 for native streams except for Kabwe whose peak macroinvertebrate colonization was on day 56 of the study (Figure 8a). Streams within exotic tree dominated forests had the same trend of macroinvertebrate colonization over time with highest peak on day 14 of the study except for Kii stream where most invertebrates colonized the leaves on day 28 of the study (Figure 8 b). All big streams had the same pattern of macroinvertebrate colonization with day 28 as the peak where most invertebrates were found (Fig. 9b) contrary to the small streams where the highest abundance of macroinvertebrates was on day 14 (Fig. 9a). In general, the trend showed an increase in the number of macroinvertebrates per litterbag within streams of different sizes as the study progressed from day 0 towards day 28 after which the numbers started reducing towards day 42.

There was no significant relationship between total number of macroinvertebrates per litter bag and decomposition rates in streams draining exotic tree dominated forests ($R^2 = 0.0166$) while macroinvertebrates contributed approximately 30% to decomposition processes in streams draining the native forests ($R^2 = 0.299$) hence the remaining percentage of decomposition was contributed to by other biotic and abiotic factors in these ecosystems.

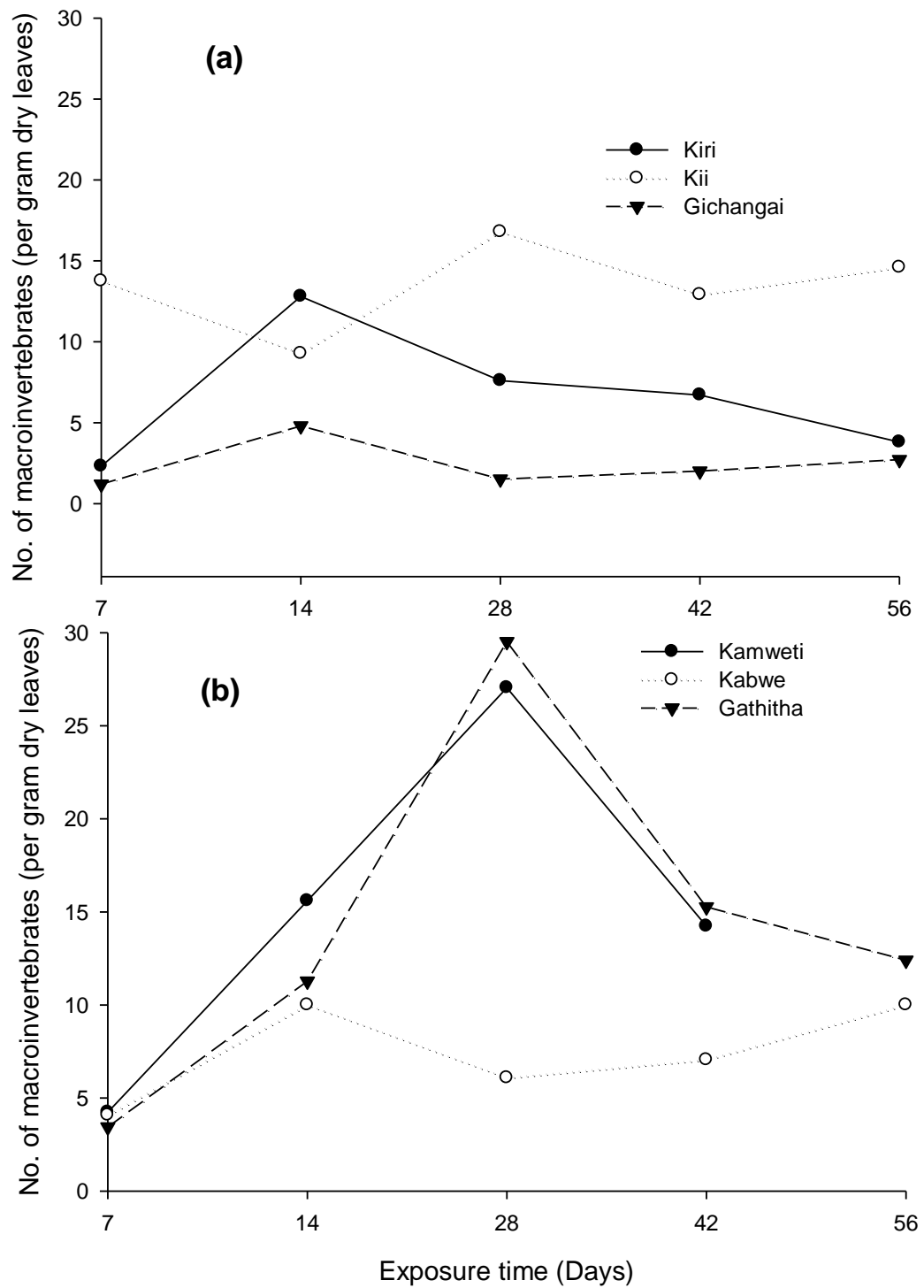


Figure 8: Colonization rate by macroinvertebrates associated with leaf decomposition in streams draining exotic forests (a) and native forests (b)

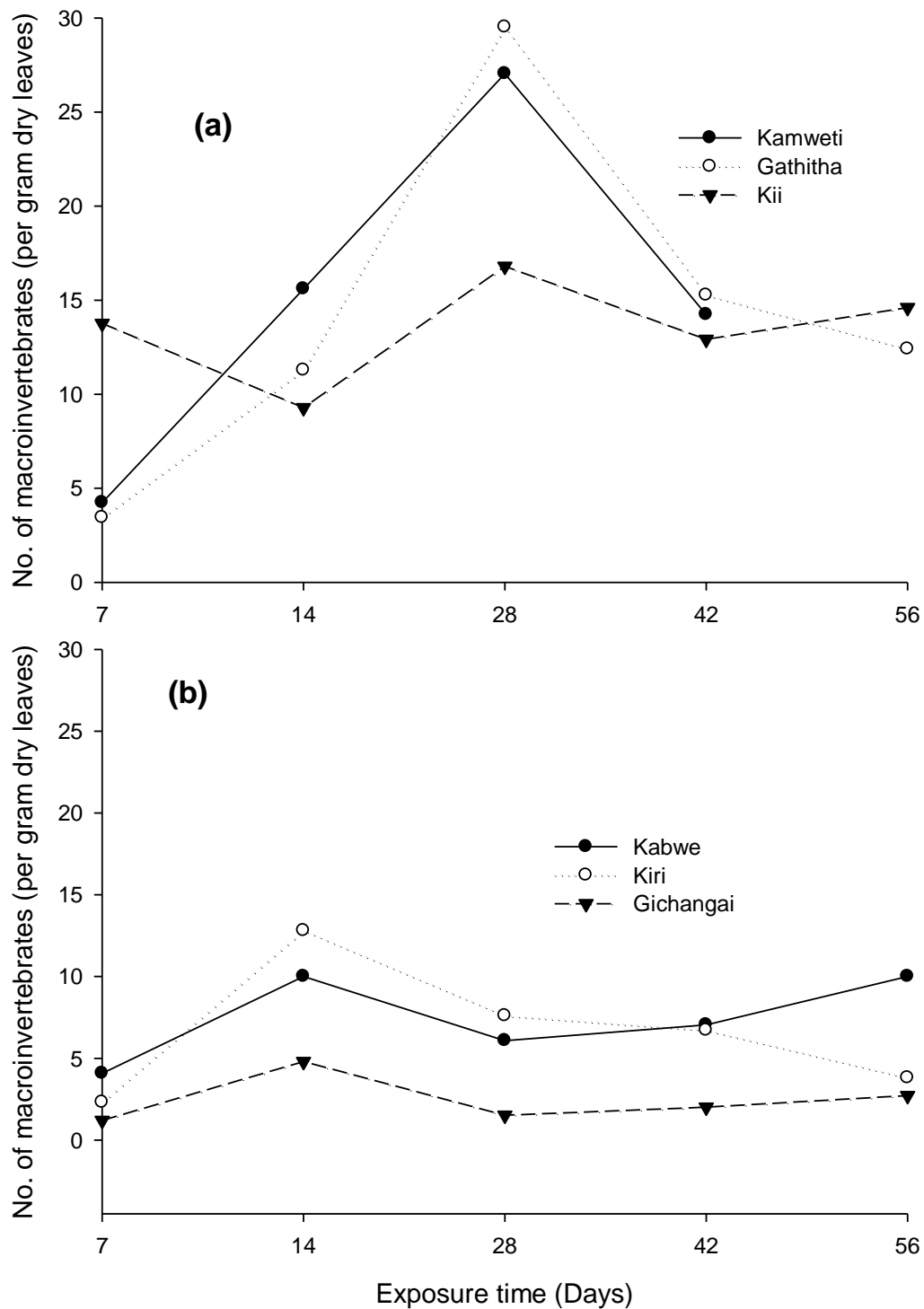


Figure 9: Colonization rate by macroinvertebrates associated with leaf decomposition in big (a) and in small streams (b)

CHAPTER FIVE

DISCUSSION

5.1 Spatial variation of physico-chemical parameters in the study sites

Some of the physico-chemical parameters in the indigenous forested streams showed significant variation from the streams in the exotic forests due to change in land use activities within these catchments. Big streams recorded significantly lower values of temperature compared to small streams. This could be explained by greater stream depths in the larger streams and higher volumes of water they contain so that heating was slower for a given sunlight exposure (Brown and Krygier, 1970). The results are consistent with previous studies where stream size influenced the magnitude and duration of temperature responses; increases in average daily maximum temperature during summer were greater in small-intermediate sized streams than in the larger streams (Quinn and Wright-Stow, 2008). The thick riparian vegetation along the big streams also protected the streams from direct insolation since most native riparian vegetation tend to grow over streams unlike Eucalyptus species which dominated the areas drained by small streams. Eucalyptus spp. are columnar to pyramidal in shape hence do not protect sufficiently the streams from direct insolation. This pattern in temperature variation was also reported in another study within the tropical streams (Masese *et al.*, 2014a).

The values of conductivity and pH showed no significant differences between the six streams in every category of consideration (size and forest type) indicating that they drain a catchment with similar geological characteristics. However, the lowest value of conductivity was recorded in Kamweti stream; big draining native forests ($32.55 \pm 0.54 \mu\text{S}/\text{cm}$) compared to the highest value in Kii stream; big draining Eucalyptus forests was attributed human activities within the study areas. Kamweti stream was within the protected area of Mt. Kenya national park unlike Kii stream which flows into agricultural farms and plantations with higher anthropogenic disturbances. The mean values of concentrations for DO, NO_3^- , and NH_4^+ in six studied streams showed no significant differences because the study was conducted only during the dry season hence posing no seasonal influences and variations in nutrient dynamics. Some of the past studies indicated that physicochemical parameters varied with seasons and seasonal activities (Mathooko, 2001 and Yillia *et al.*, 2008); TSS, turbidity, TDN, $\text{NH}_4\text{-N}$ and DOC were consistently higher during the wet

season compared to dry season in a study within tropical streams in Kenya (Masese, *et al.*, 2014a). However, the significant difference of mean values of NO_2^- and SRP concentrations between streams draining native and exotic tree dominated forests could be attributed to impacts of land uses experienced within the catchment of these streams (Minaya, *et al.*, 2013). Kibichii *et al.*, (2007) report similar results from Njoro River due to high livestock abundance and excretion of urea into streams during cattle watering. The higher mean values of discharge observed in big streams was due to higher volume of water flowing at a higher velocity within the streams compared to low volume contained within the small streams.

5.2 Riparian plant diversity

The taxonomic diversity of the plant community surveyed within the studied streams emphasizes complexity and the immense variety of ecological relationships that exist in tropical ecosystems (Laurance and Bierregaard, 1997). Myrtaceae, Rutaceae, Eurphobiaceae, Piperaceae, Rubiaceae and Apocynaceae families dominating the riparian areas of streams draining native tree dominated forests with the most dominant riparian species being *Tabernaemontania stapfiana*, *Neubotonia macrocalyx*, and *Syzygium guineense* indicates that they are the key species in the energy and nutrient dynamics of these streams. A study within a Rift Valley tropical stream in Kenya also indicated that Myrtaceae family and especially *Syzygium cordatum* species was dominant along riparian areas (Mathooko and Kariuki, 2000). Higher diversity of vegetation within the riparian areas of streams draining native forests was due to protection from human activities like agriculture, tree harvesting, settlement, road construction, and livestock interferences among other activities.

The Kenya Forest Service (KFS) through an electric fence protected the native forests and the streams from encroachment from the surrounding human populations. On contrary, the streams draining exotic forests had low diversity of riparian vegetation due to interferences from human activities. Plantation and small-scale agriculture of orchards, tea, coffee, maize and human settlements dominated the landscape of valleys where streams drained exotic forests. Most of these riverbanks composing of shrubs like *Triumfeta tomentosa*, and *Lantana camara* were degraded. Some plantations extended down to the riverbanks destroying the riparian zones evidenced by the composition of *Pennisetum purpureum* farms along these streams. However, forests of Eucalyptus plantations occurred in patches along Kiri and Kii streams. Different magnitude of land use

pressure is a key determinant of riparian vegetation species abundance and diversity as seen from the results of this study. Thus, low abundance of species and diversity within the streams draining native forests can be indicative of a highly degraded landscape. The reduced species diversity within the riverbanks of the exotic forests could also be attributed to the dominance of Eucalyptus species within the riparian zones. The allelopathy of Eucalyptus spp. reduces species diversity and alters structural attributes of native vegetation (May and Ash, 1990). There is close connection between terrestrial and aquatic ecosystems through their riparian zones; this aspect needs to be taken into consideration in the development of conservation strategies, management programs and environmental legislation (Goncalves and Callisto, 2013). The composition of riparian vegetation, especially the tree and shrub cover classes, could also partially explain the variability of the spatial patterns of riparian vegetation (Fernandes, *et al.*, 2011).

5.3 Leaf decomposition

5.3.1 Litter processing rates

Leaf litter decomposition was slower in streams draining exotic tree dominated forests than in streams draining native tree dominated forests. This could be explained by differences in ecosystem conditions in the two catchments leading to variation in biological activities and abiotic factors contributing to decomposition process. This variability may have also been contributed upon by terrestrial vegetation and its putative effects on invertebrates since the two catchments differed primarily in riparian vegetation composition (Casas, *et al.*, 2013). In addition, all the native streams were located within the headwaters explaining their faster rates of litter processing compared to streams draining the exotic forests, which were majorly within the downstream concurring to a study done in River Stradomka Southern Poland by (Fleituch, 2001) where upstream reaches had a greater capacity to break down litter than downstream reaches.

The significantly higher values of decomposition rates in big streams than in small streams could be explained by higher values of discharge in the big streams hence causing physical abrasion and fragmentation that enhances faster decay rates in rivers and streams (Wantzen *et al.*, 2008). In addition, most of the big streams drained native forests with fewer impacts from human activities. Small streams especially Kiri and Gichangai drained exotic forests with diverse human activities including agriculture and tree farming responsible for depletion of invertebrate shredders that take

part in leaf decomposition as reported in other studies that catchment characteristics and water quality also affect leaf litter decomposition rates (Sponseller and Benfield, 2001). The slower rates of decomposition in small streams could have also been attributed to by low levels of discharge within these streams compared to big streams that recorded significantly higher values of discharge since breakdown in high-velocity microhabitats, such as riffles, is faster than in pools (Stout and Coburn, 1989). A study by Wantzen *et al.* (2008) also explains that physical abrasion, fragmentation and influence of macroinvertebrates are some of the main factors that determine decay rates in rivers and streams. Exponential decay coefficients were used in this study to present decomposition information to enable comparison with decay rates from other studies that use the same method. Despite the tough structure and low quality of *Syzygium* leaves compared to other species like *Croton* (Masese *et al.*, 2014a), decay rates for this study fall within the range recorded from other studies in tropical streams (Table 13).

Table 13: Examples of coefficients of decay (k : absolute values) recorded from studies carried out in the tropics. In all cases cited, mesh size was coarse enough to allow macroinvertebrate access. The Table states whether the k value was based upon dry mass (DM).

Species	Location	k	DM	Reference
<i>Trema micrantha</i>	Costa Rica	0.559	yes	Irons <i>et al.</i> (1994)
<i>Croton gossypifolius</i>	Colombia	0.065	No	Mathuriau and Chauvet (2002)
<i>Vanguera madagascariensis</i>	Kenya	0.047	yes	Dobson <i>et al.</i> (2003)
<i>Pittosporum viridiflorum</i>	Kenya	0.043	yes	Dobson <i>et al.</i> (2003)
<i>Rhus natalensis</i>	Kenya	0.026	yes	Dobson <i>et al.</i> (2003)
<i>Clidemia sp.</i>	Colombia	0.024	No	Mathuriau and Chauvet (2002)
<i>Syzygium cordatum</i>	Kenya	0.022	yes	Dobson <i>et al.</i> (2003)
<i>Syzygium cordatum</i>	Kenya	0.019	yes	This study
<i>Syzygium cordatum</i>	Kenya	0.001	No	Mathooko <i>et al.</i> (2000)
<i>Dombeya goetzeni</i>	Kenya	0.021	No	Mathooko <i>et al.</i> (2000)
<i>Dombeya goetzeni</i>	Kenya	0.01	yes	Dobson <i>et al.</i> (2003)
<i>Pithecellobium longifolium</i>	Costa Rica	0.02	yes	Irons <i>et al.</i> (1994)

5.3.2 Decomposition trends

Gessner and Chauvet, (1994) have reported general pattern of classical negative exponential decay trend displayed by *Syzygium* leaves within the studied streams concurring with the findings of this

study. The rapid loss in mass of the leaves in water within the first few days could be attributed to leaching concurring with another case where leaves immersed in the humid zone of rivers lost mass rapidly in an experiment done within a tropical stream (Mathooko *et al.*, 2000). The first phase of decomposition involves leaching of soluble compounds, which can lead to the loss of up to 42% of the initial leaf mass (Verónica, 2006). After prolonged emersion into the streams, fragmentation of leaves was observed probably by mechanical means and macroinvertebrate activity same scenario in other studies (Moss, 2007). The higher biological half-life of *S. cordatum* leaves in streams draining exotic forests compared to streams draining native forests shows that it would take a longer period of time to decompose 50% of *S. cordatum* leaves in streams draining exotic forests than native forest streams. The higher biological half-life of the leaves in streams draining exotic forests could be attributed to poor biotic and abiotic conditions involved in litter breakdown in these streams. In addition, streams draining exotic forests were encountered with diverse human activities including agriculture and tree farming responsible for depletion of invertebrate shredders that take part in leaf decomposition similar to another study showing that catchment characteristics and water quality also affect leaf litter decomposition rates (Sponseller and Benfield, 2001).

Together these results suggest that the sensitivity of litter decomposition to forest change is higher for small streams than for big streams. This is described where it would take the longest time to process 50% of *S. cordatum* leaves in small streams draining exotic forests (Kiri and Gichangai) than a small stream in native forests (Kabwe). This case is contrary to big streams (Kamweti, Gathitha and Kii) i.e. it took twice more time for 50% and 90% of the leaves of *S. cordatum* to be processed in small streams than in big streams (Table 8). The big streams recorded significantly higher values of decomposition rates compared to small streams due to their low volumes of water, discharge and velocity values that determine leaf breakdown processes. The hard textured *S. cordatum* leaves is expected to decompose faster in big streams due to higher physical abrasion and fragmentation processes in these streams unlike small streams. *Syzygium cordatum* falls in the slow degraded leaf category (Cummins *et al.*, 1989). The hard texture of the leaves, and probably their chemical nature makes the cuticle and epicuticular waxes to form a barrier to water soluble cell compounds by impeding permeation of hydrophilic substances and by reducing wettability of the leaf surface, thus reducing leaching (Mathooko *et al.*, 2000).

The results of this study have important implications on the management of riverine ecosystems in the region by noting that small streams receive catchment pressures from various land use practices as compared to big streams, a case also reported in other studies within headwater streams impacted by timber harvesting within the riparian zones (Jackson *et al.*, 2007).

5.4 Macroinvertebrates diversity

Numerical abundance of macroinvertebrates in this study was obtained during the study within dry season. The past studies report that during the peak of the dry season, conditions can worsen in streams and rivers because, as stream discharge declines fines accumulate, temperatures rise and dissolved oxygen becomes limiting. This resulted into considerably lower abundance of most taxa during the dry than in the wet season (Harrison and Hynes, 1988; Mathooko and Mavuti, 1992; Shivoga, 2001; Masese *et al.*, 2014a). Despite natural conditions influencing taxon richness and abundance, the effects observed in this study seem to be highly exacerbated by human activities. For instance total macroinvertebrate abundance and diversity associated with decomposing litter were lower in exotic streams than in native streams and in small streams than in big streams. Two out of three small streams drain exotic forests, which were located in areas frequented by people and their agricultural activities including crop cultivation, livestock keeping and settlements. These streams occasionally could be subjected to sedimentation and input of nutrients and organic wastes that could influence the macroinvertebrate communities. The results concurred with the outcomes of a study done within tropical highland streams in Kenya (Masese *et al.*, 2014b). Significant influence of forest type and stream size on the macroinvertebrate diversity within the studied streams could be attributed to higher percentage canopy cover within the native forests, which strongly influence the distribution and abundance of scrapers and shredders. This finding is similar to a recent study where tropical riparian vegetation contributing high CPOM was responsible for high macroinvertebrate density (Mbaka, *et al.*, 2014).

Low measures of stream size within small streams (discharge and width) which results into flow reduction also contributes to variability in physicochemical conditions that could also influence macroinvertebrate communities.

Required information on morphology and behavior needed to assign FFG is particularly scarce for aquatic insects in tropical regions (Alonso and Pablo, 2014). This study assigned functional feeding group at family level using available information after a review done by Alonso and Pablo,

(2014). Assigning FFG at family level has limitations, as some families are very diverse and species within the family are likely to belong to other different groups. Readers are therefore advised to use this information with caution since the work was to provide an overview for understanding the role of aquatic insects in leaf litter breakdown. Specific studies can be conducted up to the genus level or species level for a detailed understanding of the functional feeding groups of macroinvertebrates.

Higher number of shredder taxa in streams draining native forests is attributed to closed canopy where the riparian vegetation is intact from land use pressures within riparian forests along these streams (Masese *et al.*, 2014b, Mbaka, *et al.*, 2014). Higher abundance of collectors could have resulted from leaf conditioning where bacteria and fungi form biofilms on the leaf surfaces thereby attracting the collector taxa for feeding. The higher number of shredder taxa within the studied streams prove that they are responsible biological agents of litter breakdown in tropical streams. Regression analysis between macroinvertebrate abundance and decomposition rates demonstrated that 30% of the decomposition processes within the six streams were contributed to by macroinvertebrates participation (Linear regression, $R^2 = 0.300$, d.f = 1, $F = 2.669$). This finding differs strongly from the past studies, which found an evidenced conspicuous lack of shredders in tropical streams within Africa, Asia, and the Neotropics systems (Irons *et al.*, 1994; Rosemond *et al.*, 1998; Dudgeon, 2000; Dobson *et al.*, 2002; Mathuriau and Chauvet, 2002; Rueda-Delgado *et al.*, 2006; Wantzen and Wagner, 2006).

However, very recent research in tropical highland stream in Kenya also found that shredders were diverse (19 taxa) and abundant in closed-canopy forested streams, where they made up 17 groups comprising of 20% of all taxa, and 75 groups, composing of 84% of total macroinvertebrate biomass during the dry and wet seasons, respectively (Masese *et al.*, 2014b). The general trend of macroinvertebrate colonization of leaves evidenced by the increase in the abundance of macroinvertebrates per gram dry leaves as the study progressed from day 0 towards day 28 may be explained by leaf conditioning. During this process, leaching of sugars and amino acids from leaves after a few days of emersion in water attracts fungi and bacteria to the leaves (Strauss and Lamberti, 2002), which helps in the softening of leaves due to presence of fungi and bacteria thereby increasing the food value for insects especially shredders (Wantzen *et al.* 2008).

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Hypotheses review and conclusions

6.1.1 Hypotheses

1. Due to significant difference in some physico-chemical variables for streams of various sizes draining native and exotic forests, the first hypothesis for this study is partly rejected.
2. With regard to the results, the hypothesis that there are no riparian plant diversities associated with streams draining native and exotic forests in Mt. Kenya region is rejected. No significant difference in leaf litter processing rates for the six streams of different sizes draining native & exotic forests is rejected.
3. Based on the results for macroinvertebrate abundance, diversity and litter decomposition, the hypothesis that there is no significant difference in leaf litter processing rates and

macroinvertebrate diversity in streams of different sizes draining native and exotic forests is rejected.

6.1.2 Conclusion

1. Although there was no significant variation in most of the physicochemical parameters within streams of various sizes draining both native and exotic tree dominated forests, stream size influenced the water temperature, while forest type influenced SRP and NO_2^- concentrations within these streams.
2. Forest type (native or exotic tree dominated) influenced significantly the distribution, abundance and diversity of riparian vegetation. Streams draining native forests recorded the higher values of Shannon Weiner diversity (H') for riparian vegetation with 71 species compared to streams draining exotic tree dominated forests, which had 34 species.
3. Stream size and forest type influenced significantly the distribution, abundance and diversity of macroinvertebrates and leaf litter processing rates. Total macroinvertebrate abundance and diversity associated with decomposing litter were lower in exotic streams than in native streams and in small streams than in big streams. Leaf litter decomposition was slower in streams draining exotic forests and in streams draining native forests, in small than in big streams for the six studied streams.

6.2 Recommendations

1. Environmentalists, ecologists and institutions should sensitize and create awareness to the farmers on the need of proper sustainable use and management of riverine ecosystems to mitigate land use pressure on these ecosystems.
2. Long-term studies capturing seasonal dynamics are needed in these streams in order to understanding temporal trends and to differentiate between natural variability arising from ecological process and human-induced declines in water and habitat quality.
3. There is need to evaluate the potentially important riparian tree species in energy flow and cycling within these streams and other tropical streams. Future studies therefore should emphasize on understanding the importance of each plant species to functioning of riparian zones in order to recommend the best species for agro forestry and restoration of the impacted tropical riparian zones.

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APPENDICES

Appendix 1. Values of macroinvertebrates diversity (Shannon Weiner diversity index; H) during days 7, 14, 28, 42 and 56 of exposure for rivers of different sizes draining Native and Exotic forests, * shows data missing.

TYPE OF RIVERS	DAYS				
	Day 7	Day 14	Day 28	Day 42	Day 56
BIG RIVERS					
Kamweti	1.539	0.682	1.887	1.864	*
Gathitha	1.707	1.480	1.730	1.872	1.719
Kii	0.999	1.862	1.901	1.607	1.567
SMALL RIVERS					
Kabwe	1.510	1.884	2.261	1.639	1.393
Kiri	1.214	1.056	1.819	1.849	1.116
Gichangai	1.622	1.638	1.441	0.688	0.585
NATIVE RIVERS					
Kamweti	1.539	0.682	1.887	1.864	*
Kabwe	1.510	1.884	2.261	1.639	1.393
Gatthitha	1.707	1.480	1.730	1.872	1.719

EXOTIC RIVERS

Kiri	1.214	1.056	1.819	1.849	1.116
Kii	0.999	1.862	1.901	1.607	1.567
Gichangai	1.622	1.638	1.441	0.688	0.585

Appendix 2: Summary of tree species identified from riparian zones of Rivers draining native and Eucalyptus tree dominated forests

RIVERS IN NATIVE FORESTS		RIVERS IN EXOTIC FORESTS	
TAXA	FORM	TAXA	Form
Apiaceae		Arecaceae	
<i>Centella asiatica</i>	Herb	<i>Musa sapiens</i>	Forb
Apocynaceae		Asteraceae	
<i>Tabernaemontania stapfiana</i>	Tree	<i>Ageratum conyzoides</i>	Herb
Asclepiadaceae		Euphorbiaceae	
<i>Asclepias sp.</i>	Shrub	<i>Croton macrostachyus</i>	Tree
Asteraceae		<i>Bridelia micrantha</i>	Tree
<i>Crassosephalum manii</i>	Tree	Mimosaceae	
<i>Senecio montuosum</i>	Shrub	<i>Acacia mearnsii</i>	Tree

<i>Vernonia auriculifera</i>	Shrub	Myrtaceae	
<i>Helichrysum schimperi</i>	Shrub	<i>Eucalyptus globulus</i>	Tree
		<i>Eucalyptus grandis</i>	Tree
Boraginaceae		<i>Psidium guajava</i>	Shrub
<i>Clerodendrum johnstonii</i>	Shrub	<i>Croton macrostachyus</i>	Tree
<i>Ehretia cymosa</i>	Tree		
Caesalpinaceae		Passifloraceae	
<i>Senna didymobotrya</i>	Shrub	<i>Passiflora edulis</i>	climber
Crassulaceae		Poaceae	
<i>Kalanchoe densiflora</i>	Shrub	<i>Pennisetum purpureum</i>	Grass
Euphorbiaceae		<i>Leesia hexandra</i>	Grass
<i>Neubotonia macrocalyx</i>	Tree	Proteaceae	
<i>Sapium ellipticum</i>	Tree	<i>Grevillea robusta</i>	Tree
Lamiaceae		Pteridopyte	
<i>Ocimum gratissimum</i>	Shrub	<i>Fern</i>	Forb
<i>Plectranthus barbatus</i>	Herb	Rosaceae	
Malvaceae		<i>Prunus africana</i>	Tree
<i>Abutilon mauritianum</i>	Shrub	Rubiaceae	
Meliaceae		<i>Rothmannia urcelliformis</i>	Herb
<i>Turraea holstii</i>	Climber	<i>Coffea arabica</i>	Tree
Mimosaceae		Theaceae	
<i>Albizia gummifera</i>	Tree	<i>Camelia sinensis</i>	Shrub
Moraceae		Tilliaceae	
<i>Myrianthus holstii</i>	Tree	<i>Triumfeta tomentosa</i>	Shrub
Myrsinaceae		Verbenaceae	
<i>Maesa lanceolata</i>	Tree	<i>Lantana camara</i>	Shrub
Myrtaceae		Zingiberaceae	
<i>Syzygium guineense</i>	Tree	<i>Aframomum keniense</i>	Herb

Passifloraceae

Passiflora ligularis climber

Papilionaceae

Trifolium repens Herb

Piperaceae

Piper capense Shrub

Poaceae

Leersia hexandra Grass

Cynodon dactylon Grass

Podocarpaceae

Podocarpus falcatus Tree

Pteridopyte

Fern Forb

Rosaceae

Rubus apetalus Shrub

Rubus pinnata Shrub

Rubiaceae

Rothmannia urcelliformis Shrub

Rubus steudneri Shrub

Rhamnaceae

Scutia myrtina Shrub

Rosaceae

Rubus pinnata Shrub

Rutaceae

Turraea holstii Tree

Teclea nobilis Tree

Zanthoxylum gillettii Tree

Fagaropsis angolensis Tree

Ulmaceae*Celtis africana* Tree**Verbenaceae***Clerodendrum johnstonii* shrub

Appendix 3. List of riparian vegetation species, families (bold) and forms identified at river Kabwe in native forest

KABWE RIVER				
Family	FORM	Right bank	Left bank	TOTAL
Apocynaceae				
<i>Tabernaemontana stapfiana</i>	Tree	13	10	23
Asclepiadaceae				
<i>Asclepias sp.</i>	Shrub	2	0	2
Asteraceae				
<i>Helichrysum schimperi</i>	Shrub	1	0	1
<i>Senecio montuosum</i>	Shrub	2	0	2
Boraginaceae				
<i>Clerodendrum johnstonii</i>	Shrub	3	0	3
<i>Ehretia cymosa</i>	Tree	1	0	1
Caesalpinaceae				
<i>Senna didymobotrya</i>	Tree	0	1	1
Euphorbiaceae				
<i>Neubotonia macrocalyx</i>	Tree	9	7	16

<i>Sapium ellipticum</i>	Tree	2	1	3
Lamiaceae				
<i>Ocimum gratissimum</i>	Shrub	1	0	1
<i>Plectranthus barbatus</i>	Herb	1	2	3
Meliaceae				
<i>Turraea holstii</i>	Climber	4	1	5
Moraceae				
<i>Myrianthus holstii</i>		0	2	2
Myrtaceae				
<i>Syzygium guineense</i>	Tree	6	1	7
Passifloraceae				
<i>Passiflora ligularis</i>	climber	2	0	2
Piperaceae				
<i>Piper capense</i>	Shrub	13	8	21
Poaceae				
<i>Leersia hexandra</i>	Grass	1	1	2
<i>Cynodon dactylon</i>	Grass	2	0	2
Podocarpaceae				
<i>Podocarpus falcatus</i>	Tree	1	0	1
Pteridopyte				
Fern	Forb	4	1	5
Rosaceae				
<i>Rubus apetalus</i>	Shrub	2	0	2
<i>Rubus pinnata</i>	Shrub	0	2	2
Rubiaceae				
<i>Rothmannia urcelliformis</i>	Shrub	14	1	15
<i>Rubus steudneri</i>	Shrub	0	1	1
Rutaceae				
<i>Turraea holstii</i>	Tree	2	3	5
<i>Teclea nobilis</i>	Tree	8	3	11
<i>Zanthoxylum gillettii</i>	Tree	2	2	4
<i>Fagaropsis angolensis</i>	Tree	2	1	3
Ulmaceae				
<i>Celtis africana</i>	Tree	5	4	9
Verbenaceae				
<i>Clerodendrum johnstonii</i>	shrub	2	1	3

Appendix 4. List of riparian vegetation species, families (bold) and forms identified at river Kamweti in native forest

KAMWETI RIVER					
Family	Form	Right bank	Left bank	TOTAL	
Apiaceae					
<i>Centella asiatica</i>	Herb	1	1	2	
Apocynaceae					
<i>Tabernaemontania stapfiana</i>	Tree	6	8	14	
Asteraceae					
<i>Crassosephalum manii</i>	Tree	0	2	2	
<i>Senecio montuosum</i>	Shrub	1	3	4	
<i>Vernonia auriculifera</i>	Shrub	0	3	3	
Boraginaceae					
<i>Clerodendrum johnstonii</i>	Shrub	4	2	6	
Caesalpinaceae					
<i>Senna didymobotrya</i>	Shrub	5	2	7	
Crassulaceae					
<i>Kalanchoe densiflora</i>	Shrub	1	0	1	
Euphorbiaceae					

<i>Neubotania macrocalyx</i>	Tree	1	4	5
<i>Sapium ellipticum</i>	Tree	0	1	1
Malvaceae				
<i>Abutilon mauritianum</i>	Shrub	1	0	1
Meliaceae				
<i>Turraea holstii</i>	Tree	3	1	4
Mimosaceae				
<i>Albizia gummifera</i>	Tree	0	1	1
Myrsinaceae				
<i>Maesa lanceolata</i>	Tree	2	2	4
Myrtaceae				
<i>Syzygium guineense</i>	Tree	19	6	25
Papilionaceae				
<i>Trifolium repens</i>	Herb	0	1	1
Piperaceae				
<i>Piper capense</i>	Shrub	5	4	9
Poaceae				
<i>Cynodon dactylon</i>	Grass	1	0	1
<i>Leesia hexandra</i>	Grass	1	0	1
Pteridophyte				
Fern	Forb	12	1	13
Rhamnaceae				
<i>Scutia myrtina</i>	Shrub	1	0	1
Rosaceae				
<i>Rubus pinnata</i>	Shrub	1	0	1
Rubiaceae				
<i>Rothmannia urcelliformis</i>	Shrub	4	4	8
Rutaceae				
<i>Teclea nobilis</i>	Tree	1	6	7
<i>Zanthoxylum gillettii</i>	Tree	1	3	4
<i>Toddalia asiatica</i>	Undergrowth	1	0	1
<i>Fagaropsis angolensis</i>	Tree	1	0	1
Ulmaceae				
<i>Celtis africana</i>	Tree	0	2	2
Verbenaceae				
<i>Vitex keniensis</i>	Tree	1	0	1

Appendix 5. List of riparian vegetation species, families (bold) and forms identified at river Kiri in exotic forest

KIRI RIVER				
Family	Form	Right bank	Left bank	TOTAL
Asteraceae				
<i>Ageratum conyzoides</i>	Herb	1	0	1
Euphorbiaceae				
<i>Croton macrostachyus</i>	Tree	0	1	1
<i>Bridelia micrantha</i>	Tree	1	0	1
Mimosaceae				
<i>Acacia mearnsii</i>	Tree	0	2	2
Myrtaceae				
<i>Eucalyptus globulus</i>	Tree	5	1	6
<i>Eucalyptus grandis</i>	Tree	24	16	40
<i>Ekebergia capensis</i>	Tree	1	0	1
<i>Psidium guajava</i>	Shrub	1	0	1
<i>Croton macrostachyus</i>	Tree	1	0	1
Passifloraceae				
<i>Passiflora edulis</i>	climber	0	1	1
Poaceae				

<i>Pennisetum purpureum</i>	Grass	3	2	5
<i>Leesia hexandria</i>	Grass	1	0	1
Proteaceae				
<i>Grevillea robusta</i>	Tree	0	1	1
Pteridophyte				
<i>Fern</i>	Forb	1	0	1
Rosaceae				
<i>Prunus africana</i>	Tree	1	0	1
Rubiaceae				
<i>Rothmannia urcelliformis</i>	Herb	1	0	1
<i>Coffea arabica</i>	Tree	3	3	6
Theaceae				
<i>Camelia sinensis</i>	Shrub	0	4	4
Tiliaceae				
<i>Triumfeta tomentosa</i>	Shrub	1	1	2
Verbenaceae				
<i>Lantana camara</i>	Shrub	1	1	2

Appendix 6. List of riparian vegetation species, families (bold) and forms identified at river Kii in exotic forest

KII RIVER				
Family	Form	Right bank	Left bank	TOTAL
Arecaceae				
<i>Musa sapiens</i>	Forb	0	1	1
Euphorbiaceae				
<i>Bridelia micrantha</i>	Tree	1	2	3
Myrtaceae				
<i>Eucalyptus grandis</i>	Tree	7	7	14
Poaceae				
<i>Pennisetum purpureum</i>	Grass	2	1	3
Proteaceae				
<i>Grevillea robusta</i>	Tree	1	1	2
Pteridophyte				
<i>Fern</i>	Forb	0	1	1
Rubiaceae				
<i>Coffea arabica</i>	Tree	0	3	3
Tilliaceae				

<i>Triumfetta tomentosa</i>	shrub	1	0	1
Zingiberaceae				
<i>Aframomum keniense</i>	Herb	3	2	5
