INFLUENCE OF LAND-USE ON LEAF LITTER DECOMPOSITION IN HEADWATER STREAMS OF THE NZOIA RIVER, KENYA

BY

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DECLARATION

DECLARATION BY THE STUDENT

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DEDICATION

To my lovely husband Reuben for the great support rendered during my stay away from Malawi to pursue studies in Kenya. To my lovely kids; Miracle and Watipatsa, thank you for your patience and love even at times when it was very hard to understand the reasons for my absence.

ABSTRACT

Land-use plays a crucial role in affecting river function, particularly leaf litter decomposition. The study was aimed to investigate the influence of land-use on leaf litter decomposition in headwater streams of the Nzoia River, Kenya. The breakdown rate of three common leaf species; *Syzygium cordatum*, *Vernonia myriantha* and *Eucalyptus globulus* were examined in six headwater streams of Nzoia River Basin during the dry months of February- March 2020. Leaf decomposition rates were measured by placing 216 coarse- and fine-mesh litterbags in the six streams, three draining forested land and three draining agricultural land. For each stream, physical characteristics, physico-chemistry, leaf litter decomposition rates and macroinvertebrate community composition were measured. Significantly, there were no differences in physical characteristics ($p > 0.05$) between the two land-uses, except for canopy cover which was significantly higher ($p = 0.044$) in forested streams. Physico-chemistry differed significantly, with forested streams showing higher values ($p < 0.05$) for coarse particulate organic matter ($p = 0.014$) but lower for fine particulate organic matter ($p = 0.053$), total suspended solids ($p = 0.014$) and electrical conductivity ($p = 0.043$). Leaf decomposition rates differed significantly ($p > 0.05$), with forested streams showing faster rates by the end of 28 days. Macroinvertebrates from kick samples showed that collectors were the most abundant (46.3%) while shredders were the least abundant (7.4%). Order Ephemeroptera had the highest number of individuals in both forested and agricultural sites followed by Diptera and Trichoptera. In the coarse-mesh litterbags abundance of shredders was higher in forested than agricultural streams with *Potamonaute sp.* and *Acanthiops sp.* dominating in both land-use types, while *Lepidostoma sp.* dominated the forested streams. It is concluded that the decomposition of leaf litter in the headwater streams of Nzoia River has been adversely affected by agriculture with potential threats on nutrient cycling and energy transfer to higher trophic levels. The observed decomposition rates were greatly influenced by the changes in the physico-chemical characteristics of the streams. Restoration efforts, including conservation agriculture and re-afforestation, are recommended for Nzoia River basin to regain the basin's capacity for high terrestrial and aquatic food production for the growing population in Kenya.

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AFDM	Ash-Free-Dry Mass
AGR	Streams in agriculture land-use
ANOSIM	One-way Analysis of Similarity
ANOVA	Analysis of variance
APHA	American Public Health Association
COTRA	Collaborative Training
CPOM	Coarse Particulate Organic Matter
DF	Degrees Of Freedom
DM	Dry Mass
DO	Dissolved Oxygen
DOM	Dissolved Organic Matter
FFG	Functional Feeding Group
FOR	Streams in forest land-use
FPOM	Fine Particulate Organic Matter
LML	Leaf Mass Loss
LVB	Lake Victoria Basin
NMDS	Non Metric Multidimensional Scaling
NRB	Nzoia River Basin
OM	Organic Matter
PAST	Paleontological Statistics
PCA	Principal Component Analysis
PERMANOVA	Permutational Analysis of Variance
POM	Particulate Organic Matter
SIMPER	Similarity Percentages
SRP	Soluble Reactive Phosphorus
TSS	Total Suspended Solids

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Aquatic macroinvertebrates greatly contributes in nutrient cycling in freshwater ecosystems as primary consumers that process live organic material and function as detritivores that feeds on decomposed organic matter (Tiegs *et al.,* 2019). In addition, they serve as predators by preying on other macroinvertebrates and other small organisms. Macroinvertebrates and are good food resource for fish, mammals, reptiles, amphibians and aquatic birds (Graca, 2017). Aquatic macroinvertebrates can process a great percentage of the riparian leaf litter entering a stream (Merrit *et al.,* 2002; Masese *et al*., 2014a; Fugere *et al*., 2020). The processed organic matter is a nutritious food source for most aquatic macroinvertebrates as it facilitates in the increase of biomass, growth rates and survival rates (Reis *et al.*, 2018). Aquatic macroinvertebrates are categorized into five utmost functional feeding groups; shredders, scrapers (grazers), predators, collector-gatherers and collector filterers (Cummins *et al.,* 1989; Masese *et al*., 2014a).

Macroinvertebrates are greatly involved in ecosystem-level processes and their traits and functional groups are usually adopted as indirect functional indicators of freshwater ecosystems (Merrit *et al.,* 2002). Various functional feeding groups' ratios are employed as measures of ecosystem wellbeing and used in the ecological assessment of the streams (Brady & Turner, 2010; Boyero *et al.*, 2015).

Shredders are aquatic macroinvertebrates that feed on larger pieces of organic matter like leaves and detritus found in the streams (Graca, 2017). They possess tearing suctorials that empower them to rip and shred large particles of leaves and wood as they feed hence prefer to consume leaves that have been conditioned by fungi and bacteria, as they tend to be highly palatable (Graça & Canhoto, 2006). Shredders are greatly involved in processing coarse particulate organic matter which is derived from allochthonous sources such as leaves, woody debris and other vegetation near the stream (Masese *et al.,* 2014a). Their availability in the stream greatly indicates the adequate input of allochthonous materials from the surrounding riparian zone (Reis *et al.,* 2018).

Functionally, shredders are greatly involved in leaf litter decomposition in headwater streams by changing coarse particulate organic matter to fine particulate organic matter (Fu *et al.,* 2016). This process releases nutrients in the stream and provide food sources that are utilized by collectors in forested and agricultural streams (Masese *et al.,* 2014a; Fu *et al.,* 2016). Thus, carbon cycling tends to be very complex in streams that are influenced by agricultural activities (Hepp *et al.,* 2016). Additionally, shredders greatly participate in the leaf litter disintegration and decomposition thereby providing a trophic link (Odira *et al*., 2010). Shredder activity in headwater streams is affected by changes in land-use from forestry to other uses and the introduction of exotic trees and changes in nutrient availability, which greatly influence organic matter processing and functioning of the ecosystem (Tomanova *et al*., 2008).

The quality of leaves is of utmost importance to shredders and is greatly influenced by the inherent characteristics of the leaf such as the composition of nutrients, lignin, cellulose, secondary compounds and the stage of decomposition. According to Reinhart and Vandevoort (2006), macroinvertebrate shredders prefer on good quality leaves bearing high nutrients levels and reduced concentrations of structural compounds which facilitate increased feeding, survival and growth rates.

Leaf litter is the major source of energy for aquatic organisms in low-order streams (Tomanova *et al*., 2008). Leaf litter quantity and quality in forested streams is subjected to several factors like the type of vegetation, climate, location, steam's morphologic characteristics and the age of the trees (Silva-junior *et al.,* 2014). Fractions of allochthonous organic matter input into streams include leaves and leaf fragments, wood, floral parts, fruits and other plant parts with leaves comprising the largest proportion of litter input (Chara-Serna *et al.*, 2012). The quality of leaves, water properties, biotic communities and climatic conditions determine the rate of decomposition of leaves (Minaya *et al.*, 2013).

Tropical ecosystems are greatly menaced by a hasty change in land-use that can extremely affect communities in aquatic environment and various processes of ecosystem like breakdown of leaf litter (Lecerf, 2017). Riparian ecosystems tend to be vulnerable to exotic plant invasion due to frequent natural and anthropogenic disturbances that result in the creation of conducive and diverse niches (Silva-junior *et al.,* 2014). The intrusion by trees of exotic origin into streams may change the quality of leaves entering the freshwater ecosystem thereby changing the role and composition of aquatic communities (Tomanova *et al.*, 2008). Land-use change in the catchments of many streams around the world has led to the extermination of biodiversity, shifts in the functional and structural organization of aquatic communities, and an overall extermination of ecological integrity (Masese *et al.,* 2009; Wantzen & Mol, 2013; Hepp *et al.,* 2016). For example, agricultural activities tend to increase the extermination of streams through nutrient enrichment, soil erosion and sedimentation, increase in mean water temperature and loading of toxic substances such as pesticides and herbicides into streams (Matthaei *et al.,* 2010; Jinggut *et al.,* 2012; Masese *et al.,* 2014a). Monocultures of exotic tree species in riparian zones, such as *Eucalyptus*, frequently correspond with modified food webs, alteration of flow regimes, reduced leaf processing by shredders and changes in organic matter composition (Patrick, 2013; Cooper *et al.,* 2013). It may also compromise the quality and amount of leaf litter entering streams thereby altering the systematic and functional composition of aquatic communi (Silva-junior *et al.,* 2014).

The substitution of indigenous trees by monocultures of exotic tree species may result in alteration of leaf species and perturb organic matter processing, a vital process of the ecosystem (Woodward *et al*., 2012). Agricultural activities tend to increase the extermination of forests leading to accelerated nutrient levels, water temperature, and sediment input (Odira *et al.*, 2010). Transitions in land-use as well as the destruction of riparian vegetation can have both distal and proximal controls on abiotic and biotic factors that drive different pathways of litter decomposition in headwater streams (Reis *et al.,* 2018). For instance, increase in mean water temperature because of clearance of riparian vegetation has been found to promote microbial decomposition over decomposition mediated by detritivores (Boyero *et al*., 2012; Fugere *et al*., 2016). Similarly, an increase in nutrient concentrations from fertilizer use and sediments from agricultural run-off can influence the decomposition rates of leaf litter (Matthaei *et al*., 2010; Masese *et al*., 2014b). Studies have revealed that the enrichment of nutrients in water bodies can stimulate microbial breakdown of litter (Ferreira *et al*., 2006; Fernandes *et al*., 2014) and that sedimentation and nutrients can destroy the assemblages of detritivores and their decomposition process (Danger *et al*., 2012; Woodward *et al*., 2012; Mustonen *et al*., 2016). Exotic trees such as *Eucalyptus* sp. contains high leaf auxiliary compounds like polyphenols that may delay the growth of fungal thereby affecting leaf consumption by macroinvertebrates (Kiffer *et al*., 2018). Fungal growth is vital for microbial colonization that make leaves more palatable to macroinvertebrates (Boyero *et al.*, 2015). However, these effects will highly rely on the extent of leaf quality variations among the exotic and native species (Cordero-Rivera *et al.*, 2017).

1.2 Statement of the problem

Headwater stream ecosystems are highly vulnerable to natural and anthropogenic disturbances that affect their structure and processes of the ecosystem (Odira *et al*., 2010; Masese *et al.*, 2014b; Boyero *et al.*, 2016). Vegetation destruction by anthropogenic activities has led to the creation of diverse niches that support invasive species (Aura *et al.*, 2011; Jun *et al.,* 2011; Boyero *et al*., 2016). The introduction of exotic trees into riparian areas possess a great impact on aquatic and terrestrial systems (Cordero-Rivera *et al.*, 2017).

When exotic ones in riparian areas are replacing indigenous trees, the quality of leaf litter often changes and consequently, these changes alter the physico-chemistry and functional distribution of macroinvertebrates (Jinggut *et al*., 2012; Masese *et al*., 2014a). The process of leaf litter decomposition is very crucial as it supplies energy and organic matter to communities in headwater streams (Casas *et al.*, 2013). Litter quality controls the abundance and activity of microbes and shredders (Wu *et al.,* 2018).

Land-use change from native forestry to other uses is a major concern in many parts of the world because of its negative influence on the quality of water, biodiversity and the structure and operation of streams and rivers (Allan, 2004; Odira *et al.*, 2010; Boyero *et al.*, 2016; Jun *et al.*, 2011). Land-use plays a crucial role in affecting river function as is connected with disturbances that result into sedimentation, nutrient enrichment and loading of toxic elements into streams thereby affecting biological communities (Odira *et al.*, 2010; Jun *et al*., 2011; Boyer-rechlin *et al*., 2016;). This causes adverse impact on streams'integrity (Hepp *et al.*, 2016). Also, the variations in riparian vegetation cause dynamic changes in the aquatic fauna by altering its structure and composition thereby changing the organic matter composition and stream metabolic processes (Fugere *et al*., 2020). These changes have adverse effects on the abundance, growth rates, trophic structure of the macroinvertebrates (Cooper *et al.,* 2013).

1.3 Justification

Macroinvertebrates greatly contributes in the ecosystem-level processes and their traits and functional composition are utilized as ecosystem attributes indicators (Boyero *et al.*, 2015; Merritt *et al.*, 2017). Several catchments have replace native forests to exotic ones in East African forested streams due to farming, settlement and grazing (Nyadawa &

Mwangi, 2010; Masese *et al.,* 2014a;). Land-use variations and consequent extermination of the composition of riparian vegetation can have both distal and proximal controls on abiotic and biotic factors that drive different pathways of litter decomposition and the structure and functioning of headwater streams (Mathuriau, & Chauvet, 2002; Wabusya *et al.,* 2015). For instance, the efficiency of detritivores to convert leaf organic matter to secondary production greatly depends on the quality of the leaves, as it influences the rate of consumption, growth and survival (Reinhart & Vandevoort, 2006; Danger *et al.*, 2012; Cordero-Rivera *et al.,* 2017).

Several studies have investigated the influence of catchment land-use on the functional composition of macroinvertebrates and leaf litter decomposition in tropical streams (Jinggut *et al*., 2012; Masese *et al*., 2014b; Boyero *et al*., 2015; Fugère *et al*., 2018; Cornejo *et al*., 2020). Due to the increase in water temperatures and low diversity of detritivores in tropical streams, it is suggested that litter decomposition may be driven mainly by microorganisms (Boyero *et al*., 2012). The reduction in the distribution and abundance of detritivores that are very sensitive to water quality impairment and habitat degradation could be imputed to land-use changes (Yule *et al.,* 2009; Masese *et al.*, 2014a).

Assessing the resultant effects of anthropogenic stress on ecological integrity and health is vital in the sustainable management of aquatic resources (Lecerf *et al*., 2006). Land-use change in streams across the world has led to the destruction of biodiversity and great changes in the functional and structuring of macroinvertebrates (Allan, 2004; Masese *et al*., 2009; Jun *et al.,* 2011). Hence, there is insufficient functional indicators required to measure directly the rate of ecological processes (Pozo *et al.*, 2011). This has resulted in the exclusive utilization of structural indicators that depend on the composition of the community, trait and taxonomic structure, thereby most assessment schemes of a freshwater ecosystem are based on the assumption of a positive correlation between functional and structural integrity (Masese *et al.*, 2009; Jinggut & Yule, 2015).

The rate of leaf breakdown in streams is used to estimate the functional integrity of streams reflecting the eutrophication gradient whereby the relative attributes and abundance of shredder assemblages regulate the rate of leaf breakdown in streams (Ardón & Pringle, 2008; Masese *et al.*, 2009). Various ratios of functional feeding groups are used in the assessment streams (Merritt *et al.,* 2002; Gonçalves Jr. *et al*., 2006; Masese *et al.,* 2014a, b*;* Fugère *et al.,* 2016). The response of stream ecosystems to land-use variations is very important for the conservation of streams. Forest cover in the Afrotropical catchments has been declining over the years with potential effects for stream ecosystems (Fugère *et al.,* 2016, 2018). Studies have reported negative effects of land-use changes from forestry to agriculture and urbanization in tropical streams, ranging from reduced levels in water quantity and quality, extermination of biodiversity, mainly the sensitive shredder taxa, and changes ecosystem structure and functioning (Fugère *et al*., 2016, 2018).

Several studies have investigated the influence of land-use on the functional composition of invertebrates and leaf litter decomposition in tropical streams (Jinggut *et al*., 2012; Masese *et al*., 2014b; Boyero *et al.,* 2015; Fugère *et al*., 2018; Cornejo *et al.,* 2020). Due to the increase in water temperatures and low diversity of detritivores in tropical streams, it is suggested that litter decomposition may be driven mainly by microorganisms (Tiegs *et al.*, 2019). However, a diverse detritivores guild has been reported in some regions, such as at high altitude forested streams (Yule *et al.*, 2009; Masese *et al.*, 2014a) and in other biogeographic areas (Cheshire *et al.*, 2005; Jinggut *et al*., 2012; Boyero *et al.*, 2015). This implies that further reduction in the distribution and abundance of detritivores that are very sensitive to water quality impairment and habitat loss in agricultural streams (Yule *et al*., 2009; Masese *et al.*, 2014a), would increase further microbe-driven leaf litter decomposition rates. Nzoia River Basin is largely impacted by land-use transitions with increases in human population (Nyadawa & Mwangi, 2010).

The upper Nzoia River Basin (NRB) has experienced rapid population growth, putting piles of pressure on existing natural resources as the demand for food and fiber has elevated (Wabusya *et al.,* 2015). Deforestation, crop farming, livestock grazing, sand harvesting and brick-making are on the rise along the Nzoia River Basin (Masese *et al.*, 2009; Wabusya *et al.,* 2015). These activities have resulted in the over-exploitation of resources, channel modification, extermination of riparian vegetation and land degradation. As a result, the lower catchment area of the river in the southeast has experienced severe floods largely attributed to deforestation and agricultural activities (Kithiia, 2007). According to Kithiia (2007), the in-stream water of the Nzoia River continues to experience water quality degradation and changes in leaf litter quality and quantity as a result of its catchment's and riparian's land-use activities. However, it remains unclear how land-use has influenced the trophic function of Nzoia River. This study was aimed at assessing land-use influence on the breakdown of leaf litter in the headwaters of Nzoia River, western Kenya. The findings of the study will enable policy makers to determine a land-use policy that not only promotes sustainable utilization of the Nzoia River basin resources but also maintains optimal ecological function of the river's drainage waters.

1.4 Study Objectives

1.4.1 General Objective

This study was aimed to investigate the influence of land-use changes on the decomposition rates of leaf species in headwater streams of the Nzoia River, Kenya.

1.4.2 Specific Objectives

The specific objectives of the study were:

1) To compare the abundance and diversity of macroinvertebrate shredders between forested and agricultural streams in the Nzoia River Basin.
2) To compare microbe- and shredder-mediated decomposition rates of indigenous and exotic leaf species in the streams.
3) To determine the use of leaf litter decomposition rates as a measure of functional health of the streams.
4) To determine the relationship between water quality parameters, macroinvertebrate shredders and the leaf litter decomposition rates.

1.5 Study Hypotheses

The following hypotheses were tested:

Ho$_1$: There is no variation on the biomass and composition of macroinvertebrates shredders in forested and agricultural streams.

Ho$_2$: There is no variation in microbe- vs shredder-mediated decomposition rates of *Syzygium cordatum*,*Vernonia myriantha* and *Eucalyptus globulus* leaf species.

Ho$_3$: The decomposition rates do not vary with changes in ecological health of low order water streams.

Ho$_4$: There is no relationship between water quality parameters, macroinvertebrate shredders and the leaf litter decomposition rates.

CHAPTER TWO

LITERATURE REVIEW

2.1 Effects of human activities on stream ecosystems

River ecosystems tend to be vulnerable to land-use variations and extensive exploitation (Fu *et al.,* 2016). Human activities have altered land cover in river catchments through the clearing of forests for settlement and agricultural activities thereby shifting from healthy and sustainable river ecosystems to poor unsustainable ones (Cornejo *et al.*, 2020). Water quality deterioration in rivers and streams has become a great environmental concern (Hepp *et al.*, 2010). Forested streams are being degraded continuously because of agricultural land-use through increasing inputs of pollutants thereby affecting stream channel, altering riparian habitat and stream flows (Boyer-rechlin *et al.*, 2016). Land-use causes disturbances that lead to sedimentation, eutrophication, soil erosion and accumulation of toxics in water bodies (Bo *et al.*, 2018; Camara *et al.*, 2019).

Effect of human activities greatly influence both aquatic and terrestrial ecosystems by altering landscapes (Odira *et al.*, 2010). Land-use activities like agriculture and urbanization affects hydrological, chemical, erosional, geomorphic and physical processes in water ecosystems (Guzha *et al.,* 2018; Wu *et al.,* 2018). Human activities associated with agricultural practices, extensive urbanization, population increase and industrialization have led to water quality degradation in rivers across the world (Wu *et al.,* 2018; Camara *et al.*, 2019). Human activities causes a great threat to stream ecosystems thereby causing changes in delivery of sediments , degrading the quality of water quality and resulting in biodiversity loss (Hepp *et al.*, 2010; Guzha *et al.*, 2018). Urban development and agricultural activities greatly impacts many streams around the world (Aura *et al.*, 2011; Ontumbi *et al.*, 2015; Camara *et al.*, 2019) and rapid development is highly affecting some regions (Azrina *et al.*, 2006; Boyer-rechlin *et al.*, 2016). Agricultural activities such as clearing land along the riparian area increases the vulnerability of streams to runoff and this has led to eutrophication (Wu *et al.*, 2018; Cornejo *et al.,* 2020), thereby altering trophic network structure, ecological processes and stream integrity (Cooper *et al.,* 2013). Out of the various nonpoint pollution sources, agricultural disturbances bear a significant risk to stream communities (Adriaenssens *et al.*, 2002; Wu *et al.*, 2018).

Land-use transition in streams across the world has led to the deterioration of biodiversity with great conveyance in the function and structure of macroinvertebrates (Masese *et al*., 2014b; Ding *et al.*, 2015; Cheng *et al*, 2018; Cornejo *et al.*, 2020). The functioning and attributes of macroinvertebrate communities in streams are influenced by varying land-use practices that affect the quality of water, changing the abiotic and biotic processes (Tabor *et al.*, 2010; Souto *et al*., 2011). Many studies in tropical and temperate regions have shown that deterioration of water quality in streams connected with land-use normally lead to reduction in species richness, causing an influence on alpha and beta diversity (Fu *et al.*, 2016; Hepp *et al.*, 2016). Changes in biota of ecosystems result from habitat conversion and land-use which reduces genetic and species diversity (Cheng *et al.*, 2018). Human activities in riparian zones such as deforestation, agriculture may lead to decreased rates of evapotranspiration, affecting the discharge regimes and hydrology, leading to accelerated rates of runoff (Hepp *et al.*, 2016). This leads to nutrient enrichment, changes in organic matter and disruption of biological communities and processes (Kasangaki *et al.*, 2008; Boyer-rechlin *et al.*, 2016), who's effects may result into deterioration of the biological integrity of streams (Fu *et al.*, 2016). The distribution of macroinvertebrate functional feeding groups is affected by altered trophic dynamics, nutrient enrichment in streams that enhances the rate of decomposition of leaves (Pozo *et al.*, 2011; Boyer-rechlin *et al.*, 2016). Therefore, investigating the effects of land-use changes on the decomposition rates of *Syzygium cordatum, Vernonia myriantha and Eucalyptus globulus* leaf species in the selected six streams will help in evaluating the substantial effects of human disturbances on ecosystem structure and functioning.

2.2 Macroinvertebrates as water quality indicators

Macroinvertebrates are widely used as water quality indicators and they form the vital component of the food chain (Mangadze *et al.*, 2019). The activities of macroinvertebrates in streams facilitate nutrient recycling and energy flow in streams as they greatly respond to environmental changes (Kratzer *et al*., 2006; Helms *et al.*, 2009). The availability of groups of macroinvertebrates in streams commonly reflects the variations in their composition with regard to human influences, as they are sensitive to water quality and specific anthropogenic disturbances (Janke & Trivinho-Strixino, 2007; Theodoropoulos *et al*., 2015). Having very limited migration, macroinvertebrates tend to respond to changes in their habitat and displays the cumulative effects of multiple stressors (Merritt *et al.*, 2017). There is insufficient functional indicators required to measure directly the rate of ecological processes (Theodoropoulos *et al.,* 2015). This has resulted in the exclusive utilization of structural indicators that depend on the composition of the community, trait and taxonomic structure (Camara *et al.*, 2019).

Most assessment schemes for freshwater ecosystems are based on the assumption of a positive correlation between functional and structural integrity (Patrick, 2013; Camara *et al.,* 2019). Many studies have shown that a connection exists between benthic macroinvertebrate responses and land-use modifications (Ding *et al.*, 2015; Pozo *et al.*, 2011; Boyer-rechlin *et al.,* 2016; Mangadze *et al.,* 2019). As riparian forest is degraded, there is an increase in number of grazers, with the food web having an increase in energy sources from autochthonous unlike allochthonous (Aura *et al.*, 2011).

Consistently, macroinvertebrates have been used as water quality indicators because they are present in all streams, less mobile, have relatively long life cycles (Kratzer *et al.*, 2006; Ding *et al.*, 2015) and retort to numerous aquatic disturbances with a variety of environmental pressures (Bo *et al.,* 2018). Macroinvertebrates are greatly involved in ecosystem level processes and their traits and functional groups are usually adopted as indirect functional indicators of freshwater ecosystems (Boyer-rechlin *et al.,* 2016). The clearing of vegetation in riparian areas negatively affects benthic macroinvertebrate assemblages and this is attested in a study by Roy *et al.,* (2001) who reported a dominance by intolerant taxa and a subsequent reduction in number of sensitive taxa. According to a study done in New York City by Kratzer *et al.*, (2006), they reported that alpha diversity of macroinvertebrate was reduced by deforestation and there was an increase in temporal variability in macroinvertebrate density that were observed in the deforested streams. This suggested that the diversity of macroinvertebrates in deforested streams were unstable with low resistance to disturbance than macroinvertebrates found in forested streams (Kratzer *et al.,* 2006; Menezes *et al.,* 2010). Hence, deforestation has an influence on the macroinvertebrate fauna resulting into lower alpha and beta diversity, higher temporal variability and a change in functional organizations leading to an increase in dominance of collectors (Guzha *et al.,* 2018). The dispensation and affluence of macroinvertebrates are moderated by a linkage of biological, chemical and physical factors at smaller and larger spatial scales (Fernandes *et al*., 2014). The importation of non-native leaves in tropical ecosystems influences changes in the availability nutrients thereby affecting the activity of shredders, ecosystem functioning and the processing of organic matter in streams (Chara-Serna *et al.*, 2012; Reis *et al*., 2018). Land-use variations have a large effect on macroinvertebrate community composition (Cornejo *et al.,* 2020). According to a study done by Hepp *et al.*, (2010), it was reported that deforestation and water pollution heavily affected macroinvertebrate fauna by causing a reduction in taxa richness. Deforestation for grazing and crops increases fine sediment loading into rivers through increased erosion leading to decreased habitat suitability and changes in the benthic communities (Camara *et al.*, 2019). The patterns of benthic macroinvertebrate distribution are associated with the natural variation of environmental factors and current velocity, particle size, substrate type and food resources are vital in macroinvertebrate assemblages (Theodoropoulos *et al*., 2015).

Human exertion result in a taxa depletion in number that do not tolerant much to water quality changes and a rise in pollution tolerant taxa thereby resulting in the extinction of indigenous species (Bo *et al.,* 2018). Hence agriculture and urbanization influences highly affect the diversity of aquatic organisms and the quality of water in streams (Hepp *et al.,* 2010). According to Kratzer *et al.,* (2006), macroinvertebrate communities vary with a wide range of factors associated with human development as a decrease in macroinvertebrate indices was observed when agriculture was substituted by urbanization. They concluded that biotic communities do have resistance to increasing measures of agricultural compared to that of civil land-use prior to impairment (Allan, 2004; Martínez *et al.,* 2013).

According to a study done by on macroinvertebrate community structure in Sosiani and Kipkaren Rivers, there were variations and reduction in taxa richness thereby suggesting the effects were due to anthropogenic activities and the ability of the macroinvertebrate taxa to tolerate the deteriorating environment (Aura *et al.*, 2011). Macroinvertebrate integrity can be utilized to assess stream water quality effects due to changing land-use and that river protection relies on minimizing the percent urban land cover in the catchment areas (Nyadawa & Mwangi, 2010). The modifications in land-use and alteration of the composition of riparian vegetation can negatively affect the composition and operation of headwater streams (Tsisiche *et al.*, 2019).

2.3 Macroinvertebrates shredders and the decomposition of leaf litter in streams

Benthic macroinvertebrate species play an essential role in leaf litter processing of aquatic systems (Brady & Turner, 2010; Masese *et al*., 2014a). Shredders consume primarily on large pieces of plant detritus leaves and other litter fall inputs into the streams and possess mouthparts morphological adaptations that enable them to chew and shred large particles of organic matter effectively (Cummins *et al.,* 1989; Merritt *et al*., 2002). Shredders feeding ability is aided by the availability of aquatic hyphomycetes via the enzymatic emaciation of leaves by fungi that escalate the nutritional value of the leaf detritus (Chung & Suberkropp, 2009; Reis *et al.,* 2018). Leaf litter is transformed into fine particulate organic matter by into macroinvertebrate shredders that is used as food by other functional feeding groups such as filter-feeders (Gonçalves Jr. *et al*., 2006; Hepp *et al.,* 2016). Shredders greatly contributes in the energy transfer in streams through the actions of decomposition and fragmentation of leaves thereby providing a vital trophic link between upstream and downstream (Costa *et al*., 2016). Forested headwater streams, being heterotrophic ecosystems, largely relies on allochthonous organic matter input and feeding activity of shredders (Gama *et al*.*,* 2014). Out of the total invertebrate biomass found in temperate streams, macroinvertebrate shredders habitually account for ≥40 percent (Graça *et al*., 2015).

Tropical headwater streams relies on terrestrial litter inputs as a vital germ of organic carbon on detritus based food webs (Crowl *et al*., 2006; Aura *et al.*, 2011). According to a study done by Boyero *et al*., (2012) that scrutinized the diversity of shredders across latitudes at a global scale, they reported that the diversity of shredders in temperate streams was 2.5 times greater and the species richness was 2.2 times greater than streams of tropical origin. The abundance of shredders in streams of tropical origin varies greatly in different regions (Dobson *et al*., 2002; Masese *et al*.,2014b; Jinggut *et al.*, 2012; Reis *et al.*,2018) and the shredding activity determines the rate at which detritus is being processed (Yule *et al.*, 2009). Several authors have reported the low diversity of shredders in some tropical streams (Dobson *et al*., 2002; Gonçalves Jr. *et al.*, 2006; Blanco & Gutiérrez-isaza, 2014). According to Dobson *et al*., (2002), the sampled streams in Kenya were reported as having about ten percent of shredder invertebrates. Shredders in tropical region are said to be scarce than in temperate region where they are abundant and diverse (Dobson *et al.*, 2002; Masese *et al*., 2014b), this could be imputed to availability of extremely good quality of leaves and cool temperature influences (Gonçalves Jr. *et al.*, 2006; Jinggut & Yule, 2015). However, this is in contrasting with the study done by Cheshire *et al*., (2005) in tropical Australian streams that assigned macroinvertebrate species to functional feeding groups basing on direct observation (analysis of gut content). In addition, they found that shredders were more abundant in both species richness and biomass and concluded that shredder scarcity may be due to biogeographical rather than latitudinal influences. Furthermore, Crowl *et al*. (2006) and Mathuriau, and Chauvet (2002) concurred the corrrelative abundance of shredders in streams of tropical origin receive continuous litter inputs than temperate streams because of less seasonality unlike temperate climates and this could facilitate the abundance of shredders in some tropical streams, a suggestion for more research in tropical streams. Still more, studies indicate that shredders significantly contributes to leaf-litter breakdown rates in some tropical streams (Dobson *et al*., 2004; Crowl *et al*., 2006; Minaya *et al.*, 2013).In headwater streams, leaves from riparian trees represent the major energy source for heterotrophs, as shading by riparian vegetation do limit primary productivity (Gessner *et al*., 2010).

Shredders feeding behavior is largely determined by the quality of leaf and they prefer certain types of leaf species over others, for example conditioned leaves over unconditioned ones (Patrick, 2013; Masese *et al.*, 2014a). Being aware of the functioning and composition of macroinvertebrates in tropical streams is vital as it helps in understanding the energy flow, trophic relationships, detritus processing and employing strategies and measures in managing the functioning of ecosystem (Masese *et al*., 2014b; Boyero *et al*., 2016). It is estimated that up to 64 percent of the leaf biomass that enters into streams is consumed by shredders thereby highly contributing to leaf litter breakdown (Graça *et al.*, 2015). Shredders feeding activities are accelerated by the availability of aquatic hyphomycetes, softening of leaves by fungal, high nutrient concentration and fungal biomass (Graça *et al*., 2015). Shredders constitute at least 40 percent of total invertebrate biomass in most temperate, low order streams (Boyero *et al.*, 2012; Guzha *et al.*, 2018). According to a study done by Medina-villar *et al*., (2015), the colonization of leaves by aquatic macroinvertebrates varied according to the quality of leaf in the mesh bags and shredder survival increased on those fed with high quality leaves. This is in agreement with Graça and Canhoto (2006), suggesting that the quality of leaf litter is a good aid in attracting the shredder macroinvertebrates in the bags. The breakdown process of leaf litter is as a result of several factors such as the colonization of microorganisms, direct consumption by invertebrates, leaching soluble compounds and physical abrasion (Patrick, 2013; Graça *et al.*, 2015).

The quantity of leaves depends on the input, decomposition and retention processes where the input of litter in the stream greatly is determined by the composition, density and the productivity of riparian canopy (Tiegs *et al.*, 2008). Leaf-litter decomposition rate relies on several factors, such as climate, altitude, and latitude, geology, thereby greatly responds to changes in environmental variables caused by anthropogenic effects (Pozo *et al.,* 2011). The quantity and spread of detritus on the sediment surface affect species diversity thereby playing a key part in the composition, distribution, and biomass of macroinvertebrates (Lecerf, 2017).

In most studies on litter decomposition, fine and coarse -mesh litterbags are used as standard tools in assessing the decomposition rates (Dobson *et al.,* 2002; Yule *et al.*, 2009; Matthaei *et al.,* 2010; Masese *et al.,* 2014a ; Fugere *et al*., 2020). Macroinvertebrate colonization in litterbags, diversity and composition differs according to the type of litterbags used (Lecerf, 2017; Reis *et al.*, 2018).

The utilization of fine mesh bags in leaf litter decomposition studies tend to exclude the availability and activity of shredders leading to a slow litter decomposition process (Silva-junior *et al.,* 2014). This is in agreement with Jinggut and Yule (2015) reported faster rates of leaf decomposition in coarse mesh litterbags where shredders were not excluded than in fine mesh litterbags. Another example is a study done in Switzerland by Tiegs *et al.,* (2008) who found no presence of large macroinvertebrate in fine mesh bags while coarse-mesh bags had about thirty-two macroinvertebrate taxa of which forty-six percent comprised of shredders, thereby eliminating the most important shredders in fine mesh bags. Macroinvertebrate shredders are said to be agents of leaf litter breakdown in agricultural streams unlike forested streams and their significance greatly associate land-use effects with stream processes (Masese *et al.*, 2014a). It is said that shredders mostly aggregate in litterbags that are exposed to resource-depleted environments hence the variation in decomposition rates of leaf according to the characteristics of litter (Tiegs *et al.,* 2008; Martínez *et al.,* 2013). Investigating the role of macroinvertebrate shredders on leaf decomposition is of paramount importance since knowledge about the functional role in streams will assist in providing a support structure for managing headwater streams affected by anthropogenic stresses.

2.4 Decomposition rates as a measure of stream health

Macroinvertebrate shredders consume leaf litter by breaking it down into small fragments, through a process known as leaf litter breakdown (Graca, 2017). The process of converting large particulate organic matter into smaller particles is very crucial in the functioning of streams and rivers (Boyero *et al*., 2015). The resulting transformed fine particulate organic matter is an important energy source for gatherers, filter-feeding and other organisms (Crowl *et al*., 2006; Jinggut & Yule, 2015). The breakdown of leaf litter is due to the physical process of abrasion, leaching, fragmentation of leaves and biological process of microbial and invertebrate colonization (Rincon & Martınez, 2006; Gessner *et al*., 2010).

Leaf litter breakdown is normally subjected to chemical and physical changes induced by biological communities such as microorganisms and macroinvertebrates (Gonçalves Jr. *et al.,* 2006; Graça, 2017). As the leaves move down from the banks into the stream and from within the stream channel, they breakdown through microbial colonization and conditioning process by altering the leaf substrate (Crowl *et al.,* 2006; Tsisiche *et al.,* 2019). During the movement of leaves within the stream, the breakdown of leaves progresses because of physical abrasion, the ongoing process of microbial colonization and feeding by detritivores (Crowl *et al.*, 2006; Lecerf, 2017). Aquatic food webs highly depend on the quantity of energy engulfing on the detrital food cycle which is generally above the amount produced through primary production (Graça *et al.*, 2015). In temperate streams, microbial decomposers and macroinvertebrates shredders are the main drivers of litter breakdown whereas in streams of tropical origin, microbial action and physical fragmentation facilitate the litter breakdown processes (Jinggut & Yule, 2015; Boyero *et al.*, 2015).

Varying rates of decomposition are exhibited among different types of tree leaves according to their specific differences (Abelho, 2001; Brady & Turner, 2010). In tropical streams, the breakdown rates of leaf litter tend to be faster than in most streams of temperate origin (Graça *et al.*, 2015) and this could be imputed to the excessive leaf-associated microflora available in tropical region (Graça *et al.*, 2015). The breakdown of leaf litter is influenced by temperature, thereby making it more rapid in tropical than temperate regions (Boyero *et al*., 2016). However, some tropical streams have reported to have slow decomposition rates (Ferreira *et al.*, *2*012) and this could be ascribed to adverse environmental conditions and poor quality of tree species (González & Grácá, 2003; Graça *et al*., 2015).

Several studies have showed great differences in breakdown rates of leaves within tropics streams and stronger variation between tropical and temperate streams with fastest rates being recorded in tropical regions because of warmer temperatures (Rueda-delgado *et al.*, 2006; Wantzen *et al;* 2008; Chara-Serna *et al.*, 2012; Graça *et al.*, 2015). Tropical leaves are reported to possess higher concentration of toxic compounds, as a form of resistance to herbivory (Wantzen *et al;* 2008; Patrick, 2013). These toxic compounds may disrupt shredders digestion efficiency, act as feeding inhibitors and reduce palatability of leaves for shredders in the stream ecosystem (Odira *et al*., 2010). According to some studies, leaves of tropical species tend to have high concentrations of tannins and phenolics which inhibit colonization by insects and microbes thereby delaying the leaf litter breakdown (Ardón & Pringle, 2008; Yule *et al.*, 2009). Leaf litter quality may affect macroinvertebrate feeding trend in a way that the secondary compounds of the leaf such as essential oils or polyphenols may delay the growth of fungi and in turn affecting microbial colonization, leading to hardness of leaves thereby affecting the consumption of leaf by macroinvertebrates as they become less palatable (Medina-villar *et al*., 2015). Different types of leaf species have varying structural and chemical attributes, decomposing at varying rates and these bears great influence on the effective utilization of leaf litter by shredders (Bastian *et al.*, 2007; Wantzen *et al;* 2008).

Many plant species in the tropics tend to produce secondary metabolites that inhibit microbial colonization and makes the leaves less palatable to herbivores (Hepp *et al.*, 2016). In a feeding preference study of tropical Shredder *Phylloicus sp.* done by Rincon and Martınez (2006), they noted some variations in shredders feeding patterns among leaf species containing different chemical composition. Determining the physical and synthetic attributes of the leaves, as the main drivers of decomposition rates, is very essential (Ardón & Pringle, 2008). Arthropod shredders contribute to leaf decomposition process but some studies propose that some taxa of Gastropod may partake in leaf litter processing in aquatic systems (Brady & Turner, 2010). The physical composition of the leaf such as its toughness and leaf mass greatly constitute the status of leaf (Lecerf *et al.*, 2006; Medina-villar *et al.*, 2015). The moment leaves fall into a stream, a compound action of decomposition starts that contain the discharge of soluble compounds, then physical abrasion and microbial action and colonization by invertebrates (Medina-villar *et al*., 2015; Cornejo *et al.*, 2020).

The diversity and density and macroinvertebrate shredders may be affected by the composition of exotic tree leaves, especially high secondary compounds in *Eucalyptus* spp. (Gama *et al.*, 2014; Reis *et al*., 2018). According to Hood & Naiman (2000), the riparian ecosystems were highly disturbed due to invasion by exotic species, making them highly vulnerable. Frequent human and natural effects may correlate these disturbances (Kiffer *et al.*, 2018). Riparian annexation by tropical trees may significantly lead to alteration of leaf quality inputs into the streams, thereby causing adverse effects on nutrient cycles and structure and function of aquatic communities (Hood & Naiman, 2000; Blanco & Gutiérrez-isaza, 2014).

The decomposition rate of leaves in a stream is determined by the inherent characteristics of flow, water temperature, the nature of streambed, pH, the chemical composition of leaf litter and the composition of biotic communities (Gonçalves Jr. *et al.*, 2006; Patrick, 2013). The availability of compounds that inhibits shredder activity or conditioning by microbes and the nutrient composition of the leaves affect the processing rate of leaf litter (Graça & Canhoto, 2006; Jinggut *et al*., 2012; Masese *et al.*, 2014a). The processing rate of terrestrial leaves differs greatly among species due to physical and chemical composition of leaves and this aids in varying rated of decomposition (Gessner *et al.*, 2010). Therefore, the use of decomposition rates as a measure of ecological health of the streams greatly allows comparisons on land-use effects on streams and the ability to offer ecosystem services.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

This study was conducted in three agricultural (Kipsinende, Mlango and Seger) and three forested (Sabor, Kipkaren and Chepkoilel) streams in the headwaters of the Sosiani River in western Kenya (Figure 1). As a tributary of the Nzoia River, Sosiani River originates from the western slopes of the Kerio Escarpment (Figure 1). The Nzoia River originates from the southeast part of Mount Elgon and the Western slopes of Cheranganyi Hills and Kerio Escarpment and channeled into the Lake Victoria at an altitude of nearly 1000 m above sea level (asl) (Nyadawa & Mwangi, 2010). The area's climate is considerably tropical humid, with an annual mean rainfall range from 901 to 2201 mm and temperature range from 13°C to 26°C which differs greatly with elevation. The rainfall pattern in the area is bimodal with March to June having long rains and short rains are experienced from August to October.

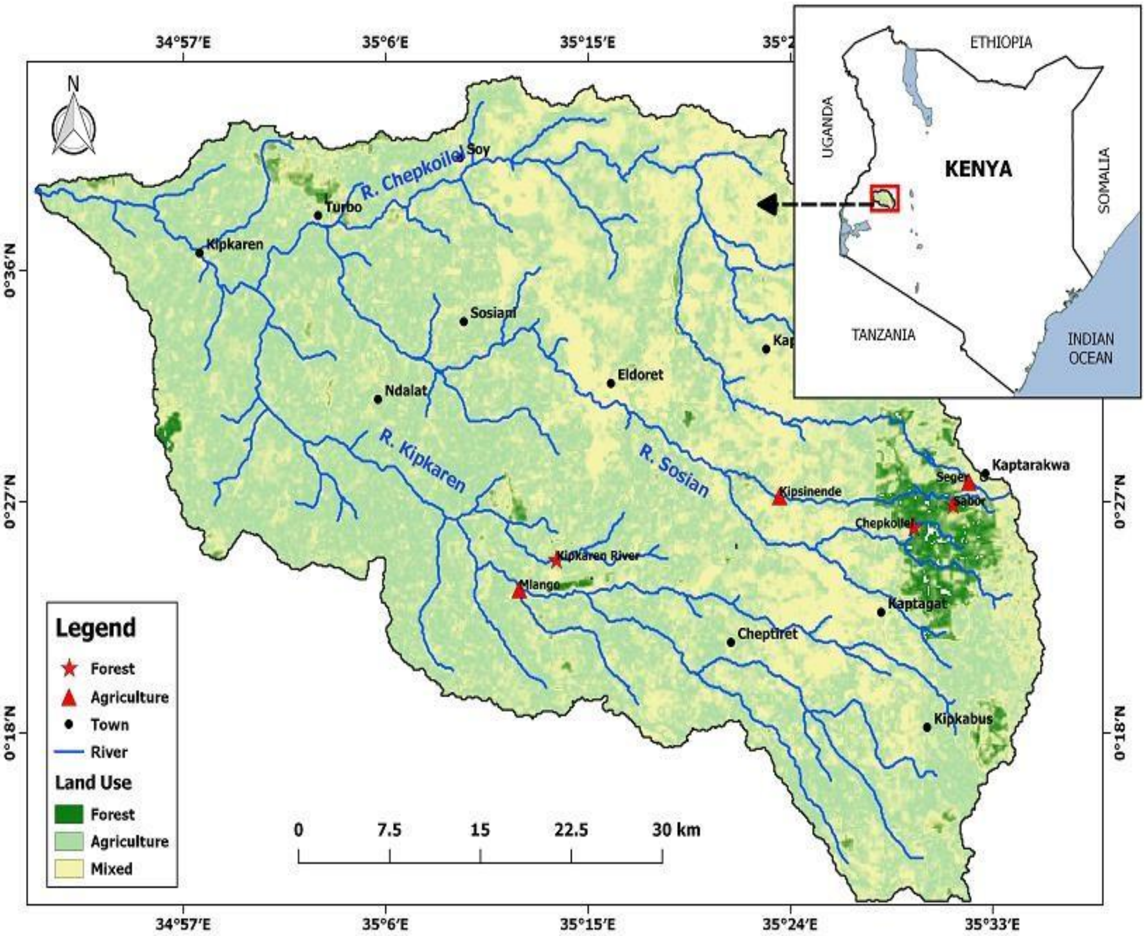

Figure 1: Map of Sosiani River Basin showing the position of forested (n = 3) and agricultural (n = 3) streams used for the study

3.2. Human activities in the area

The upper Nzoia River Basin (NRB) has experienced rapid population growth over time, which put forth pressure on available land resources. The demand for food and fibre has increased leading to deforestation, crop farming along river banks, draining of wetlands for livestock, horticulture grazing, harvesting of sand (winning) from streams and rivers, and brickmaking (Masese *et al.*, 2009; Wabusya *et al.*, 2015). The Nzoia River has been impacted by multiple stressors in the past, but agriculture has been a major source of concern due to increasing growth of human population and the resultant demand of agricultural land for crops and livestock production (Masese *et al.,* 2009; Wabusya *et al.*, 2015). In the headwater of the Sosiani River, land-use is dominated by native forest but as they flow downstream, land-use shifts from forest cover to mixed croplands (mainly maize, wheat and potatoes) and grazing areas for improved breeds of cattle. In the agricultural areas, most streams have a well-protected riparian zone. Study sites were categorized into forested or agricultural depending on catchment and riparian land-use in the study area.

3.3 Physicochemical variables

At each site, water depth, velocity, stream width, percent canopy cover and discharge were ascertened within a 100 m long stream reach. General Oceanics mechanical (2030) flow-meter was used to measure water velocity. Stream width of each stream was determined at transects of 10 placed at 10m mid-point intervals. The measurement of water depth was done by placing 1-m ruler on each transect of at least 5 points across the stream. The velocity-area method was used to measure stream discharge at each study reach (Wetzel & Likens, 2013). Coarse particulate organic matter (mainly leaf litter, sticks, seeds, flowers and fruits) for estimation of percentage coverage of the streambed were collected at each study reach in triplicates using a quadrat (0.5*0.5 m^2). The quadrat was randomly placed in the study reach and the various fractions of coarse particulate organic matter that was captured within the quadrat were handpicked and put in zip lock bags for carrying to the university laboratory for further processing. Percentage canopy cover in each study reach was also estimated visually (Masese *et al.,* 2014a).

Instream and riparian habitat conditions for each study reach was characterized by using a qualitative habitat evaluation index, which is a method by Rankin (1995) with modifications used in the Lake Victoria Basin (Masese *et al.*, 2009; Raburu & Masese, 2012). The index is based on six variables, namely; instream cover substrate composition, bank erosion, riparian zone and channel morphology, and, pool/glide, riffle /run depth and riffle /run quality. Visual characterization of substrate composition was employed as the proportion of various types of streambed substrate (boulder, cobble, pebbles, hardpan, muck, gravel, sand, mud and detritus) (Barbour *et al.,* 1999; Fernandes *et al*., 2014).

Measurements of electrical conductivity, pH, temperature, dissolved oxygen and salinity were performed in situ by using a YSI multi-probe water quality meter (556 MPS, Yellow Springs Instruments, Ohio, USA). The water samples were collected and immediately filtered on-site for particulate organic matter and total suspended solids using pre-weighed Whatman GF/F filters (0.7µm pore size, 47mm diameter). Filters with sediments were carefully enveloped in bauxite foil envelopes, preserved in a cold box at 4^{o}C and transported to the laboratory where they were preserved in a refrigerator together with the water samples awaiting laboratory analysis.

In the laboratory, water quality variables such as TSS, nitrite (NO_2), soluble reactive phosphorus (SRP), nitrate (NO_3) and ammonium (NH_4) were analyzed following standard methods for concentration (APHA, 2005). Filters having the suspended solid matter were dried at 95^{o}C for 48 hours and reweighed using an analytical balance (Citizen, Model CY220, 0.001g) and total suspended solids was determined gravimetrically. The dried filters were subsequently ashed at 450ºC for 5 hours in a muffle furnace and then re-weighed to determine POM in TSS as the variance between ash-free dry mass and TSS (APHA, 2005). Coarse particulate organic matter was then dried at 60^{o}C to a constant weight for 48 hours where various fractions of leaves, flowers, sticks and seeds were weighed independently using an analytical balance (0.001 g).

3.4 Leaf litter breakdown experiment

To determine decomposition rates of leaf litter, an experiment was conducted during the dry months of February- March 2020. Three common riparian tree species were selected for study: an indigenous tough species *Syzygium cordatum* (Family *Myrtaceae*) [Commonly referred as *Syzygium*], a soft indigenous species, *Vernonia myriantha* Hook. f. (Family *Asteraceae*)

[Commonly referred as *Vernonia*], and a tough non-native species *Eucalyptus globulus Labill* (Family *Myrtaceae*) [Commonly referred as *Eucalyptus*]. *Vernonia* exhibits very soft leaves, and thus, represented the highest quality of the three leaves. In comparison *Syzygium l*eaves are tough and smooth and it was assumed that its breakdown rate could be comparable to that of Eucalyptus within the same family (Mathooko *et al.*, 2001; Masese *et al.*, 2014b).

Recently abscised leaves were collected and air-dried for a period of two weeks at room temperature under the shade until a constant mass was attained, 4g of each species were then weighed and put into two litterbag types: coarse-mesh (10 mm mesh size) and fine-mesh (0.5 mm mesh size) litterbags. The fine mesh litterbags were utilized to exclude macroinvertebrate entry and allow only microbial decomposition, whereas coarse-mesh litterbags were used to allow both macroinvertebrate and microbial-mediated processing of leaf litter. A total of 228 litterbags were used in the experiment from which 216 litterbags were divided into 3 replicates per litterbag type (fine- vs. coarse-mesh) per plant species (*Eucalyptus*, *Syzygium* and *Vernonia*) in each site (3 forested and 3 agriculture), for two retrieval dates (Day 14 and Day 28). The aim of using the extra 12 litterbags was to ascertain the initial ash-free-dry mass conversion factor for every type of leaf species (4 replicates each). Before deployment, the litterbags were tied along nylon lines to secure them and avoid any overlaps, as well as for easy retrieval. The litterbags were finally deployed on February18, 2020, at the six study sites by attaching the nylon lines to metal stakes that were hammered into the streambed. Litterbags were set far apart to prevent overlapping and transfer of macroinvertebrates colonizing the bags from one bag to the other. The fine- and coarse-mesh litterbags were retrieved two times on the 14th and 28th days to study macroinvertebrates colonization.

During retrieval, litterbags were carefully enclosed in a 300mm mesh net and placed in zip-lock plastic bags to prevent dropping of invertebrates and leaf particles. After each collection, the preservation of samples was done in 5% formalin solution, the plastic bags were sealed and kept in a cooler and transported to the laboratory for processing. Upon reaching the laboratory, the litterbags were gently rinsed with tap water and sieved using a 250µm mesh size to separate macroinvertebrates from the leaves. Leaf pieces from the litterbags were rinsed and dried in the oven at 105^{o}C for 48 hours to obtain dry mass remaining, then ashed at 550^{o}C for 4 hours and then weighed to obtain Ash-Free Dry Mass (AFDM).

3.5 Macroinvertebrates in kick samples and litterbags

At each study reach macroinvertebrates kick samples were collected from riffle, run, pool and marginal vegetation biotopes for each stream along a 100m reach, thereby collecting four random kick samples, respectively on two sampling occasions; day 1 of litterbag deployment and day 28 of final litterbags retrieval. After sorting, macroinvertebrates from coarse-mesh litterbags and kick samples were preserved in vials in 75% ethyl ethanol until identification and enumeration. Macroinvertebrates that were collected from the coarse mesh litterbags were placed in vials, kept in 70% ethanol solution. Identification was performed to the family level and classified into their functional feeding groups. Macroinvertebrates from both kick samples and coarse litterbags were counted and identification was done to genus level by using several macroinvertebrates guides (Day *et al.,* 2002a, b; de Moor *et al.,* 2003a, b; Merritt *et al.,* 2008). Macroinvertebrates were classified into four main functional feeding groups (FFGs; scrapers, predators shredders and collectors) according to Merritt *et al*. (2008) and Masese *et al.* (2014a). The taxonomic richness and total invertebrate abundance for taxa and each FFG were recorded per litterbag per site (for coarse-mesh litterbags) and per site (for kick samples).

3.6 Statistical Analysis

Two-sample t-test was employed to compare water quality variables, organic matter, nutrients and variables for stream size between forested and agricultural streams. Principal Component Analysis was used to lower the dimensionality and explore variations among riparian attributes, organic matter and physico-chemical variables in the study area.

Macroinvertebrate community and functional structure in coarse-mesh litterbags and kick samples were expressed as taxa richness, abundance and the four FFGs: shredders, collectors, scrapers and predators. Two-sample t-tests were also used to test for differences in number of taxa ,total abundance of all taxa, non-shredder abundance and richness in kick and coarse-mesh litterbags samples between forested and agriculture streams. Testing for significant differences in multivariate water and habitat quality and organic matter characteristics was done using permutational analysis of variance in the R package vegan (Oksanen *et al.,* 2020).

Statistical differences in macroinvertebrate community structure between forested and agricultural streams in litterbags and kick samples were tested with one-way analysis of similarity (ANOSIM). Non-metric multidimensional scaling was used to display macroinvertebrate community structure between forested and agricultural streams based on Bray and Curtis (1957), dissimilarity distance. Statistical differences in macroinvertebrate community structure and functional feeding groups between forested and agricultural sites in both coarse-mesh litterbags and kick samples were tested with a permutation analysis of variance (PERMANOVA). The ordination of the goodness of fit was determined through the vastness of the correlated stress value; as an estimate of <0.2 correlate to a superior order (Kashian *et al.,* 2007). The similarity percentages (SIMPER) routine was used to calculate the percentage contribution of individual taxa to the comprehensive dissimilarity between agricultural and forested land-use (Clarke & Warwick, 2001)

Ash free dry mass (AFDM) was calculated basing on the following formula by Benfield (1996):

$$\% \text{ OM} = \frac{(\text{DM}_{\text{sample}} - \text{AM}_{\text{sample}}) \times 100}{\text{DM}_{\text{sample}}}$$

Where OM is organic matter, DM $_{\text{sample}}$ is the sample dry mass and AM $_{\text{sample}}$ is the sample ash mass.

The dry mass values are later converted to ash-free dry mass as follows:

$$\text{AFDM} = (\text{DM}) \times (\%\text{OM})$$

Then AFDM values for each leaf litter bag are converted to percentage AFDM remaining using the formula

$$\%\text{loss AFDM} = \frac{(\text{Initial AFDM} - \text{Final AFDM}) \times 100}{(\text{Initial AFDM})}$$

$$\% \text{ remaining AFDM} = (100\% - \% \text{ loss AFDM})$$

The rates of decomposition were evaluated by an exponential decay model (Boulton & Boon, 1991):

Wt= W0e-kt

Where Wt = AFDM residual at time t (28days);

W_0 =inceptive AFDM

-k= rate of decay

The calculation of the breakdown rates of leaves in the litterbags for coarse (kc) and fine-mesh (kf) was done individualy. Coefficients for kc/kf were calculated for each stream to find out the effect of eliminating potential macroinvertebrate shredders from fine mesh bags during breakdown (Masese *et al*., 2014b).

Correspondingly, the calculation of ki/kr coefficients for fine and course- mesh litterbags was done to determine land-use effect on microbial and macroinvertebrate shredder leaf breakdown (Gessner *et al*., 2010). Where i stands for agriculture (impacted) and r is for forested streams (Gessner & Chauvet, 2002).

The differences in leaf litter decomposition rates (-*k*) or percentage leaf mass loss (%) were tested using three-way ANOVA where leaves (*Syzygium Vernonia* and *Eucalyptus*), land-use (forested and agricultural), and mesh size (coarse- and fine-mesh), including interactions, were treated as the main factors and leaf litter decomposition rates as the response variables.

Two-way ANOVA was used to explore variations in leaf decomposition rates (-*k*) with leaf species (*Vernonia*, *Syzygium* and *Eucalyptus*) and by mesh size (coarse- and fine-mesh) after 14 and 28 days of deployment in agricultural and forested streams were re-run.

All statistical analyses were conducted by using Minitab software (Version 18) and PAST software (version 3.21), while figures were created in MS Office Excel (2016).

CHAPTER FOUR

RESULTS

4.1 Physico-chemical water quality parameters

Significant differences ($p < 0.05$) were observed in physical water quality variables of coarse particulate organic matter coverage of the streambed (% CPOM), between forested and agricultural streams. Significant differences were also noted on sticks biomass (gm^{-2}) and canopy cover (% cover) between forested and agricultural streams, as forested streams recorded higher CPOM and canopy cover percentages of 54 and 66.4% than that of agricultural streams which was below 40% with a record of 31.1% and 37.8% respectively (Table 1). Correspondingly, PCA ordination for habitat variables shows forested streams having significant increases in CPOM and canopy cover (figure 2b). Chemical water quality parameters of POM, TSS and electrical conductivity also varied significantly ($p < 0.05$) between the two Land-uses, with agricultural streams showing higher values. There was no difference in abundance of leaf litter (gm^{-2}) between land-uses ($p = 0.856$) (Table 1). Principal component analysis on physicochemical variables shows significant increase of POM and temperature in agricultural streams (figure 2a) even though the differences in temperature were not statistically significant.

4.2 Leaf litter decomposition

Trends in leaf litter decomposition rates ($-k$) and percentage leaf mass loss (%LML) were the same during day 14 and day 28. At day 14, *Vernonia* had the highest decomposition rate (-k/day) across all land-use type (agriculture and forest) in both coarse ($-k$=0.059)-

and fine (*-k*=0.035) - mesh litterbags followed by *Eucalyptus* then *Syzygium* that exhibited similar trend values.

Table 1: Mean (±SD) physico-chemical and stream size variables in agricultural and forested streams in the headwaters of the Sosiani River.* significant values ($p < 0.05$) in bold

Water physico-chemistry				
	Agriculture	**Forest**	**t-value**	**p-value**
Stream size				
Depth (m)	0.3±0.03	0.4±0.1	4.303	0.687
Width (m)	6.3±0.8	5.5±1.4	12.706	0.529
Velocity (m/s)	0.6±0.1	0.6±0.05	3.182	0.99
Discharge (m3/s)	2.1±0.4	2.2±0.4	4.303	0.808
Organic matter fractions				
%CPOM	31.1±4.0	54±4.9	3.182	**0.014**
%Canopy cover	37.8±6.8	66.4±2.8	4.303	**0.044**
Sticks/wood (g/m2)	6.5±3.4	16.8±8.4	3.182	**0.018**
Leaves (g/m2)	32.1±15.3	24.7±4.2	4.303	0.856
Fruits and flowers (g/m2)	1.4±0.9	4±2.01	3.182	0.311
Seeds (g/m2)	0.03±0.03	0.2±0.2	12.706	0.451
Standing stock (g/m2)	40.0±18.9	45.8±14.6	4.303	0.396
Water quality variables				
POM (mg/L)	21.6±2.0	14.8±1	3.182	**0.053**
TSS (mg/L)	38.1±1.1	28.5±0.1	4.303	**0.014**
Temperature (^{0}C)	16.8±0.6	15.3±1	3.182	0.073
DO (mg/L)	5.0±0.3	6.2±1.7	4.303	0.435
pH	7.1±0.1	7.1±0.01	4.303	0.818
TDS (mg/L)	0.03±0.01	0.02±0.01	12.706	0.983
EC (µS/cm)	56.9±9.2	29.7±1.3	4.303	**0.043**
Salinity (ppt)	0.02±0.01	0.01±0.01	4.303	0.22
Nutrients				
NH_3 (mg/L)	0.9±0.02	0.9±0.02	4.303	0.317
SRP (mg/L)	0.2±0.05	0.1±0.01	3.182	0.383
NO_2 (mg/L)	0.3±0.01	0.3±0.07	12.706	0.873
NO_3 (mg/L)	1.8±0.9	1.1±0.3	4.303	0.693

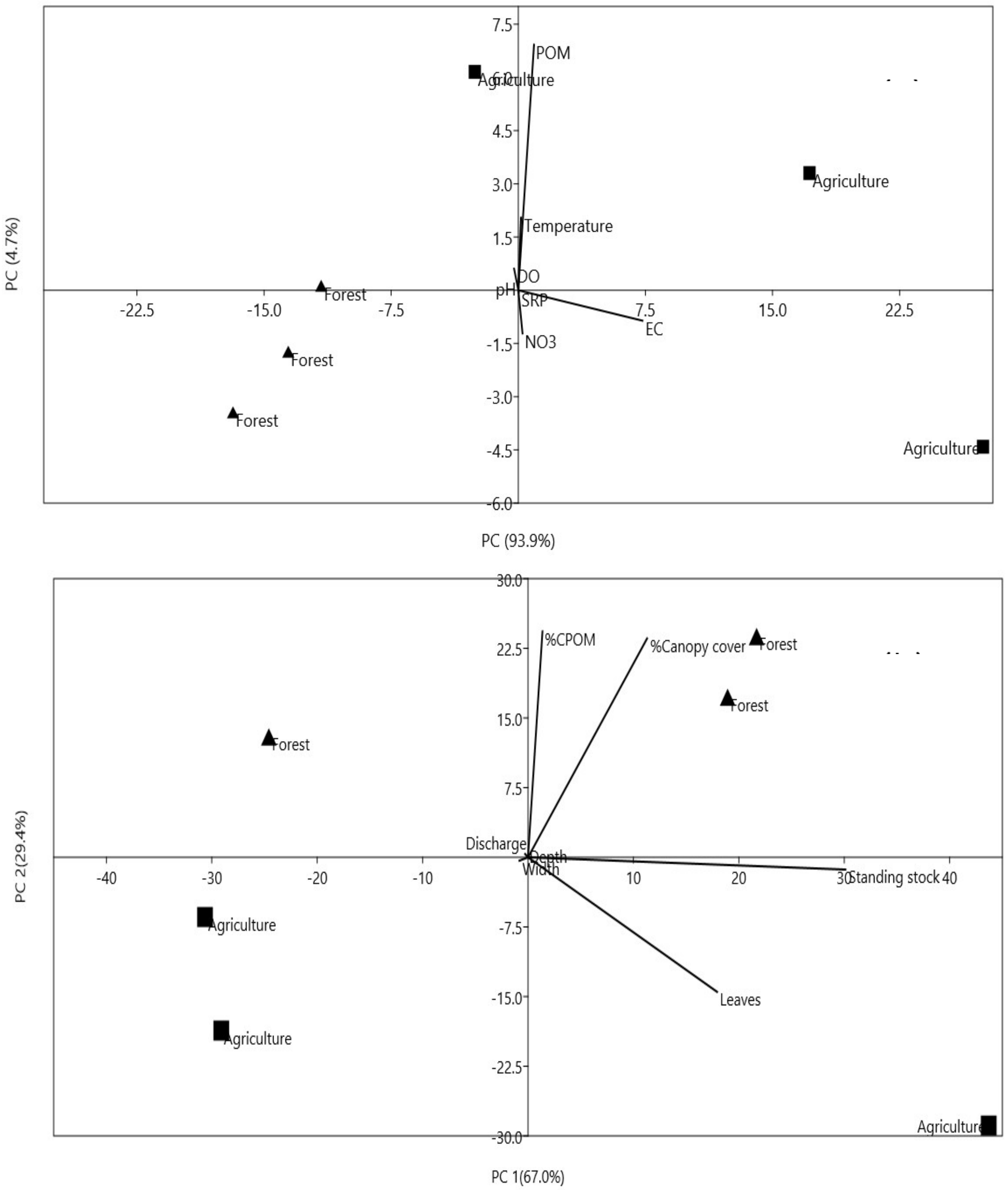

Figure 2: PCA on (a) physico-chemical parameters and (b) habitat variables in the study sites.

Decomposition for coarse (-*k*=0.011) - in both land-use types had slight differences from fine mesh litterbags (-*k*=0.011) and (-*k*=0.090) respectively (Figure 3a). At day 28, *Vernonia* had the highest decomposition rate (-k/day) in both forested and agricultural streams, and in both coarse (*k*=0.041) - and fine (-*k*=0.039) -mesh litterbags, followed by *Eucalyptus* (-*kc*=0.011 and *kf*=0.008), then *Syzygium* (-*kc*=0.008 and -*kf*=0.006) (Figure 3b). However, *Eucalyptus* and *Syzygium* showed similar rates of decomposition in coarse as well as fine -mesh litterbags, except for *Syzygium* that showed higher rates of leaf decomposition in coarse mesh litterbags in agricultural streams. Differences in decomposition rates or percentage leaf mass loss (%LML) was significant between leaf species but not with mesh-size or land-use (Table 2).

There were also no interactions among the factors considered (land-use, mesh size and leaf species). At day 14 variations in the rates of litter decomposition among leaf species and between land-use and mesh sizes were significant, which was not the case on day 28 (Figure 3). *Vernonia* recorded the highest %LML of >50% in coarse-mesh litterbags and >30% in fine-mesh litterbags. Variation in decomposition rates (-*k*) or %LML was significant according to treatment by mesh size and leaf species ($p < 0.05$) but not with land-use (Table 2).

The interaction between leaf species and mesh size treatment was significant whereas the interaction that incorporated land-use in either leaf species or mesh sizes or both showed no significant interactions (Table 2) for all leaf species. During day 14 and day 28, higher decomposition rates were noted in coarse than in fine-mesh litterbags (kc/kf >1) (Table 3). Except for *Eucalyptus* in forested streams, rates of leaf decomposition in fine-mesh litterbags were higher on Day 28 than on Day 14, indicating a delay in microbial colonization in the first 2 weeks, but an increase during the last 2 weeks (Day 14-28).

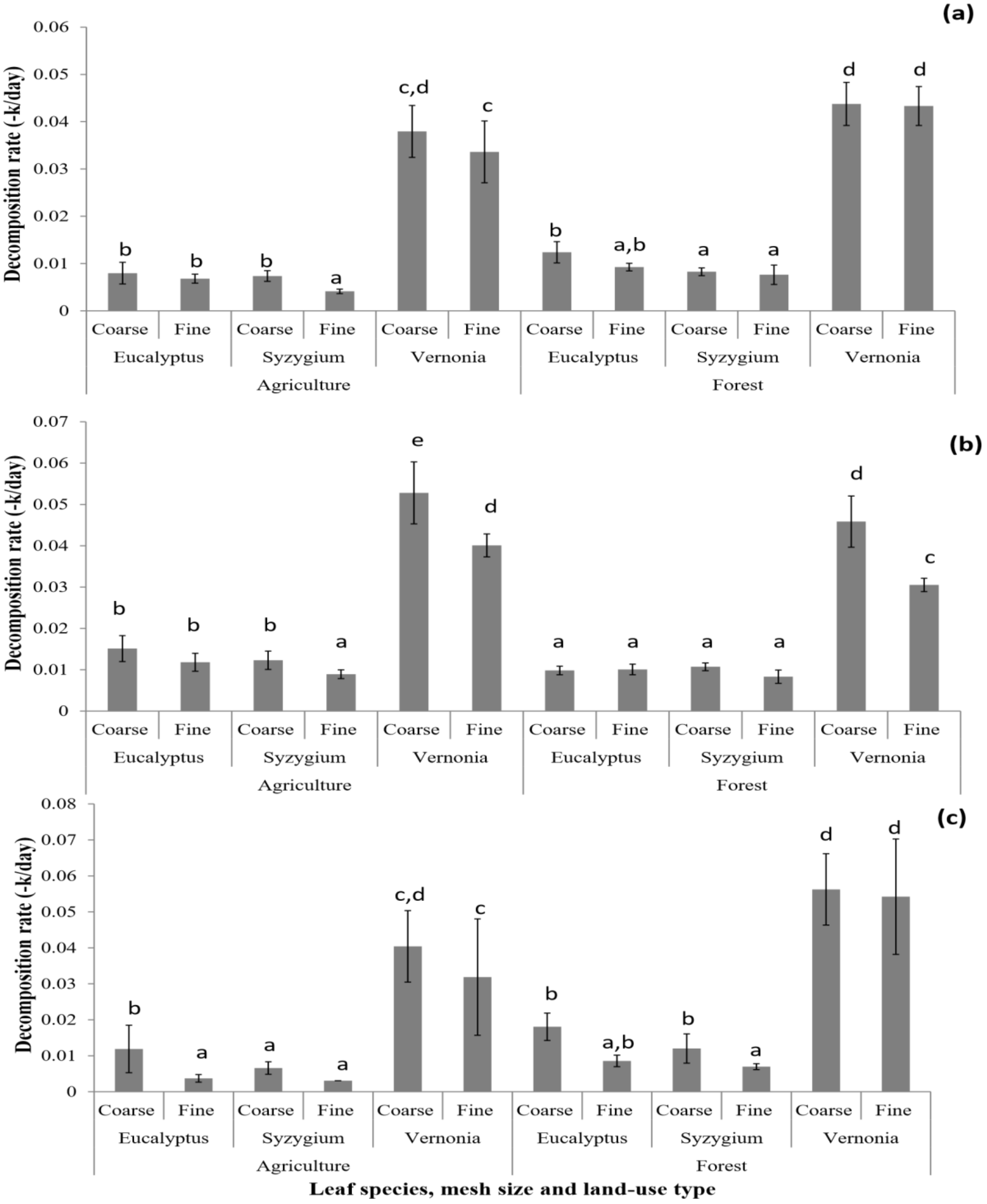

Figure 3: Decomposition rates (-k/day) of Eucalyptus, Syzygium and Vernonia leaves in coarse- and fine mesh litterbags in forested and agricultural streams after (a) 28 days, (b) days 0-14 days and (c) days 14-28 of deployment

The contributions of shredder breakdown rates relative to microbes known as kc/kf coefficients were higher for *Vernonia* in forested streams (kc/kf=2.28) than in agricultural streams (kc/kf=1.31) followed by *Syzygium* which recorded higher breakdown rates in Agriculture streams (kc/kf=1.477) than in forested streams (kc/kf=1.357). However, *Eucalyptus* had the lowest decomposition rates in both forested and agriculture streams (lowest kc/kf values) compared to the other leaf species (Table 3).

The ki/kr coefficients in coarse mesh litterbags showed that higher rates of leaf litter breakdown for *Eucalyptus* in coarse mesh litterbags (ki/kr=1.540) than in fine mesh litterbags (ki/kr=1.144). Whereas *Vernonia* had higher ki/kr coefficients in fine mesh litter bag (ki/kr=1.331) but recorded lower values of ki/kr=0.793 in coarse mesh bags (Table 3). During day 14, except for *Vernonia* in coarse-mesh litterbags the other two leaf species had higher decomposition rates in agricultural (impacted) streams (ki/kr > 1) (Table 3). The ki/kr coefficients in coarse-mesh litterbags was highest for *Eucalyptus* (ki/kr =1.54) and lowest for *Vernonia* (ki/kr = 0.79). However, this was reversed for fine-mesh litterbags with *Vernonia* recording the highest value decomposition in forested streams (ki/kr = 1.33). During Day 28, the same trend in fine-mesh litterbags was recorded, but in coarse-mesh litterbags, *Syzygium* had the highest decomposition rate in forested streams (ki/kr=0.97) while *Eucalyptus* had the lowest (ki/kr = 0.63). Moreover, during Day 28 increased rates of leaf decomposition were observed in forested than in agricultural streams for all leaf species and litterbag types similar to that of *Eucalyptus* (Figure 3). Decomposition rates were faster during the first phase of the experiment (days 0-14; Figure 3b), as compared to the second phase (days 14-28; Figure 3c).

Table 2: Two-way ANOVA showing differences in leaf litter decomposition rates (-k) with leaf species type after 14 and 28 days of deployment in agricultural and forested streams

	Day 14				**Day 28**			
Sources of variation	**df**	**SS**	**F**	***p* -value**	**df**	**SS**	**F**	***p* -value**
Forested streams								
Leaf sp.	2	0.017	26.7	**<0.001***	2	0.0073	39.4	**<0.001***
Mesh size	1	0.002	6.6	**0.013***	1	0.00008	0.87	0.36
Leaf sp.*Mesh size	2	0.004	5.5	**0.007***	2	0.00002	0.09	0.92
Error	52	0.037			37	0.0103		
Agricultural streams								
Leaf sp.	2	0.013	47.88	**<0.001***	2	0.013	17.6	**<0.001***
Mesh size	1	0.001	3.68	**0.06**	1	0.00001	0.03	0.86
Leaf sp.*Mesh size	2	0.0002	0.89	0.42	2	0.00003	0.04	0.96
Error	47	0.02			47	0.027		

During the first phase, there were differences in decomposition rates between fine- and coarse-mesh litterbags in *Vernonia* and *Syzygium*, but not with *Eucalyptus* leaves, indicating that shredders potentially discriminated against *Eucalyptus* leaves. During the second phase, differences in decomposition rates between fine- and coarse-mesh litterbags were notable for all species in forested and agricultural streams. During the first phase of decomposition, except for *Vernonia* in coarse-mesh litterbags, decomposition rates were higher in agricultural (impacted) streams (ki/kr > 1) (Table 3). However, overall decomposition rates were higher in forested (reference) streams (ki/kr <1) than in agricultural streams for all leaf species and litterbag types.

Comparisons were made in kc/kf and ki/kr coefficients with other studies in Kenya where riparian zones along streams have been lost (Masese *et al.,* 2014b; Tsisiche *et al.,* 2019) and other tropical, Mediterranean and temperate streams (Table 3). Most notably, kc/kf coefficients were much higher in Mediterranean and most temperate streams irrespective of land-use (reference and impacted). For ki/kr, most values in the Mediterranean and temperate streams were within the range of tropical values in both coarse- and fine-mesh litterbags, although values were much higher in coarse-mesh litterbags for two leaf species in Portugal (Gulis *et al.,* 2006).

4.3 Macroinvertebrates community composition

4.3.1 Kick samples

Cumulatively, about 17,114 macroinvertebrates individuals were amassed from the six sites, of which 7,999 were from agricultural streams while 9,115 were from forested streams. The macroinvertebrates samples comprised of 14 orders, 51 families and 75 genera. About 119 taxa were found in the study of which eight taxa (*Neoperla, Rheoptilum, Potamonaute sp. 1, Orthotrichia, Crambidae, Sciomyzidae, Chrysomelidae* and *Oligoneuriopsis spp*.) were restricted only to forested streams and another six taxa (*Mesovelia, Musca, Ranatra, Gerris, Planorbis and Aranaea spp*.) were restricted to agricultural streams only. Order Ephemeroptera had the highest number of individuals in both forested and agricultural sites (6,671), followed by Diptera (3,351) and Trichoptera (2,207). A total of 30 predators, 19 collectors, 17 shredders and 9 scrapers were identified from kick samples with three shredder taxa (*Crambidae, Chrysomelidae* and *Potamonaute sp.* 1) being restricted to forested streams. Collectors (47.5% and 45.3%) were the most abundant while shredders (7.3% and 7.5%) were the least abundant in Agricultural and Forested streams respectively. Predators were more abundant in agricultural streams (21%) than forested streams (4.64%) while scrapers were more abundant in forested streams (42%) than agricultural streams (24%). Even though insignificant, the aggregate of taxa and non-shredder taxa were more abundant in the agricultural streams (Figure 4). Shredder abundance and shredder taxa were significant in forested streams than agricultural streams (Figure 4).

Table 3: Means of kc /kf coefficients in litter decomposition rates amongst coarse (kc) and fine (kf) -mesh litterbags and ki /kr coefficients of decomposition rates in impacted (ki) and reference (kr) streams in coarse- and fine-mesh litterbags across different streams with varying days of deployment.

Country	**Climate**	**Leaf Species**	**Deployment period (days)**	***kc/kf***		***ki/kr***		
				Reference	**Impacted**	**Coarse Mesh**	**Fine mesh**	**Reference**
Kenya	Tropical	*Vernonia myriantha*	14	2.28	1.31	0.79	1.33	Present study
Kenya	Tropical	*Syzygium cordatum*	14	1.36	1.48	1.18	1.1	Present study
Kenya	Tropical	*Eucalyptus globulus*	14	0.98	1.28	1.54	1.14	Present study
Kenya	Tropical	*Vernonia myriantha*	28	1.38	1.28	0.89	0.76	Present study
Kenya	Tropical	*Syzygium cordatum*	28	1.1	1.84	0.97	0.56	Present study
Kenya	Tropical	*Eucalyptus globulus*	28	1.36	1.1	0.63	0.75	Present study
Portugal	Temperate	*Alnus glutinosa*	26	2.3	1.5	0.54	0.81	Ferreira *et al.*, 2012
Portugal	Temperate	*Quercus*	57	1.5	1.2	0.72	0.9	Ferreira *et al.*, 2012
Spain	Mediterranean	*Alnus glutinosa*	31	5.7	1.7	0.29	0.98	Ferreira *et al.*, 2012
Spain	Mediterranean	*Quercus*	104	4.6	3.5	0.78	1.05	Ferreira *et al.*, 2012

France	Temperate	*Alnus glutinosa*	28	8.2	2.8	-	-	Lecerf *et al.*, 2006
Portugal	Temperate	*Alnus glutinosa*	26	2.54	3.59	2.01	1.27	Gulis *et al.*, 2006
Portugal	Temperate	*Quercus*	57	1.92	3.72	2.76	1.56	Gulis *et al.*, 2006
Borneo	Tropical	*Indegenious leaves*	35	1.98	0.78	0.3	0.8	Jinggut *et al.*, 2012
Kenya	Tropical	*Croton macrostachyus*	56	1.65	1.3	0.84	1.26	Masese *et al.*, 2014b
Kenya	Tropical	*Eucalyptus globulus*	56	1.48	1.16	1.39	1.38	Masese *et al.*, 2014b
Kenya	Tropical	*Syzygium cordatum*	56	1.52	1.64	0.99	1.92	Masese *et al.*, 2014b
Kenya	Tropical	*Eucalyptus saligna*	48	-	-	1.14		Tsisiche *et al.*, 2019
Kenya	Tropical	*Neoboutonia macrocalyx*	48	-	-	1.55		Tsisiche *et al.*, 2019
Uganda	Tropical	*Neoboutonia macrocalyx*	28	3.82	0.98	0.14	0.53	Fugere *et al.*, 2018

4.3.2 Coarse-mesh litterbags

A total of 1884 macroinvertebrates individuals were collected from the coarse-mesh litterbags during day 14 and day 28, of which 14.6% were classified as shredders. The number of shredder taxa and abundance of shredders was higher in forested streams compared to agricultural streams with *Potamonaute sp.* and *Acanthiops sp.* dominating in both land-use types, while *Lepidostoma sp.* dominated the forested streams. Number of non-shredder taxa was more abundant in the agricultural streams (Figure 4). Accordingly, *Syzygium* had the highest number of macroinvertebrate individuals on day 14, seconded by *Vernonia* while *Eucalyptus* had the least number of macroinvertebrates colonizing them. However, *Vernonia* recorded the highest number of invertebrates (43.1%) followed by *Syzygium* (31.3%) then *Eucalyptus* (25.6%) on day 28. In overall in coarse litterbags cumulatively, *Vernonia* had the highest number of detritivore colonizing them in all land-use types. ANOSIM showed no significant variations in macroinvertebrates assemblages for kick samples of macroinvertebrates between agriculture and forest streams (R-statistic = 0.11, $p < 0.391$) but were significantly different for the coarse litter bag macroinvertebrates (R-statistic = 0.21, $p < 0.028$).

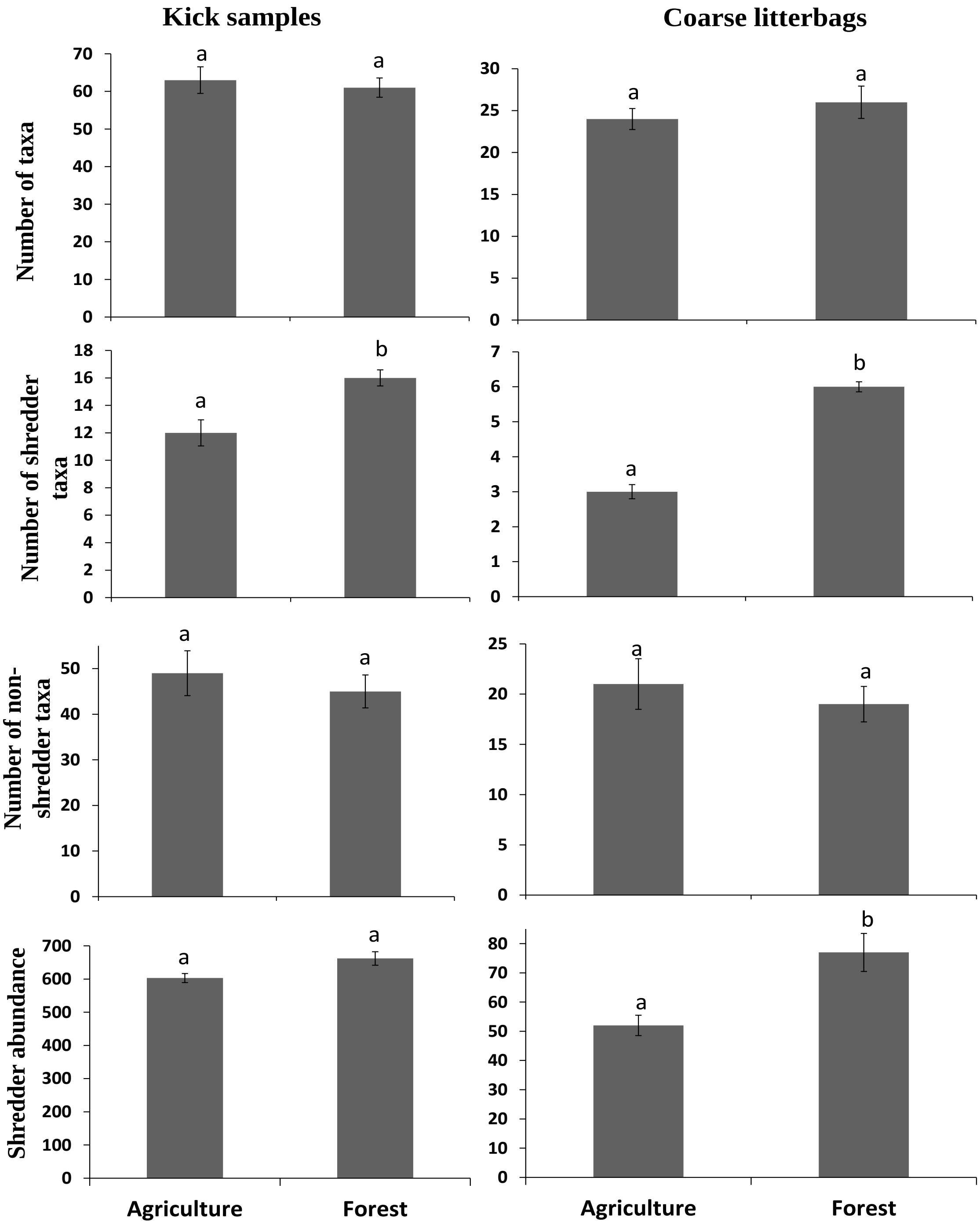

Figure 4: Mean (±SE) aggregate of taxa, aggregate of shredder and non-shredder taxa, abundance of shredder in agriculture and forest sites for kick samples and coarse-mesh litterbags

Non-metric multidimensional scaling ordination of macroinvertebrate abundance data of various taxa showed unification of the abundance of taxa in forested and agricultural streams (Figure 5).

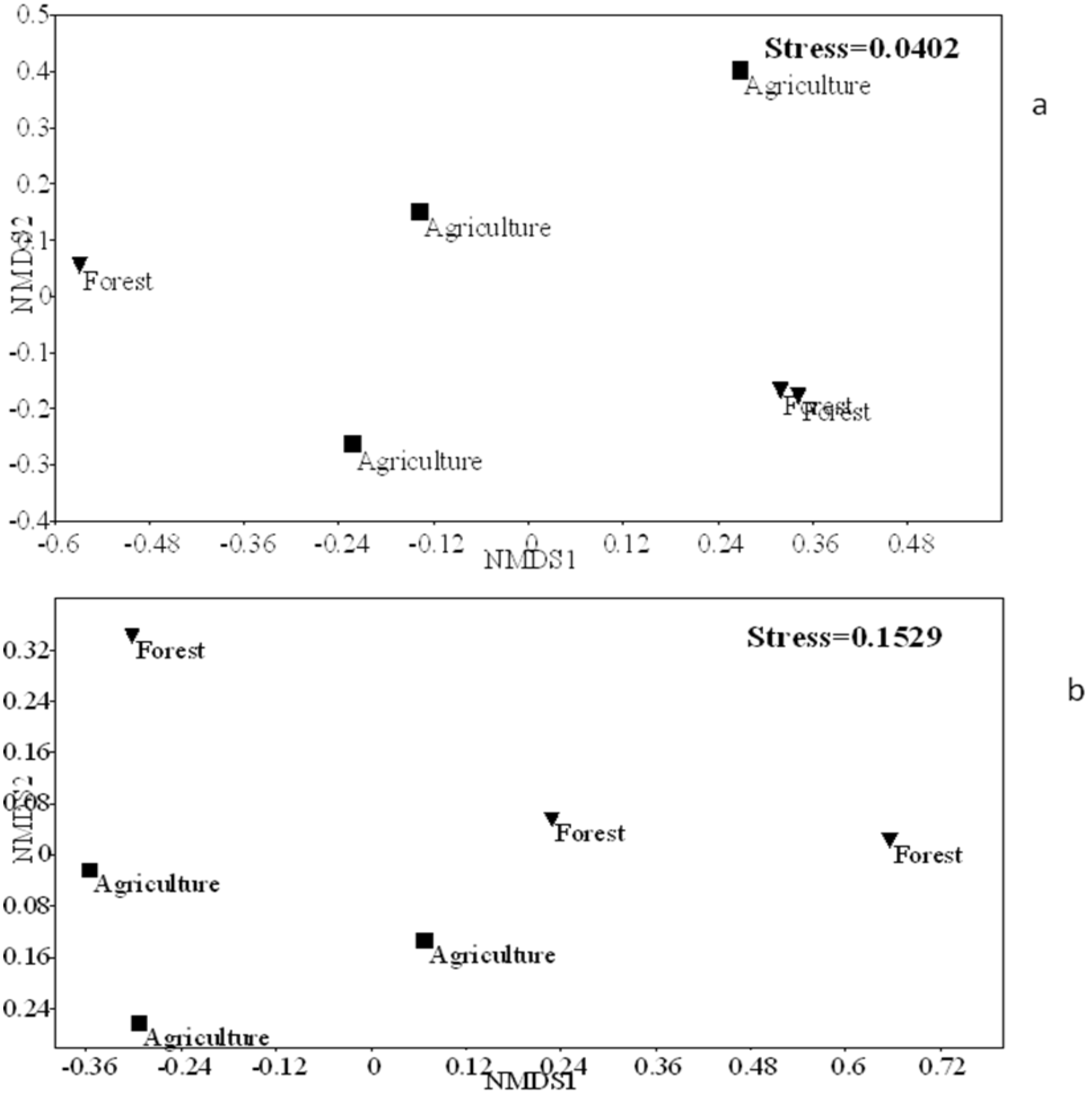

Figure 5: Non-metric multidimensional scaling ordination of invertebrate assemblages from coarse-mesh litterbags and kick samples collected from 3 forested streams and 3 agricultural streams during Day 14 and Day 28

The most common taxon according to SIMPER influencing the variation in the distribution of macroinvertebrate taxa between agriculture and forested site categories were *Simulium sp.* (16.87%), *Baetis sp.* (16.68%), and *Afronurus sp.* (13.54) for the kick samples macroinvertebrates (Table 4). For the coarse-mesh macroinvertebrates, *Hydropsyche sp.* (21.74%) and *Simulium sp.* (20.14%) accounted for the differences observed between the two site categories (Table 4).

Table 4: SIMPER displaying top contributors in abundance of invertebrate taxa in coarse-mesh litterbags and kick samples between agricultural and forested streams

Taxon	Mean Abundance			
	Agricultural	**Forested**	**% Contribution**	**% Cumulative**
Kick samples				
Simulium sp.	178	618	16.87	16.87
Baetis sp.	264	784	16.68	33.55
Afronurus sp.	349	452	13.54	47.08
Pisidium sp.	332	243	7.46	54.54
Hydropsyche sp.	326	180	6.37	60.91
Hirudo sp.	195	3	5.08	65.99
Tanypodinae sp.	164	25	4.67	70.66
Lumbricus sp.	138	28	4.03	74.69
Tubifex sp.	129	117	3.7	78.39
Cheumatopsyche sp.	77	27	1.92	80.3
Acanthiops sp.	41	92	1.81	82.11
Lestes sp.	64	10	1.81	83.92
Chironomus sp.	64	21	1.63	85.55
Adenophlebia sp.	20	60	1.6	87.15
Trianodes sp.	54	2	1.41	88.56
Elodes sp.	16	48	1.3	89.86
Coarse-mesh litterbags	**Agricultural**	**Forested**		
Hydropsyche sp.	110	24	21.74	21.74
Simulium sp.	49	117	20.14	41.88
Elodes sp.	3	38	9.52	51.4
Baetis sp.	46	24	8.12	59.51
Hirudo sp.	12	1	4.8	64.31

Acanthiops sp.	11	22	4.74	69.05
Caenis sp.	8	18	4.68	73.72
Lepidostoma sp.	3	16	4.2	77.93
Tanypodinae sp.	20	18	3.96	81.89
Cheumatopsyche sp.	10	1	2.18	84.07
Neoperla sp.	0	7	1.95	86.02
Afronurus sp.	8	1	1.84	87.85
Leptocerus sp.	7	1	1.67	89.53
Tubifex sp.	1	5	1.66	91.19
Bezzia sp.	3	4	1.28	92.47
Adenophlebia sp.	5	5	1.28	93.75

CHAPTER FIVE

DISCUSSION

5.1 Physico-chemical water quality parameters

This study shows significant differences in organic matter (leaf litter) and nutrient concentrations between agricultural and forested streams. The reduction of coarse particulate organic matter in agricultural streams than forested streams could be imputed to accelerated human activities occurring around the streams such as grazing, farming and deforestation. Organic matter is vital in streams as it is the major supply of carbon for food webs, its reduction and alteration in agricultural streams is an evidence of the impacts of land-use variations as they usually change the composition and abundance of organic matter that enters stream from riparian vegetation thereby affecting microbial and invertebrate communities (Cooper *et al.,* 2013). The higher canopy cover in forested streams that elicited the shading of the streams may have facilitated the lower mean water temperature levels recorded in forested streams (Masese *et al.,* 2014a; Ontumbi *et al.,* 2015).

There were significant increases in total suspended solids, electrical conductivity and particulate organic matter in agriculture streams as contrasted to forested streams even though temperature. The elevation in electrical conductivity in agricultural streams could be highly attributed to the increase in anthropogenic induced activities (Masese *et al.*, 2014b). Similar observations are supported by a study of Ontumbi *et al.,* (2015) along river Sosiani in Kenya who found accelerated levels of temperature, electrical conductivity, and total suspended solids among others and suggested to be attributed to the increased anthropogenic activities hence interfering water quality in the river. The reduction in canopy cover in agricultural streams could have attributed to a rise in water temperature and sedimentation that in turn reduces the quality of the stream habitat (Miserendino *et al*., 2008). The PCA decomposition of water physico-chemistry data reported much scatter in agricultural sites, suggesting that they were influenced to different degrees by changes in water (Figure 2). Agricultural land-use often accelerates nutrient accumulation and water temperature in streams thereby increasing the decomposition rates of microbes (Young *et al.,* 2008; Tank *et al.,* 2010). Although our agriculture streams had higher water temperatures than forested streams, they also recorded reduced nitrogen and phosphorus concentrations, the opposite of what is usually reported (Aura *et al.*, 2011; Woodward *et al.*, 2012). Thus, potential stimulating effects of breakdown rates by warmer temperatures in agricultural streams were constrained by nutrient limitation. Warmer tropical biomes have been noted to display remarkable heterogeneity in organic matter processing rates than cooler temperate regions (Tiegs *et al.,* 2019), which implies that other factors such as nutrient accumulations, can negatively affect the rate of litter processing warmer temperatures (Graça *et al.*, 2015). Although our agricultural streams had significantly elevated levels of particulate organic matter ,total suspended solids and electrical conductivity, which are indicators of anthropogenic activities on water quality (Ontumbi *et al.*, 2015; Masese *et al.*, 2017), these were deemed within tolerable limits of most sensitive taxa, including shredders, in these streams. Similarly, nutrient concentrations, which have been reported to increase organic matter processing in streams (Woodward *et al.,* 2012; Ferreira *et al*., 2012), did not differ between forested and agricultural streams in this study (Table 1). These findings are significant for stream management and biodiversity conservation as they reinforce the important role played by intact riparian zones on modulating negative effects of agriculture on water quality, biodiversity and the functioning of streams.

5.2. Leaf litter breakdown

The breakdown of leaf litter is a crucial function of the ecosystem as it aids in carbon and nutrient cycling in a stream ecosystem. The process of decomposition of leaves is of paramount importance as it provides food and organic matter and to communities in headwater streams (Casas *et al.*, 2013). Leaf decomposition as one of the measures of stream ecological integrity greatly responds to land-use alteration (Young *et al.*, 2008; Silva-junior *et al*. 2014). Characteristics of leaf litter can have a strong influence on decomposition rates (Martínez *et al.*, 2013), with high quality ones exhibiting faster decomposition rates than more low quality litter (Gessner *et al*., 2010; Masese *et al.*, 2014b; Boyero *et al.*, 2016).

Shredders' ability in converting leaf litter to secondary production greatly depends on the quality of the leaf (Graca, 2017). The input of allochthonous coarse particulate organic matter is the major source of energy for macroinvertebrates in forested streams. Essential stream ecosystem processes are greatly influenced by availability of coarse particulate organic matter. Additionally, CPOM acts as a refuge to stream organisms (Tsisiche *et al.*, 2019). The attribute and quantity of particulate organic matter processes are greatly influenced by seasonality and the characteristics of the riparian vegetation as forested streams are said to have higher particulate organic matter inputs than agricultural streams (Tank *et al.*, 2010). Organic matter processing rate in streams is largely influenced by environmental factors, the biota, physical and chemical properties of organic matter (Jinggut & Yule, 2015).

Land-use changes alters decomposition rates of leaf litter and the growth, species composition, and biomass of microbial communities by altering the composition of riparian vegetation (Pozo *et al*., 2011). Agriculture impacts highly affect aquatic heterogeneity and the quality of water in streams (Hepp *et al.*, 2010). Macroinvertebrate shredders are said to be agents of leaf litter breakdown in agricultural streams unlike forested streams and their significance greatly associate land-use effects with stream processes (Masese *et al.*, 2014a). Land-use variations can modify leaf litter breakdown rates by changing species composition, biomass and growth of microbial communities in streams. Through invasion by exotic trees in riparian zones, the input of leaves in streams with varying properties from indigenous ones may greatly destruct the composition and structure of aquatic fauna (Medina-villar *et al*., 2015). Basing on the results shown in this study, *Vernonia* had the highest decomposition rate (-k/day) across agriculture and forested streams in both coarse and fine mesh litterbags followed by *Syzygium* and *Eucalyptus*, having the least decay rates (Figure3). However, *Eucalyptus* and *Syzygium* showed similar decomposition rates in both coarse-and fine mesh litterbags, except for *Syzygium* that showed higher rates of litter breakdown in coarse-mesh litterbags in agricultural streams indicating that shredders discriminated against *Eucalyptus* leaves. These outcomes could be imputed to the fact that the native *Vernonia* leaves are softer compared to the native tough *Syzygium* and exotic tough *Eucalyptus*, therefore, may be preferred because of their palatability. This assumption is supported by findings of a research study by Reis *et al*., (2018) on the feeding behavior of shredder *Phyloicus* sp. They reported that *C. oliviforme* leaves were hard and contained higher tannin concentrations that resulted into low feeding levels by the shredder concluding that the quality of the leaves greatly influenced the unpalatability and poor feeding response by the invertebrate (Reis *et al*., 2018).

The existence of some secondary compounds in leaves like tannins may cause leaf toughness and serve as repellents for plant feeding organisms thereby becoming unpalatable to macroinvertebrates (Graça *et al.,* 2015). Corresponding findings were reported by Masese *et al.,* (2014b) in the headwaters of Mara River in Kenya who tested three different leaf species on the impact of litter attribute on macroinvertebrate colonization and leaf breakdown. According to their results, *Croton* had the fastest decomposition rate seconded by *Syzygium* and *Eucalyptus* had the least decay rate. Overall, the decomposition rates were considerably more in coarse other than in fine mesh litterbags mesh in all three types of leaves suggesting that the higher breakdown rates may be as a result of shredder mediated activity. The same trends were reported by Jinggut and Yule (2015) and Masese *et al*., (2014b). Hence, it is suggested that the rates of decomposition may change across streams basing on different attributes like nutrient concentration, pH, dissolved oxygen, water depth temperature, macroinvertebrates composition and riparian vegetation (Tiegs *et al.,* 2008; Brady & Turner, 2010; Medina-villar *et al.*, 2015).

Reports by different studies have shown that agricultural streams in tropical regions often have reduced litter breakdown rates as compared to forested streams (Masese *et al.*, 2014a, b; Silva-junior *et al.,* 2014; Fugère *et al*., 2020). For example, agricultural land-use was the main factor to have reduced leaf breakdown in coarse-mesh bags but did not affect microbial breakdown (Fugère *et al.,* 2020). However, the statistics done in this study found that land-use had no effect on the invertebrate mediated and microbial breakdown of all leaf species in all streams during the study period. Among the leaf species, *Syzygium* recorded highest kc/kf coefficients rates (kc/kf =1.842) in agriculture streams while *Vernonia* recorded the higher mean values in forested streams (kc/kf =1.364) suggesting that leaf breakdown was greatly influenced by litter quality (Table 3). These findings are similar with those from Masese *et al*. (2014b) who found corresponding results on litter breakdown experiments of *Eucalyptus* and *Syzygium* where *Croton* had highest kc /kf coefficient values seconded by *Syzygium* and *Eucalyptus* having the least kc /kf coefficients in both agriculture and forested streams. Similar findings by a study done in three tropical streams in southern Thailand, Parnrong *et al*., (2002) reported no variations in the decay rates between concluding that the varying leaf breakdown rates were subjective to leaf species but not specific streams, seasons or sites. Therefore, the difference in the rates of decomposition of leaf litter were not between land-uses, and most of the ki/kr values were below 1, which implies that agricultural land-use has not severely compromised organic matter processing in these streams.

5.3. Macroinvertebrate community and functional composition

The differences in the structure of macroinvertebrates in forested and agricultural streams found in this study could be imputed to the effects of human activities such as farming, grazing and settlements (Fu *et al.,* 2016). These changes may modify the composition of macroinvertebrate species, decomposition rates of leaves and the biomass and growth of microbial communities by changing the structure of the riparian vegetation (Medina-villar *et al.,* 2015). Accelerated number of macroinvertebrates in forested than agricultural streams found in this study may be imputed to the increased levels of heterogeneity among the streams that greatly influence the abundance and distribution of species, the trophic structure and the biotic interactions among the biological communities (Bastian *et al.,* 2007; Boyero *et al.,* 2015). The elevated number of collectors may be collated to the presence of organic wastes that are directly deposited by livestock hence increasing the presence of fine particulate organic matter (Wabusya *et al.,* 2015; Masese, *et al.,* 2017). Fine particulate organic matter is an important source of energy for collector invertebrates, explaining for a greater concentration of these invertebrates in agricultural streams (Wabusya *et al.,* 2015). Collectors, which do not directly participate in the fast decomposition of leaves, may have taken advantage of the increased amount of FPOM that in turn accelerated their abundance in the streams and may have utilized the coarse litterbags as a habitat (Bo *et al.,* 2018).

In temperate streams, shredders have demonstrated to partake in the decomposition of leaf litter because of their higher abundance that renders them as the key element inducing the rates of decomposition for leaf litter as reported by several studies done

(Graca *et al*., 2001; Bruder *et al*., 2014; Medina-villar *et al.*, 2015). However, the scarcity of macroinvertebrate shredders in the tropics has been highly stated (Dobson *et al.*, 2004; Yule *et al.,* 2009; Masese *et al*., 2014b; Blanco & Gutiérrez-isaza, 2014). It is reported that geographical and temporal variations affect the diversity and abundance of macroinvertebrate shredders in the tropical streams (Cheshire *et al.*, 2005; Masese *et al.*, 2014a).

The least number of shredders found in this study (about 7% of the entire macroinvertebrates collected in coarse litter bags) clearly demonstrate the importance of microbial breakdown of leaves in tropical streams (Dobson *et al.,* 2002; Wantzen *et al*., 2008; Graça *et al.,* 2015). Even though microbial breakdown of the leaves was only determined by the inclusion of fine-mesh litterbags in the study, suggesting that the reduction in shredder activity may be the reason for increased microbial activity triggered by escalated temperatures in the tropics (Mathuriau & Chauvet, 2002; Davies & Boulton, 2009).

The elevation in number of shredders in forested streams as compared to agricultural streams in this study could be due to the effects of land-use changes. These human influences render agriculture streams to be characterized with altered habitat structure, decreased habitat indexes that lead to reduction in shredder taxa richness whereby tolerant taxa are being replaced by non-tolerant ones in agriculture streams (Karaouzas *et al.*, 2007; Miserendino *et al.,* 2008; Helms *et al.,* 2009). Numerous studies have reported that a decrease in vegetation cover may influence greatly in the reduction of shredder diversity and abundance in headwater streams (Cooper *et al*., 2013; Salmah *et al.,* 2014;

Hepp *et al.,* 2016). Furthermore, this study found that the abundance of shredder taxa in coarse litterbags was higher in forested streams than agricultural stream. This is in agreement to the hypotheses stated in the study that the biomass and composition of macroinvertebrates shredders is higher in forested stream than in agricultural area. These results are similar with those found through a study done by Masese *et al.*, (2014a) in Kenyan highland stream where they reported a reduction in shredder abundance at agriculture sites and an increase in shredder abundance at forested sites. However, on the contrary, Salmah *et al.*, (2014) reported a decrease in shredder abundance in forested streams and an overall increase in shredder taxa diversity and abundance of macroinvertebrate shredders as compared to other studies done in tropical streams. The attenuation in the number of shredders and a surge in the number of collectors and other functional feeding groups could also be attributed to the recalcitrant of many tropical tree leaf species (Wantzen *et al.,* 2008; Yule *et al*., 2009; Li & Dudgeon, 2009; Masese *et al.,* 2014b). In addition, their series of recurrence in the streams may disrupt shredder breakdown of leaves thereby leading to the reduction of shredder macroinvertebrates (Wantzen & Mol, 2013).

The escalated concentration of toxic substances found in the leaves of several tropical tree species may lead to the input of leaves in the streams that may not be palatable to the aquatic insects (Wantzen &Wagner, 2006; Davies & Boulton, 2009; Minaya *et al.,* 2013). This is following the observation made by Cordero-Rivera *et al.,* (2017) in a study conducted in Spain and ascertained that streams running through *Eucalyptus globulus Labill* plantations comprised of reduced taxon affluence and decreased diversity of macroinvertebrates than those of native forests. The introduction of exotic Eucalyptus in the streams may disturb the growth, performance and survival of macroinvertebrate shredders in the riparian areas. This is affirmed by a food preference study done by Kiffer *et al.,* (2018) that reported that the larvae of *Tipula lateralis Meigen* that was fed with *Eucalyptus globulus* leaves had injuries on their mouthparts and observed variations in their gut microbiota. The essential oils in the leaves caused a decline in absorption and enzymatic and capacities of the shredder. Hence, suggested that the decline in absorption capacities of the shredder was due to the effects of the essential oils present in *Eucalyptus* leaves (Kiffer *et al.,* 2018)

Land-use plays a major role in determining stream ecosystem characteristics and function (Wu *et al.,* 2018; Fugère *et al.,* 2020). Organic matter processing in streams is greatly influenced by agriculture, consequently result in extermination of macroinvertebrate shredders and increased microbial processing through boosted nutrient availability (Silva-junior *et al.,* 2014; Fugère *et al.,* 2020). Understanding how stream ecosystems respond to land-use changes is critical for stream management and conservation. Forest cover in the Afrotropical catchments has been declining over the years with potential effects for stream ecosystems (Fugère *et al.,* 2016, 2018).

Studies have reported negative effects of land-use changes from forestry to agriculture and urbanization in tropical streams, ranging from declines in water characteristics and quantity, extermination of biodiversity, mainly the sensitive shredder taxa, and changes ecosystem structure and functioning (Masese *et al.,* 2014a, b; Fugère *et al.,* 2016, 2018). Given observed changes in diversity and distribution of macroinvertebrates between forested and agricultural streams, conservation and management efforts need to clearly understand how land-use is impacting tropical stream ecosystems so that management measures can be put in place.

5.4 Decomposition rates as indicators of stream health

Human activities can degrade river habitats, change water flow and biotic conditions (Cheng *et al.,* 2018). Leaf litter breakdown is a good indicator for direct assessment of rivers and streams affected by eutrophication .Litter diversity is most often assessed by the use of litterbags (Ferreira *et al., 2*012). Leaf litter decomposition is affected by different changes in species composition on riparian zones. In this study, litter decomposition rates were ultimately higher in coarse-mesh litterbags than in fine-mesh litterbags in forested streams than agriculture streams indicating faster breakdown rates when shredders were included, thereby being important agents in leaf litter breakdown. The slow decomposition rates reported in this study and in some tropical streams could be due to adverse environmental conditions and poor quality of tree species (Graça *et al*., 2015). Leaf litter decomposition rates were ultimately faster in the forested than agricultural streams. The slow initial leaf decomposition in forested streams could be imputed to the increased availability of FPOM in the river system, which provided enough food to the invertebrate shredders thereby delaying them from taking advantage of the food in the coarse litterbags (Young *et al.,* 2008).

The subsequent higher rates of leaf decomposition in forested than agricultural streams implies that agriculture slowed leaf litter decay, which was faster in forested streams during the latter half of the study period. Several studies have reported that agricultural streams in tropical regions often have reduced litter breakdown rates as compared to forested streams (Masese *et al.,* 2014b; Silva-junior *et al.,* 2014; Fugère *et al*., 2020). This is attributed to multiple physico-chemical stressors acting progressively, constituting accelerated levels of particulate organic matter, nutrients, agrochemicals and fine sediment or suspended solids in agricultural streams (Bruder *et al.,* 2014). The ratio of leaf decomposition coefficients in coarse- to fine-meshed litterbags (kc/kf) indicating the higher rates of decomposition rates in coarse than in fine-meshed litterbags. Thus suggesting greater invertebrate shredder involvement than microbial participation in the decay of leaf litter for all leaf species throughout the study period.

Forested streams had more abundant shredders (taxa and individual numbers) than agricultural streams, suggesting a greater leaf decomposition capacity in forested than agricultural streams. Forested streams had higher concentration of coarse particulate organic matter, a vital source of carbon for invertebrate shredders, which then colonize these food resources in their great numbers before consumption by microbial communities (Cooper *et al.,* 2013). Leaf litter decomposition react to even moderate eutrophication levels, thereby making it a very useful functional measure in assessing the ecological integrity of streams. Leaf litter breakdown imparts an integrated assessment of ecosystem functioning in streams; hence, breakdown rates may be crucial for evaluating the effects of human disturbances in streams (Graca, 2017).

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Land-use changes can modify breakdown rates of leaf litter by changing species composition, biomass and growth of microbial communities in streams. Leaf litter decomposition in the headwater streams of Nzoia River has been affected by land-use in the catchment area, with agricultural streams showing slower rates of leaf decomposition than forested streams. The biomass and composition of macroinvertebrates shredders was higher in forested stream than in agricultural area and this could be imputed to the higher levels of heterogeneity among the streams found in this study. *Vernonia* had the highest decomposition rate across agriculture and forested streams in both coarse and fine mesh litterbags because of its palatability, hence being preferred unlike the native tough *Syzygium* and exotic tough *Eucalyptus* .Overall decomposition rates were higher in coarse-mesh than in fine litterbags in agricultural streams indicating the importance of macroinvertebrate shredders in the processing of organic matter. The increased loads of suspended solids, fine particulate organic matter and sediments reported in the study may be contributed to the increase in farming activities in the catchment area, thereby bringing changes in water characteristics and adverse effects on the abundance of shredders. Changes in the physico-chemical characteristics of streams appear to be the main drivers behind observed leaf litter decay rates. It is therefore concluded that leaf litter decomposition in the headwater streams of Nzoia River has been adversely affected by agriculture, with potential threats on nutrient cycling and energy transfer to higher trophic levels.

6.2 Recommendation

There is need to protect riparian zones and catchment areas along the streams in order to reduce the adverse land-use effects. Proper monitoring and effective agricultural stream management measures should be employed that will help in reducing ecological disturbances that may restrict the survival of macroinvertebrates in these streams. Furthermore, preservation of native tree species in streams is vital in maintaining the quality and quantity of leaf litter that determines the effective functioning of the streams. Restoration efforts, including conservation agriculture and re-afforestation, are recommended for Nzoia River basin to regain, improve and sustain the basin's capacity for escalated terrestrial and aquatic food production for the growing human population. Lastly, there is great need to employ integrative management measures for managing, conserving and restoration of streams integrity and ecosystem functioning.

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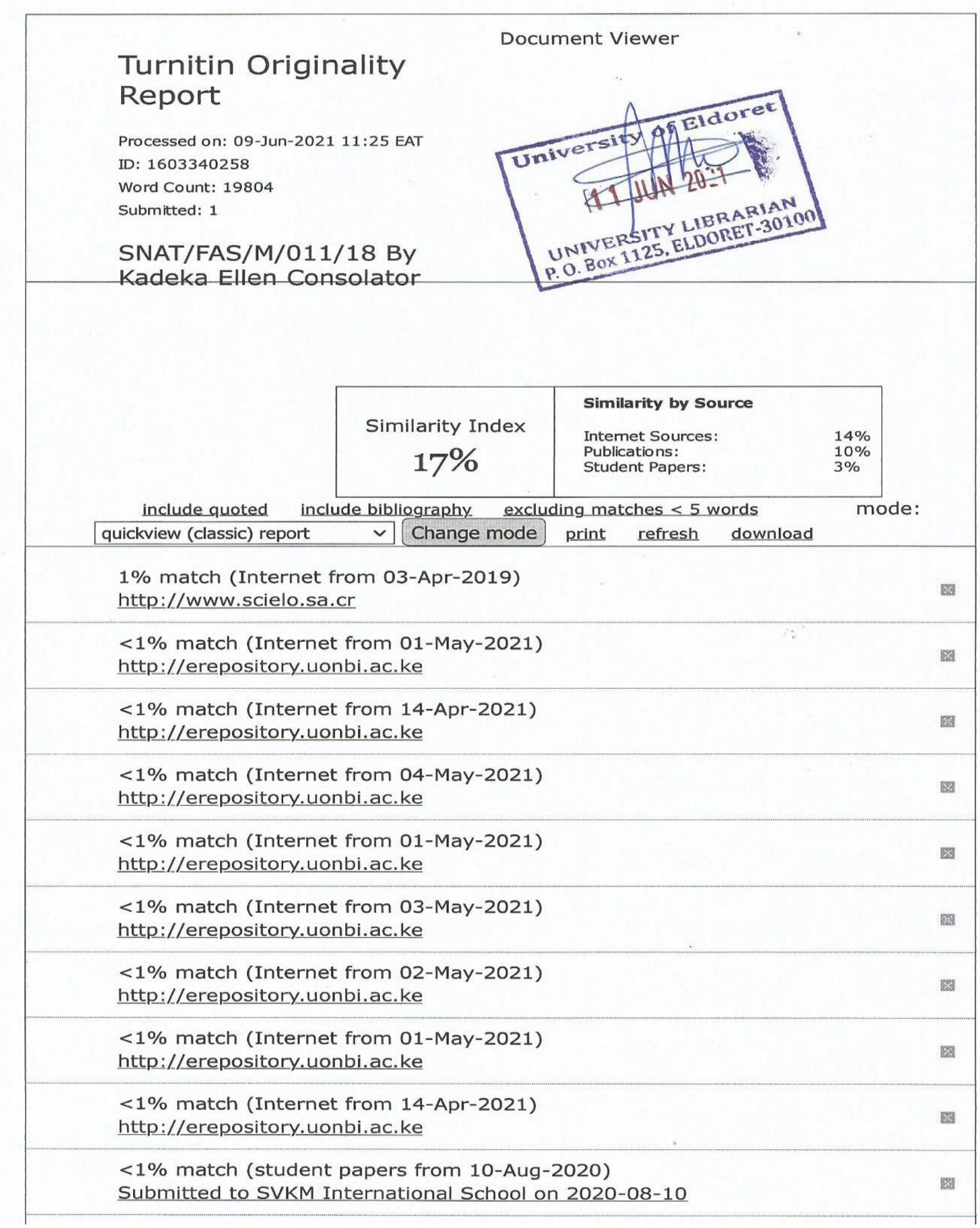
APPENDIX

Appendix 1: Similarity report



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