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Structural and functional responses of macroinvertebrate communities to land use patterns - a case study at Mt Elgon, Kenya

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Master Thesis

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ABSTRACT

Benthic macroinvertebrates play a unique role in aquatic ecosystems by acting as processors of nutrients and organic energy from allochthonous and autochthonous sources. Mt. Elgon, the catchment area for the drainage systems of Lake Victoria, is experiencing anthropogenic influences of deforestation and expansion of agricultural lands. These actions impact the integrity of streams through degradation of habitat and water quality. This study investigated the shifts in structural and functional composition of macroinvertebrate communities influenced by changes in land use within Mt. Elgon catchment. A total of 21 sampling sites in 12 streams, ten within forested areas and eleven within agricultural areas, were sampled for physico-chemical water parameters, substrate distribution and macroinvertebrate community composition. Significant ($p < 0.05$) spatial variation was observed in total suspended solids (TSS), total dissolved solids (TDS) and electrical conductivity (EC) between forested and agricultural areas with higher values recorded in agricultural streams. Simuliidae and Baetidae taxa were the most abundant and widely distributed within the investigated catchment. Higher taxa richness, biomass and abundance occurred in forested streams than in agricultural streams. Non-Metric Multidimensional Scaling and Hierarchical Cluster Analysis of macroinvertebrate communities showed a clear separation between land-use types and altitudinal zones. Water temperature, EC, TSS, TDS and sediment size distribution were significantly associated with the structure of macroinvertebrate communities. Land use change from forest to agriculture was seen to be a major driver of changes in physico-chemical water parameters and habitat quality, which significantly influenced the diversity and distribution of macroinvertebrate taxa. This work highlights the need to conserve forested areas and riparian zones to preserve sustainably the ecological integrity and functioning of streams within Mt Elgon catchment and the linked aquatic biodiversity.

Keywords: *Land use, macroinvertebrates, functional composition, bioindication, afro-tropical streams, Nzoia river basin*

Declaration

I hereby declare that this thesis is my original work and has not been submitted or presented for examination in any other university. The thesis has been submitted for examination with the recommendation and approval from my University Supervisors; Assoc. Univ. Prof. Dr. Wolfram Graf (University of Natural Resources and Life Sciences (BOKU)) and Dr. Frank Masese (University of Eldoret).

Ms. Mourine Jesire Yegon

11836757

Signature : 

.... Date :.......02/04/2020.......

Dedication

This work was inspired by my grandfather's love for education and my grandmother's passion for the conservation of brooks and the life that dwells in them.

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Above all, I thank God for his love, care and good health.

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List of abbreviations and acronyms

ANOVA	Analysis of variance
CPOM	Coarse Particulate Organic Matter
DO	Dissolved Oxygen
EC	Electrical Conductivity
EPT	Ephemeroptera, Plecoptera and Trichoptera
FFGs	Functional Feeding Groups
FAO	Food and Agriculture Organisation
POM	Particulate Organic Matter
HCA	Hierarchical Cluster Analysis
ISA	Indicator Species Analysis
IV	Indicator Value
MHS	Multihabitat sampling
NMDS	Non-metric Multidimensional scaling
PPT	Parts per thousand
YSI	Yellow Spring Instruments
DO	Dissolved Oxygen
DOM	Dissolved Organic Matter
NMDS	Non-Metric Multidimensional Scaling
POM	Particulate Organic Matter
RCC	River Continuum Concept
TDS	Total Dissolved Solids
TSS	Total Suspended Solids

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

A recurring theme in the study of freshwater systems has been a focus on the impacts of land use change and overexploitation of freshwater resources which has attracted scientific and management interests globally (Dubois *et al*., 2017). Anthropogenic modifications in aquatic systems have resulted in the un-anticipated and unprecedented changes in the physical, chemical, and biotic shifts in interactions in the system (Cooper, 2013). Streams in watersheds have been subjected to changes in biogeochemistry, habitat simplification, increased pollution, canopy opening, and hydrological alterations (Allan, 2004). These changes in habitat conditions have modified stream species diversity and abundance in many regions of the world (Minaya *et al.,* 2013).

Biodiversity in tropical streams has often been considered as diverse due to the availability of multiple habitats and climatic conditions (Cairns and Pratt, 1993). The capacity of organisms to adapt to the conditions in these streams coupled with their tolerance to a wide range of environmental conditions has served a big role in maintaining the diversity of aquatic communities. Aquatic biodiversity serve a big role in the functioning of streams due to their roles in organic matter processing, facilitating food web interactions and pollution control. Among the diverse biodiversity in streams are the benthic invertebrates which have been used in developing biotic and other indices used for biomonitoring ecological condition of streams and rivers (Masese *et al.,* 2009; Dickens & Graham, 2002).

Benthic macroinvertebrates are large-bottom dwelling invertebrates lacking a backbone found in aquatic ecosystems (Karr, 1999). They exist in different habitats ranging from fast flowing mountainous streams to slow-flowing muddy waters (Dallas, 2007). These organisms utilize rocks and stones, logs, vegetation and soft sediments in aquatic systems as their habitats (Barbour *et al*., 1999). Benthic invertebrates represent a dynamic component of streams due to the evolution of species depending on their requirements and traits (Ollis *et al.,* 2006). Thus, they serve as good candidates in studies of dynamic aspects of streams attributed to both human and natural occurrences. These organisms are valuable indicators of ecosystem health due to their benthic and sedentary nature, which renders them unable to migrate away from environmental stress (Barbour *et al.,* 1999). The many species with different adaptations enable them to react differently to environmental stressors of pollution, sediment loading and habitat changes. Their use as biological indicators is also complimented by their ability to detect the dynamic changes in water quality and thus giving a cumulative effect of environmental stress, unlike the use of physico-chemical parameters, which only reflect immediate effects of environmental disturbance (Kibichii *et al.*, 2007).

Benthic macroinvertebrates also play an important ecological role in aquatic-terrestrial systems by acting as subsidies of aquatic-terrestrial food chains (Richarson *et al*., 2014) therefore, forming an important link between basal resources and higher organisms in these systems. They also act as processors of organic material of both allochthonous and autochthonous origin in aquatic ecosystems.

Macroinvertebrates occur in distinct units with physical uniformity referred to as habitats. These habitats form unique patches that offer uniform environmental conditions providing a living space for specific assemblage of organisms (Gibbins, 2010). Habitats strongly influence stream ecosystem biotic assemblages as they comprise environmental factors of hydraulic, physico-chemical and substrate characteristics that govern ecological interactions in these systems (Dallas, 2007). Habitats are often associated with specific flow velocities and depth profiles which in turn influence the benthic macroinvertebrates found in these habitats.

Benthic macroinvertebrates have evolved life history strategies primarily in direct response to the natural flow regimes and available habitats (Dallas, 2007). Their greatness in diversity and capacity to colonize different habitats gives them an important role in being used as biological indicators in assessing the ecological condition of aquatic ecosystems (Buss *et al.*, 2015). These organisms are, however, strongly influenced by the availability of habitats in the aquatic ecosystems which governs their utility as indicators of water quality and ecological health.

Habitats in these stream systems are however threatened by land use changes in surrounding catchments. These changes in land use are often associated with disturbances that lead to soil erosion, sedimentation, nutrient enrichment, and input of toxic substances to aquatic habitats and biological communities (Imre, 2000). Land use changes in the riparian land to riverine ecosystems through activities such as deforestation can directly influence stream benthic macroinvertebrates through changes in resource availability, habitat quality, hydrological alterations (Tanaka & De Santos, 2017).

Mt Elgon is one of the five major water towers in Kenya, and a key water catchment system for Lakes Victoria, Kyoga and Turkana. Among the many rivers draining Mt Elgon is the Nzoia River which flows south and serves 123 sub-locations in Kenya and approximately 3.5 million people, as per the Kenyan 2019 population census. The mountainous landscape and its environs are experiencing a multitude of human induced modifications, including deforestation for agriculture and degradation of rivers due to increased sedimentation resulting from poor agricultural practices and clearance of riparian forests for cultivation (Mugagga *et al*., 2012).

1.2 Problem statement and Justification

Population growth in Kenya annually increases by 3% which conjointly occurs with an increase in agricultural land by 55% (United Nations Educational, Scientific and Cultural Organization, 2011). This increase in the population exerts pressure on the natural resources in the region. Rapid population growth in the catchment area of the Nzoia River, has increased anthropogenic modifications such as deforestation, expansion of agricultural fields, and intensification in the use of agricultural fertilizers and pesticides. Human disturbances in catchment areas of streams and rivers increases their susceptibility to negative impacts in several ways. Among these impacts are the habitat modifications and loss, negatively impacting their availability and suitability for aquatic communities. This is likely to impact on the integrity of stream communities through changes in habitat quality, hydraulic and hydrological dynamics. It has been noted that external disturbances at broad scales often affect an ecosystem at the local scale of individual habitats. Interaction among the natural features of depth, substrate type and flow velocity with anthropogenic factors such as pollution and deforestation often result in a set of characteristics that strips habitats of their uniqueness (Imre, 2000).

Activities such as deforestation and agriculture for example have led to erosion and increased flow velocities in streams (Piggot *et al*, 2015). This causes increased hydraulic roughness and the rate of sediment deposition, which in turn alters the community composition through the elimination of some species from the community. Gore *et al*. (2001) illustrated how a change in the channel flow characteristics can predict the change in the density and distribution of lotic species, and more specifically the availability of usable habitats for these species. Dudgeon (2010) and Masese & McClain (2012) further describe how anthropogenic changes in the riparian corridor alter the functional composition of benthic macroinvertebrates by modifying the supply of food resources and producing changes in habitat structure and quality**.** Assessing these anthropogenic disturbances on streams relies mostly on monitoring metrics of aquatic communities and water physico-chemistry (Barbour *et al.*, 1999).

There are limited studies on diversity, distribution and habitat requirements of benthic macroinvertebrates in upland streams of the Nzoia River basin, especially those draining Mt Elgon. These streams are characterized by endemic taxa (Cumberlidge & Clark, 2010), but have been poorly studied and with the current increase in population and land use changes, the habitats and diversity of benthic invertebrates in these streams may change.

This study is important in identifying and documenting the diversity of benthic macroinvertebrates of streams draining Mt Elgon. The study is also important for determining the structural and functional responses of these macroinvertebrate communities to changes in land use along altitudinal and longitudinal gradients. The study presents data that contributes to the on-going development of a macroinvertebrate-based biotic index for Kenya. The data also informs management decisions of water catchment areas in Kenya, including the Nzoia River basin. Previous studies in East African catchments with intense land cover conversion have documented alterations to natural flow regimes, degradation of habitats, loss of biota and changes in ecosystem function (Masese and McClain, 2012; Masese *et al*., 2009; Mathooko, 2001).

1.3 Objectives

1.3.1 General Objective

To investigate the influence of land use patterns on the structural and functional composition of macroinvertebrate communities through its influence on habitat and physico-chemical water parameters in Mt Elgon catchment, Kenya.

1.3.2 Specific Objectives

1. To determine the influence of forested and agricultural land use types on physico-chemical water quality parameters and substrate composition in Mt Elgon streams of the Nzoia River basin, Kenya.

2. To document the diversity, composition and distribution of macroinvertebrates in the selected streams.

3. To determine the impact of land use change on the structural and functional composition of macroinvertebrates in the selected streams.

4. To determine habitat (depth, substrate and velocity) suitability of selected macroinvertebrate taxa (Perlidae, Oligoneuriidae, Potamonautidae) in the Nzoia River basin.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Streams as integrators of catchment influences

Streams are important ecosystems supporting a rich biodiversity. Whereas tropical montane cloud forests are ranked among the most important ecosystems for sustaining life in tropical regions (Bubb *et al.*, 2004), a high number of its biodiversity is still undocumented (Tomanova *et al.*, 2006). These streams are often dynamic in nature and are influenced by factors both in the reach and catchment-scale. Catchment-scale influences are responsible for the characterization of substrate composition, channel morphology and water quality in streams. The co-occurrence of catchment-scale activities such as urbanization, forestry and agriculture with reach-scale activities such as riparian area management influence habitat conditions in streams (Richards and Host, 1994).

In the recent past, human activities in the catchment areas of streams have intensified. In the East-Africa region, only 28% of its original forest cover remains (Martin, 1991). Most Afro-montane forests and agro-ecological zones have lost their extensive areas of native vegetation to exotic forests, farming, settlement and grazing (Mati *et al.*, 2008; Kasangaki *et al.*, 2007). In the region, forest conversion rates of 0.4-0.5% per year (FAO, 2005) presents a worrying case with East Africa alone predicted to lose up to 95% of its forest area by 2040 according to Barnes' (1990) predictive model. The accelerating rates of forest conversion and degradation have implications on surrounding catchments; stream ecosystems included. This is due to the fact that the extent of most freshwater systems is not confined to the wetted perimeter, but includes the catchment from which water and material are drawn (Hynes, 1975).

Developing landscapes to meet human needs has altered surface water hydrology, geomorphology and physico-chemistry, impacting the ecology of streams (Allan, 2004; Dudgeon *et al.,* 2006; Vorosmarty *et al.*, 2010). Clearing of forests within stream catchments has led to changes in; resource base, flow and channel characteristics, sediment regime and producing homogeneity in habitats. The associated increase in surface runoff and river sediment loads has led to habitat alterations such as smothering of littoral habitats, clogging of river bottoms and floodplain aggradation (Dudgeon *et al.,* 2006). Chapman & Chapman (2003) in their work have shown a dramatic increase in sedimentation in rivers following deforestation. This is due to the fact that forests provide an important linkage between terrestrial ecosystems and aquatic ecosystems by acting as buffers to materials exchanged between the two systems. Their roots which act as a mat holding soil particles together minimize soil deposition within aquatic ecosystems, while their canopy cover reduces flooding while increasing seepage and therefore minimizing the effects of high rainfall events. Their leaves supply organic matter which serve as an important food resource base for biodiversity living in streams (Mbaka *et al*., 2015)

2.2 Stream habitats

A variety of habitats exist in stream ecosystems. Habitats often result from a balance between hydrodynamic parameters and geomorphic features of streams. These hydrodynamic and geomorphic factors influence the habitat types in streams and rivers inhabited by diverse benthic macroinvertebrate communities (Dallas, 2007).

Streams vary substantially as they progress from headwaters towards mouth, with the variations occurring in the width, depth, gradient, discharge and water temperature. River flowpaths respond to a wide range of factors such as flooding, bed topography and sediment composition (Vannote *et al*., 1980) which are often subsets of what is happening in their catchment systems. Spatial and temporal heterogeneity of surface and sub-surface flows in riffle-pool sequences often lead to mosaic of depositional and erosional areas characterized by differing grain size distribution (Boulton & Stanley, 1995). Patterns and sediment deposition directly influence the structure and composition of invertebrate communities (Dallas, 2007). McClain *et al*. (2014) points to the variability of flows in river a system as a major variable controlling riverine structure and function and regulates river biogeochemistry. Vegetation habitats are other important habitats in streams and rivers which are shaped by flow conditions (Karr, 1999). Vegetation along the margins of streams provides attachment points for filter-feeding macroinvertebrates, refuge from current and fish predation, complex habitat structure and food for a variety of herbivores and detritivores and exit points for emerging insects with aerial adult stages.

Streambed sediment size is a major factor governing macroinvertebrate richness and abundance (Bryce *et al.,* 2010). Fine sediments fill interstices among coarse gravel and cobble surfaces to interfere with the anchoring, feeding, and respiration of benthic macroinvertebrates and larval amphibians (Wood and Armitage, 1997). Stream substrates are other habitats in streams often influenced by currents in riverine ecosystems. High currents initiate high drift densities of most species habiting below these substrates (Tanaka and Dos Santos, 2017). On the other hand, low flows enhance siltation, change the composition of aquatic vegetation, alter channel shape and affect water chemistry. With receding water levels transcend thresholds between critical habitats, creating new environmental conditions for aquatic macroinvertebrates and thus may result in a shift of these organisms (Piggot *et al*., 2015). The loss of current eliminates many taxa, prevents drift as a means of recolonisation and in deterioration of water quality.

The loss of stream habitats that are often associated with increased flows and shear stress which reduce the availability of adequate habitats for some species while increasing habitat availability for others (Bunn & Arningthon, 2013). These changes in habitat dynamics often affects functionality of community structure and food-web structure which in turn can result in the elimination of some species in the community (Brussen & Pranther, 2019) and the imminent reduction of the bio-indicative role of these organisms.

In this study, the substrate composition and distribution were investigated in each of the study sites. Their composition and distribution in agricultural and forested sites were determined and correlated with macroinvertebrate assemblages occurring at the these sites. The information generated adds to the discussion on how change in land use influences macroinvertebrate communities and the role of these communities as bioindicators to land use change in stream catchments.

2.3 Land use influences on stream habitat quality and availability

As integrators of the effects of land-use practices within their catchments, streams and rivers can help in the diagnosis of the environmental health of the landscapes that they drain (Dallas, 2007). Changes anywhere on the landscape that influence rivers are reflected in the composition of resident biota. Their functional and structural composition varies, both spatially and temporally, in relation to environmental factors (Karr, 1999). These factors include discharge, substrate type, dissolved substances, turbidity, riparian vegetation, land use, temperature, altitude and latitude. However, human activities influence the effects of these factors, which in turn affect the composition and distribution of macroinvertebrates

Agricultural activities along rivers and streams have increased the degradation of forests in recent decades (Dallas, 2007). Land use is often associated with disturbances that lead to soil erosion, sedimentation, nutrient enrichment, and input of toxic substances to aquatic habitats and biological communities (González *et al.,* 2001). Riparian zones are very important for the maintenance and regulation of the aquatic environment. Riparian vegetation influences the structure and functioning of stream macroinvertebrate communities through the provision of organic matter and by shading the stream (Allan, 2004). Anthropogenic changes in the riparian corridor may subsequently alter the functional feeding group composition of macroinvertebrates by modifying the supply of food resources and producing changes in habitat structure and quality (Dudgeon, 2006). The presence of riparian vegetation acts as a barrier to sediment input and thus performing a hydrological role and assisting in water quality maintenance. Forest cover reduces runoff of water, sediments, nutrients, maintain stable flows, water temperature and channel morphologies and to supply coarse organic material and debris to provide food and habitat for aquatic life. Anthropogenic disturbance of the riparian vegetation on the other hand increases runoff; destabilizes flow, temperature and channel morphology and reduces the supply of coarse organic material (Wang *et al.*, 1997).

Deforestation can directly influence stream macroinvertebrates through changes in resource availability, habitat quality, hydrological alterations (Tanaka & Dos Santos, 2017). Hydrological alterations can interact with land-use changes to determine community dynamics at local scales. Land use changes for agriculture has large impacts on rural landscapes, with strongly influence on stream ecosystem functioning, water quality and quality (Allan, 2004).

Sedimentation in streams and rivers is a function of land use shift from dominance of riparian vegetation to agriculture, and is often accompanied by deterioration in water quality, reduced light penetration, and the filling of interstitial spaces in benthic substrates and integrity of their physical environments (Karr *et al*., 1999; Graf, 2005). Sedimentation or siltation is widely acknowledged as a major cause of degradation of instream habitats (Wood *et al.,* 2005) with Increased sediment delivery loads have been widely documented as a major cause of degradation to freshwater ecosystems

Clearing of riparian vegetation for tilling increases the vulnerability to surface runoff and this can lead to high concentrations of nutrients and explosive increases in algal growth in aquatic ecosystems. When natural riparian vegetation is removed for agricultural uses, the water temperature, nutrient concentration and sediment input tend to increase in streams, causing negative effects to the ecological integrity of aquatic ecosystems (Allan, 2004).

Based on this objective, the study seeks to contribute to the discussion on shifts in macroinvertebrate communities that result from changes in land use in river catchments. The study also presents cases of human influence on habitat availability and suitability for some specific macroinvertebrate taxa. This can be incorporated in ecological explanations on prevailing water quality conditions in riverine ecosystems.

2.4 Benthic macroinvertebrates as indicators of stream systems' integrity

Benthic macroinvertebrate communities have been popularized in their bioindicative role in streams as they are sensitive to environmental disturbance, integrating as well as reflecting the effects of stress, both natural and human induced, over extended periods of time (Rosenberg *et al*., 2008; Barbour *et al*., 1999). The distribution, composition and abundance of these groups of organisms have an indicative role on the changing ecological conditions that alter ecosystem functioning, degrade water quality and overall ecological integrity. Benthic macroinvertebrate communities have been long used as bioindicators of stream conditions and environmental impacts due to the capacity of these macroinvertebrate communities to exhibit clear responses to human disturbances (Buss *et al*., 2002) and present a large diversity of traits to these conditions as well as coping up with differential resource availability (Lange, 2014). Most of these organisms exist in narrow range as of hydraulic and physical conditions and thus their capacity to act as ecosystem surrogates will be limited if their habitats will be interfered with. Gore (1978) documents large shifts in benthic invertebrate abundance, composition and distribution associated with small changes in their habitats. With these arguments, benthic macroinvertebrates have been established to be good indicators of assessing the effects of environmental stressors on aquatic ecosystems. This has been achieved through careful analysis of biological and ecological responses along gradients of human disturbance, the identification of indicator assemblages and species among assemblages with known responses to human alterations and the identification of driving variables acting on aquatic ecosystems (Dubois *et al*., 2017).

2.5 Adaptations of benthic macroinvertebrates to environmental conditions

Benthic macroinvertebrates in streams and rivers are either sessile, move around actively or are passively moved around by current (Tanaka & Dos Santos, 2017). Stream metrics, biotic and abiotic factors, water quality and the riparian environment do affect the diversity, richness and distribution of macroinvertebrates communities (Dallas, 2007). Stream habitats are often associated with specific flow velocities. Differences within mesohabitat communities are determined by flow fluctuations producing physical changes and by the type of substrate present which often produces seasonal shifts in species composition (Townsend, 1997).

River flows (floods, pulses and base-flows) serve different functions in moulding the available physical habitat and therefore dictate life history stages of riverine organisms (Bunn & Arningthon, 2002). Habitat preferences of mayflies can be based on their feeding strategies during their larval stages while grazers and scrapers prefer feeding on materials attached to biofilms. Shredders and gatherers on the other hand occur in substrates containing decomposing coarse and fine particulate organic matter (Masese *et al*., 2014).

Pardo & Armitage (1996) found collector gathering organisms burrowing in sediments under low flow conditions while streamside vegetation with silted beds were inhabited by burrowers and sediment-surface organisms, collector-gatherers and shredders. Dallas (2007) also noted that in South African rivers, stone biotopes had higher number of taxa relative to vegetation and sand samples.

This suggests that changes in the availability of different biotopes might influence community structure and informs the need for this study which will focus on investigating the community structure of macroinvertebrate communities with changing habitats along land use, altitude and longitudinal gradient.

From the above literature review, the following hypotheses were developed:

2.6 Hypotheses

H_{01}: Physico-chemical water quality parameters (TSS, TDS, temperature, DO, pH, EC and salinity) display higher levels in streams in agricultural areas than in streams in forested areas.

H_{02}: The substrate sizes in streams within agricultural catchments are smaller in comparison with streams within forested catchments.

H_{03}: The diversity, abundance and biomass of macroinvertebrates is higher in streams within forested catchments than in streams within agricultural catchments.

H_{04}: A shift in land-use from forested to agricultural will result in a reduction in both the abundance and biomass of shredders.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of study area and study sites

3.1.1 Study area location

The study was conducted in Mt. Elgon streams in Nzoia River basin, draining into L. Victoria, Kenya (Figure 1). Mt. Elgon catchment area located in Trans-Nzoia and Bungoma counties in western Kenya has a size of 72,874 hectares lying between latitudes 0^o 47’ N and 0^o 54’ N and longitudes 34^o 34’E and 34^o 45’E. The Nzoia River has a length of 257km, and flows south and west of Mt. Elgon and into Lake Victoria discharging approximately $118m^3/s$ of its water making it the second biggest river in Kenya by discharge and the largest river basin in Kenya's Lake Victoria basin. The river is forested in the upper reaches in the Mt. Elgon National park and flows into floodplain zones in the lower reaches.

3.1.2 Topography and drainage

Mt. Elgon catchment is characterized by a high topographic relief with steep slopes. The elevation ranges from 878m a.s.l. to 4304 m a.s.l. at its peak. The upper reaches of Mt. Elgon is covered in protected afro-montane forests (Musau *et al.*, 2014). The climate of the area is mainly tropical humid, with mean annual rainfall of 1400–1800 mm and an average temperature of 14 –24 °C, though both climate parameters vary strongly with elevation. Mean temperature is lowest in June to September (Githu *et al.*, 2009). These climatic parameters also vary seasonally. The annual rainfall pattern is bimodal, with long rains between March and June, and short rains from September to November. The south-east of the mountain is the wettest windward side, while the north-east is the leeward side. Flooding is experienced in the basin during heavy rains attributed to reduction in forest cover with the intensive agricultural activities in the area.

3.1.3 Geology and soils

Mt Elgon is an extinct volcano estimated to be 24 million years old that is located on the border between Kenya and Uganda. The western sector of Mt. Elgon is overlaid by granite-gneiss rocks of the central African craton while the eastern side contains meta-sediments of Neoproterozoic origin (Roger, 2017). The host rock on the region is the pyroclastic rock, a sodium- rich agglomerate (McFarlane & Lundberg, 2006). These rocks are rich in Apatite and Zircon components of alkaline composition. Caves found within the area occur in pyroclastic rocks rich in sodium, often utilized by wild animals. The region is also reported to have bodies of carbonatite (Woolley, 2001) with some basins dominated by Miocene age sedimentary rocks. Nutrient rich soils at the base of the volcano are as a result of weathering processes at the lower slopes often causing severe landslides. The soils in the constitute of clay, loamy and sandy types with the lowlands dominated by the clayey soils at 77% (Ngaina & Opere, 2017)

3.1.4 Social economic and livelihood activities

Approximately 3.5 million people live within the Nzoia River basin. High population densities exist in the basin with the average population density being 190-persons/ km^2 (WKIEMP report, 2004). Areas around the base of the mountain are densely populated with communities utilizing the deeply rich volcanic soils for agriculture. Agriculture is the livelihood for a large proportion of the basin's population. Communities practise farming of maize, onions, cabbages, potatoes, beans as well as keeping of livestock. The farmlands range between smallholder intensive farms to medium scale semi-intensive farming activities. Water from the basin plays an important economic role and serves many purposes, including domestic use, watering animals, irrigation, industrial purposes, aquaculture and cultural and spiritual services.

3.1.5 Sampling design and description of the sampling sites

Field sampling was done in Mt Elgon streams between 11th October 2019 and 10th November 2019 (Table 2). Streams were chosen based on accessibility and were distributed on the upper (> 2200m a.s.l.), mid (1850-1950m a.s.l.) and downstream (1600-1700m a.s.l.) areas of the catchment. These sites were targeted to be in forested (reference sites) and in the agricultural land uses (disturbed sites). A total of 21 sites in 12 streams ranging in altitude from 1624m a.s.l. to 2435m a.s.l. were sampled for macroinvertebrates and associated physical-habitat conditions (Table 1). Tributary sections of 4 streams (Teremi, Kimurio, Kapkateny and Kibisi) in the upstream section and 2 streams; Kapkateny and Kibisi (site codes; 2 & 9) were sampled on a longitudinal scale.

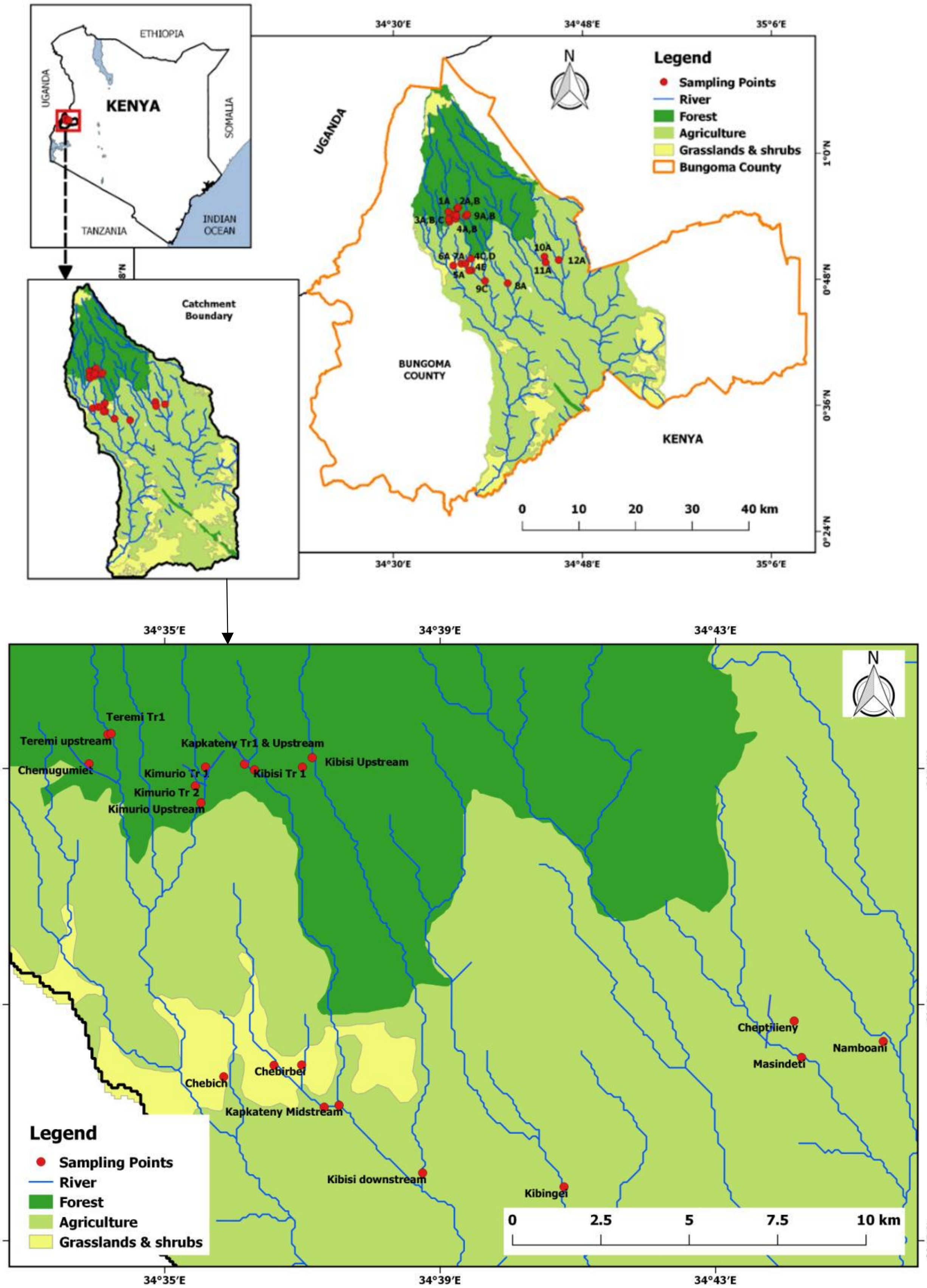


Figure 1: Map of the study area with sampling sites and the associated land use types

Table 1: Sites, distances from source, coordinates, altitude and dominant substrate type. For site codes, numbers represent different streams while letters represent longitudinal gradient from upstream to downstream sites within a stream. CPOM = coarse particulate organic matter

Site name	Site code	Distance from source (km)	Coordinates		Altitude(m)	Dominant substrate (%)
			Latitude	Longitude		
Chemugumiet	1A	1.36	00° 54' 25" N	34° 35' 15" E	2317	80% Microlithal
Teremi upstream	2A	1.96	00° 54' 46" N	34° 36' 06" E	2407	70% Macrolithal
Teremi Tr1	2B	0.57	00° 54' 32" N	34° 36' 10" E	2380	85% CPOM
Kimurio Upstream	3A	12.6	00° 53' 28.8" N	34° 35' 21.2" E	2239	65% Macrolithal
Kimurio Tr1	3B	0.63	00° 54' 08" N	34° 35' 51" E	2435	55% Akal, 45% Macrophytes
Kimurio Tr2	3C	1.8	00° 53' 44" N	34° 35' 16" E	2347	60% Macrolithal
Kapkateny Upstream	4A	4.19	00° 53' 45.28" N	34° 35' 56.28" E	2293	85% Macrolithal
Kapkateny Tr1	4B	0.3	00° 54' 04" N	34° 36' 01" E	2350	50%Macrolithal, 40% Detritus
Kapkateny Midstream(1st MHS)	4C	10.33	00° 49' 57.18" N	34° 37' 24.34" E	1896	85% Akal
Kapkateny Midstream(2nd MHS)	4D	10.33	00° 49' 57.18" N	34° 37' 24.34" E	1896	75%Macrolithal
Kapkateny downstream	4E	12.43	00° 48' 51.9" N	34° 37' 27.5" E	1660	90% Macrolithal
Chebich	5A	5.46	00° 49' 17.99" N	34° 35' 42.02" E	1950	40% Microlithal
Kapkasobei	6A	8.32	00° 49' 28.50" N	34° 36' 28.0" E	1881	80% Macrolithal
Chebirbei	7A	4.49	00° 49' 28.78" N	34° 36' 53.33" E	1878	85% Akal
Kibingei	8A	15.3	00° 47' 37.23" N	34° 40' 53.40" E	1633	45% Akal
Kibisi Tr1	9A	0.26	00° 54' 01.3" N	34° 36' 54" E	2246	50% woody debris
Kibisi Upstream	9B	22.75	00° 54' 10" N	34° 37' 03" E	2298	60% Macrolithal
Kibisi downstream	9C	30.2	00° 47' 50" N	34° 38' 44" E	1624	70% Mesolithal
Cheptilieny	10A	1.47	00° 50' 9" N	34° 44' 24" E	1701	85% Akal
Masindeti	11A	7.47	00° 49' 35.66" N	34° 44' 30.79" E	1676	70% Earth(hardpan)
Namboani	12A	7	00° 49' 50.28" N	34° 45' 45.54" E	1662	50% Akal, 35% Microlithal

Table 2: Site codes, sampling dates, number of Multi-habitat samples (MHS) taken and number of sampling units per site

Site Name	Site code	Sampling Date	MHS samples	Number of units
Chemugumiet	1A	13.10.2019	1	20
Teremi upstream	2A	13.10.2019	1	20
Teremi Tr 1	2B	13.10.2019	1	20
Kimurio	3A	11.10.2019	1	20
Kimurio Tr 1	3B	08.11.2019	1	20
Kimurio Tr 2	3C	08.11.2019	1	20
Kapkateny upstream	4A	11.10.2019	1	20
Kapkateny Tr 1	4B	08.11.2019	1	20
Kapkateny Midstream(1st MHS)	4C	12.10.2019	1	20
Kapkateny Midstream(2nd MHS)	4D	12.10.2019	1	20
Kapkateny Downstream	4E	14.10.2019	1	20
Chebich	5A	12.10.2019	1	20
Kapkasobei	6A	12.10.2019	1	20
Chebirbei	7A	12.10.2019	1	20

Kibingei	8A	14.10.2019	1	20
Kibisi Tr 1	9A	09.11.2019	1	20
Kibisi Upstream	9B	09.11.2019	1	20
Kibisi downstream	9C	14.10.2019	1	20
Cheptilieny	10A	15.10.2019	1	20
Masindeti	11A	15.10.2019	1	10
Namboani	12A	15.10.2019	1	20

Chemugumiet (1A)

This site sampled on 13th Oct 2019 is located within the coordinates (00° 54' 04.34" N, 34° 33' 38.77" E) and at an altitude of 2317 m a.s.l. Steep slopes were a characteristic feature in this site. Microlithal and sand were the main substrate types. Woody substrate was also present in this site. The site had an average wetted width was 1.5 m, average depth of 0.07 m and an average velocity of 0.24 m/s. The site was used as a livestock watering point, and was characterized by grazing fields on both banks. Upstream of this site were however forested area with a canopy cover of 40%.

Figure 2: (a) Chemugumiet site (1A); (b) Grazing fields on both banks of Chemugumiet (1A)

Teremi upstream (2A)

This site was sampled on 13.10.2019, and is located within coordinates (00° 54' 34" N, 34° 35' 58" E) at an altitude 2407 m asl. Located upstream within a forested reach, the site was characterized by forested banks and steep slopes. Stony substrate dominated the site. The major substrate sampled at the site was macrolithal. Macrophytes were also present at this site. The average wetted width 6 m, average water depth was 0.2 m and average water velocity was 0.86 m/s. The colour of the water at this site was clear. Canopy cover at the site was around 60% with the surrounding vegetation being natural.

Figure 3: (a) Teremi upstream site (2A); (b) Forested reach within Teremi upstream (2A)

Teremi tributary (2B)

This site was sampled on 13.10.2019 is found within the coordinates of (00° 54’ 32” N, 34° 34’ 00” E) and at an altitude of 2380 m a.s.l. The site was characterized by the abundance of detritus substrate with muddy substrate underneath. The average wetted width in this site was 1m, average water depth of 0.06 m and an average water velocity of 0.24 m/s. The colour of water in the site was clear. Canopy cover was approximately 98%.

Kimurio upstream (3A)

The site sampled on 11.10.2019 is found within the coordinates of (00° 53’ 28.8” N, 34° 35’ 21.2” E) and at an altitude of 2239m a.s.l. The left bank was characterized by a maize plantation within 30m riparian width while the right bank was a grazing field. The site dominated by riffles constituted of 90% stony substrate (boulders, cobbles and pebbles). The main sampled substrate in the site was macrolithal. Instream and marginal vegetation were also present making macrophytes the other sampled substrate in this site. The average wetted width within the reach was 11m, average water depth of 0.36 m and average water velocity of 0.86 m/s. Colour of the water in this site was clear. The canopy cover at this site was approximately 40% with forested area located in within a 100 m. This site served as cattle crossing point.

Figure 4: (a) Kimurio upstream site (3A); (b) Substrate types in Kimurio upstream (3A)

Kimurio tributary 1 (3B)

This site sampled on 08.11.2019 is found within the coordinates of (00° 54' 08" N, 34° 35' 51" E) and at an altitude of 2435 m a.s.l. The site which is a tributary system of the main Kimurio channel had its right bank utilized as a grazing field while its left bank was forested. The sampled substrates within this site were akal and macrophytes. This site had an average wetted width of 1.5 m, average water depth of 0.13 m and average water velocity of 0.4 m/s. The water colour in this site was clear. Canopy cover at the site was 80%. This site also served as cattle drinking point.

Kimurio tributary 2 (3C)

This site sampled on 08.11.2019 is found within the coordinates of (00° 53' 44" N, 34° 35' 16" E) and at an altitude of 2347 m a.s.l. The site consisted of steep banks with both banks being forested. Riffles dominated the site with the major substrate type comprising of macrolithal substrate. The average wetted width was 6 m, average water depth was 0.2 m and average water velocity was 0.61 m/s. The water at this site was clear and canopy cover was 80%.

Figure 5: (a) Kimurio tributary 2 site (3C); (b) Water clarity and riffle section in Kimurio tributary 2 (3C)

Kapkateny upstream (4A)

This site sampled on 11.12.2019 is located within the coordinates of (00° 53’ 45.28” N, 34° 35’ 56.28” E) and at an altitude of 2293 m a.s.l. Located upstream, the site had a forested left bank while the right bank was under a maize plantation. The slopes in this site were steep characterized by erosional activities on the right bank where the agriculture was prevalent. Cobbles and boulders dominated the site. The average wetted width was 3.2 m while the average depth was 0.28 m. The average water velocity at the site was 0.67 m/s. The water colour was clear and canopy cover was < 5%. However, forested area was less than 20 m upstream.

Figure 6: (a) Channel section in Kapkateny upstream (4A); (b) Steep slopes with eroded right bank in Kapkateny upstream (4A)

Kapkateny tributary 1 (4B)

This site sampled on 08.11.2019 is located within the coordinates of (00° 54’ 04” N, 34° 36’ 01” E) and an altitude of 2350 m a.s.l. The site which is a tributary system of Kapkateny main channel had gently sloping banks. The right bank was a grazing field while the left bank and upstream of this site was forested. The main substrate types in the were macrolithal and coarse particulate organic matter. The wetted width in the site was 1m, average water depth of 0.1 m and an average water velocity of 0.37 m/s. The water colour in this site was clear. The site which was less than 10m from the nearest forest had a canopy cover of 90%.

Kapkateny midstream (4C, D)

This site was sampled on 12.10.2019 is located within the coordinates of (00° 49' 57.18" N, 34° 37' 24.34" E) and at an altitude of 1896 m a.s.l. Two Multi-Habitat Samples (MHS were taken from this stream. The first MHS was sampled immediately after the bridge which was a cattle watering point and subject to disturbances from the animals drinking from the site. The second MHS sample was taken a few metres away from the bridge in a site surrounded by planted Eucalyptus trees on its right bank. The main substrate in sampled in the 1st MHS was psammal while the dominating substrate in the 2nd MHS was macrolithal substrate. The average wetted width within this reach was 5m, average water depth was 0.19 m and average water velocity was 1.1 m/s. Generally, the water in this site was brown in colour and both banks were characterized by maize plantations. Canopy cover in the 2nd MHS site was 70% provided by the plated Eucalyptus trees while the canopy in the 1st MHS site was open. Erosional activities were evident in the banks where the 1st MHS was taken.

Figure 7: (a) Kapkateny midstream 1st MHS site (4C); (b) Kapkateny midstream 2nd MHS site (4D)

Kapkateny downstream (4E)

This site sampled on 14.10.2019 was located within coordinates (00° 48' 51.9" N, 34° 37' 27.5" E) and at an altitude of 1660 m a.s.l. The site characterized by agricultural practices on both of its banks was dominated by rapids and riffles with boulders and cobbles being the dominant substrate. The average wetted width in this site was 5.5 m, average water depth was 0.3 m and the average water velocity was high (1.5 m/s). The water at this site was in colour. Planted Eucalyptus trees were part of the left bank providing a canopy cover of approximately 50%. A waterfall was located in 30 m upstream of this site.

Figure 8: Coffee crop in Kapkateny downstream (4E); (b) Channel width and substrate in Kapkateny downstream (4E)

Chebich (5A)

This site was sampled on 12.10.2019 is located within coordinates (00° 49’ 17.99” N,34° 35’ 42.02” E) and at an altitude of 1950 m a.s.l. Both of its banks were characterized by agricultural practices (banana and maize plantations). The dominant substrate sampled at this site was macrolithal substrate. The substrate in this site was heavily embedded with fine loamy sand sediments. The average width of the river in this site was 1.2 m, average water depth was 0.17 m and average water velocity was 0.7 m/s. The water in this site was brown in colour. Eucalyptus trees were found few metres upstream of the sampling site. Canopy cover at the site was approximately 30%. Some parts in this site were also utilized for washing clothes.

Figure 9: (a) Channel size and riparian characteristics in Kibingei site (5A); (b) Riparian vegetation in Kibingei (6A)

Kapkasobei (6A)

This site was sampled on 12.10.2019 is located within the coordinates of (00° 49' 28.50" N,34° 36' 28.0" E) and at an altitude of 1881 m a.s.l. The site had gently slopes with its right bank utilized for agriculture (Banana, Onions & Maize plantations) while the left bank was naturally forested with little agricultural activities. Substrate composition constituted of 70% boulders and bedrock as the main substrate. Cobbles formed 30% of the substrate while the 10% was sand substrate embedded on the main substrate. The average width in the site was 3m, average water depth was 0.26 m and average water velocity was 0.53 m/s. The water colour was brown indicative of erosional activities at the site. Canopy cover was approximately 30% within the sampled reach. The site also served as a livestock watering point (Figure 10).

Figure 10: (a) Disturbance from animals drinking from Kapkasobei site (6A); (b) substrate types in Kapkasobei (6A)

Chebirbei (7A)

This site was sampled on 12.10.2019 and is located within the coordinates of (00° 49' 28.78" N,34° 36' 53.33" E) and at an altitude of 1878 m a.s.l. Its right bank was utilized for agriculture (crops and livestock) while the right bank had planted Eucalyptus trees. The main substrate sampled in the site was akal. Average wetted width in this site was 2.8 m, average water depth was 0.17 m and average velocity was 0.44 m/s. The stream located in an agricultural catchment was characterized by erosional activities on its banks with a lot of sedimentation evident (Figure 11). The water in this site was brown in colour. Canopy cover in this site < 5%.

Figure 11: (a) Livestock grazing on the right bank of Chebirbei (7A); (b) Section of the eroded banks and sedimentation processes in Chebirbei (7A)

Kibingei (8A)

This site was sampled on 14.10.2019 and is located within the coordinates of (00° 47' 37.23" N, 34° 40' 53.40" E) and at an altitude of 1633 m a.s.l. Its banks were gently sloping and were surrounded by planted Eucalyptus trees while upstream comprised of sugarcane and banana plantations. Sampling in this site was done below a bridge. The main substrate type at this site was akal. The other substrate types in this site were mesolithal and macrolithal substrates. The average wetted width of the sampled reach was 6 m, average water depth was 0.35 m and average water velocity was 0.64 m/s. The water colour in this site was brown. The canopy cover at this site was 70% with the shading comprising of planted eucalyptus trees on its banks.

Figure 12: (a) Kibingei site (8A) below the bridge; (b) Kibingei site (8A) above the bridge

Kibisi tributary 1 (9A)

This site was sampled on 09.11.2019. It is located within the coordinates (00° 54' 01.3" N, 34° 36' 54" E) and an altitude of 2246 m a.s.l. This site located in a plateau in a forested area was characterized by forested banks with main substrate in the stream being woody debris. Other sampled substrates included pelal and macrophytes. The stream was small with an average water depth of 0.08 m, average wetted width of 1.5 m and average water velocity of 0.32 m/s. The water colour in this site was clear and had a canopy cover of 90% (Figure 13).

Figure 13: (a) Kibisi triburaty 1 site (9A); (b) Canopy cover at Kibisi tributary 1 site (9A)

Kibisi upstream (9B)

This site sampled on 09.11.2019 is located within the coordinates of (00°54'10" N, 34°37'03" E) and at an altitude of 2298 m a.s.l. The site was located within a forested catchment with both of its banks being surrounded by a natural forest. The slopes of the river in this site were steep. The site was dominated by stony substrate majorly comprising of boulders and cobbles. The main substrate sampled was macrolithal. Instream vegetation were also present within the site. The average width of the river within the sampled reach was 5 m, average water depth was 0.28 m and the average water velocity was 0.93 m/s. The water in this site was clear. Canopy cover in this site was 90% (Figure 14).

Figure 14: (a) Riparian character in Kibisi upstream (9B) site; (b) Forested reaches of Kibisi upstream site (9B)

Kibisi downstream (9C)

This site was sampled on 14.10.2019 and is located within the coordinates of (00° 47’ 50” N, 34° 38’ 44” E) and an altitude of 1624 m a.s.l. Located downstream, the slopes of the river were gentle. This site surrounded by agricultural activities on both banks was dominated by cobbles. The main substrate sampled in this site was mesolithal. The other substrate sampled in this site was macrophytes. The average wetted width in the site was 4.5 m, average water depth was 0.7 m and average water velocity was 0.93 m/s. The water colour in this site was brown. Canopy cover in the area was approximately 5%. This site acted as a cattle watering point (Figure 15).

Figure 15: (a) Sampling Kibisi downstream site (9C); (b) Cattle drinking from Kibisi downstream site (9C)

Cheptilieny (10A)

The site sampled on 15.10.2019 is located within the coordinates of (00° 50’ 9” N,34° 44’ 24” E) and at an altitude of 1701 m a.s.l. The site which was a cattle watering point had agricultural activities of maize and sugarcane plantations on both of its banks (Figure 16). The major substrates sampled in this site akal. The average wetted width in this site was 1.5 m, average water depth was 0.09 m and average water velocity was 0.63 m/s. The stream which was seasonal in nature had water brown in colour. Canopy cover in this site was approximately 5% with the shading being provided by planted trees along its banks.

Figure 16: Cheptilieny site (10A)

Masindeti (11A)

This site was sampled on 15.10.2019 and is located within the coordinates of (00° 49’ 35.66” N,34° 44’ 30.79” E) and at an altitude of 1676 m a.s.l. This site characterized by a meandering, deep incised (up to 2 m) and narrow channel had its banks surrounded by sugarcane plantations, livestock grazing sites and small-scale agricultural activities (Figure 17). The main substrate in this site was hardpan. The average wetted width within this site was 2.5 m, average water depth was 0.7 m and average water velocity of 1.0 m/s. The colour of the water in this site was brown. This site had a canopy cover of approximately 40%.

Figure 17: (a) Sugar cane plantations on the banks of Masindeti (11A); b) Deep incised banks

Namboani (12A)

This site sampled on 15.10.2019 is located within the coordinates (00° 49’ 50.28” N,34° 45’ 45.54” E) and at an altitude of 1662 m a.s.l. Both banks in this site were utilized for agriculture. The major substrate in the site was a mixture of akal and microlithal. Average wetted width in this site was 1.5 m, average water depth of 0.16 m an average water velocity of 0.84 m/s. The colour of the water in this site was brown (Figure 18). This site which is surrounded by planted Eucalyptus trees and sugarcane plantations had a canopy cover of 40%.

Figure 18: Namboani site (12A)

3.2 Field methods

3.2.1. Physico-chemical parameters

At each sampling site, water quality physico-chemical parameters were measured *in situ* using a YSI (Professional Plus) multiprobe water-quality meter. These included dissolved oxygen concentration (DO, mg/L), temperature (^{o}C), electrical conductivity (EC, µs/cm), total dissolved solids (TDS, mg/L) and pH Known volumes of water samples were filtered through pre-combusted Whatman GF/F Glass filters of 0.42mm thickness, 0.7 µm pore size and 47mm diameter (Figure 19). These filters were thereafter transported to the University of Eldoret laboratory for determination of total suspended solids (TSS) and particulate organic matter (POM). At each site, measurements of water depth, velocity and width were taken using a meter rule and a velocity plank. Discharge was then calculated from the velocity and depth measurements following Herschy (1995).

Figure 19: Filtering of water for total suspended solids determination

3.2.2 Substrate composition

Substrate characterization in the sampling sites was done by identifying the substrate types that constituted more than 5% coverage of the streambed. Habitat characterization was based on the classification by Moog, (1999) and adapted by Graf *et al*. (2017) as presented in Table 3. Percentages were assigned to these substrates depending on their distribution.

Table 3: Characterization of habitats (Moog, 1999).

Mineral habitat	Particle size class
Megalithal	>40 cm; large cobbles, boulder, blocks, bedrock
Macrolithal	20cm-40cm; coarse blocks, head sized cobbles with variable percentage of cobbles, gravel and sand
Mesolithal	6cm -20cm fist to hand sized cobbles with variable percentage of gravel and sand
Microlithal	2cm-6cm coarse gravel size of pigeon egg to child fist with variable percentages of Medium to fine gravel.
Akal	0.2cm -2cm fine to medium sized grave
Psammal	6µm -2mm sand
Psammolpelal	Mixture of sand with mud
Pelal	6µm mud/organic mud and sludge
Argyllal	Silt; loam, clay(inorganic)
Organic habitat	
CPOM	Deposits of particulate organic matter, coarse particulate organic matter, like fallen leaves
Submerged macrophytes	Totally immersed macrophytes, including water mosses, water ferns and algae
FPOM	Deposition of particulate organic matter, fine particulate organic matter
Woody debris	Fallen dead trees and remains of large branches

Table 4 presents the substrates types occurring at the sampled sites depending on their distribution within a representative reach that is100 m long. Most of the sites had between two and five major substrate types sampled. Some sites (2B, 3A, 3B, 4A, 4D, 4E, 9C and 11A) were only limited to two major substrate types while some sites (9A, 5A) had up to five substrate types. Hardpan was the major substrate type in Masindeti (11A). CPOM in the Table 4 comprises of both woody debris and detritus.

Table 4: Distribution of substrate types. CPOM = Coarse Particulate Organic Matter (woody debris and detrital substrate).

Site Code	Substrate									
	Megalithal (%)	Macrolithal (%)	Mesolithal (%)	Microlithal (%)	Akal (%)	Psammal (%)	Pelal (%)	Hardpan (%)	CPOM (%)	Macrophytes (%)
1A	-	-	-	80	-	5	-	-	15	-
2A	-	70	-	10	-	5	-	-	-	15
2B	-	-	-	-	-	-	15	-	85	-
3A	-	65	-	-	-	-	-	-	-	35
3B	-	-	-	-	55	-	-	-	-	45
3C	-	60	20	-	-	20	-	-	-	-
4A	-	85	-	-	-	-	-	-	-	15
4B	-	40	-	5	-	-	-	-	55	-
4C*	-	5	-	10	85	-	-	-	-	-
4D*	-	75	-	-	-	10	-	-	-	15
4E	10	90	-	-	-	-	-	-	-	-
5A	20	15	15	40	-	10	-	-	-	-
6A	5	80	-	15	-	-	-	-	-	-
7A	-	5	-	10	85	-	-	-	-	-
8A	-	25	20	-	45	-	5	-	-	5
9A	-	-	-	10	-	15	10	-	50	15
9B	10	60	20	-	-	-	-	-	-	10
9C	-	-	70	5	-	-	-	-	-	25
10A	-	-	-	-	85	-	-	-	-	15
11A	-	-	-	-	30	-	-	70	-	-
12A	-	-	15	35	50	-	-	-	-	-

3.2.3 Sampling macroinvertebrates

A multi-habitat sampling technique was employed during sampling of macroinvertebrates from the sites (Graf *et al*., 2017; AQEM sampling manual, 2002). The sampling of habitats depended on the proportion of their presence within a sampling reach. At each site, a total of 20 sampling units were collected from substrate types with more than 5% coverage within a representative reach that was 100 m long. The selection of defined habitats was based on the principle that each habitat is colonized by a unique assemblage of macroinvertebrates (Rosenberg & Resh, 1993). The proportion of each substrate type per site determined the number of units among the 20 MHS samples that were collected from that particular substrate type. Therefore, initial identification of the substrate types and percentage coverage of the streambed is necessary. The 20 sampling units from the different substrate types constitute one Multi-Habitat Sample (MHS).

Sampling of macroinvertebrates was done by disturbing the substrates using a brush and collecting the dislodged organisms using a multi-habitat sampling net (1000 microns mesh size) (Figure 20a). An area of 0.0625 m^2 was sampled for each sampling unit. Inspection of organisms attached to the substrates was done by scrubbing the substrate with a brush and washing the organisms into the net. Sampling was done from downstream to upstream within a reach to minimize drift.

Adult caddisflies were trapped and collected at dusk with a light-trap placed on tray with water treated with a detergent (Figure 20b). This was done in Kimurio Upstream (8/11/2019), Kapkateny Upstream (11/10/2019) and Kibingei (14/10/2019) sites.

Macroinvertebrate samples were preserved in 98% ethyl ethanol or in 4% formalin solution, packaged and stored in cooler boxes for transport to the laboratory for further processing. Sorting, identification and weighing of taxa were done at The University of Eldoret and University of Life Sciences, Vienna (BOKU).

Figure 20: (a) Scrubbing of macrolithal substrate; (b) Adult caddisflies light trap set-up

3.2.4 Determination of habitats of selected macroinvertebrate taxa

To determine habitat preferences of Potamonautidae, Perlidae and Oligoneuriidae families, sampling was done using a multi-habitat sampling approach in an area of 0.0625 m^2 using a dip net (1000 microns mesh size). The macroinvertebrates were scrubbed off from the substrate using a brush and thereafter collected in the macroinvertebrate net. Thereafter, the substrate where the organisms were scrubbed off was noted, the water depth measured using a meter rule or velocity plank and the velocity at that point measured using a velocity plank. The number of Perlidae, Potamonautidae and Oligoneuriidae were counted and recorded. These macroinvertebrates are large and can be easily seen with the naked eye. After counting is done, the animals were put back into the stream.

3.2.5 Land use characterization

The land use in the area was characterized by forested uplands and intensive agricultural activities in the lower reaches. There was a high (> 60%) canopy cover in the riparian section in the forested sites while in the agricultural areas, some streams were completely stripped off of the riparian zones. The land use patterns included natural vegetation, agricultural crops and grass/shrublands. Landcover data within 1500m buffer of the sampled sites were generated form satellite imagery and percentages were calculated (Table 6). Sites were targeted to be in forested (reference sites) and in the agricultural land uses (disturbed sites). The distance of these sites to the nearest forest was calculated from Google earth.

Figure 21: Land use types within the sampled reaches; (a) forested uplands with strips grassland, (b) agricultural land use

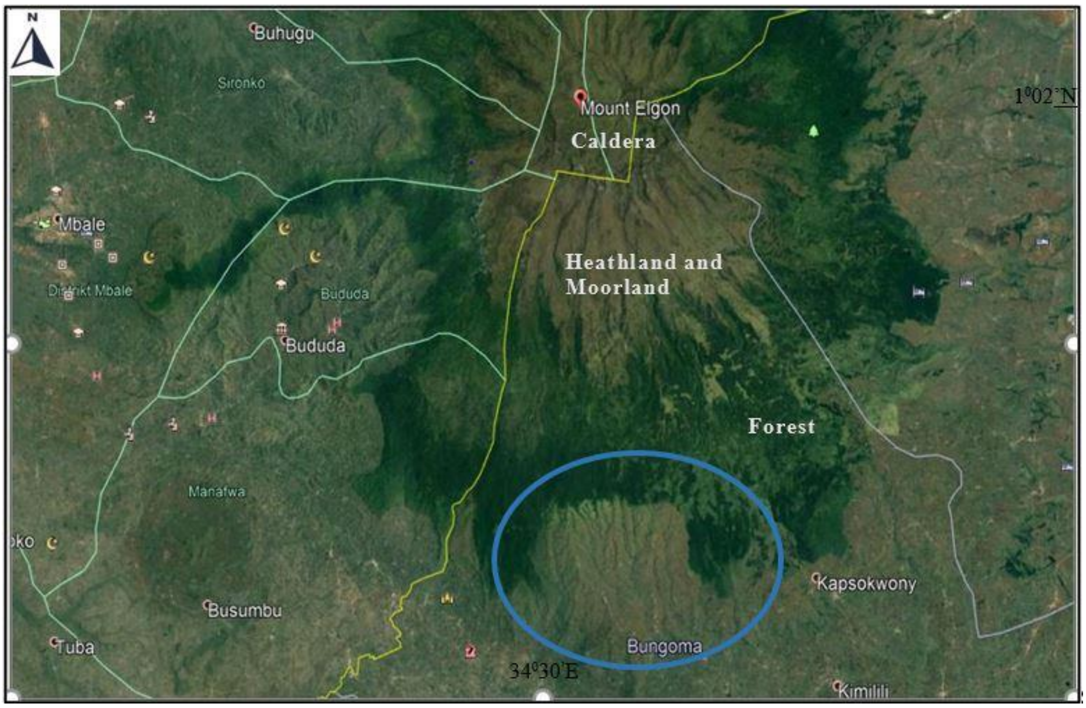


Figure 22: Google-Earth image of Mt. Elgon showing the extensiveness of the afro-tropical montane forests (dark green) and agricultural land use (Light green). Circled area shows region where the investigated streams were distributed.

3.3 Laboratory procedures

3.3.1 Total suspended solids and Particulate organic matter determination

The GF/F filters from the field that had been folded and neatly stored in known weights of aluminium foils were dried in an oven at 60 ^{o}C for 72 hours and weighed using a sensitive weighing scale. The dry filters were reweighed and placed in a muffle furnace at 450 ^{0}C for 5 hours for ashing and thereafter reweighed again. These weights were used to calculate total suspended solids (TSS) and particulate organic matter (POM) in the water column using the following equations:

$$TSS\ (mg/L) = ((A-B)/V) * 10^6$$

$$POM(mg/L) = ((C-B)/V) * 10^6$$

Where: A= Weight of filter (g) + residue
B= Weight of pre-combusted filter without residue(g)
C = Weight of ashed filter (g)
V= Volume of water filtered (ml)

Coarse particulate organic matter samples from the field were dried in an oven for 72 hours at 60^{0}C and their dry weights recorded.

3.3.2 Sorting, identification and weighing of macroinvertebrates

Macroinvertebrate samples were washed in a series of sieves under flowing water to remove the preservative and for easier sorting procedures. Sorting was done with different taxa placed in separate petri-dishes for ease of identification, counting and weighing. Complex and large samples were sub-sampled into smaller fractions for easier and thorough sorting. This was done by dividing the larger samples into equivalent fractions of (1/2, 1/4, 1/8) and working on each fraction at a time. The samples were thereafter preserved in 75% ethyl ethanol for archiving

Identification was done under a dissecting microscope to the genus level with the aid of keys in several guides (Gerber & Gabriel, 2002; Day *et al*., 2002, Stals and de Moor 2007, Merritt *et al*., 2008). Most of the identification was done with the help of Wolfram Graf (BOKU University). Individual taxa in different samples from different sites were weighed using a sensitive weighing scale (4 decimal places) and weights recorded. Macroinvertebrates were then assigned functional feeding groups (FFGs) (Table 5) following Cummins *et al*. (2008) and Masese *et al.* (2014).

Table 5: Functional feeding group (FFG) assignment of macroinvertebrates. CG=collector gatherers, CF= collector filterers, SHR= shredders, PRD= predators, SCR= scrapers according to Cummins *et al*. (2008) and Masese *et al.*(2014).

Family	FFG
Baetidae	CG
Caenidae	CG
Calamoceratidae	SHR
Ceratopogonidae	PRD
Coenagrionidae	PRD
Dixidae	PRD
Dolichopodidae	PRD
Dytiscidae	PRD
Elmidae	SCR
Empididae	PRD
Gerridae	PRD
Glossiphoniidae	PRD
Gomphidae	PRD
Gyrinidae	PRD
Heptageniidae	SCR
Hydrophilidae	PRD
Hydropsychidae	CF
Hydroptilidae	SCR
Lepidostomatidae	SHR
Leptoceridae(*Trichosetodes*)	CG
(Oecetis)	PRD
(Adicella, Triaenodes)	SHR
Leptophlebiidae	SCR/CG
Libellulidae/Corduliidae	PRD

Limoniidae	SHR
Mesoveliidae	PRD
Muscidae	PRD
Oligochaeta	CG
Oligoneuriidae	CF
Perlidae	PRD
Philopotamidae	CF
Physidae	SCR
Pisuliidae	SHR
Planariidae	PRD
Planorbidae	SCR
Polycentropodidae	PRD
Potamonautidae	SHR
Psychomyiidae	SCR
Scirtidae	SCR
Simuliidae	CF
Sphaeriidae	CF
Stratiomydae	SCR
Tabanidae	PRD
Tipulidae	SHR
Tricorythidae	CG

Figure 23: (a) Analysis of samples in the laboratory; (b) Sorted organisms in separate petri-dishes

3.4 Data Analysis

Descriptive statistics were applied in the analysis of water quality parameters. The parameters were expressed as the mean $\pm$ SE. Pearson correlation was applied to test the strength and significance of the relationship between water quality parameters and the percentages of landcover in the sampled sites. The Kolmogorov-Smirnov test in SPSS software was performed on water quality variables. The dataset was thereafter analysed with the non-parametric Kruskal-Wallis test for significance between forested and agricultural land use types.

Substrate compositions between sites were expressed as percentages and comparisons between forested and agricultural land use types presented in excel using bar graphs. Cluster analyses based on abiotic variables of physico-chemical water parameters, habitat conditions (depth, width, velocity, discharge) and substrate percentages were performed in PC-ORD 5.33 software (McCune & Mefford, 2006) using Wards' method with Bray-Curtis distance measure. The results were presented as dendrograms using land use type and altitude classes as overlays.

Comparisons of the abundance, biomass, diversity and richness of the macroinvertebrates among sites and between land use types was done in excel using bar graphs. Data was logarithmically transformed to minimize instances where huge variations existed in the abundance between sites. Shannon diversity (Shannon, 1949) and evenness indices were used as a measure of diversity and dominance, respectively, of macroinvertebrates per site.

Habitat suitability curves for the families Perlidae, Potamonautidae and Oligoneuriidae were drawn in excel with the habitat suitability index expressed as a proportion of animals occurring in a specific velocity/ depth class to the maximum number of organisms sampled. The highest number of individuals sampled in depth and velocity classes was taken to be the preferred for that particular taxon.

The distribution of macroinvertebrate functional feeding groups (FFGs) among sites and between land use types were presented in bar graphs in excel. Pearson correlation was performed to test the strength and significance of the relationship between FFGs and ecosystem attributes of landcover and organic matter biomass. Sites were further classified as upstream, midstream and downstream based on altitude classes of (2200-2500m, 1850-1950m, and 1600-1700m a.s.l.) respectively generated from histograms in excel and were used to portray the longitudinal trends in the distribution of FFGs.

The taxonomic similarity between sites was then investigated by cluster analyses using the Ward's method and Bray-Curtis distance measure. The log-transformed macroinvertebrate abundances were used to reduce the variation brought in by mass occurrence taxa in some sites. The results are presented as dendrograms using land use type and altitude classes as overlays.

Indicator species analysis was calculated to identify the most discriminant taxa for land use and altitude classes. The statistical significance of the indicator species values was evaluated using a monte Carlo test randomization procedure with 4,999 permutations (Dufrene and Legendre, 1997). These tests were done in PCORD 5 software.

Non-multidimensional Scaling (NMDS) ordination using Bray-Curtis distance measure was performed with the log-transformed macroinvertebrate abundance data using abiotic data as overlays to investigate the grouping of sites and identify the direction and magnitude of the dissimilarity.

Biotic indices of streams using Tanzanian River scoring system (TARISS), Ethiopian invertebrate scoring system (ETH-bios), South African Invertebrate Scoring system (SASS) and the Biological Monitoring Working Party (BMWP) were calculated for each of the sites based on the macroinvertebrate assemblages present to assess stream ecological integrity. Each taxon was assigned a tolerance/sensitivity score from these biotic indices and summed up to provide total scores for the indices. Average score per taxon (ASPT) was also calculated by dividing the total score by the number of taxa.

CHAPTER FOUR

4.0 RESULTS

4.1 Land use classification

Ten sites (1A, 2A, 2B, 3A, 3B, 3C, 4A, 4B, 9A, 9B) were classified under forested land use while eleven sites (4C, 4D, 4E, 5A, 6A, 7A, 8A, 9C, 10A, 11A, 12A) were classified under agricultural land use. Figure 24 shows the land cover percentages in the sampled sites. Sites with more than 60% vegetation were considered forested while those with more than 60% cropland were considered agricultural.

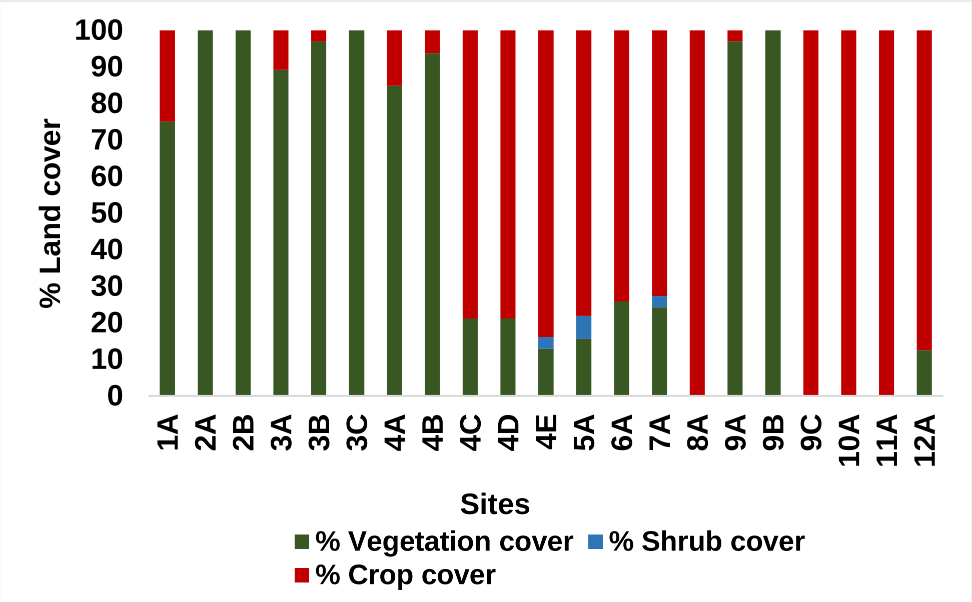


Figure 24: Landcover percentages within 1500 m buffer in the sampled sites. On the x-axis are the sampling sites. Numbers represent different streams while letters represent the longitudinal gradient from upstream to downstream within a stream

Table 6: Percentage vegetation, shrub and crop cover in the sampled sites

Site	Site code	% Vegetation cover	% Shrub cover	% Crop cover
Chemugumiet	1A	75	0	25
Teremi upstream	2A	100	0	0
Teremi Tr1	2B	100	0	0
Kimurio Upstream	3A	89,19	0	10,8
Kimurio Tr1	3B	96,88	0	3,13
Kimurio Tr2	3C	100	0	0
Kapkateny upstream	4A	84,85	0	15,15
Kapkateny Tr1	4B	93,75	0	6,25
Kapkateny Midstream (1st MHS)	4C	21,21	0	78,79

Kapkateny Midstream (2nd MHS)	4D	21,21	0	78,79
Kapkateny downstream	4E	12,90	3,22	83,87
Chebich	5A	15,63	6,25	78,12
Kapkasobei	6A	25,80	0	74,19
Chebirbei	7A	24,24	3,03	72,72
Kibingei	8A	0	0	100
Kibisi Tr 1	9A	96,97	0	3,03
Kibisi Upstream	9B	100	0	0
Kibisi downstream	9C	0	0	100
Cheptilieny	10A	0	0	100
Masindeti	11A	0	0	100
Namboani	12A	12,5	0	87,5

Table 7: Sampled sites under agricultural and forested land use types

Forested sites	Agricultural sites
Chemugumiet	Kapkateny Midstream
Teremi upstream	Kapkateny Midstream
Teremi Tr1	Kapkateny downstream
Kimurio Upstream	Chebich
Kimurio Tr1	Kapkasobei
Kimurio Tr2	Chebirbei
Kapkateny upstream	Kibingei
Kapkateny Tr1	Kibisi downstream
Kibisi Tr 1	Cheptilieny
Kibisi Upstream	Masindeti
	Namboani

4.1.1 Physico-chemical water quality parameters and land use patterns

The mean and absolute values of physico-chemical water quality parameters in the sampled sites are presented in (Table 8). The highest temperature of 20.38 ^{o}C was recorded in Cheptilieny (10A) while the lowest temperature of 13.48 ^{o}C was recorded in Kibisi upstream (9B). Highest dissolved oxygen concentration (15.32 mg/L) was recorded at Kimurio Tr1 (3B) while the lowest (7.25 mg/L) was recorded in Kibisi tributary (9A) and Kapkateny upstream (4A). pH ranged between 6.96–8.04 with the lowest recorded in Kapkateny Tr1 (4B) and the highest recorded in Kimurio Tr1 (3B). Salinity was recorded lowest of 0.03 (ppt) in (2A, 3B, 3C, 9B & 9A) and highest of 0.11 (ppt) in Kibingei (8A). Total Dissolved Solids ranged between 0.01mg/L - 0.14 mg/L with the lowest TDS recorded in Kibisi downstream (9C) and highest in Kibingei (8A). Electrical conductivity ranged between 56-224 µS/cm. The lowest electrical conductivity was recorded in Kimurio Tr2 (3C) and the highest in Kibingei (8A). Total suspended solids (TSS) ranged between 3.2 mg/L and 450 mg/L. The lowest being recorded in Kibisi Tr1 (9A) while Kibingei (8A) recorded the highest TSS quantity.

Table 8: Physico-chemical parameters. TSS values expressed as mean ± SEM while other parameters expressed as absolute values. Temp = Temperature, TDS = Total Dissolved solids, EC = Electrical Conductivity, DO = Dissolved Oxygen, TSS =Total suspended Solids.

Site name	Site Code	Temp (ºC)	TDS (mg/L)	Salinity (ppt)	EC (µS/cm)	D.O (mg/L)	PH	TSS (mg/L)
Chemugumiet	1A	16.09	0.052	0.04	81	8.23	7.03	89.4+9.4
Teremi Upstream	2A	14.31	0.039	0.03	59	7.99	7.07	31.9+3.3
Kimurio upstream	3A	15.56	0.055	0.04	86	8.08	6.99	20.4+4.6
Kimurio Tr1	3B	15.25	0.047	0.03	72	15.32	8.04	21.4+3.4
Kimurio Tr2	3C	14.56	0.036	0.03	56	11.89	7.86	43.6+2.0
Kapkateny Upstream	4A	15.47	0.057	0.04	87	7.25	6.97	43.2+3.0
Kapkateny Tr1	4B	15.11	0.06	0.04	93	10.82	6.96	29.2+3.0
Kapkateny Midstrm (1st MHS)	4C	18.79	0.083	0.06	127	8.37	7.1	213.3+30.6
Kapkateny Midstrm (2nd MHS)	4D	18.75	0.083	0.06	127	8.37	7.1	213.3+30.6
Kapkateny Downstream	4E	17.66	0.091	0.07	142	10.63	7.04	264.4+15.5
Chebich	5A	18.77	0.112	0.08	172	11.37	7.07	301.2+45.6
Kapkasobei	6A	19.61	0.1	0.07	155	8.33	7.06	147.7+21.2
Chebirbei	7A	20.21	0.126	0.09	193	8.94	7.05	397.6+29.1
Kibingei	8A	19.74	0.14	0.11	224	10.51	7.09	450+31.9
Kibisi Tr1	9A	15.64	0.048	0.03	73	7.25	7.51	3.2+1.6
Kibisi Upstream	9B	13.48	0.047	0.03	72	8.71	7.62	13.9+0.9
Kibisi Downstream	9C	16.3	0.011	0.06	127	10.79	7.12	79+12.2
Cheptilieny	10A	20.38	0.119	0.09	183	10.57	7.01	46.7+7.2
Masindeti	11A	19.37	0.131	0.1	202	11.37	7.06	176+6.5
Namboani	12A	19.04	0.096	0.07	148	10.96	7.04	181.7+9.2

Percentage crop cover was significantly positively correlated with the variables of temperature, TDS, TSS, EC and salinity. Percentage crop cover was however significantly negatively correlated with pH. Percentage vegetation cover was significantly negatively correlated with temperature, TDS, EC, salinity and TSS. It was however significantly positively correlated with pH (Table 9). Altitude was strongly correlated with land-use percentages. Vegetated areas were strongly significantly positively correlated with altitude. Temperature, total dissolved solids, total suspended solids, salinity, conductivity showed a negative correlation with altitude. Percentage landcover values, used to assign land use classes, were used to run the correlation.

Table 9: Pearson correlation bi-plot; Physico-chemical variables, altitude and landcover percentages in the investigated streams (n=20). Values in bold indicate significant (p<0.05) correlations. Temp = Temperature, DO = Dissolved Oxygen, TDS = Total Dissolved Solids, EC = Electrical conductivity, Sal = salinity, TSS = Total Suspended Solids

	Variables									
	% Veg cover	**% Crop cover**	**Altitude (m)**	**Temp (ºC)**	**DO (mg/L)**	**pH**	**TDS (mg/L)**	**EC (µs/cm)**	**Salinity (ppt)**	**TSS (mg/L)**
% Veg cover	1	-.999**	.910**	-.857**	-.104	.539*	-.656**	-.845**	-.858**	-.680**
% Crop cover	**-.999****	1	-.911**	.854**	.099	-.538*	.648**	.840**	.854**	.666**
Altitude (m)	**.910****	**-.911****	1	-.818**	-.121	.473*	-.642**	-.857**	-.865**	-.650**
Temp (ºC)	**-.857****	**.854****	**-.818****	1	.059	-.489*	.876**	.915**	.907**	.736**
DO (mg/L)	-.104	.099	-.121	.059	1	.476*	.092	.162	.168	.070
pH	**.539***	**-.538***	**.473***	**-.489***	**.476***	1	-.420	-.487*	-.493*	-.358
TDS (mg/L)	**-.656****	**.648****	**-.642****	**.876****	.092	-.420	1	.900**	.894**	.761**
EC (µs/cm)	**-.845****	**.840****	**-.857****	**.915****	.162	**-.487***	**.900****	1	.995**	.796**
Sal (ppt)	**-.858****	**.854****	**-.865****	**.907****	.168	**-.493***	**.894****	**.995****	1	**.793****
TSS (mg/L)	**-.680****	**.666****	**-.650****	**.736****	.070	-.358	**.761****	**.796****	**.793****	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

The means of physico-chemical water quality parameters in forested and agricultural land use types showed that agricultural land use recorded the highest values for TSS, Temp, DO, EC, salinity and TDS. Agricultural land use however had lower pH values than forested land use (Table 10). The non-parametric Kruskal-Wallis test showed significant ($p < 0.05$) differences for the variables TSS, TDS, salinity, EC and temperature between agricultural and forested land use types (Table 10). Sites with >60% crop cover were classified under as agricultural land use while sites with > 60% Vegetation cover were classified as forested land use.

Table 10: Kruskal-Wallis test for significance of physico-chemical parameters among the two land use types, agricultural and Forested (n=21). Physico-chemical parameters expressed as mean ± SE. Values in bold indicate significance p<0.05.

	Land use type		
Physico-chemical parameters	**Agriculture**	**Forested**	**P***
TSS (mg/l)	222 ± 30.7	32.9 ± 27.4	**0.000**
Temperature (^{0}C)	18.9 ± 0.5	15.1 ± 0.5	**0.000**
pH	7.1 ± 0.1	7.3 ± 0.1	0.704
DO (mg/L)	10.2 ± 0.5	9.5 ± 0.5	0.183
EC (µS/cm)	168.6 ± 13.5	67.4 ± 13.9	**0.000**
Salinity	0.1 ± 0.01	0.03 ± 0.01	**0.000**
TDS (mg/L)	0.1 ± 0.01	0.05± 0.01	**0.002**

P* Significance < 0.005

4.1.2 Land use and substrate composition

Substrate distribution between the two land use types showed the dominance of macrolithal substrate in streams within forested areas while akal substrate dominated in streams within in agricultural areas. CPOM (which comprised of detritus and woody debris) and macrophytes substrate types were also higher in forested sites than in agricultural sites (Figure 25). Hardpan was found only in agricultural areas. Percentage of fine substrate (substrate size < 2 cm) was higher in agricultural streams than in forested streams.

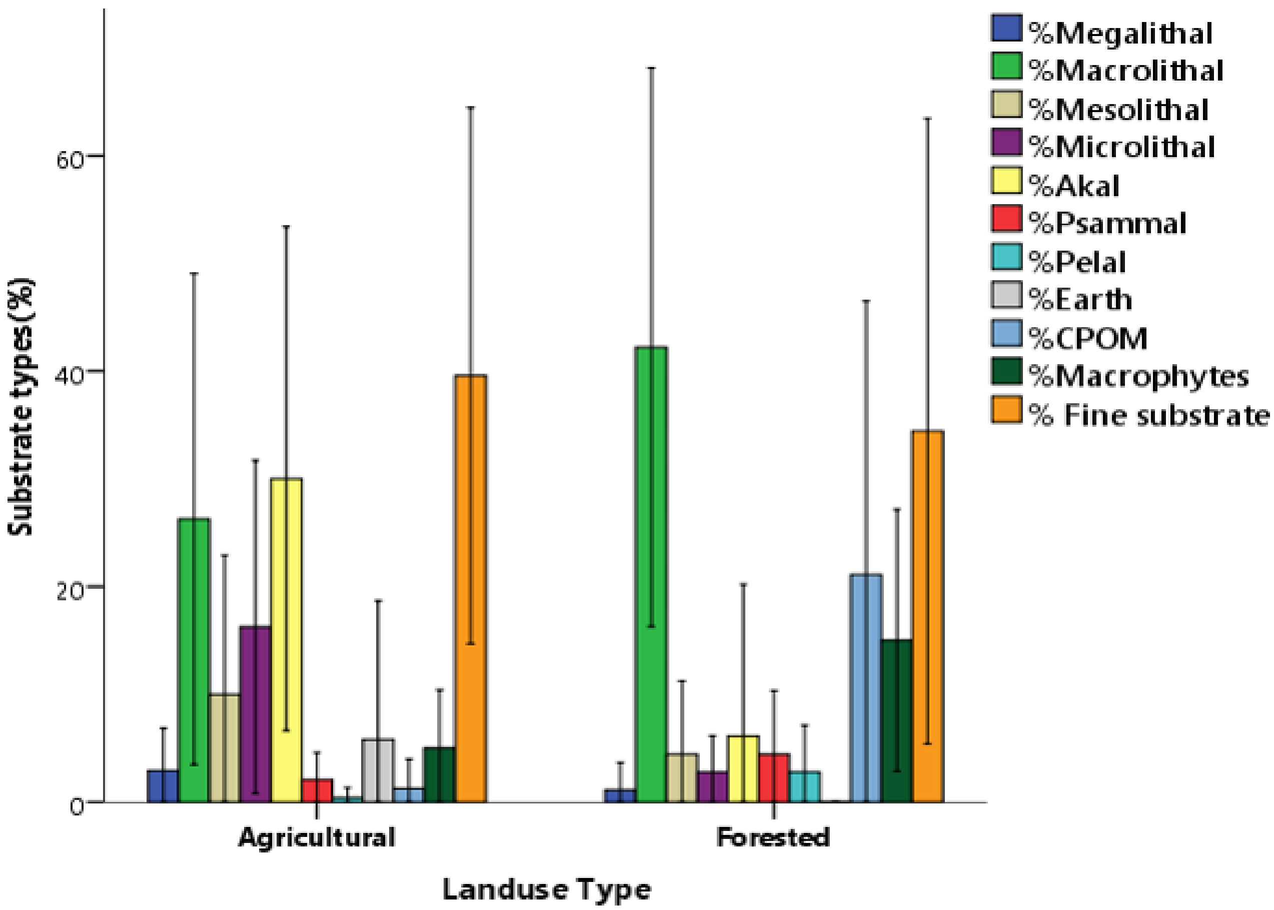


Figure 25: Mean Percentage of substrates per land use (agricultural, forested). Error bars represent 95% confidence interval.

4.2 Land use, abiotic parameters and altitudinal patterns.

Cluster analysis performed on catchment scale characteristics of altitude, land-use and substrate composition among sites was done to determine the habitat conditions of the sites that could be used predictively to determine which macroinvertebrate taxa will be occurring in the clustered sites. The analysis showed the aggregation of sites into two major clusters (Figure 26 & Figure 27). An overlay matrix based on altitude (Figure 26) and land use (Figure 27) clusters showed that the two clusters were a function of both land use and altitude gradient. Sites above 2000m a.s.l. clustered together and apart from sites below 2000m a.s.l. The clustering was also based on land use with sites in agricultural land use aggregating together away and apart from those in forested land use.

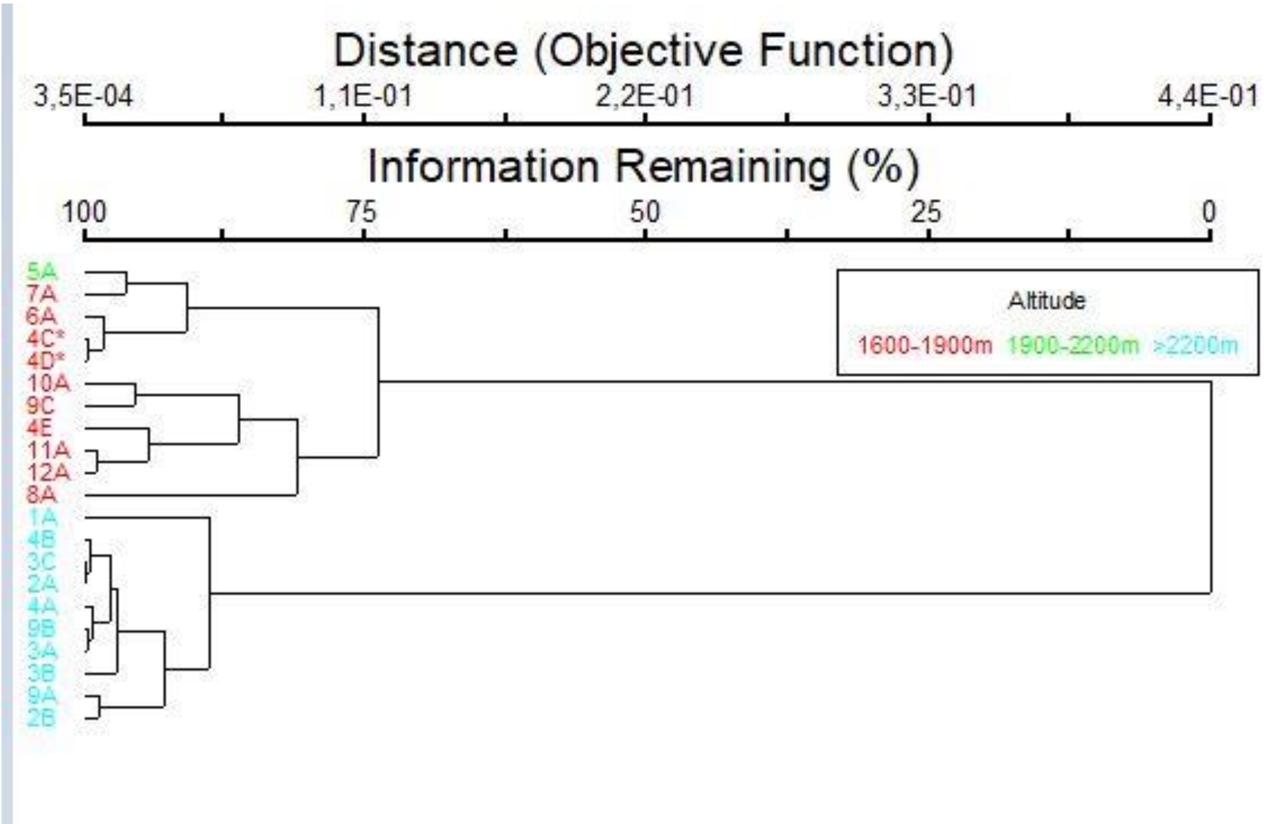


Figure 26: Cluster dendrograms of sites based on abiotic variables (overlay: altitudinal gradient)

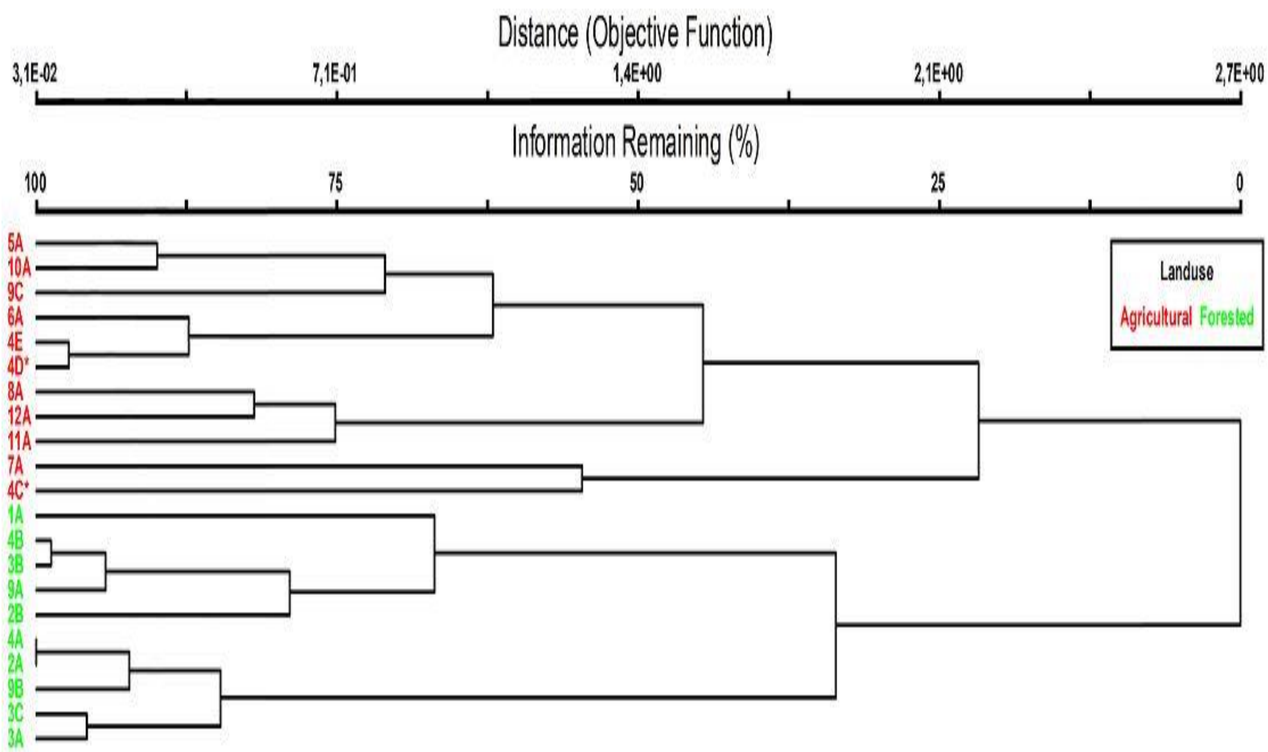


Figure 27: Cluster dendrograms of sites based on abiotic variables (overlay: agricultural and forested land use types)

4.3 Macroinvertebrates taxa list

A total of 281,024 specimens from 12 orders and 46 families were sampled at 21 sites in 12 streams within Mt. Elgon region (Table 11). Order Diptera had the highest number of families represented with a total of 12 families. Trichoptera was represented by nine families, Ephemeroptera with seven families, Coleoptera with five families, Plecoptera by one family and genus (Perlidae: *Neoperla*), Decapoda by one family and genus (Potamonautidae: *Potamonautes*), Mollusca by three families, Odonata by four families, Hemiptera by two families, Hirudinea, Tricladida and Oligochaeta each were represented by one family. There were three genera and five taxa groups identified from the family Hydropsychidae (*Cheumatopsyche* A, B & C, *Hydropsyche* and *Diplectrona* (Appendix 1) for differences in the head structure and the front clypeus anterior margin). Baetidae family was represented by three taxa groups (*Baetis* & type B - 3-tailed and type C - 2-tailed) based on their tail and body structure. Kimurio tributary1 (3B) had the highest abundance of specimens (42,112 individuals/m^2) while the lowest abundance was recorded in Chebirbei (7A) and Kapkateny midstream 1^{st} MHS (4C) both with 304 individuals/m^2. Kimurio upstream (3A) and Kibisi tributary (9A) had the highest taxa richness (30 taxa) while the lowest number of taxa was recorded in (4C) Kapkateny midstream 1^{st} MHS (7 taxa).

Table 11: Macroinvertebrate taxa composition, functional feeding types (according to Meritt *et al.*, 2008; Masese *et al.*, 2014) and abundance (ind/m^2) in the Nzoia river basin streams.

			Sites																				
Order	**Family**	**Genus**	**1A**	**2A**	**2B**	**3A**	**3B**	**3C**	**4A**	**4B**	**4C**	**4D**	**4E**	**5A**	**6A**	**7A**	**8A**	**9A**	**9B**	**9C**	**10A**	**11A**	**12A**	**FFG**
Oligochaeta	Oligochaeta	Oligochaeta	1200	16	112	48	96	-	16	6352	16	48	128	80	96	32	16	1296	16	32	160	-	-	CG
Tricladida	Planariidae	Planaria	-	32	96	240	496	256	80	176	-	128	48	48	-	-	-	208	-	16	48	-	-	PRD
Hirudinea	Glossiphoniidae	Glossiphoniidae	-	-	-	16	352	-	-	-	-	-	-	-	-	-	-	800	-	-	-	-	-	PRD
Gastropoda	Physidae	Physidae	-	-	32	-	-	-	-	-	-	-	-	-	-	-	-	32	-	-	-	-	-	SCR
	Planorbidae	Planorbidae	16	-	-	-	-	-	-	-	-	-	-	-	-	-	32	-	-	-	32	32	-	SCR
Bivalvia	Sphaeriidae	*Pisidium*	288	96	256	1536	992	96	400	736	-	16	48	32	-	16	48	6048	64	-	16	32	-	CF
Decapoda	Potamonautidae	*Potamonautes*	16	272	16	32	-	96	480	528	-	96	-	-	-	-	-	80	368	16	-	-	-	SHR
Ephemeroptera	Baetidae	*Baetis* (3-tailed)	-	2752	1840	3792	4896	4768	8960	3856	112	1952	912	1040	3056	80	352	4448	5728	640	3696	3456	400	CG
		Type B (3-tailed)	96	480	48	224	240	896	464	480	-	144	16	32	448	-	96	144	352	16	192	896	32	CG
		Type C (2-tailed)	-	-	-	16	-	288	-	-	16	416	96	-	272	-	-	-	112	-	-	32	16	CG
	Caenidae	*Afrocaenis*	-	-	80	-	96	-	16	-	-	-	-	-	-	-	-	80	-	-	-	-	-	CG
		Caenis	256	128	1136	32	1424	-	688	16	-	48	-	-	32	16	32	992	48	224	32	2112	48	CG
	Heptageniidae	*Afronurus*	96	720	-	656	480	800	576	32	80	352	528	16	-	-	576	-	1200	576	32	1696	560	SCR
	Leptophlebiidae	*Euthraulus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	-	-	-	-	SCR/CG
		Leptophlebiidae	-	-	16	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	SCR/CG
	Oligoneuriidae	*Oligoneuriopsis*		544	-	176	-	752	144	-	16	112	32	-	-	-	-	-	240	-	-	-	-	CF
	Prosopistomatidae	*Prosopistoma*	-	16	-	-	-	-	128	-	-	-	-	-	-	-	-	-	-	-	-	-	-	PRD
	Tricorythidae	*Tricorythus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32	-	-	16	-	-	-	CG
Odonota	Coenagrionidae	Coenagrionidae	-	-	-	-	-	-	-	-	-	16	-	16	-	-	-	144	32	736	48	160	-	PRD
	Gomphidae	Gomphidae	-	-	-	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	PRD
	Libellulidae/ Corduliidae	Libellulidae/ Corduliidae	-	-	-	-	-	-	-	-	-	-	16	-	-	-	64	-	-	-	-	-	-	PRD
Plecoptera	Perlidae	*Neoperla*	-	656	-	384	-	480	32	-	-	-	-	-	-	-	-	-	224	-	-	-	-	PRD
Hemiptera	Gerridae	Gerridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32	-	PRD
	Mesoveliidae	Mesoveliidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	64	-	PRD
Coleoptera	Dytiscidae	Dytiscidae	-	-	-	-	16	-	-	-	-	-	-	-	-	-	-	176	-	-	-	-	-	PRD
	Elmidae	Elmidae	-	-	-	16	-	-	-	-	-	160	-	-	-	16	-	-	-	-	16	-	-	SCR

	Gyrinidae	Gyrinidae	-	-	-	176	-	16	-	-	-	16	-	16	16	-	-	-	-	-	48	32	-	PRD
	Hydrophilidae	Hydrophilidae	-	16	-	-	-	-	-	16	-	-	-	-	-	-	16	32	-	-	-	-	-	PRD
	Scirtidae	Scirtidae	-	128	336	-	240	-	-	224	-	-	-	-	-	-	16	832	16	-	-	-	-	SCR
Trichoptera	Calamoceratidae	*Anisocentropus*	-	-	112	32	-	-	-	208	-	-	16	-	-	-	-	64	-	-	-	96	-	SHR
	Hydropsychidae	*Cheumatopsyche* A	-	240	-	-	-	-	-	-	-	-	-	-	32	-	-	-	80	-	-	-	-	CF
		Cheumatopsyche B	-	-	-	32	-	-	-	-	-	32	-	-	-	-	160	16	208	-	80	160	48	CF
		Cheumatopsyche C	-	672	32	288	-	240	144	-	-	1728	2464	160	320	-	-	-	80	304	80	-	-	CF
		Diplectrona	912	304	-	64	272	80	48	720	-	144	16	-	64	-	48	208	-	-	64	-	-	CF
		Hydropsyche	-	-	-	-	-	16	-	-	-	512	-	-	-	-	-	-	-	-	32	-	-	CF
	Hydroptilidae	*Orthothrichia*	-	16	-	-	-	-	-	-	-	-	-	-	32	-	-	-	-	-	16	-	-	SCR
	Lepidostomatidae	*Lepidostoma*	256	32	304	96	1712	16	64	560	-	16	64	-	16	-	48	208	-	448	-	960	16	SHR
	Leptoceridae	*Adicella*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32	-	-	32	-	-	-	SHR
		Oecetis	-	-	-	48	-	-	16	64	-	-	-	-	16	-	-	-	-	-	-	64	16	PRD
		Triaenodes	-	240	-	128	1200	80	80	240	-	-	-	-	-	-	-	96	48	96	-	-	-	SHR
		Trichosetodes	-	-	-	-	32	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	CG
	Philopotamidae	*Wormaldia*	-	-	-	-	48	-	64	96	-	-	-	-	-	-	-	912	-	-	-	-	-	CF
	Pisuliidae	Pisuliidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	80	-	-	-	-	-	SHR
	Polycentropodidae	*Polycentropus*	-	-	-	48	-	144	432	-	-	-	-	-	48	16	-	560	-	-	-	-	-	PRD
	Psychomyiidae	*Tinodes*	32	64	192	48	128	128	16	80	-	-	-	-	-	-	-	144	48	-	-	-	-	SCR
Diptera	Ceratopogonidae	Ceratopogonidae	-	-	32	-	-	-	-	-	-	-	-	-	-	16	-	16	-	-	-	-	-	PRD/SCR
	Chironomidae	Chironomidae	160	112	160	352	1152	-	144	1312	32	448	368	-	224	-	160	1648	160	112	48	96	16	I
	Dixidae	Dixidae	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	PRD
	Dolichopodidae	Dolichopodidae	-	32	-	16	64	-	-	208	-	-	-	-	-	-	-	-	-	-	-	-	-	PRD
	Empididae	Empididae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	-	-	PRD
	Ephydridae	Ephydridae	16	32	-	-	-	-	-	-	-	-	-	-	-	16	-	-	16	-	-	-	-	SHR/COL
	Limoniidae	Limoniidae	16	48	160	128	32	-	16	272	-	-	-	-	-	-	-	32	-	32	-	-	-	SHR
	Muscidae	Muscidae	16	-	-	32	16	64	-	-	-	-	48	-	32	-	-	16	-	-	-	32	-	PRD
	Simuliidae	Simuliidae	2560	1504	448	3056	28064	10304	7168	18512	32	32016	15072	960	7888	80	48	6416	464	144	224	-	192	CF
	Stratiomydae	Stratiomydae	-	-	-	-	-	-	-	64	-	-	32	-	-	-	-	-	-	-	16	32	-	SCR
	Tabanidae	Tabanidae	16	-	-	-	-	-	-	720	-	-	-	-	-	-	-	48	-	-	-	-	-	PPR
	Tipulidae	Tipulidae	16	-	64	32	64	16	-	368	-	48	32	16	16	16	-	128	-	16	16	32	-	SHR
No.of taxa			**17**	**25**	**21**	**30**	**23**	**22**	**23**	**24**	**7**	**21**	**18**	**11**	**17**	**10**	**17**	**30**	**21**	**17**	**21**	**19**	**10**	
Total (indv/m²)			**5968**	**9152**	**5488**	**11776**	**42112**	**19568**	**20176**	**35840**	**304**	**38448**	**19936**	**2416**	**12608**	**304**	**1776**	**25904**	**9520**	**3456**	**4912**	**10016**	**1344**	**281024**

4.3.1 Similarity of macroinvertebrate communities, land use patterns and altitudinal distribution

Two major clusters were observed from the hierarchical clustering of sites based on macroinvertebrate communities present. Simuliidae, *Cheumatopsyche*, Oligochaeta, Sphaeriidae, Chironomidae, Lepidostomatidae, *Diplectrona*, Baetidae, Tipulidae, Caenidae and *Afronurus* were the most commonly occurring taxa in most of the sites (Figure 28 & 29). *Adicella*, Trycorythidae, Libellulidae/Cordulidae and Empididae were limited to agricultural streams and an altitude range of < 2000 m a.s.l. Leptophlebiidae, *Afrocaenis*, Physidae, Dixidae, Pisuliidae, Wormaldia, Glossiphoniidae, Gomphidae, *Trichosetodes*, Prosopistomatidae, *Neoperla* and Dolichopodidae were limited to forested streams in altitudes > 2000 m a.s.l. Planorbidae, *Tinodes* and Tabanidae were found at altitudes > 2000 m a.s.l but also occurred in agricultural streams. Scirtidae, Limoniidae, *Triaenodes* and *Potamonautes* were highly occurring in forested streams though were found in some agricultural streams.

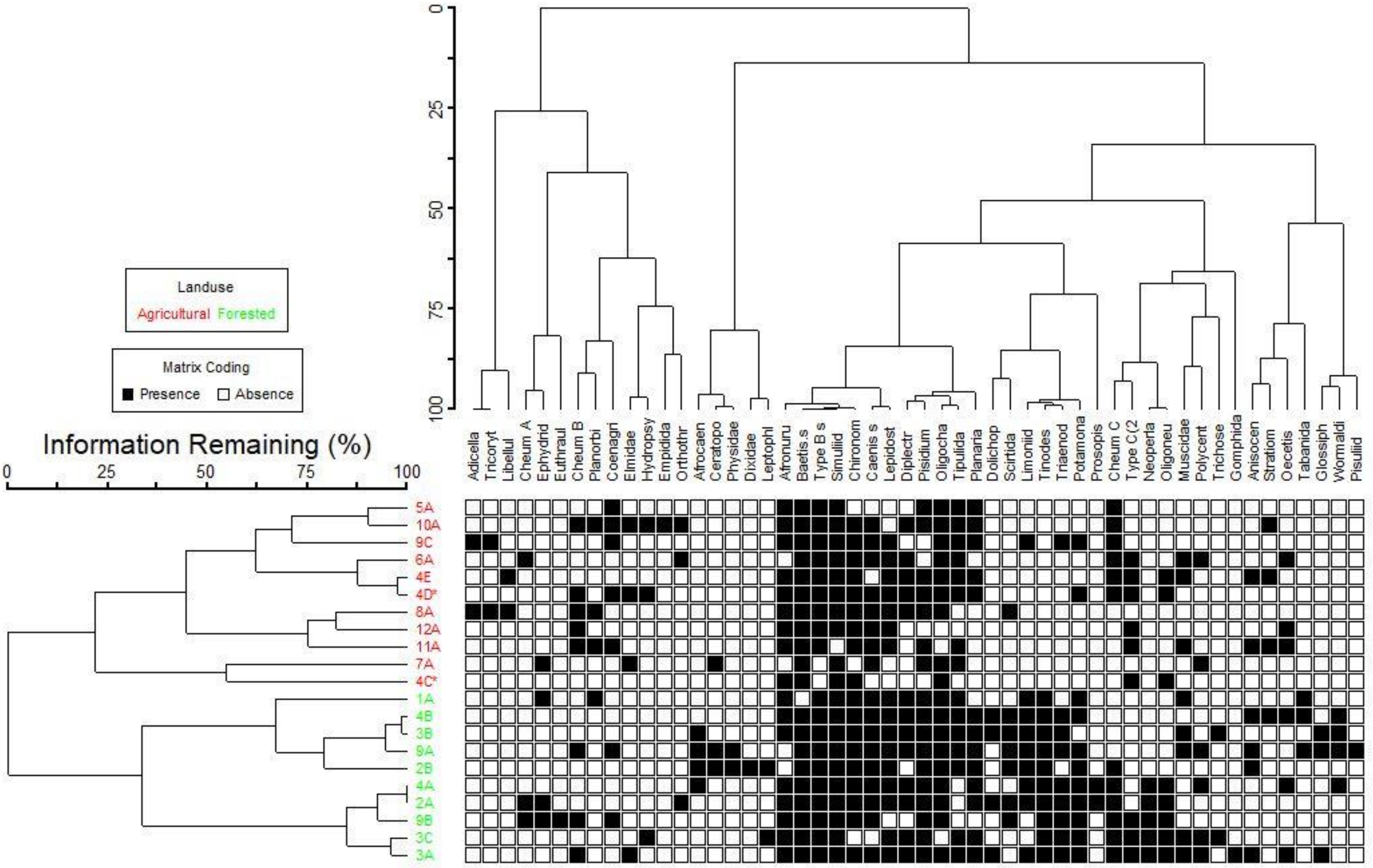


Figure 28: Two-way cluster dendrogram of macroinvertebrate distribution (presence and absence data; overlay: forested and agricultural areas).

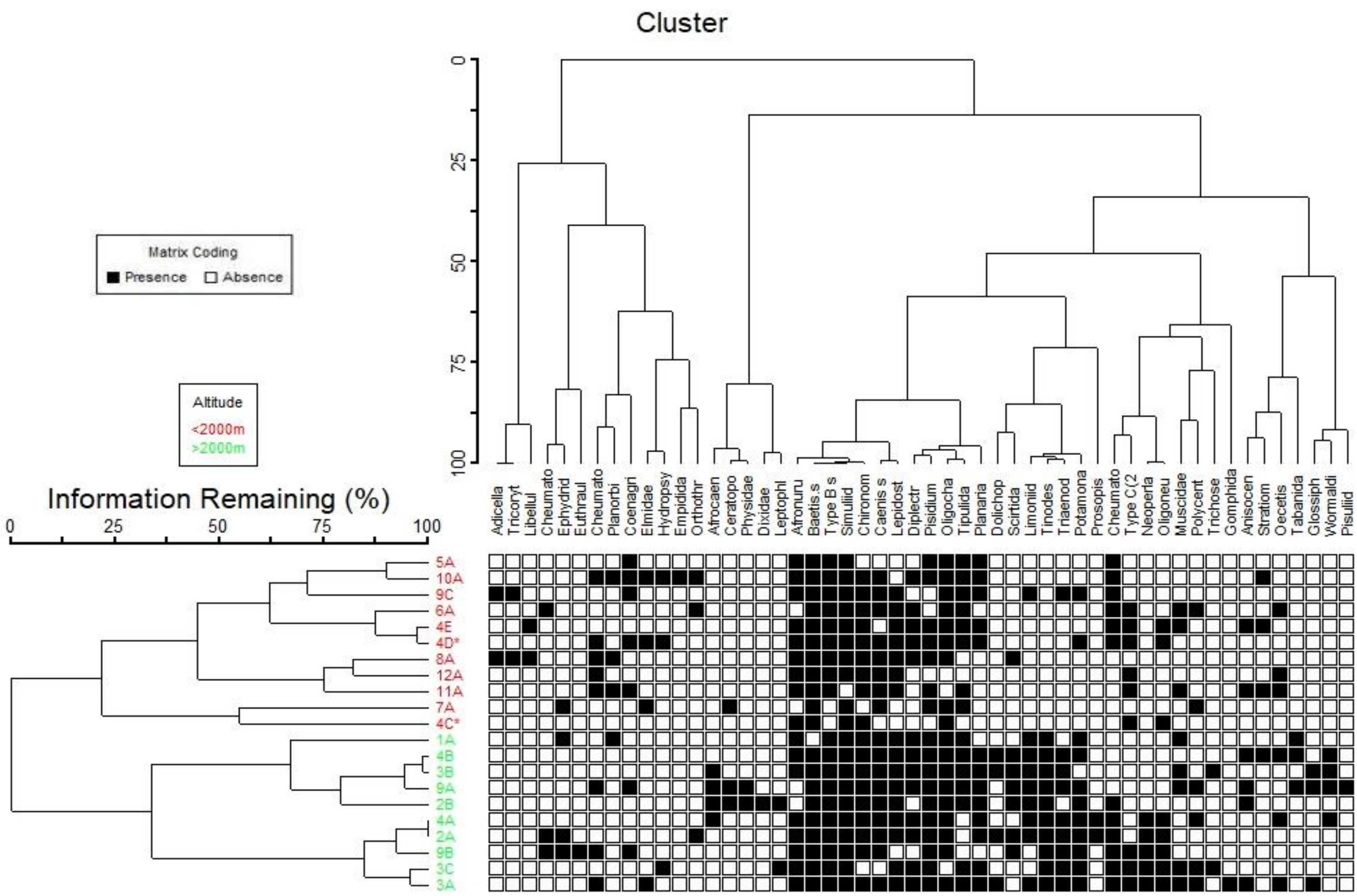


Figure 29: Two-way cluster dendrogram of macroinvertebrate distribution (presence and absence data; overlay: altitude).

4.4 Macroinvertebrate community structure

4.4.1 Abundance and richness

The highest number of individuals was recorded in site 3B (Kimurio Tr1) while the lowest abundance was recorded in sites 4C (Kapkateny midstream 1st MHS) and 7A (Chebirbei). Diptera was the most abundant order among sites with the highest Diptera abundance recorded in 4D (Kapkateny midstream 2nd MHS). Highest number of taxa were recorded in 3A (Kimurio upstream) and 9B (Kibisi upstream) (Figure 30). Ephemeroptera, Trichoptera and Diptera had higher taxa richness across the sites (Figure 30). Ephemeroptera and Diptera were the dominant taxa across the sites. Relative taxa richness across sites was dominated by Diptera, Ephemeroptera and Trichoptera (Figure 31). Sites in forested areas recorded higher taxa richness and abundance than those in agricultural areas (Figure 32).

a) Major Groups

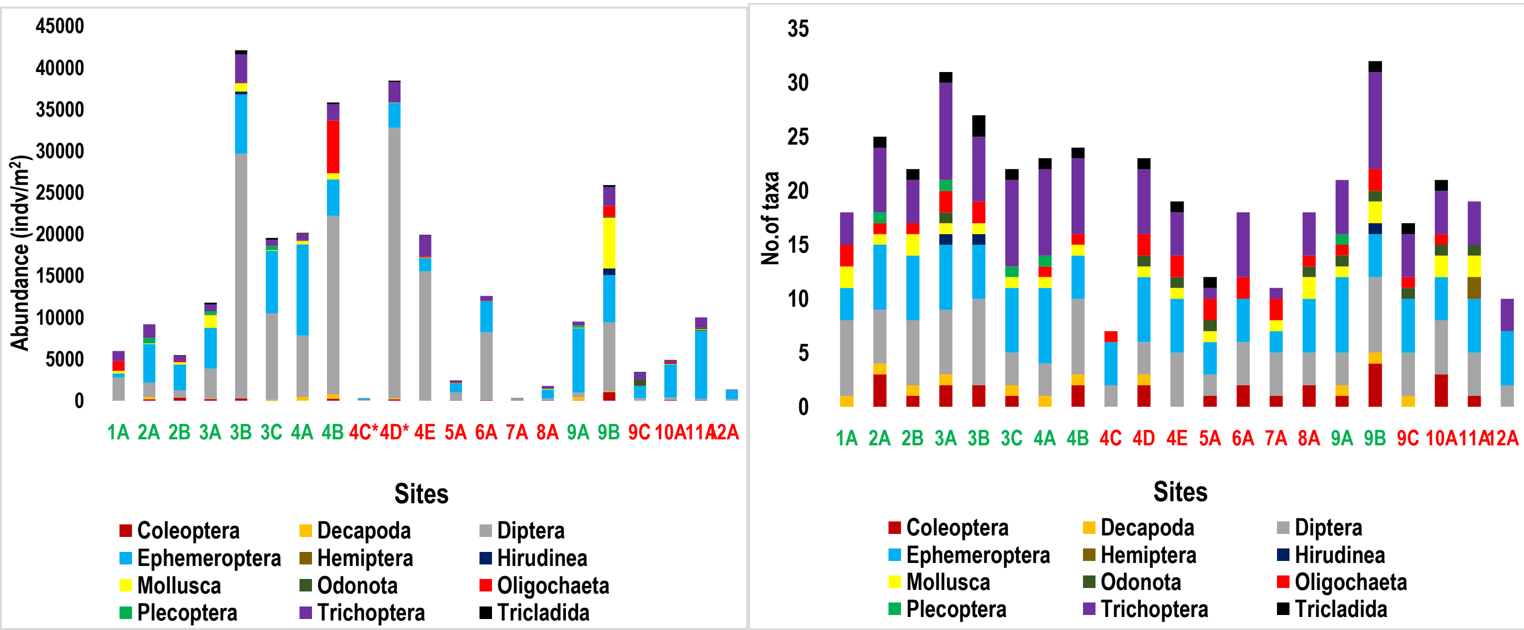


Figure 30: Abundance (left) and richness (right) of different macroinvertebrate orders. Sites labelled with * indicate same sites with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agricultural areas.

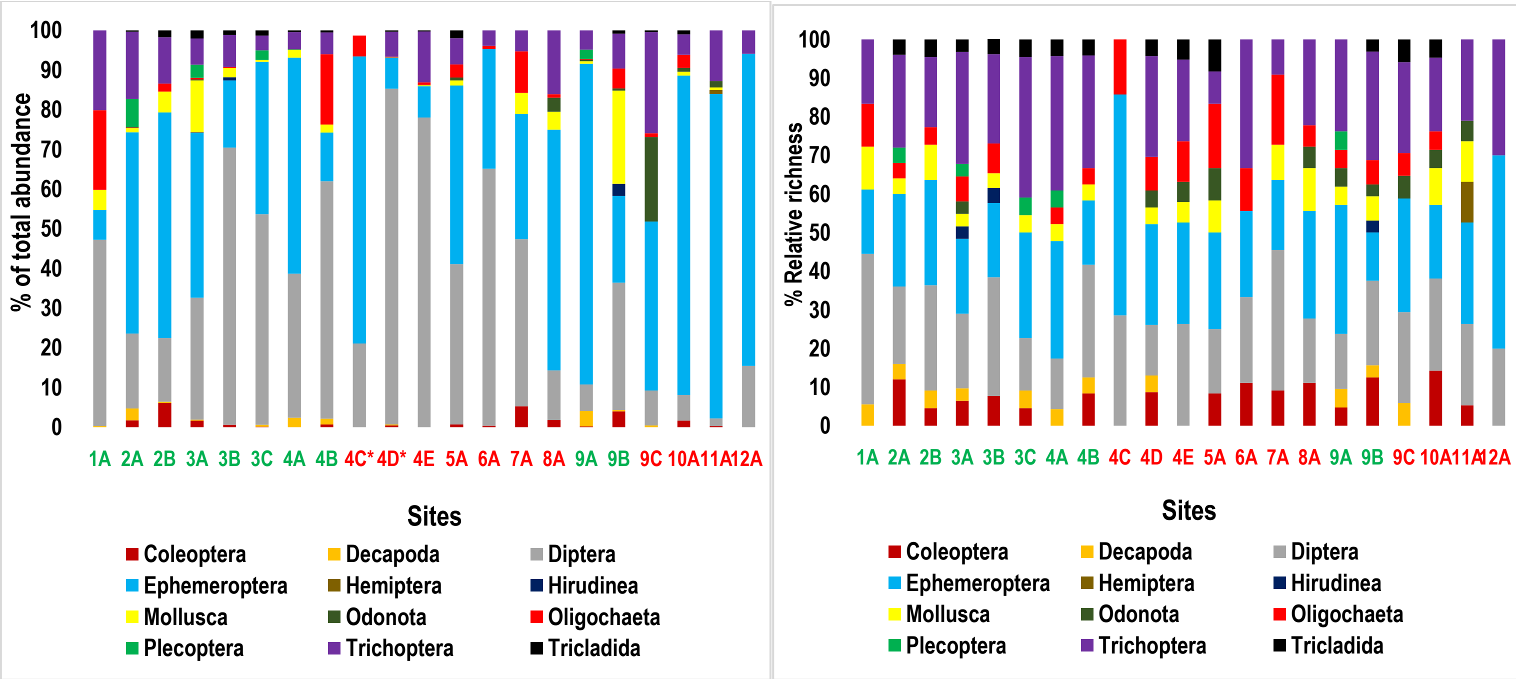


Figure 31: Dominance (%) in abundance (left) and in taxa richness (right) of macroinvertebrate orders. Sites labelled with * indicate same site with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agriculture areas.

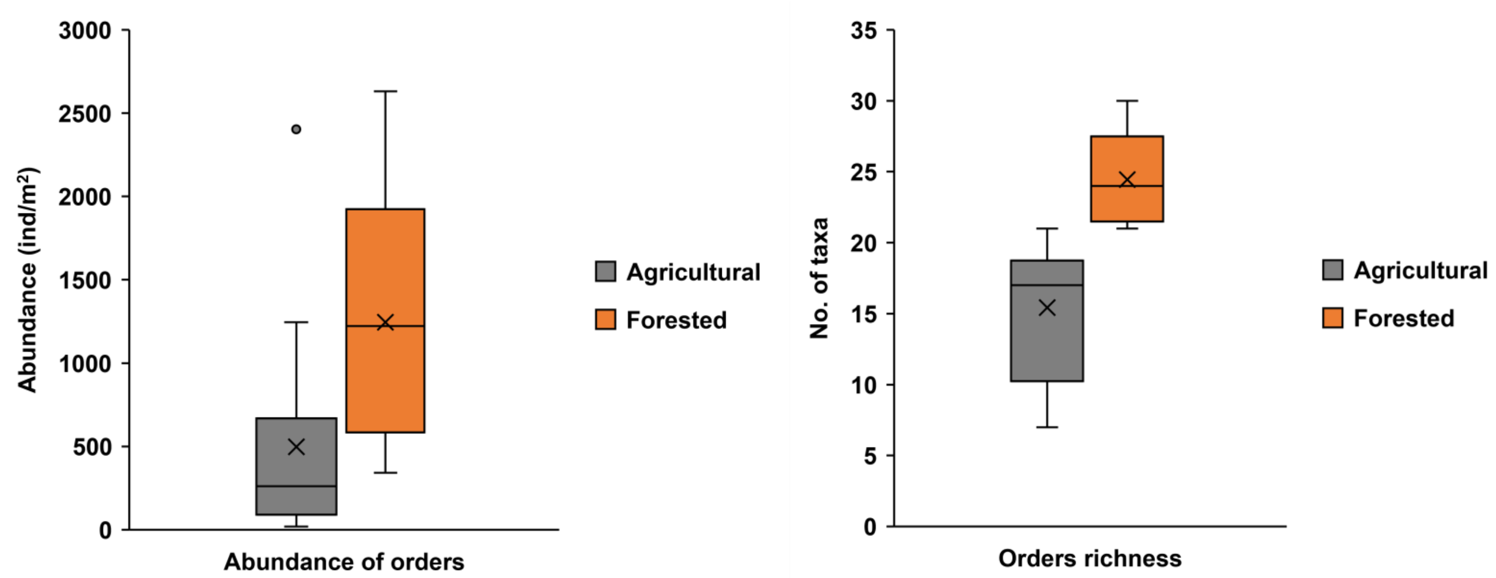


Figure 32: Abundance (left) and richness (right) of macroinvertebrate orders in agricultural and forested land use types

b) Ephemeroptera

The order Ephemeroptera was represented by seven families (Baetidae, Heptageniidae, Oligoneuriidae, Tricorythidae, Caenidae, Leptophlebiidae and Prosopistomatidae). Baetidae was the most abundant family across sites (Figure 33). Highest Ephemeroptera abundance and richness was recorded in 4A (Kapkateny upstream) while the lowest was in 7A (Chebirbei). Ephemeroptera richness was equally high in 9A (Kibisi tributary) as in 4A (Kapkateny upstream). Caenidae dominated in site 1A (Chemugumiet) while Heptageniidae dominated in sites 8A (Kibingei) and 12A (Namboani). Baetidae and Caenidae families had the highest relative richness across sites (Figure 34). Abundance and richness of Ephemeroptera was higher in forested streams than in agricultural streams (Figure 35).

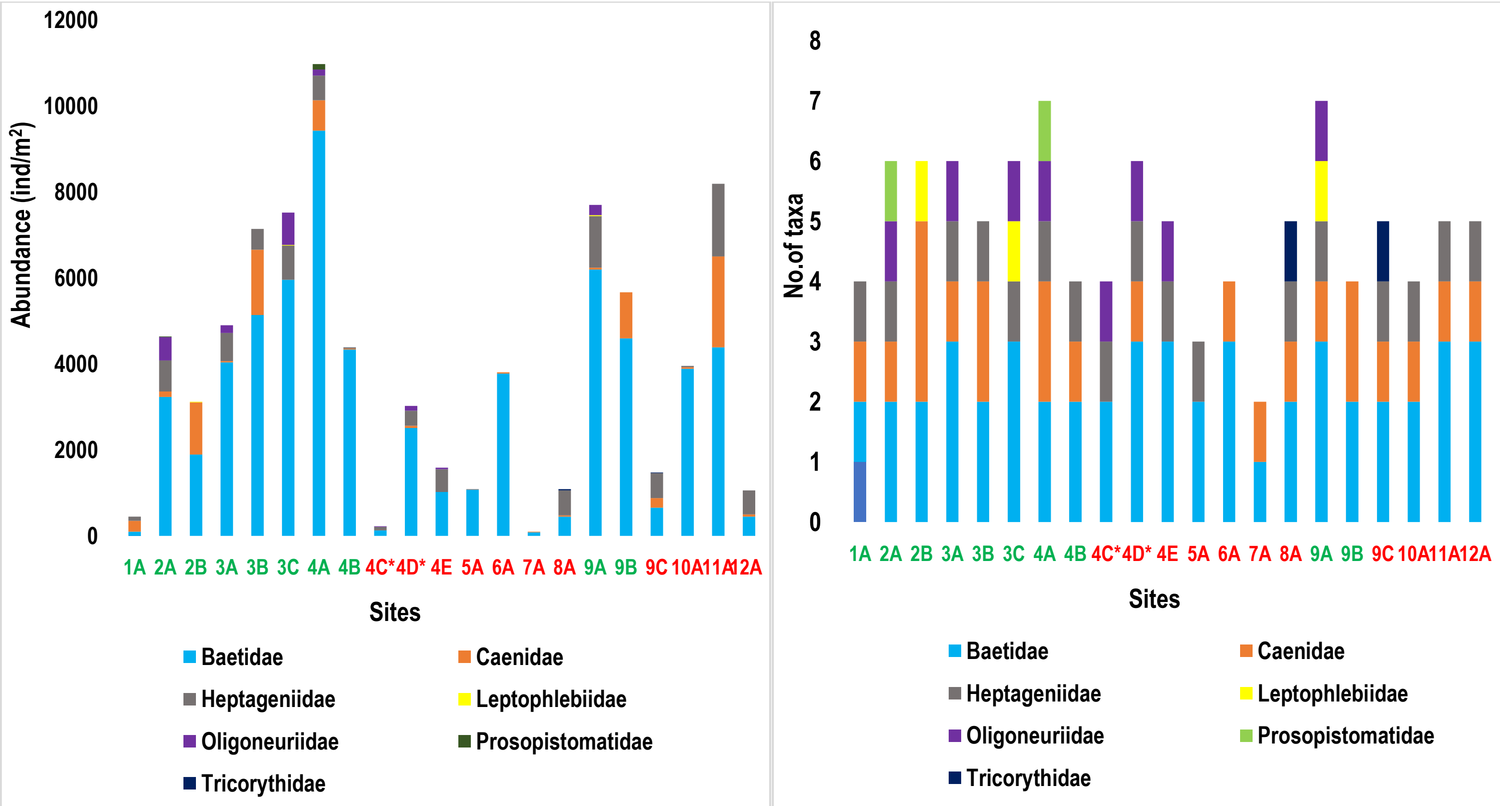


Figure 33: Abundance (left) and richness (right) of Ephemeroptera families. Sites labelled with * indicate same sites with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agricultural areas.

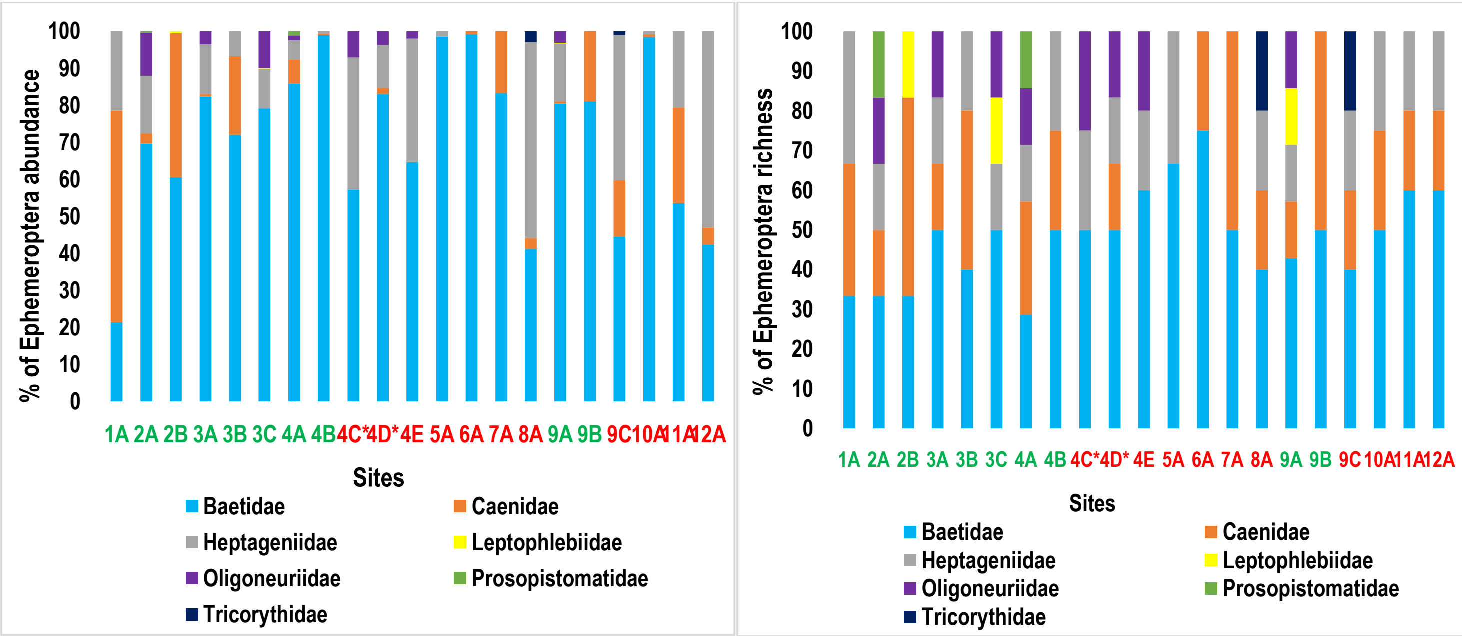


Figure 34: Dominance (%) in abundance (left) and in taxa richness (right) of Ephemeroptera families. Sites labelled with * indicate same site with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agriculture areas.

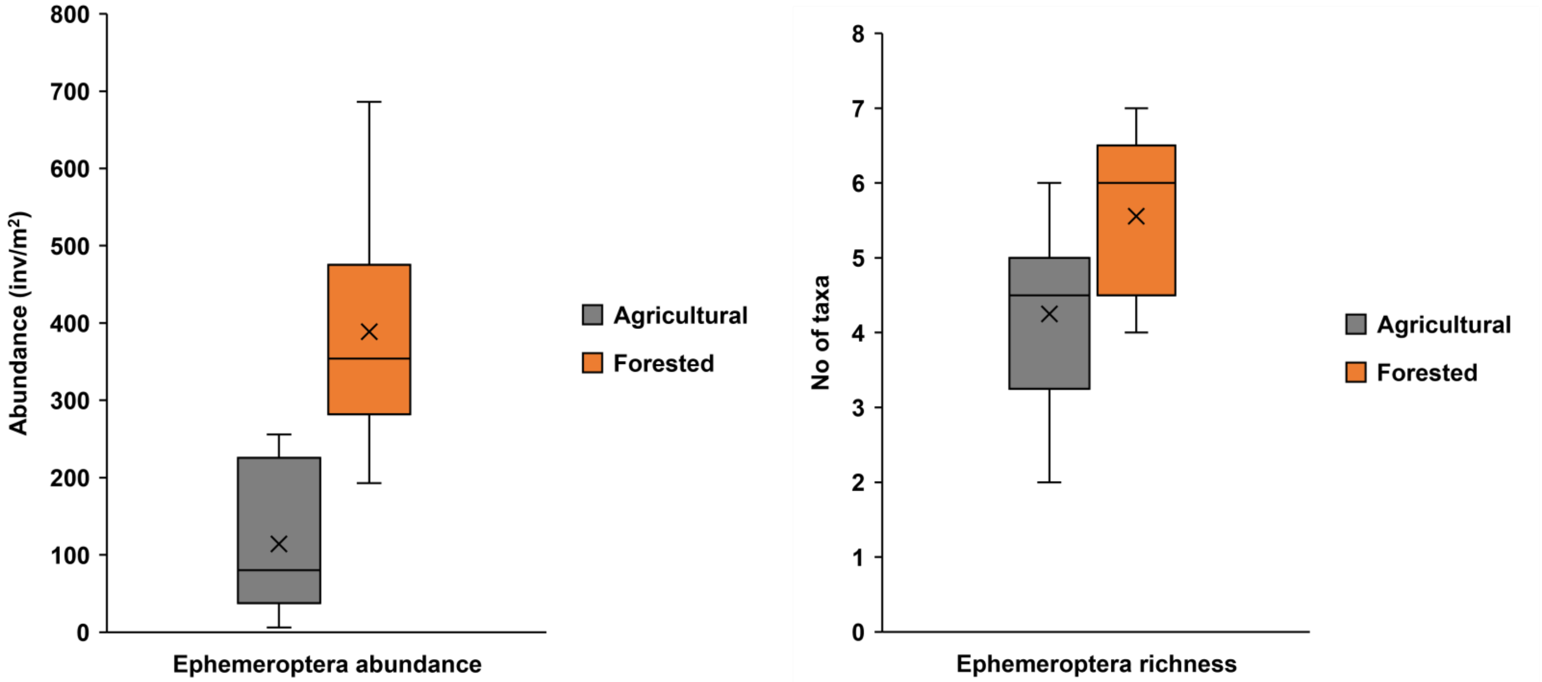


Figure 35: Abundance (left) and richness (right) of Ephemeroptera in forested and agricultural land use types

c) Trichoptera

The order Trichoptera was represented by nine families (Calamoceratidae, Lepidostomatidae, Pisuliidae, Polycentropodidae, Leptoceridae, Hydropsychidae, Hydroptilidae, Philopotamidae and Pychomyiidae). Hydropsychidae was the common family distributed across all sites (Figure 36). Lepidostomatidae was also distributed across most of the sites except in Chebich (5A), Chebirbei (7A) and Cheptilieny (10A). There were no Trichoptera recorded in site 4C (Kapkateny midstream 1st MHS). Highest Trichoptera abundance was recorded in Kimurio Tr1(3B). Highest Trichoptera diversity was recorded in Kimurio upstream(3A) and Kibisi tributary (9A). Lowest Trichoptera diversity was recorded in sites Chebich (5A) and Chebirbei (7A). Hydropsychidae was the dominant taxa across most sites (Figure 37). Polycentropodidae was the only Trichoptera in Chebirbei (7A) while Hydropsychidae was the only taxa in Chebich (5A). Philopotamidae occurred only in streams in forested areas and was the dominant taxa in Kibisis tributary(9A). Trichoptera diversity and richness was higher in forested streams than in agricultural streams (Figure 38).

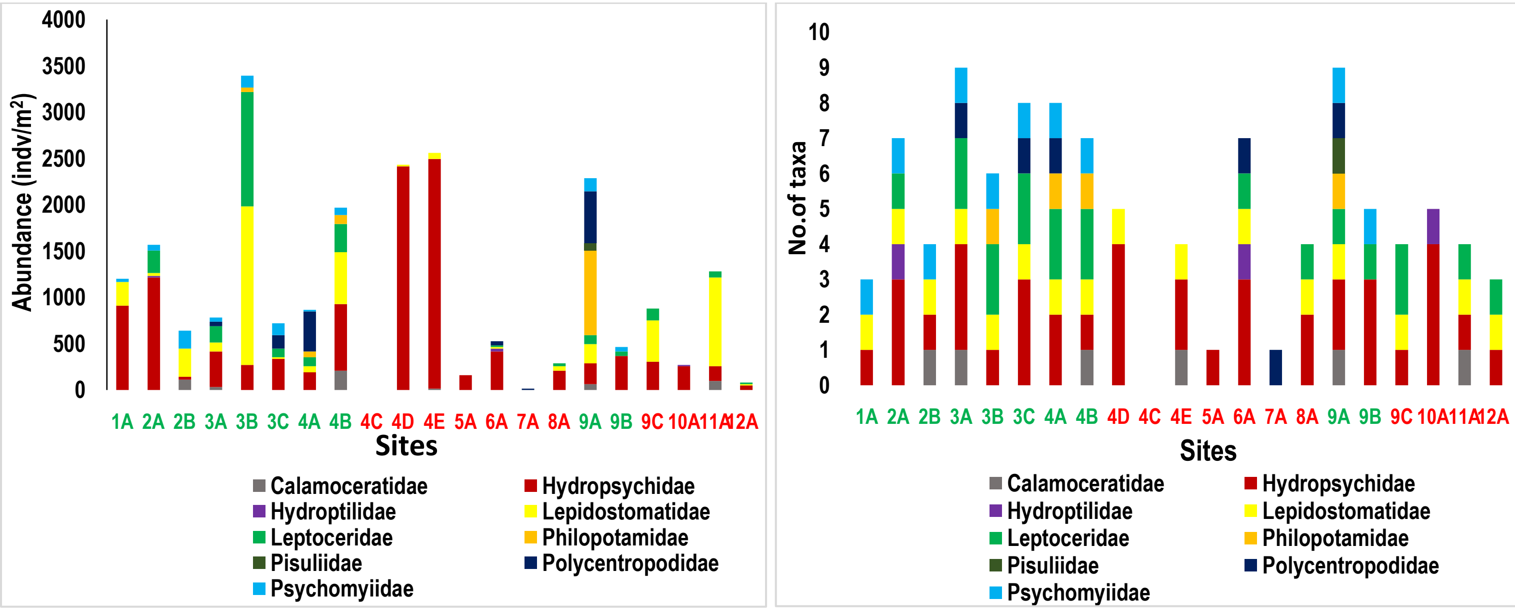


Figure 36: Abundance (left) and richness (right) of Trichoptera families. Sites denoted with green in x-axis are in forested areas while those in red are in agricultural areas.

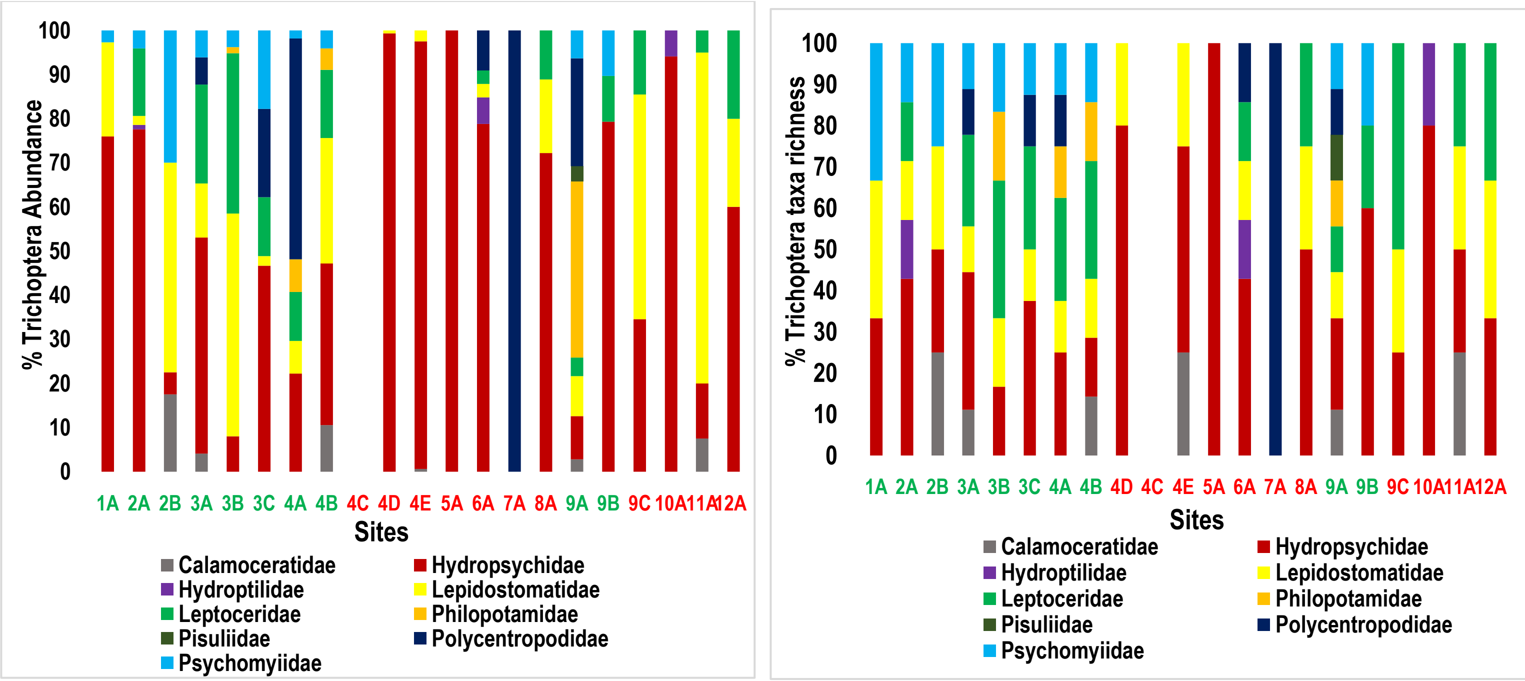


Figure 37: Dominance (%) in abundance (left) and in taxa richness (right) of Trichoptera families. Sites denoted with green in x-axis are in forested areas while those in red are in agriculture areas.

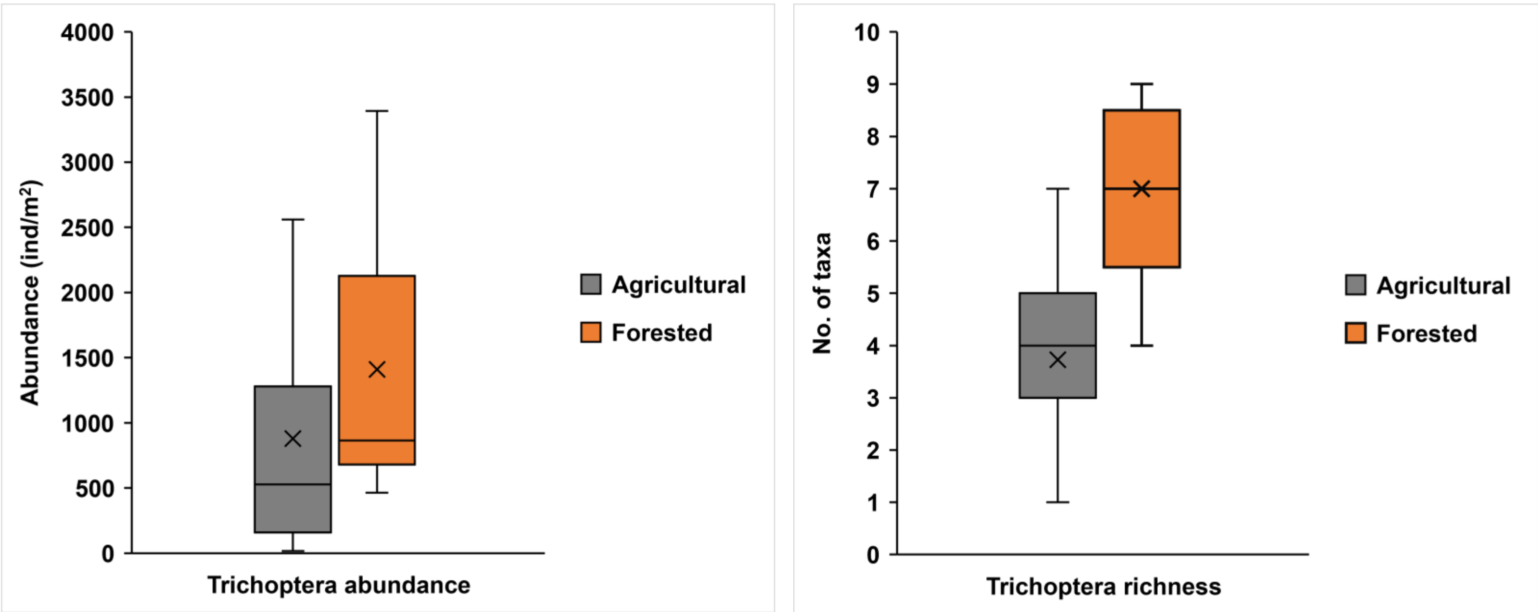


Figure 38: Abundance (left) and richness (right) of Trichoptera in forested and agricultural land use types

d) Diptera

The order Diptera was represented by 12 families with Simuliidae being the most abundant family (Figure 39). Kapkateny midstream (4D) had the highest Diptera abundance. Chemugumiet (1A), Kapkateny Tr1 (4B) and Kibisi upstream (9B) had the highest diversity of Diptera families (Figure 39). Simuliidae and Chironomidae were the dominant Diptera taxa across the sites (Figure 40). Simuliidae, Chironomidae and Tipuliidae had the highest relative richness across the investigated sites. Diptera abundance and richness was higher in streams in forested areas than in streams in agricultural areas (Figure 41).

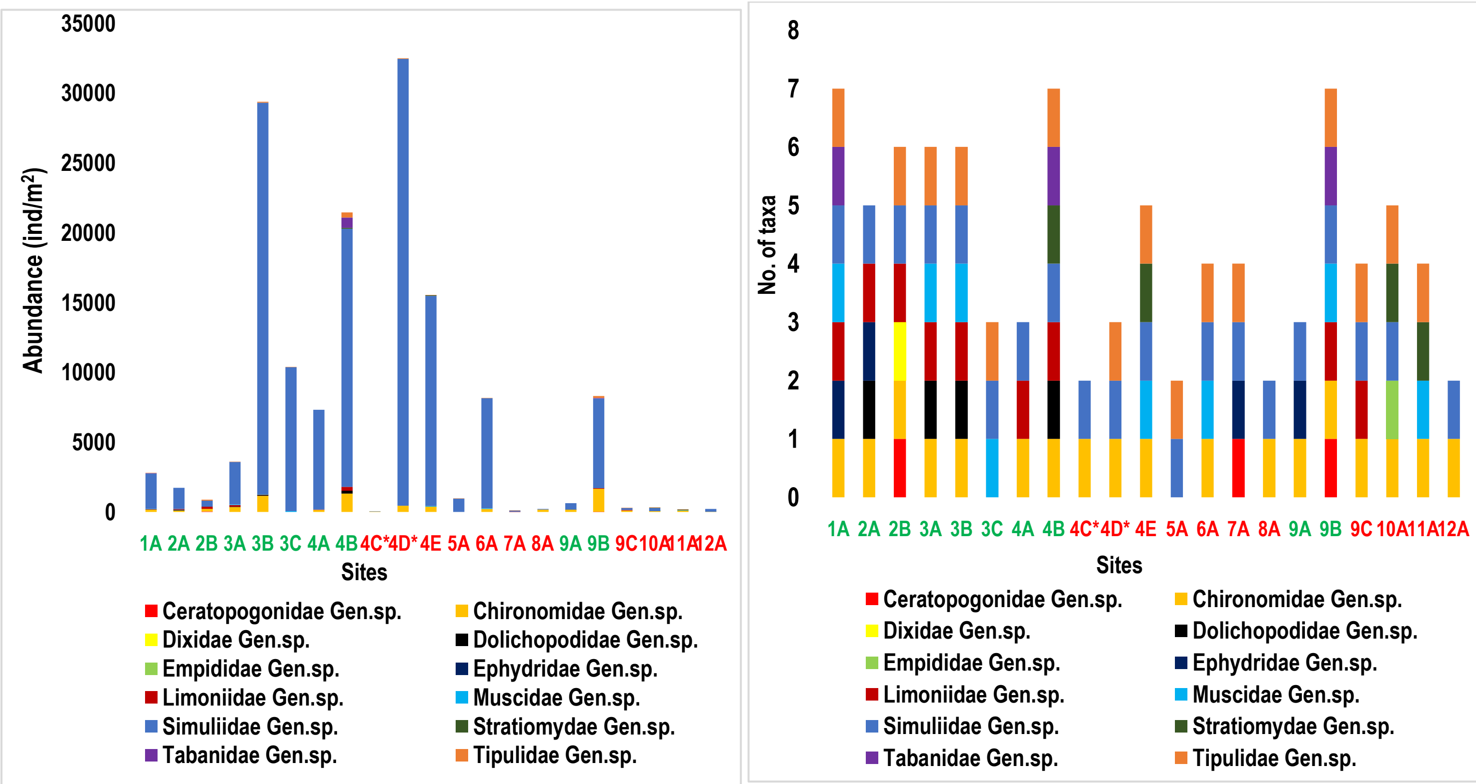


Figure 39: Abundance (left) and richness (right) of Diptera families. Sites labelled with * indicate same sites with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agricultural areas.

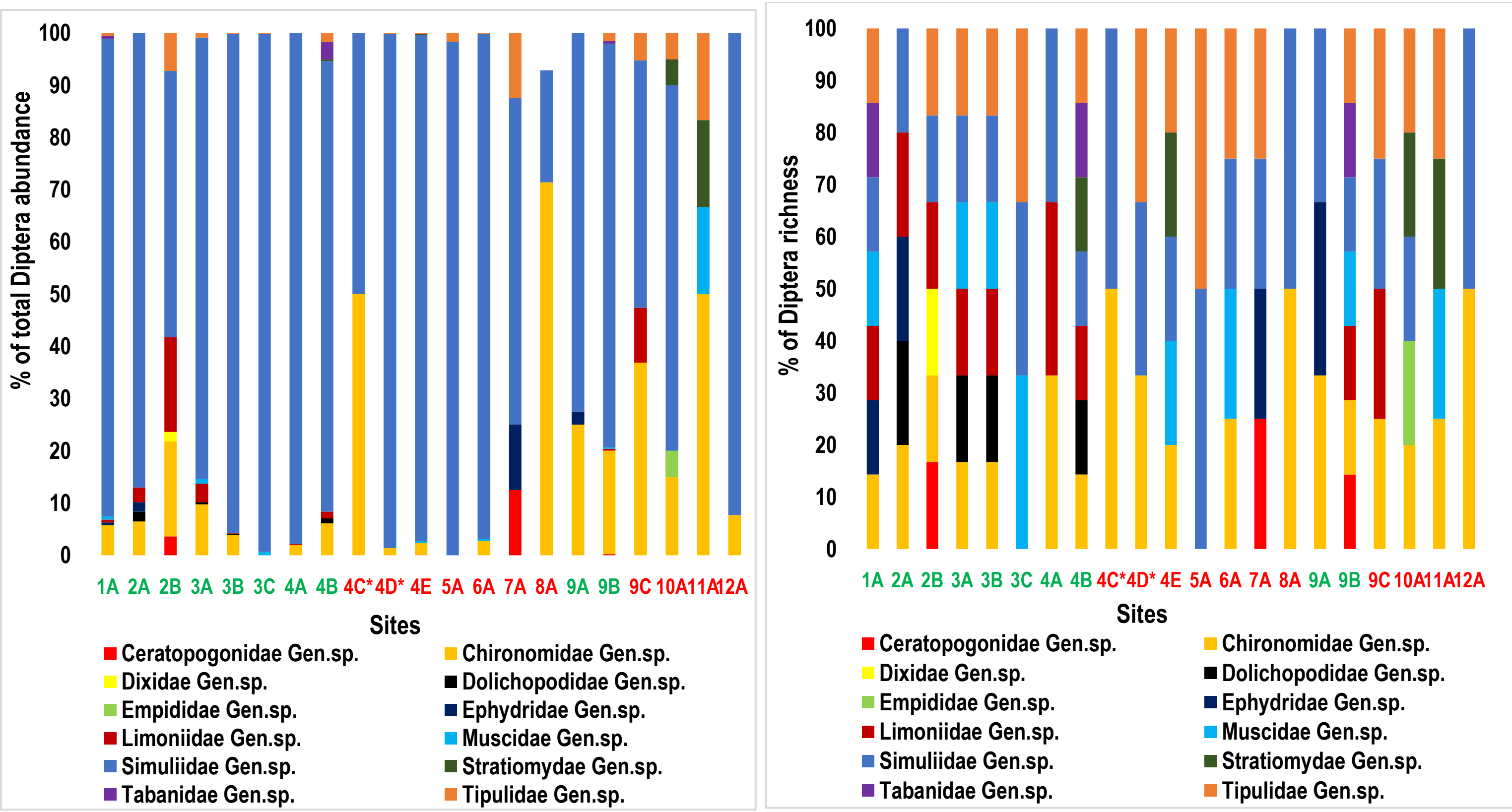


Figure 40: Dominance (%) in abundance (left) and in taxa richness (right) of Diptera families. Sites labelled with * indicate same site with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agriculture areas.

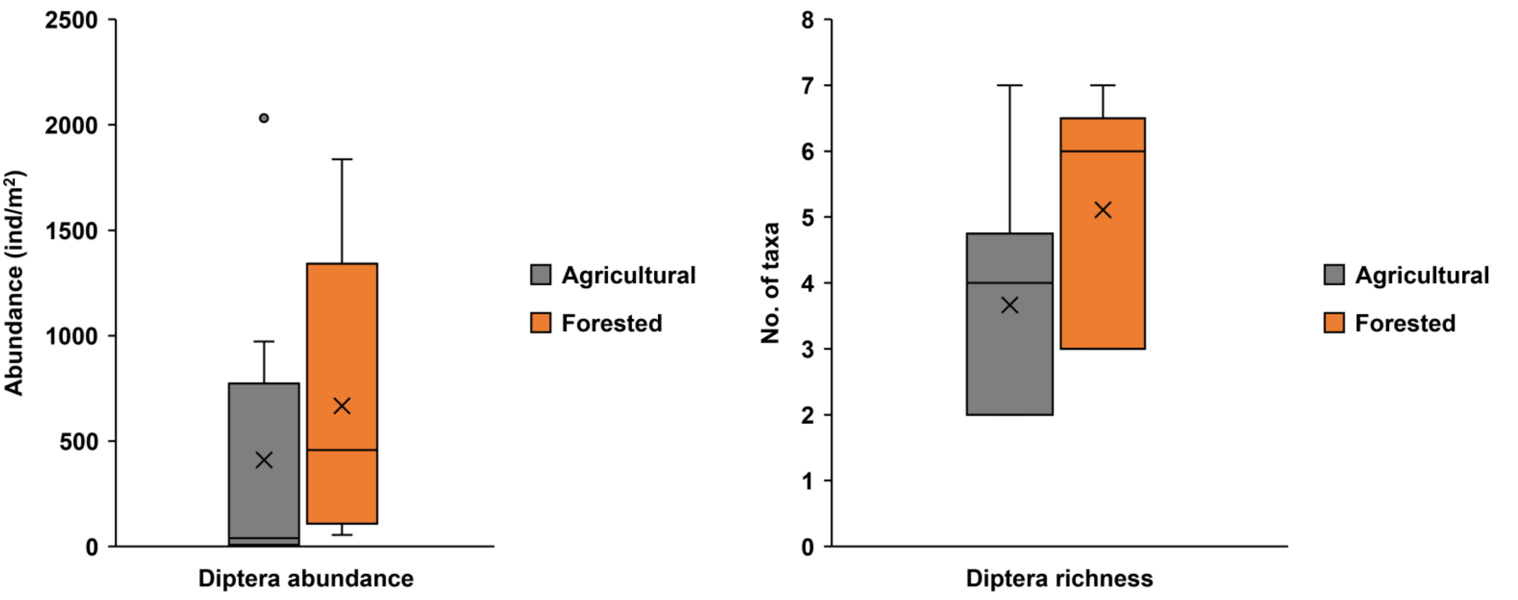


Figure 41: Abundance (left) and richness (right) of Diptera in forested and agricultural land use types

e) Coleoptera

Coleoptera were represented by five families (Dytiscidae, Gyrinidae, Scirtidae, Elmidae and Hydrophilidae). This order was limited to some sites and was absent in sites 4A, 4C, 4E, 9C and 12A. Kibisi upstream (9B) had the highest number of Coleoptera taxa compromising mostly of Scirtidae (Figure 42). Highest Coleoptera diversity was also found in Kibisi upstream (9B). The occurrence of Coleoptera families were generally low across sites with most sites containing one or two families. The highest number of Coleoptera families occurring in a site Kibisi upstream (9B) with only three families (Figure 43). The number of taxa was the same in agricultural and forested sites. Total abundance of Coleoptera families were however higher in forested sites (Figure 44).

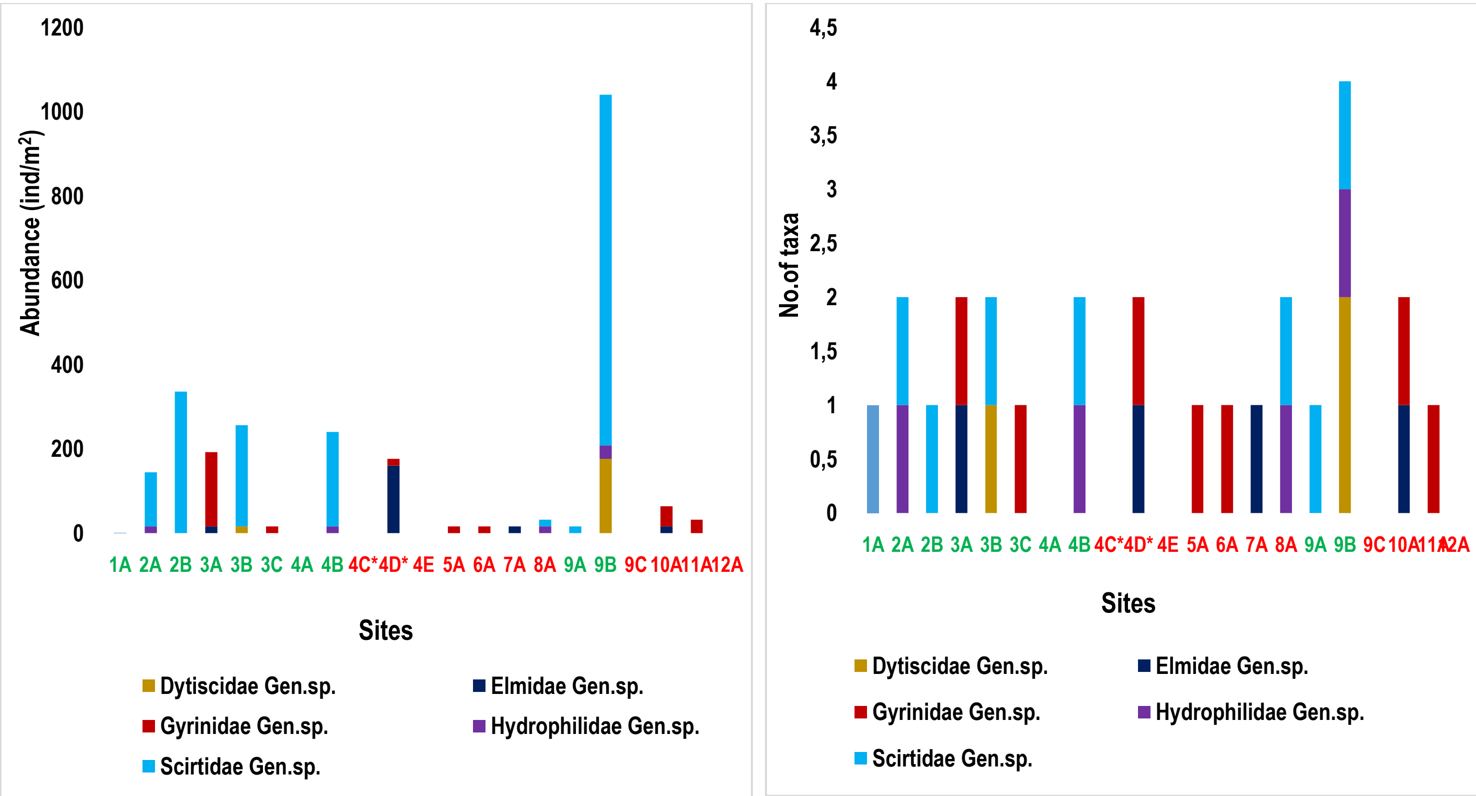


Figure 42: Abundance (left) and richness (right) of Coleoptera families. Sites labelled with * indicate same sites with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agricultural areas.

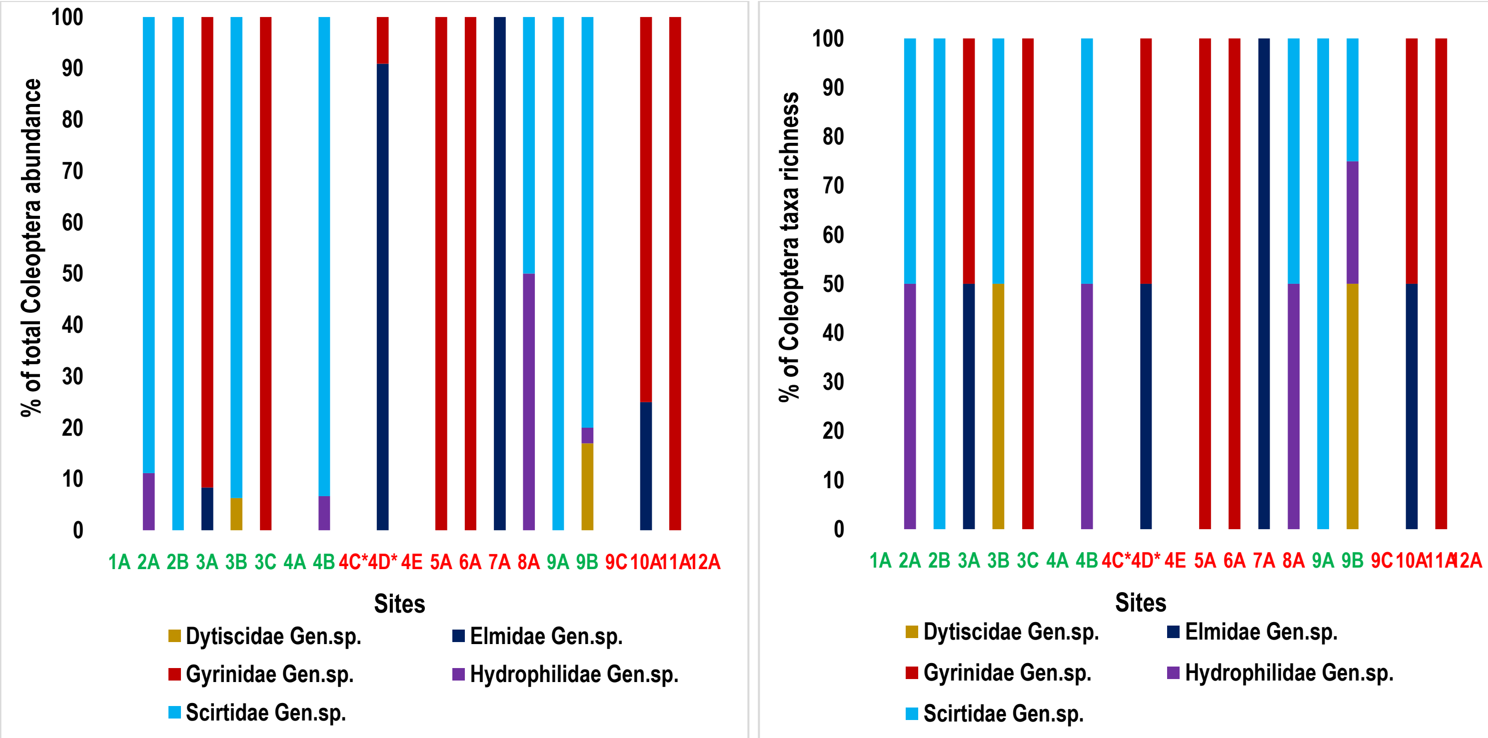


Figure 43: **Dominance (%) in abundance (left) and in taxa richness (right) of Coleoptera families. Sites labelled with * indicate same site with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agriculture areas.**

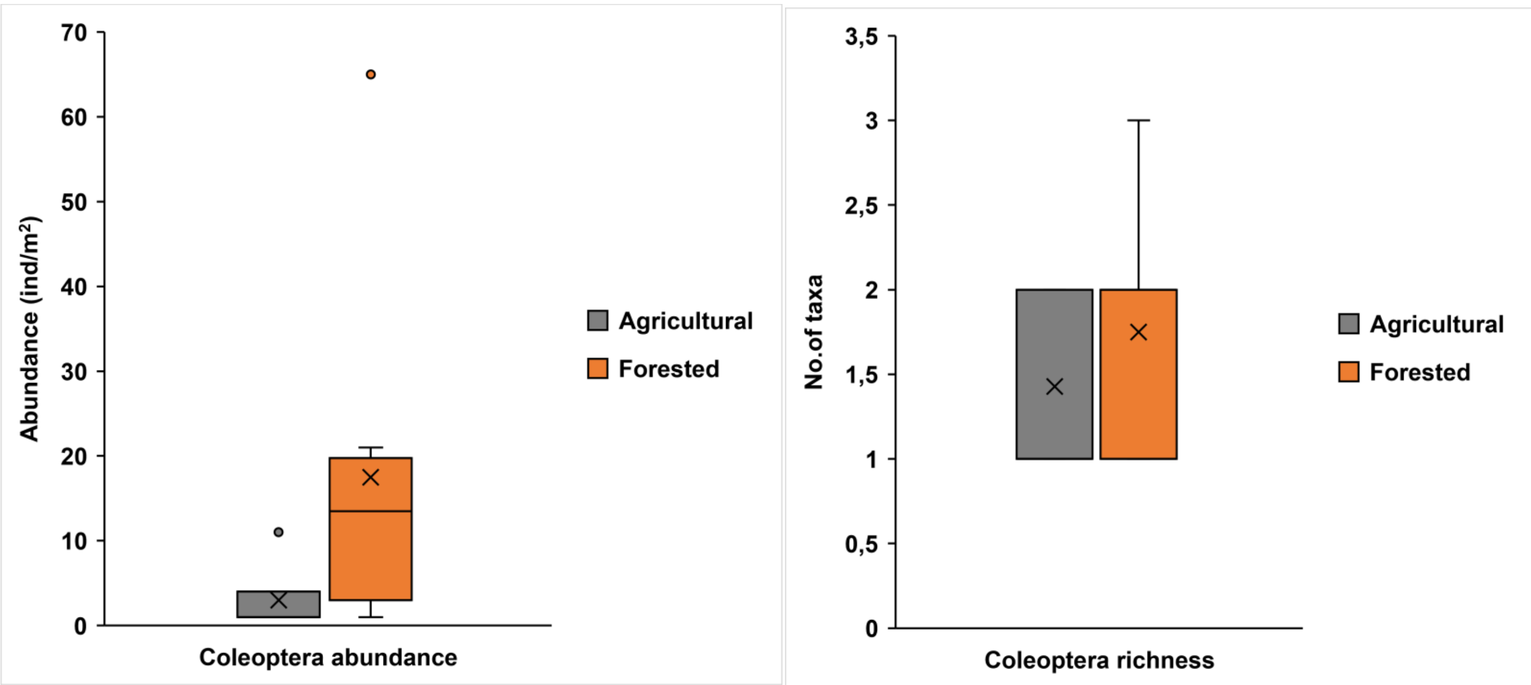


Figure 44: Abundance (left) and richness (right) of Coleoptera in forested and agricultural land use types

f) EPT taxa distribution

Ephemeroptera were the most abundant and dominant taxa among the EPT taxa distributed across all sites. Highest EPT abundance and diversity was recorded in 4A (Kapkateny upstream) while the lowest abundance and diversity was recorded in Chebirbei (7A). Kimurio upstream (3A) also recorded as high EPT diversity as in Kapkateny upstream (Figure 45). Plecoptera represented by the genus *Neoperla* had the least diversity and abundance among the EPT taxa only limited to streams in forested areas. Site 4C (Kapkateny midstream 1st MHS) was represented by only one EPT taxa (Ephemeroptera). There was higher diversity and richness of EPT taxa in streams in forested areas than in streams in agricultural areas (Figure 45). Richness of EPT taxa across sites were dominated by both Trichoptera and Ephemeroptera families (Figure 46).

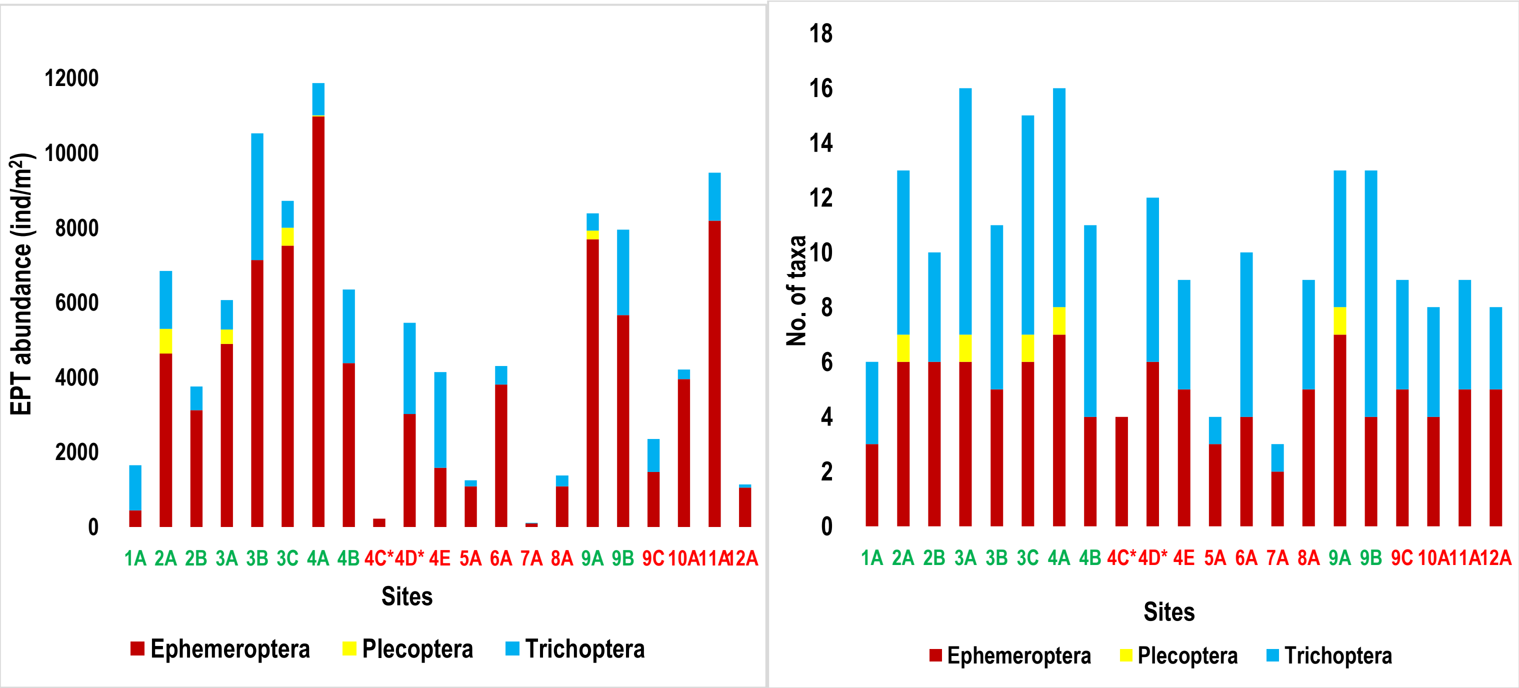


Figure 45: Abundance (left) and richness (right) of Ephemeroptera, Trichoptera and Plecoptera (EPT) taxa. Sites labelled with * indicate same sites with different MHS samples. Sites marked with green in x-axis are in forested areas while those in red are in agricultural areas.

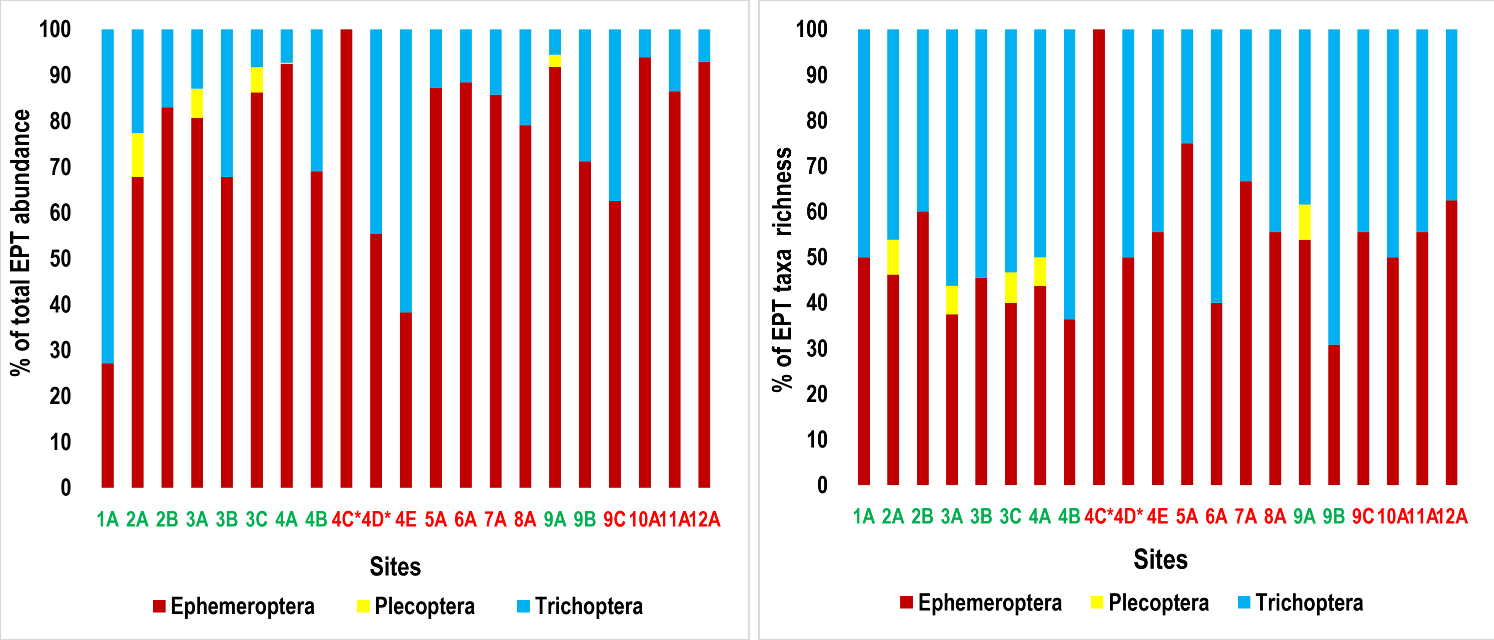


Figure 46: **Dominance (%) in abundance (left) and in taxa richness (right) of Ephemeroptera, Trichoptera and Plecoptera (EPT) taxa. Sites labelled with * indicate same site with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agriculture areas.**

4.4.2 Functional feeding groups (FFGs) diversity and richness among sites

Filtering-collectors and gathering-collectors were the most abundant and dominant FFGs distributed across all sites (Figure 47 & 48). Predators and shredders were the least abundant FFGs. Lowest FFG abundance and richness was recorded in Kapkateny 1st MHS (4C) and Chebirbei (7A). The low FFG abundance and richness correspond to the low taxa abundance in these two sites.

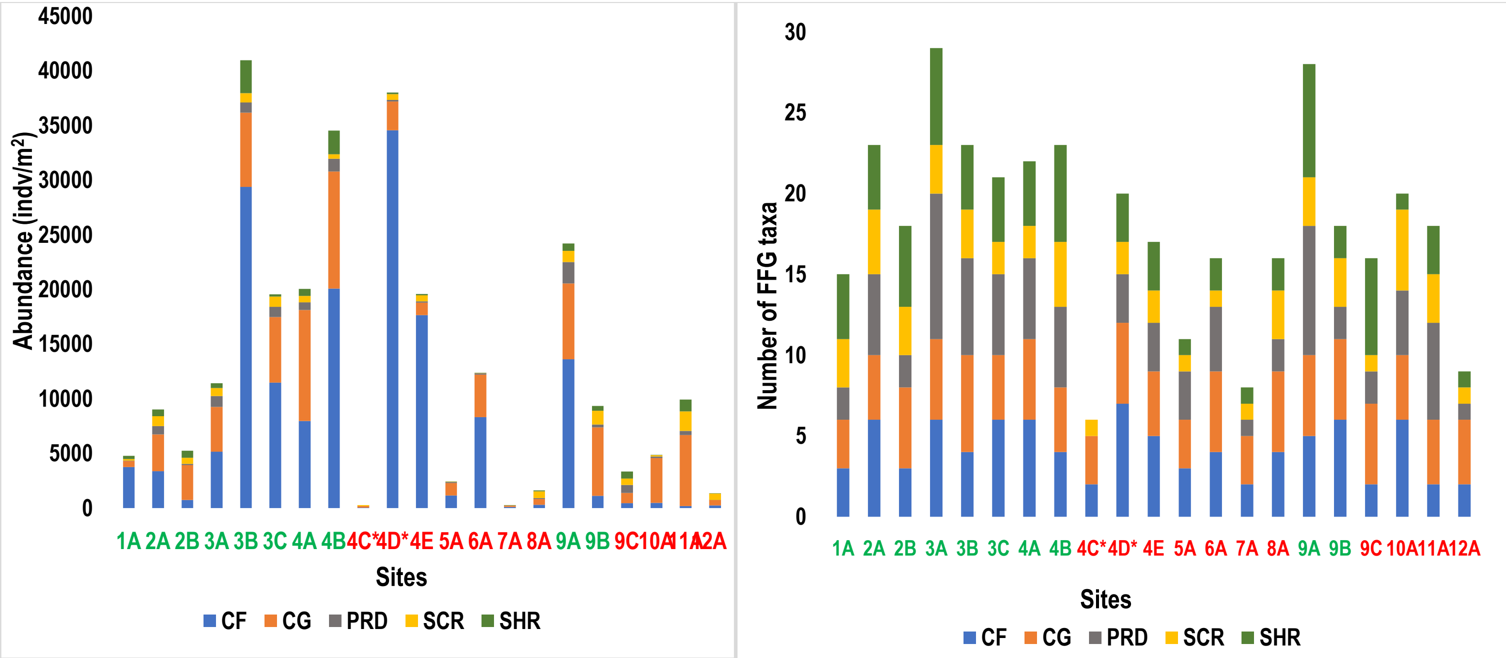


Figure 47: Abundance (left) and richness(right) of functional feeding groups. Sites labelled with * indicate same sites with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agricultural areas (CF=collector-filterers, CG=collector-gatherers, SCR=scrapers, SHR=shredders)

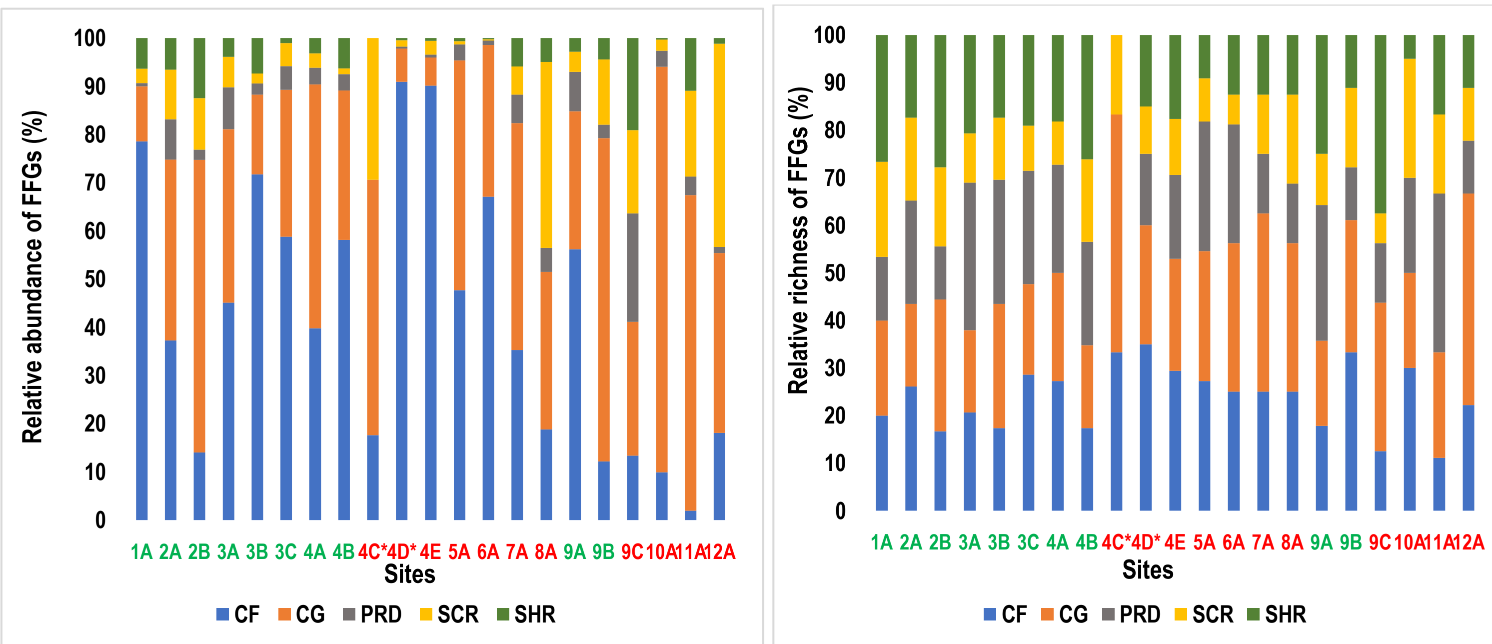


Figure 48: Dominance (%) in abundance (left) and in taxa richness (right) of functional feeding groups. Sites labelled with * indicate same site with different MHS samples. Sites denoted with green in x-axis are in forested areas while those in red are in agriculture areas. CF=collector-filterers, CG=collector-gatherers, SCR=scrapers, SHR=shredders

4.4.3 Biomass of Functional Feeding Groups

Kapkateny tributary (4B) recorded the highest biomass while Kapkateny midstream 1st MHS (4C) recorded the lowest biomass. Shredder biomass was high (contributed majorly by shredders) across sites with the highest being recorded in Kapkateny tributary (4B). There were however no scrapers recorded in this site. There were no shredders in site 4C (Kapkateny midstream 1st MHS). In this site, scrapers were the dominant functional feeding group. In Cheptilieny (10A), the biomass of collector-gatherers dominated the other feeding guilds while in Kapkateny downstream (4E), collector-filterers biomass dominated (Figure 49).

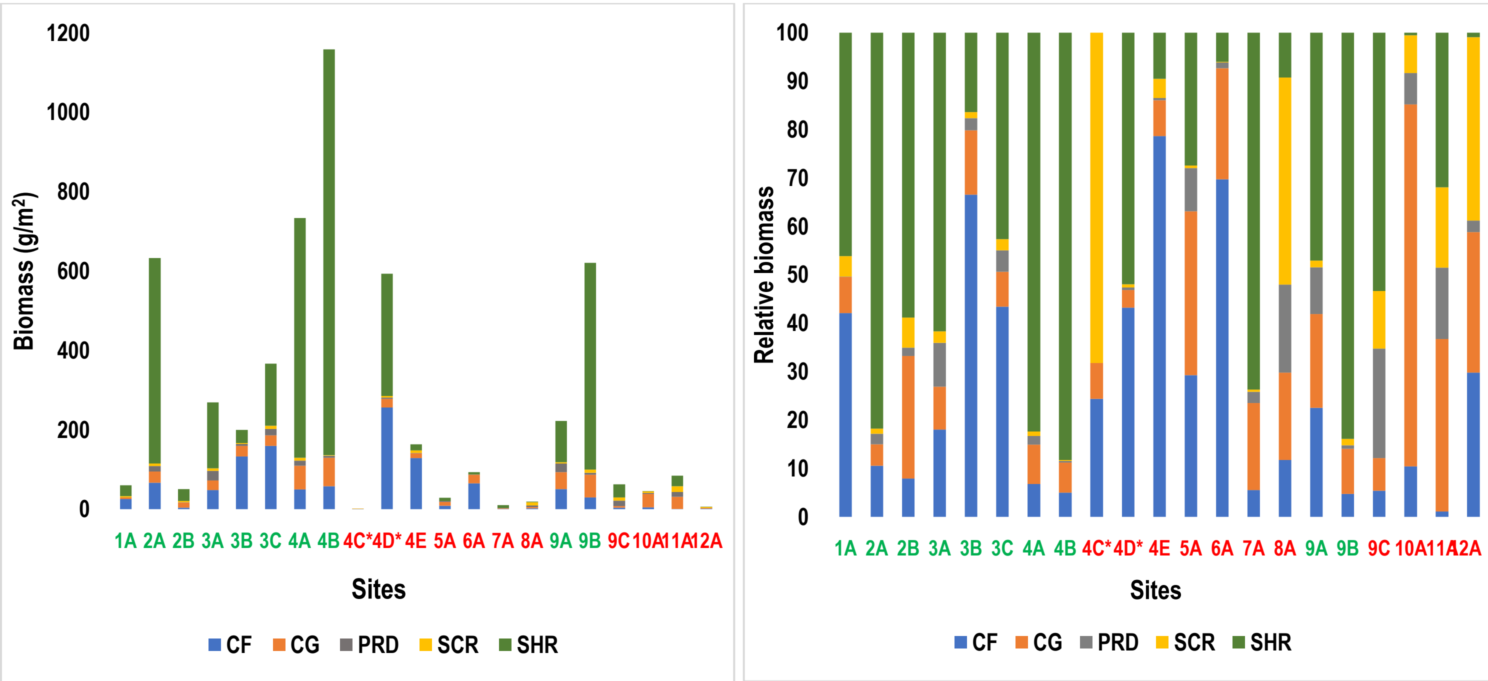


Figure 49: Total Biomass (left) and dominance (%) of biomass (right) of functional feeding groups. CF=collector-filterers, CG=collector-gatherers, SCR=scrapers, SHR=shredders

4.5 Land use patterns and macroinvertebrate composition

Forested land use type had a higher abundance of macroinvertebrates than agricultural land use type (Figure 50). Order Diptera (contributed significantly by Simuliidae) was the most abundant in both forested and agricultural land uses. Ephemeroptera (contributed significantly by Baetidae) and Trichoptera (contributed significantly by Hydropsychidae) were also recorded in high abundances in the two land use types. Order Plecoptera was not found in streams in agricultural land use. Order Trichoptera had the highest taxa richness in forested land use while Ephemeroptera and Diptera had the higher taxa richness in agricultural land use (Figure 51). Total biomass and total abundance of functional feeding groups was higher in forested than in agricultural land use type (Figure 52).

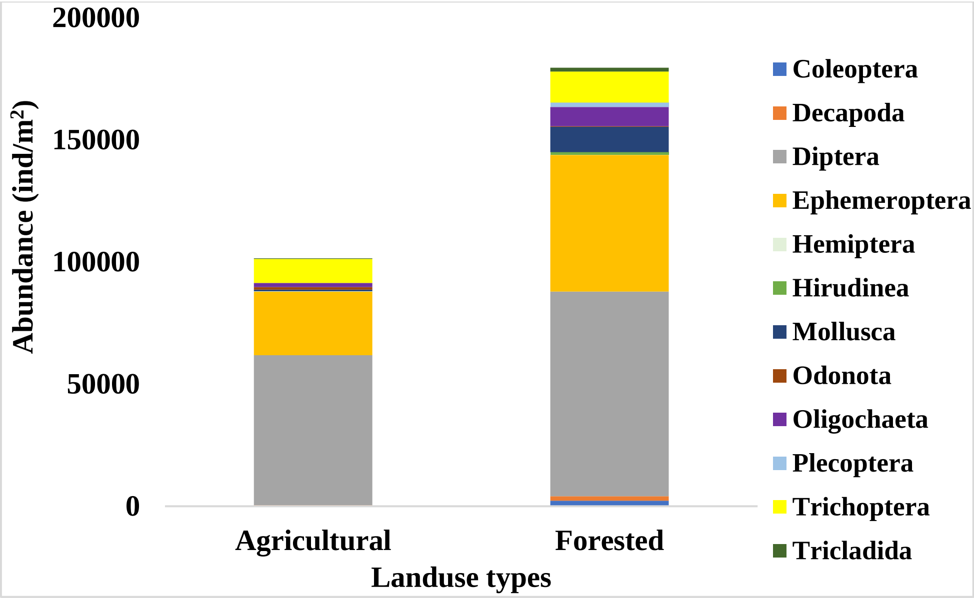


Figure 50: Mean abundance of macroinvertebrate groups across agricultural and forested land use types.

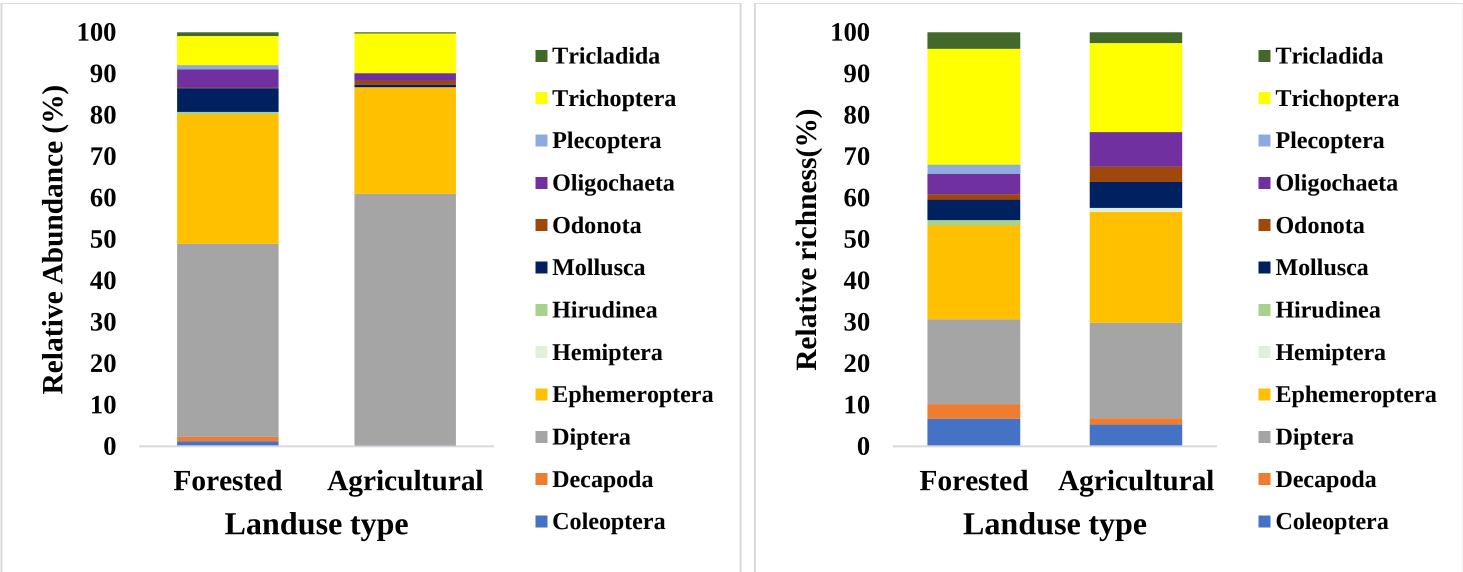


Figure 51: Dominance (%) in total abundance (left) and in total taxa richness (right) of orders across forested and agricultural land use types.

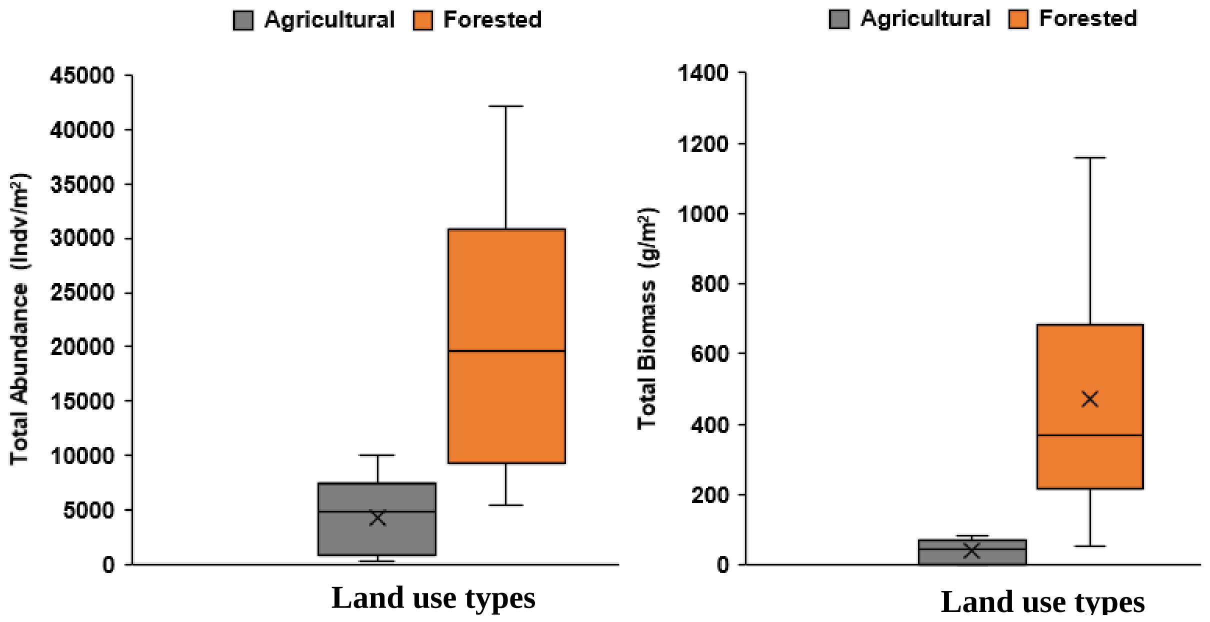
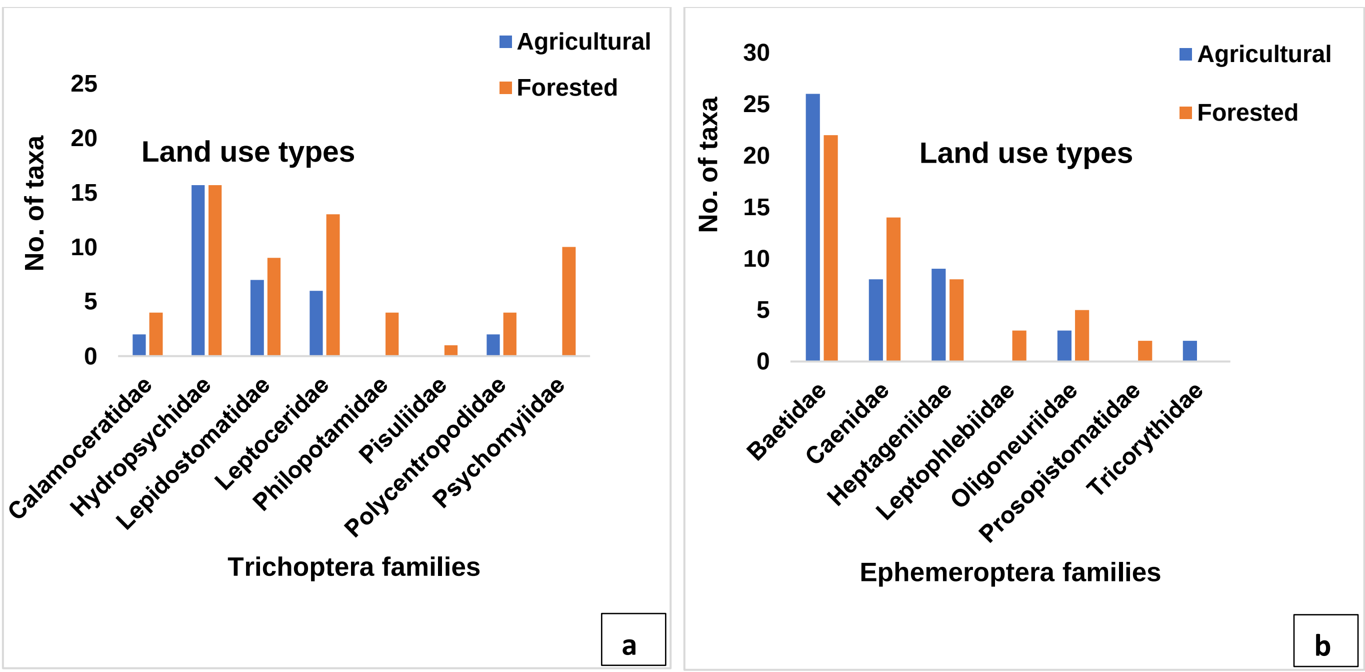


Figure 52: Abundance (ind/m^2) (left) and biomass (g/m^2) (right) of macroinvertebrate taxa in forested and agricultural land use types

Among the Trichoptera families Philopotamidae and Psychomyiidae were found only streams in forested land use (Figure 53). Leptophlebiidae and Prosopistomatidae in Ephemeroptera family were limited to streams in forested sites. Dixidae, Dolichopodidae and Tabanidae were limited to forested land use while Psychodidae and Empididae were limited to streams in agricultural land use. The Hydropsychidae were distributed in both agricultural and forested land use types.



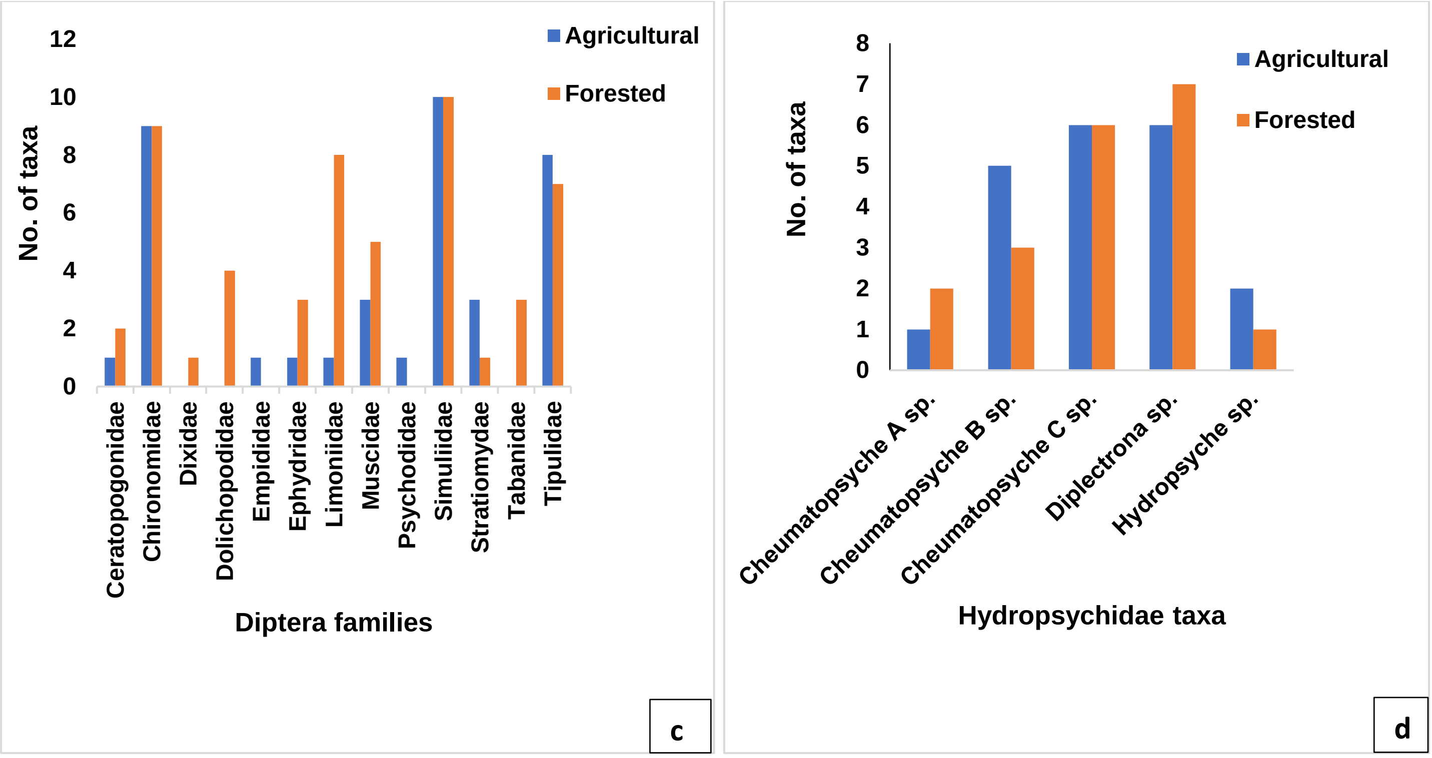


Figure 53: Distribution of Trichoptera (a), Ephemeroptera (b), Diptera (c) and Hydropsychidae (d) taxa in streams in agricultural and forested land use types.

4.5.2 Land use patterns and functional feeding groups

Biomass of functional feeding groups (FFGs) was significantly higher in streams within forested land use than in streams within agricultural land use ($t_{(20)} = -1.92$, $p = 0.001$). Although not significant, there was also a higher abundance recorded in forested streams than in agricultural streams (Figure 54). Collectors were the most abundant FFG in streams within the two land use types with filtering collectors being the most dominant functional group in the two land use types (Figure 55). Collector-gatherers, shredders and predator dominance were higher in forested streams than in streams within agricultural land use. Comparison between streams in the two land use types using biomass showed that shredder biomass contributed significantly ($p<0.05$) in the streams within forested land use.

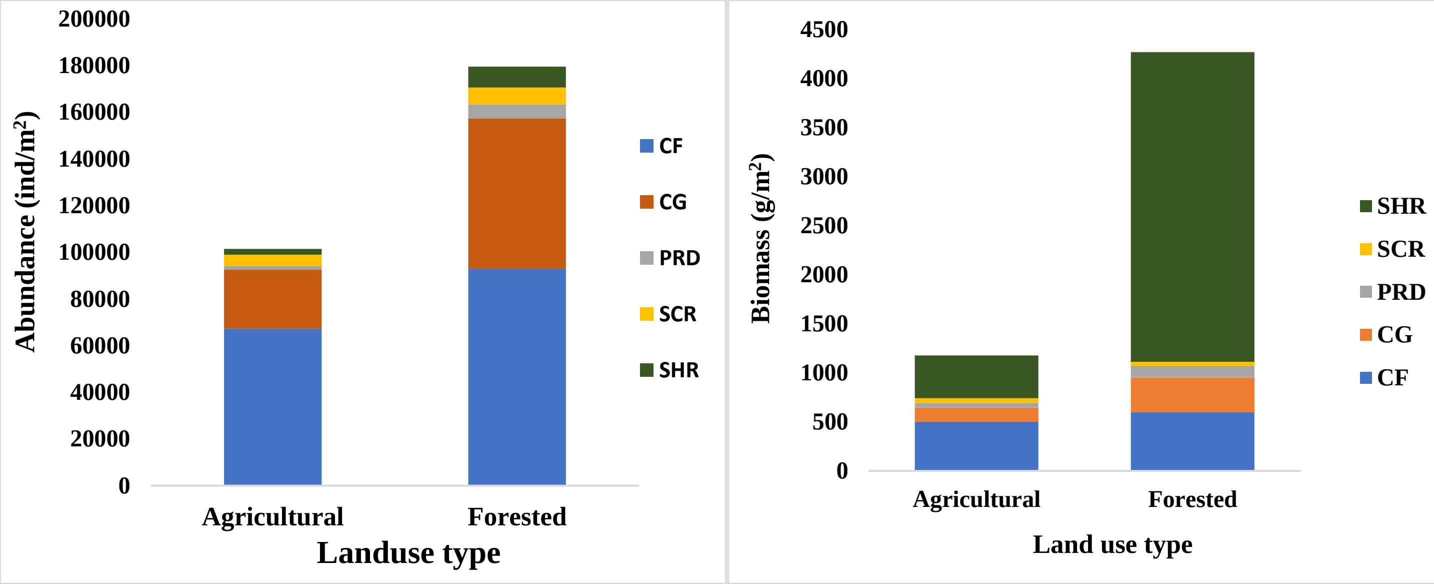


Figure 54: Abundance (left) and biomass (right) of macroinvertebrate FFGs in forested and agricultural land use types. CF = collector-filterers, CG = collector-gatherers, SCR = scrapers, SHR = shredders.

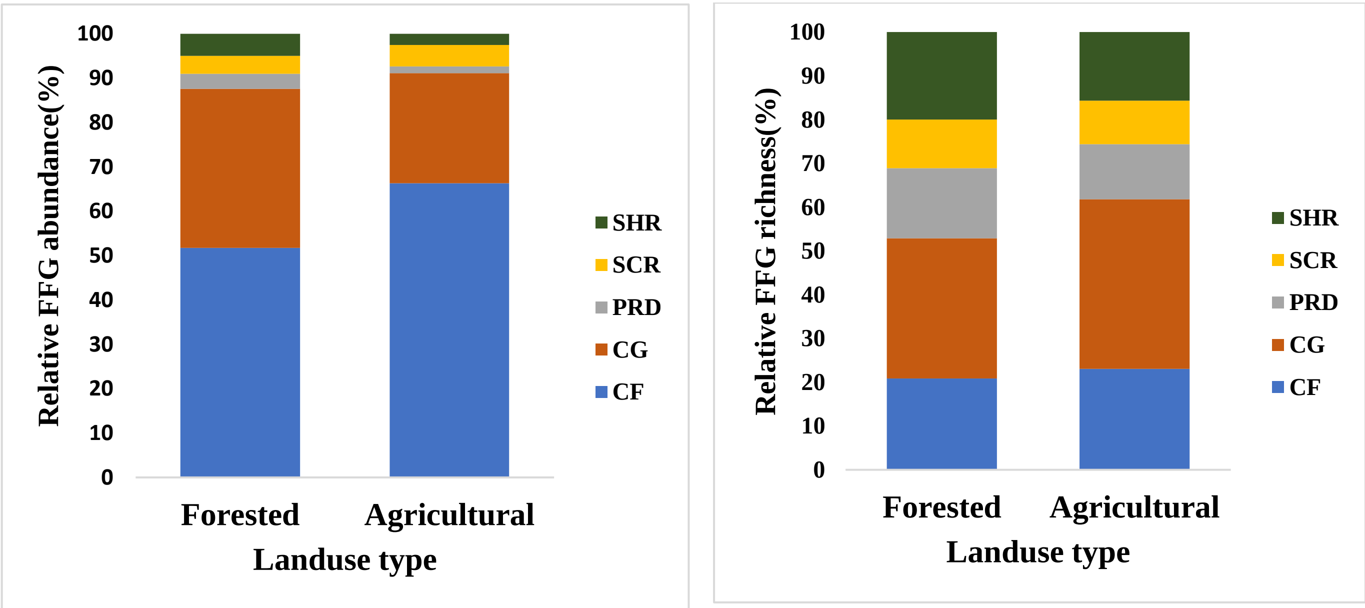


Figure 55: Dominance (%) in abundance (left) and in richness (right) of macroinvertebrate FFGs in agricultural and forested land use types. CF = collector-filterers, CG = collector-gatherers, SCR = scrapers, SHR = shredders.

The biomass of collector-filtering was dominant (42.3%) in agricultural streams while the biomass of shredders were dominant (73.9%) in forested streams (Figure 56). Scraper biomass was the least dominant in forested streams.

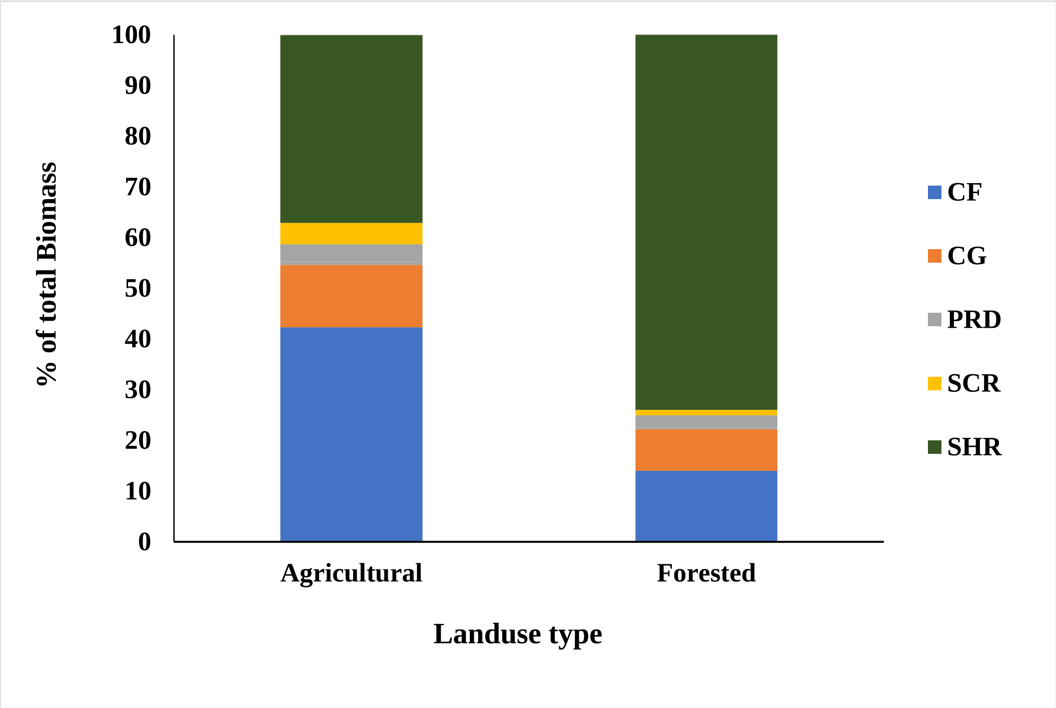


Figure 56: Dominance (%) in biomass of macroinvertebrate FFGs in agricultural and forested land use types. CF=collector-filterers, CG=collector-gatherers, SCR=scrapers, SHR=shredders.

Cluster analysis performed on the grouping of sites based on functional feeding groups showed streams within agricultural and forested land use grouping apart (Figure 57a.). Similarly, the groupings were also a function of altitudinal gradient with the streams forming two major clusters; between 1600 - 2200 m a.s.l. and above 2200 m a.s.l. (Figure 57b)

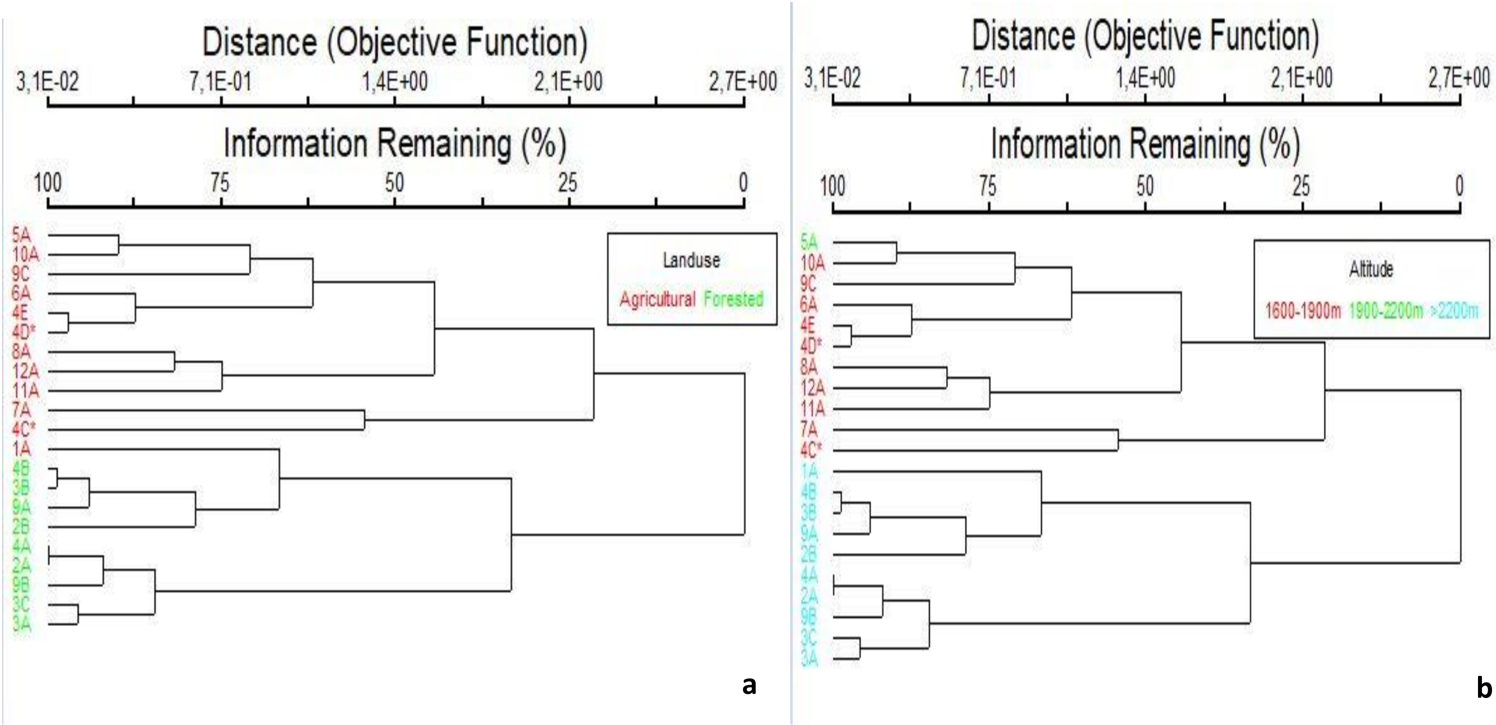


Figure 57: Cluster dendrogram of site groupings on logarithmic transformed abundance of macroinvertebrates based on functional groups; overlays: (a) Land use types, (b) Different altitudinal gradients

There was a significant negative correlation between % crop cover and all macroinvertebrate functional feeding guilds (predators, scrapers, shredders, Filterers and gatherers). Coarse particulate organic matter was also significantly negatively correlated with percentage crop cover. Vegetation cover was significantly positively correlated with collector gatherers, predators, shredders and filterers. CPOM was strongly and significantly correlated with the abundances of collector gatherers, scrapers, predators and shredder communities (Table 12). Percentage landcover values, used to assign land use classes, were used to run the correlation.

Table 12: Pearson correlation on percentage of land cover, CPOM, density (indv/m²) and biomass (g/m²) of macroinvertebrate functional feeding groups (n=21, P<0.05). CPOM = Coarse particulate organic matter.

	Predator		Scraper		Shredder		Filtering collectors		Gathering collectors		
Attributes	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	CPOM (g/m²)
% Crop cover	**-.623****	-.415	-.353	-.032	**-.471***	**-.558***	-.244	**-.642****	**-.602****	-.273	**-.558****
% Vegetation cover	**.628****	.422	.363	.043	**.476***	**.561***	.245	**.649****	**.606****	.273	**.561****
CPOM (g/m²)	**.655****	.439	**.741****	.402	**.575****	1	.236	**.686****	**.665****	.388	.375

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Abiotic variables and macroinvertebrate communities

The joint plot of the NMDS analysis for macroinvertebrate assemblages shows separated clear separation of the sites into forested and agricultural areas (Figure 58). Streams in forested sites were majorly characterized by high vegetation cover, altitude and CPOM quantity. These sites were separated from the sites within agricultural land use correlating with the parameters discharge, velocity, depth, temperature, salinity, conductivity, TSS, TDS, % of akal and crop cover.

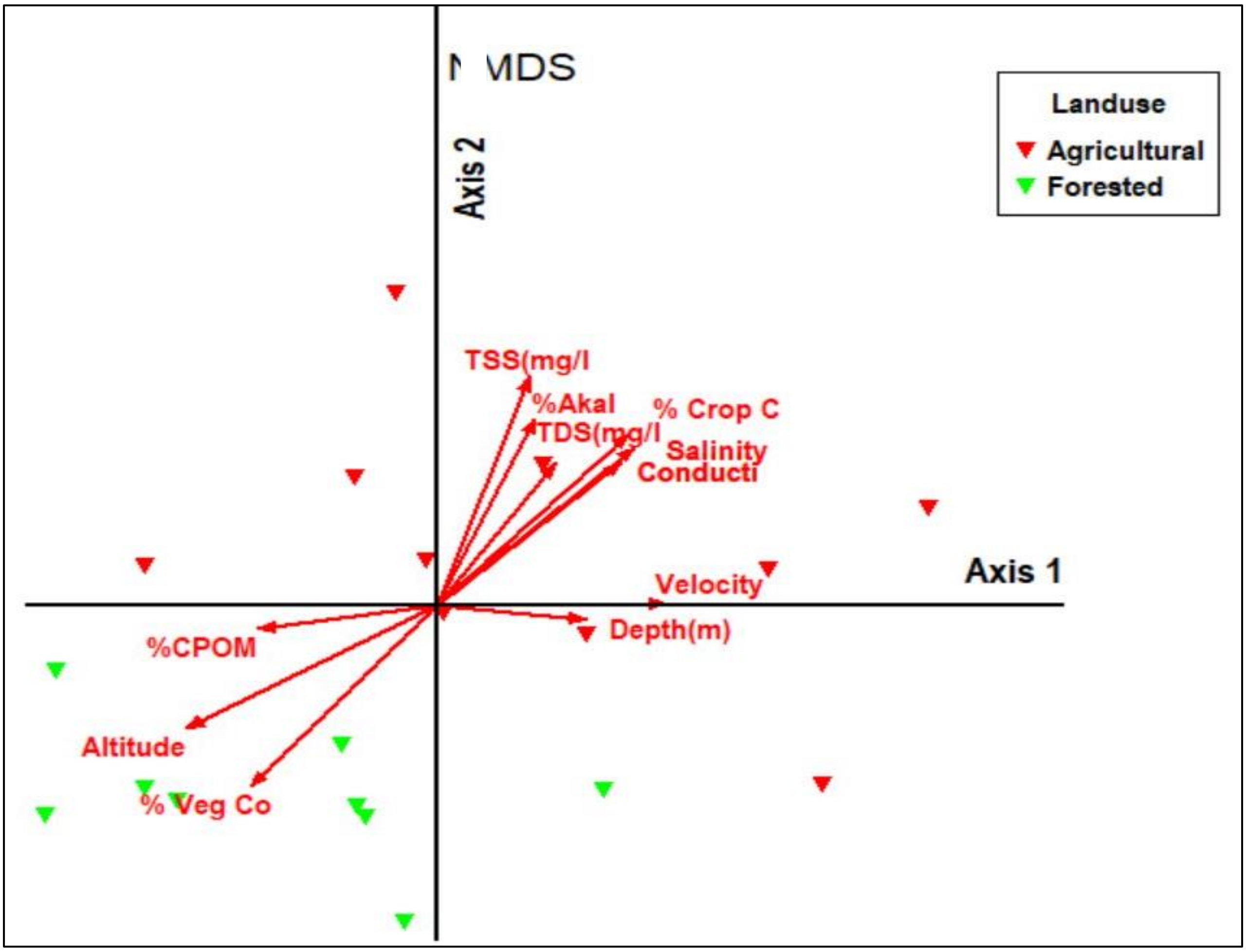


Figure 58: NMDS ordination graph on macroinvertebrate abundance and abiotic variables (Overlay: Forested and agricultural areas)

4.6 Indicator Species Analysis

Indicator species analysis performed on the log transformed abundance of taxa from all the sites indicated that the species occurrence of 13 taxa (Table 13) were significantly ($p<0.05$) assigned to streams occurring in forested land use type. *Tinodes* sp. from the family Psychomyiidae (Trichoptera) had the highest indicator value (97.2) with a p value of (< 0.05). Coenagrionidae and *Cheumatopsyche* B had high indicator values (31.6 & 28.7 respectively) in agricultural land-use type (Table 14).

Table 13: Abundance-based indicator species analysis for macroinvertebrates in forested land use type. *Bolded values showing significance (p<0.05) with a strong indicator value of > 70%

Taxon	land use type	Indicator value (%)	Mean	S. Dev	p*
Afrocaenis	Forested	44.4	18.9	8.1	0.0206
Baetis.sp	Forested	**77.7**	55.9	6.1	**0.0008**
Dolichopodidae	Forested	44.4	19.9	8.39	0.0208
Limoniidae	Forested	**73.9**	33.9	10.23	**0.0024**
Neoperla	Forested	55.6	22.2	8.67	0.0078
Oligoneuriopsis	Forested	52.2	31.1	10.09	0.038
Sphaeriidae	Forested	**96.5**	63.1	11.12	**0.0012**
Planariidae	Forested	**78.2**	42.9	9.6	**0.002**
Potamonautidae	Forested	**84.6**	38.8	10.64	**0.0018**
Scirtidae	Forested	66.2	28.7	9.94	0.0034
Tinodes	Forested	**97.2**	34.9	9.28	**0.0002**
Triaenodes	Forested	**86**	35.7	10.66	**0.0002**
Wormaldia	Forested	44.4	21.2	8.17	0.0196

Table 14: Abundance-based indicator species analysis for macroinvertebrates in agricultural land use type. Bolded values showing indicator values > 25%.

Taxa	Land use	Indicator Value (%)	Mean	S.Dev	P-Value
Adicella	Agricultural	18.2	11.8	6.89	0.4781
Cheumatopsyche B	Agricultural	**28.7**	29.2	8.59	0.4587
Coenagrionidae	Agricultural	**31.6**	26.9	8.50	0.2635
Elmidae	Agricultural	21.2	18.6	7.99	0.4557
Empididae	Agricultural	9.1	9.5	0.47	0.948
Hydropsyche	Agricultural	13.8	16.0	6.81	0.5963
Libellulidae	Agricultural	18.2	12.0	6.66	0.4749
Orthothrichia	Agricultural	12.2	15.9	6.52	0.8590
Planorbidae	Agricultural	21.1	18.2	8.22	0.3679
Stratiomyidae	Agricultural	18.5	18.3	8.17	0.5831
Tricorythidae	Agricultural	18.2	11.8	6.87	0.4781

Seven taxa were assigned to altitude ranges of above 2200m a.s.l. (Table 15). *Tinodes* sp. occurrence was 100% in this altitude class. Occurrence of *Potamonautes* sp. and Sphaeriidae within this altitude class was also high.

Table 15: Abundance-based indicator species analysis on altitude classification. *Bolded values showing significance (p<0.05) with a strong indicator value of > 70%.

Taxon	Altitude (m)	Indicator Value (%)	Mean	S. Dev	P*
Diplectrona	>2200	66.0	40.6	12.52	0.0438
Limoniidae	>2200	**75.7**	33.2	13.13	**0.0116**
Sphaeriidae	>2200	**96.7**	57.5	14.18	**0.0002**
Potamonautes	>2200	**83.8**	36.7	12.75	**0.001**
Scirtidae	>2200	59.3	30.1	13.48	0.0268
Tinodes	>2200	**100.0**	33.3	11.65	**0.0002**
Triaenodes	>2200	**75.7**	35.3	13.97	**0.024**

4.7 Longitudinal distribution of functional feeding guilds

Shredder biomass dominated in the upstream reaches which decreased gradually downstream (Figure 59). Scraper biomass was higher in downstream reaches in comparison to scraper dominance in upstream and midstream reaches. Filterers abundance were however dominating in all the reaches being highest in midstream reaches. In Kapkateny stream, the only site sampled in all the reaches, similar trends were recorded in distribution of the biomass and abundance of the macroinvertebrate functional guilds (Figure 60).

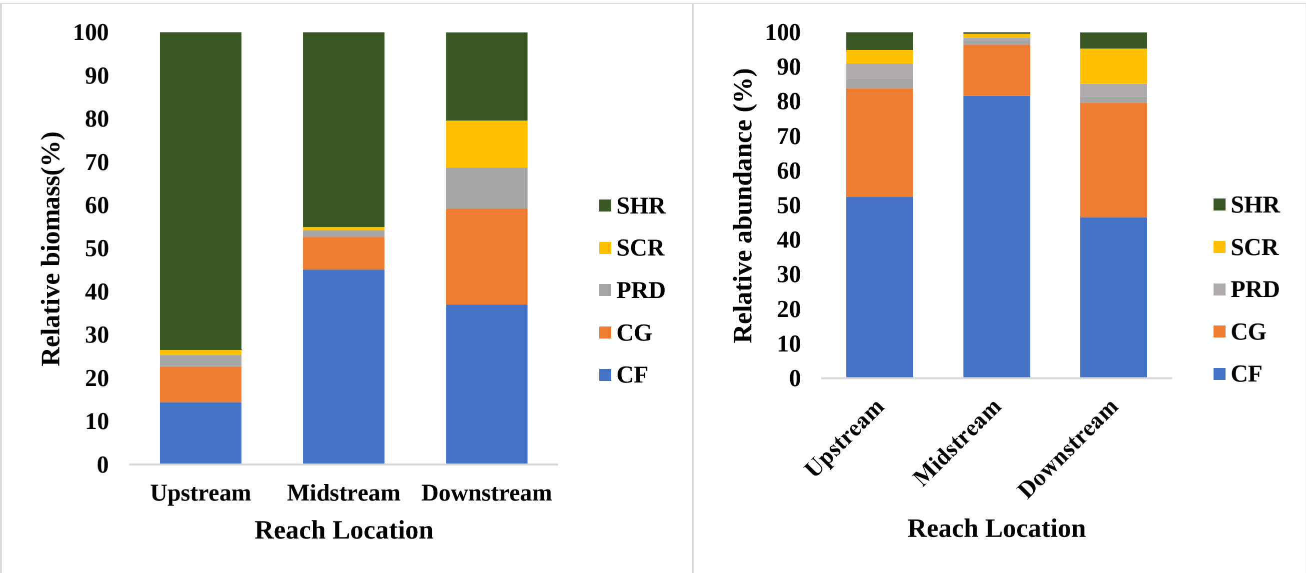


Figure 59: Dominance (%) in abundance and biomass of macroinvertebrate FFGs along a longitudinal gradient in all the sites; Upstream sites (2239-2435 m a.s.l.), Midstream sites between (1850-1950 m a.s.l.) and downstream sites of altitude range (1624-1701m a.s.l.) CF=collecting collector-filterers, CG=collector-gatherers, SCR=scrapers, SHR=shredders.

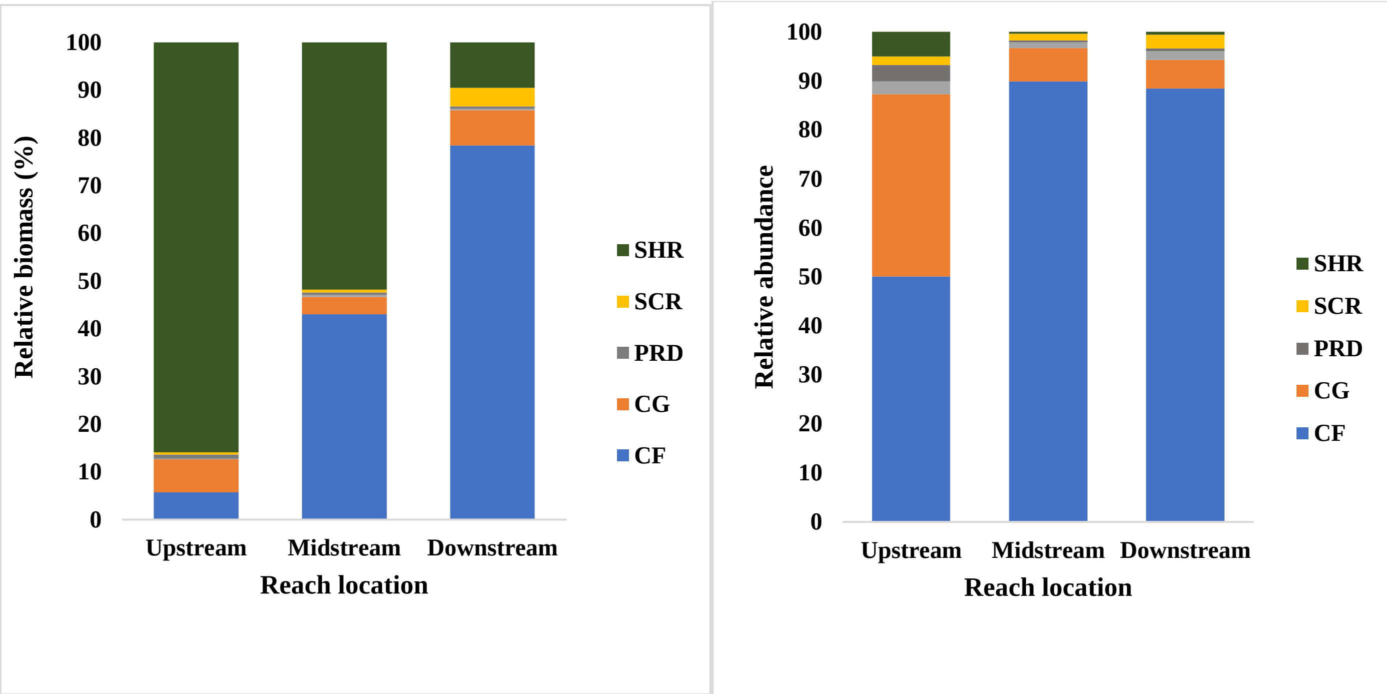


Figure 60: Dominance (%) in abundance and biomass of macroinvertebrate FFGs along a longitudinal gradient in Kapkateny stream. (Upstream – 2293 m a.s.l., Kapkateny midstream-1896 m asl Kapkateny downstream - 1660 m asl). CF=collector-filterers, CG=collector-gatherers, SCR=scrapers, SHR=shredders.

4.7.1 Distance to the forest

A correlation between the proximity of sites to the forest and their assigned percentage land cover was done and the results showed a strong significant correlation. Percentage crop cover was significantly negatively correlated with percentage vegetation cover. Percentage crop cover was however positively significantly correlated with the distance to the nearest forest (Table 16).

Table 16: Pearson correlation; landcover percentages and the distance to the nearest forest. (N = 20). Values in bold indicate significant (p<0.05) correlations between variables.

		%crop cover	% Veg cover	Nearest Forest(m)
% Crop cover	Pearson Correlation	1	**-.999****	**.881****
	Sig. (2-tailed)		**.000**	**.000**
% vegetation cover	Pearson Correlation	**-.999****	1	**-.880****
	Sig. (2-tailed)	**.000**		**.000**
Nearest Forest (m)	Pearson Correlation	**.881****	**-.880****	1
	Sig. (2-tailed)	**.000**	**.000**	

**. Correlation is significant at the 0.01 level (2-tailed).

4.7.2 Local effects of disturbance overrides large-scale conditions (Kapkateny midstream, sites 4C & 4D).

Effects of utilizing streams as livestock watering points on macroinvertebrate communities was investigated by taking different MHS samples within the same site in Kapkateny midstream. The first MHS was taken from a site frequently disturbed by livestock while the 2nd MHS was taken further away from the point of disturbance. The results presented in Figure 61 showed great reduction in macroinvertebrate taxa in site subjected to the disturbance. Only three orders were found within this site (Oligochaeta, Ephemeroptera and Diptera) while the 2nd site had nine orders. The abundance of taxa in the 2nd MHS was higher, 28,448 (ind/m^2) than in the first site, which had a total taxa of 304 (ind/m^2). The diversity of families (16 families) in the 2nd MHS was also higher than in the 1st MHS (six families). The most abundant family in the 1st MHS was the Baetidae while in the 2nd MHS was Simuliidae. Baetidae was the family with a higher number of taxa in the 1st MHS while Hydropsychidae family in the 2nd MHS had a higher number of taxa (Figure 62).

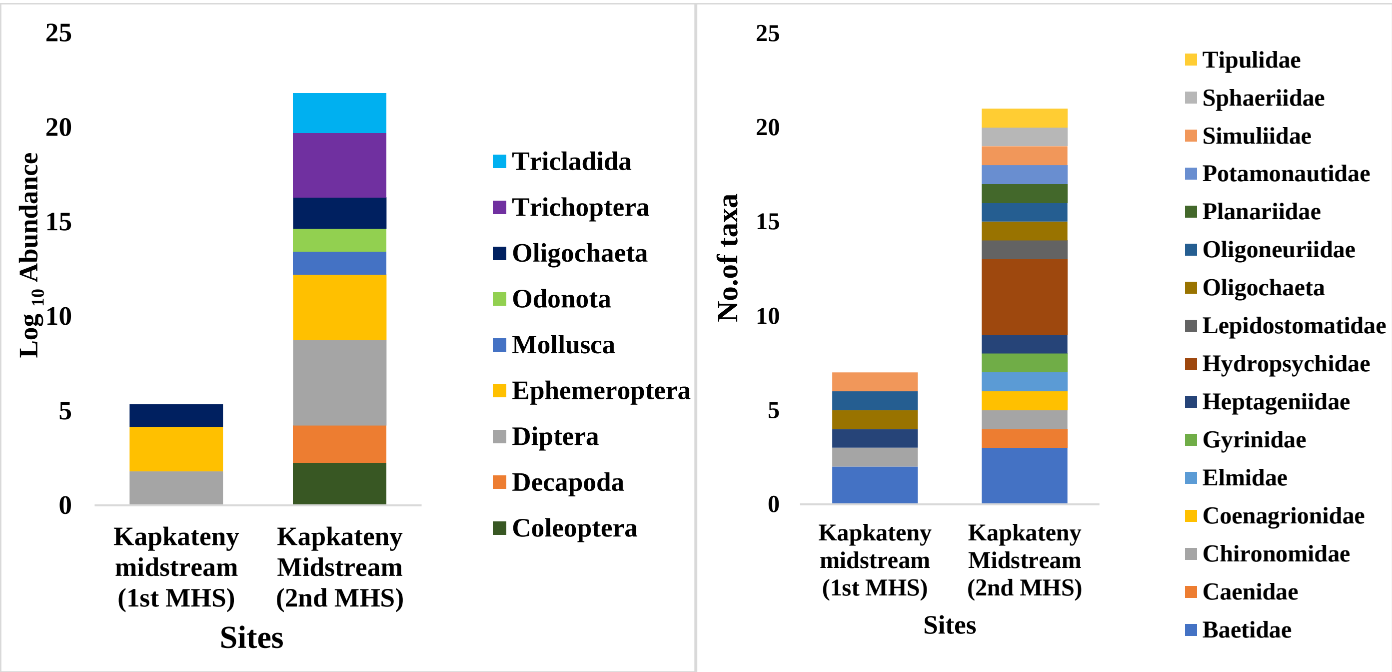


Figure 61: Logarithmic transformed abundance of orders and taxa-richness (families) in Kapkateny Midstream sites.

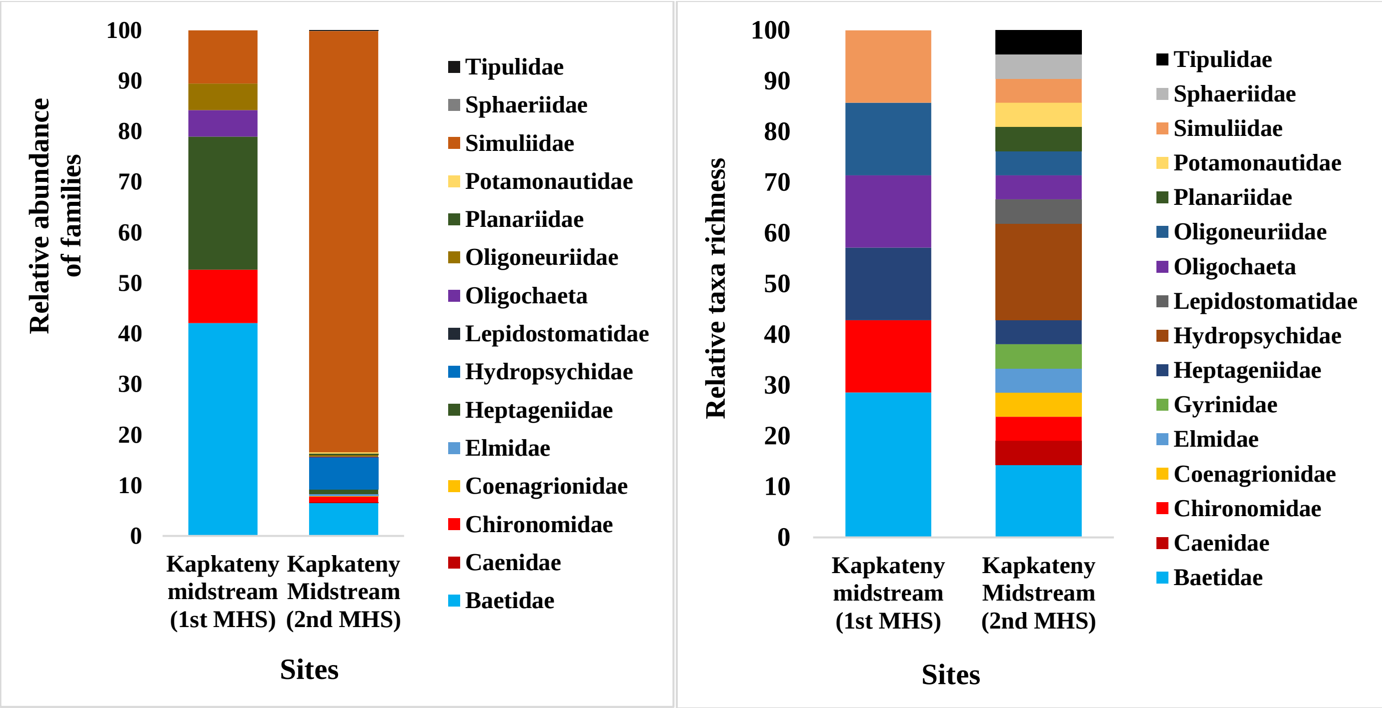


Figure 62: Dominance (%) in abundance and in richness of macroinvertebrate families in Kapkateny midstream sites

4.8 Assessment of ecological status of sampled streams

To assess the ecological integrity of the investigated streams, biotic indices of TARISS, ETH-bios, SASS and BMWP were calculated from the data collected on macroinvertebrate community (Table 17). Assessment of streams using biotic indices showed the distribution of sites within classes A (natural), B (good) and C (moderate) that depict different levels of disturbance (Table 17). Sites that were classified as natural by all the four biotic indices include (Teremi upstream (2A), Kimurio upstream (3A), Kimurio Tr1 (3B) & Tr2 (3C), Kapkateny upstream (4A), Kapkateny Midstream 2nd MHS (4D), Kibisi upstream (9B) and Kibisi Tributary (9A). These were the streams distributed within the forested land use with an exception of Kapkateny midstream 2nd MHS (4D). All the other sites were classified under either A, B or C disturbance classes. Sites classified as of disturbance class A by some biotic indices include Teremi tributary (2B), Kimurio tributary 1 (3B), Kapkateny tributary 1 (4B), Kapkateny midstream 1st MHS (4C), Kapkateny downstream (4E), Kapkasobei (6A), Cheptilieny (10A) and Masindeti (11A). These differences in biotic indices classification of streams is attributed to the different scores assigned by the different indices to organisms. Additionally, some taxa have not been assigned scores by some biotic indices. For instance, ETH-bios did not have scores for Calamoceratidae, Dixidae, Dolichopodidae, Hydroptilidae, Pisuliidae, Planariidae, Polycentropodidae, Prosopistomatidae and Stratiomyidae. SASS did not have score values for Scirtidae, Dolichopodidae and Stratiomyidae. TARISS was the closest biotic index applied for the taxa from Mt. Elgon region as it had scores for most of the taxa with the exception of Dolichopodidae and Stratiomyidae. The taxa that were not assigned scores were not included in the analyses of the total scores and subsequently in the calculation of the ASPT.

Table 17: Ecological classification of streams based on different biotic indices (TARISS, SASS, ETH-bios, BMWP) Scores

Site	TARISS Score	TARISS ASPT	Class	ETH-bios Score	ETH-bios ASPT	Class	SASS Score	SASS ASPT	Class	BMWP Score	Class
1A	83	4.88	B	77	4.81	B	81	4.76	C	76	B
2A	163	7.76	A	113	7.06	A	152	7.60	A	134	A
2B	123	6.47	A	97	6.47	B	116	6.44	B	116	A
3A	201	8.38	A	150	7.89	A	205	8.54	A	170	A
3B	127	7.06	A	119	7.00	A	117	6.88	B	116	A
3C	195	10.94	A	137	10.54	A	190	11.18	A	139	A
4A	165	8.68	A	115	8.21	A	167	8.79	A	150	A
4B	135	6.75	A	120	7.06	A	125	6.58	B	125	A
4C*	50	8.33	A	23	5.75	C	48	8.00	B/C	36	C
4D*	169	10.56	A	128	9.85	A	169	10.56	A	114	A
4E	123	8.79	A	81	8.10	A	125	8.93	B/A	95	B
5A	55	5.50	C	51	6.38	B	57	5.70	C	53	C
6A	115	8.85	A	85	8.50	A	113	8.69	B/A	87	B
7A	54	5.40	C	38	4.75	C	52	5.20	C	49	C
8A	107	7.13	B	97	6.93	B	93	6.64	B	89	B
9A	176	6.52	A	144	6.55	A	168	6.46	A	166	A
9B	152	8.94	A	117	7.80	A	138	8.63	A	113	A
9C	94	6.27	B	94	7.23	B	96	6.40	B	104	A
10A	118	7.38	A	91	7.00	B	120	7.50	B	95	B
11A	119	7.44	A	105	7.00	A	119	7.44	B	102	A
12A	58	7.25	C	51	7.29	B	58	7.25	C/B	57	C

A correlation of diversity indices, total scores from each of the biotic indices calculated per site and landcover percentages to deduce their relationship that would translate to the interpretation of the ecological condition of the streams was done. The Shannon diversity index and % vegetation cover were significantly ($p<0.05$) positively correlated with all the biotic indices. The diversity index and biotic indices' total score were however negatively correlated with % crop cover (Table 18). Percentage landcover values, used to assign land use classes, were used to run this correlation.

Table 18: Pearson correlation; percentage land cover values, Shannon Wiener diversity index of macroinvertebrates and the ecological indices total score (n=21).

		H	% Crop cover	% Veg cover	BMWP Score	TARISS Score	SASS Score	ETHBIOS Score
Shannon Wiener index (H)	r^2	1	**-.509***	**.513***	**.655****	**.668****	**.653****	**.709****
% Crop cover	r^2	**-.509***	1	-.999**	**-.695****	**-.637****	**-.581****	**-.590****
veg cover	r^2	**.513***	-.999**	1	**.705****	**.647****	**.590****	**.603****

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.9 Habitat suitability of *Oligoneuriopsis* (Ephemeroptera), *Neoperla* (Plecoptera) and *Potamonautes* (Crustacea)

4.9.1 Abiotic variables

To analyse the habitat preferences of the three taxa, the interrelationships existing in the habitat variables (substrate, velocity and depth), where these organisms were sampled from, was plotted (Figure 63). The abundance of *Oligoneuriopsis*, *Neoperla* and *Potamonautes* species at Mt.Elgon was recorded in the different substrate types, flow velocities and depth. The results indicated that water depths did not vary greatly across substrates (Figure 63) while a high variabilitity of water velocities across substrates was established. Highest velocities were recorded in macrolithal substrate. Similarly, megalithal and mesolithal velocities were relatively higher than microlithal, psammal and woody debris substrates. Woody debris substrate recorded the lowest velocities.

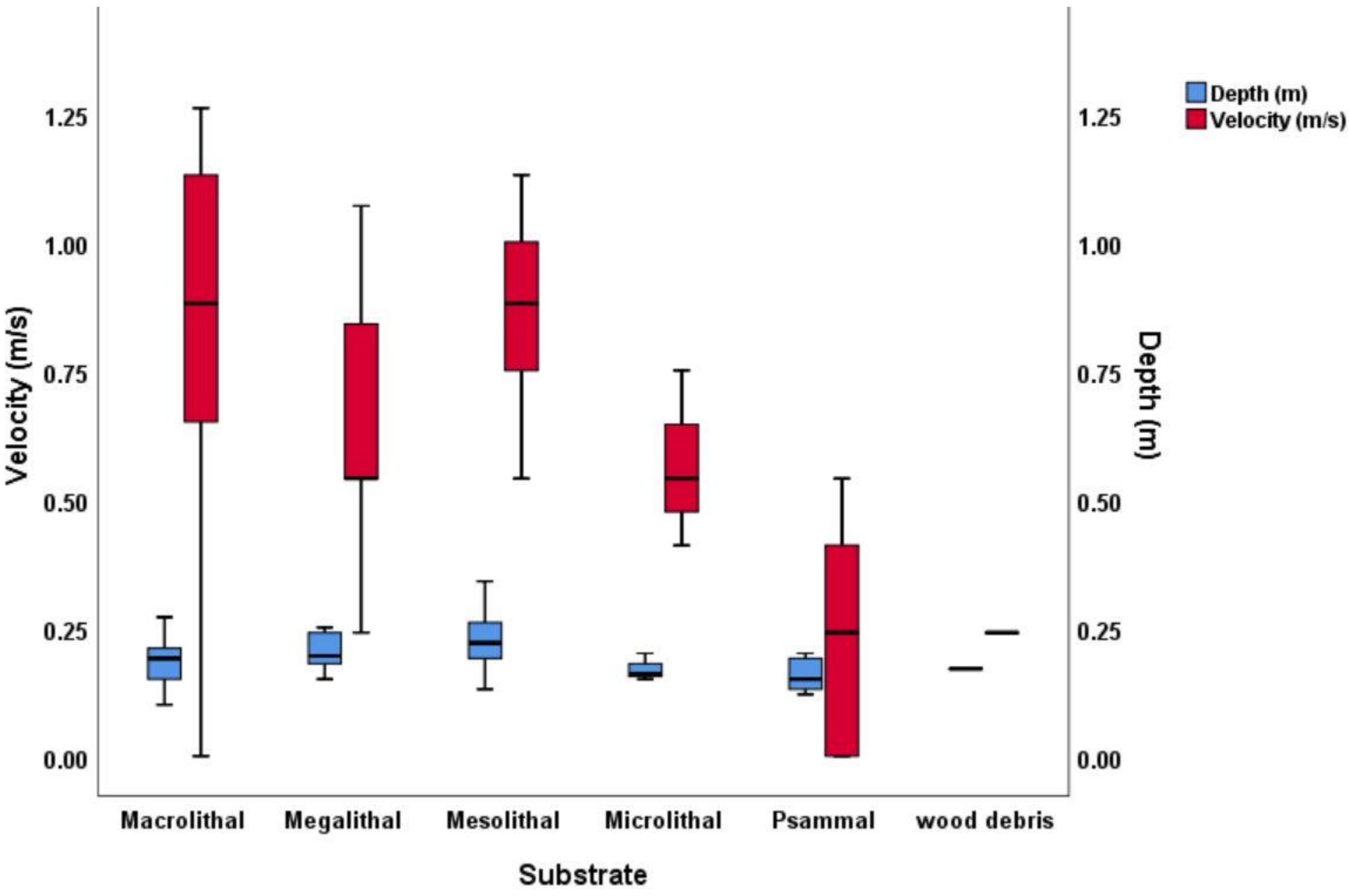


Figure 63: Velocity and water depths across different substrates

4.9.2 Substrate preferences of *Oligoneuriopsis, Neoperla* and *Potamonautes*

The abundance of the three taxa across substrates indicated that *Potamonautes* sp. highly preferred woody debris but occurred across all the sampled substrates. *Oligoneuriopsis* sp. was abundant in the megalithal substrate and lowest in psammal and microlithal substrates. *Neoperla* sp. was found in a range of substrates and were abundant in megalithal and mesolithal substrates. Microlithal and Psammal substrates contained the lowest abundances of the three taxa from the sampled sites (Figure 64).

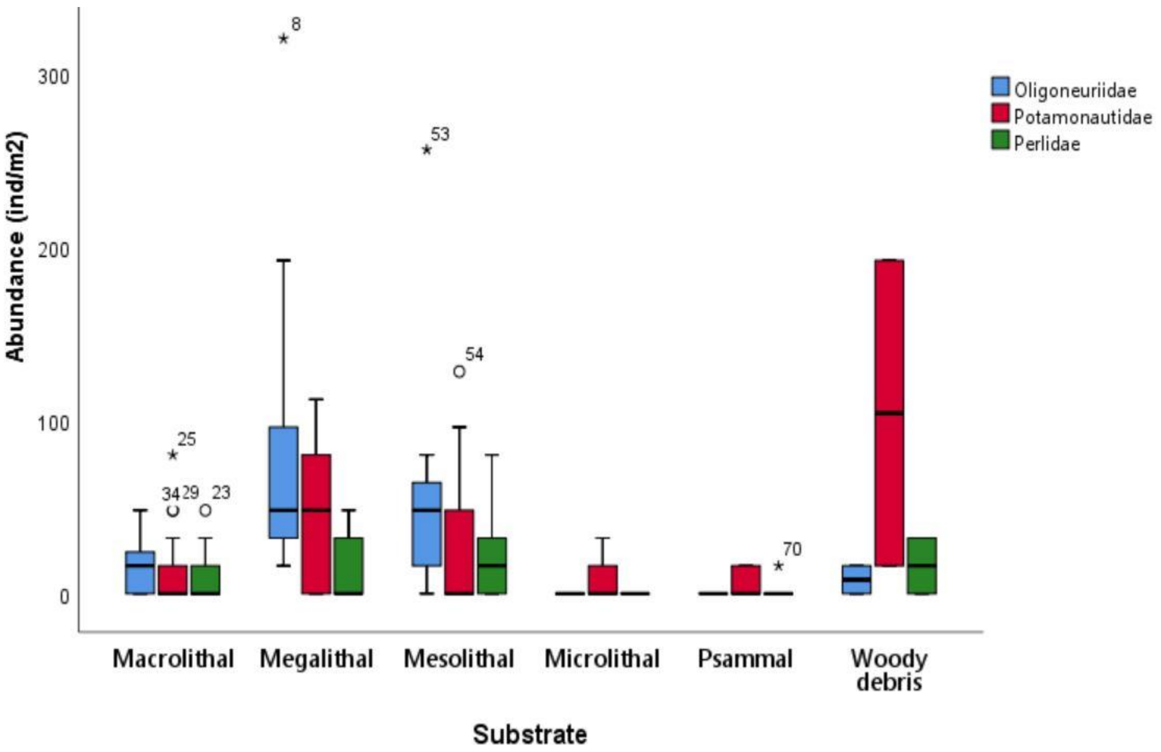
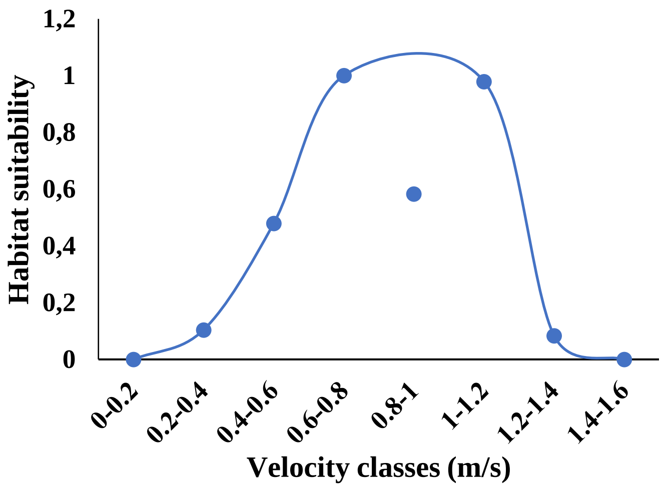


Figure 64: Preferences of *Oligoneuriopsis, Neoperla* and *Potamonautes* across different substrates.

4.9.3 Velocity and depth preferences of *Oligoneuriopsis, Neoperla* and *Potamonautes* species

Oligoneuriopsis sp. preferred velocity ranges between 0.4 m/s and 1.2 m/s and depths ranges of between 0.12 m and 0.28 m (Figure 65). *Potamonautes* sp. preferred velocity ranges of between 0.2 m/s and 0.6 m/s and depth ranges of between 0.08 m and 0.2 m (Figure 66). *Neoperla* sp. preferred velocity ranges of between 0.2 m/s and 1.2 m/s and depth ranges from 0.02 - 0.2 m (Figure 67).

a) *Oligoneuriopsis* sp.



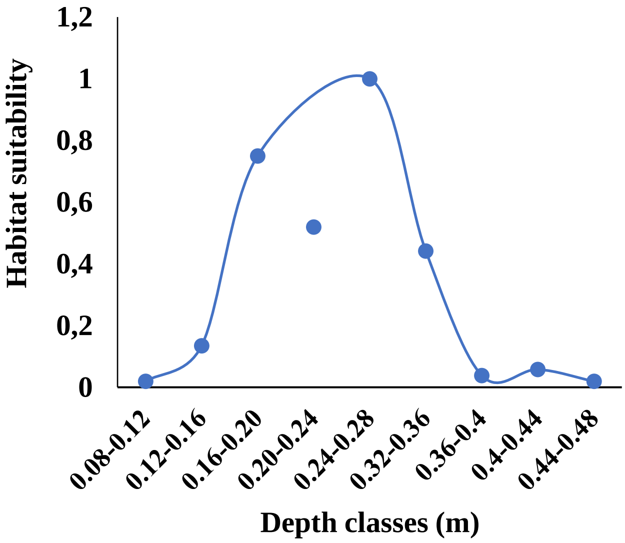


Figure 65:Velocity (left) and depth (right) preferences of *Oligoneuriopsis* sp.

b) ***Potamonautes* sp.**

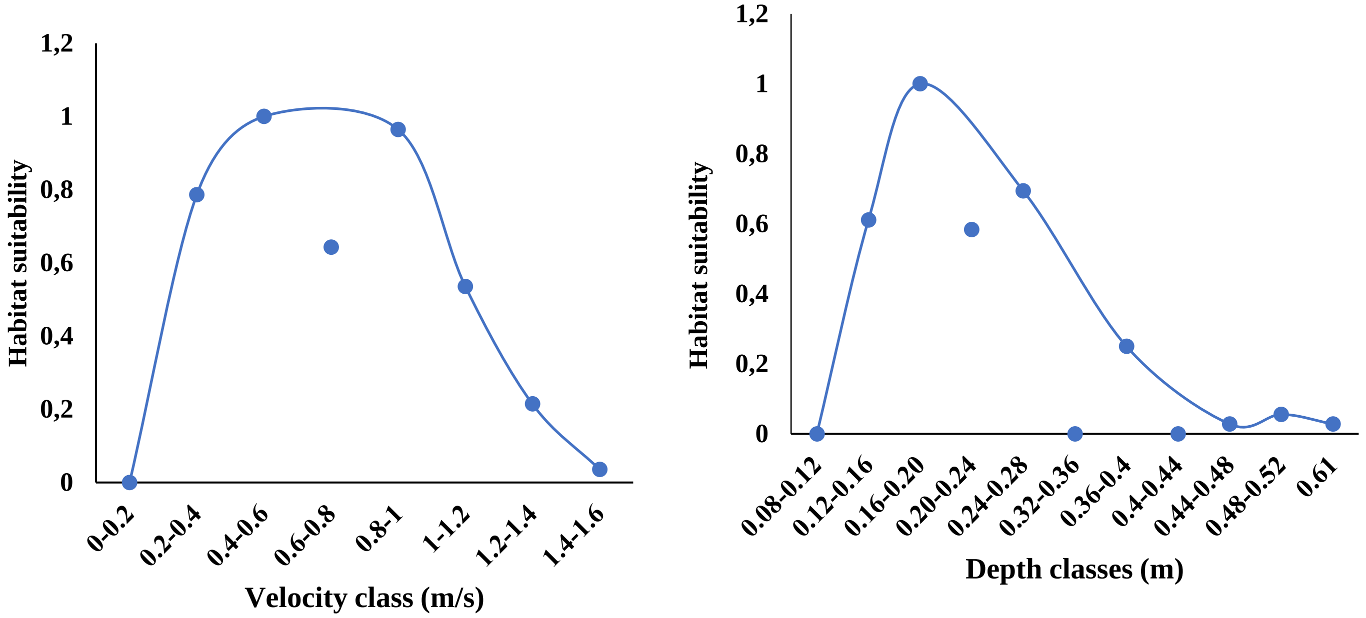


Figure 66: Velocity (left) and depth (right) preferences of *Potamonautes* sp.

c) ***Neoperla* sp.**

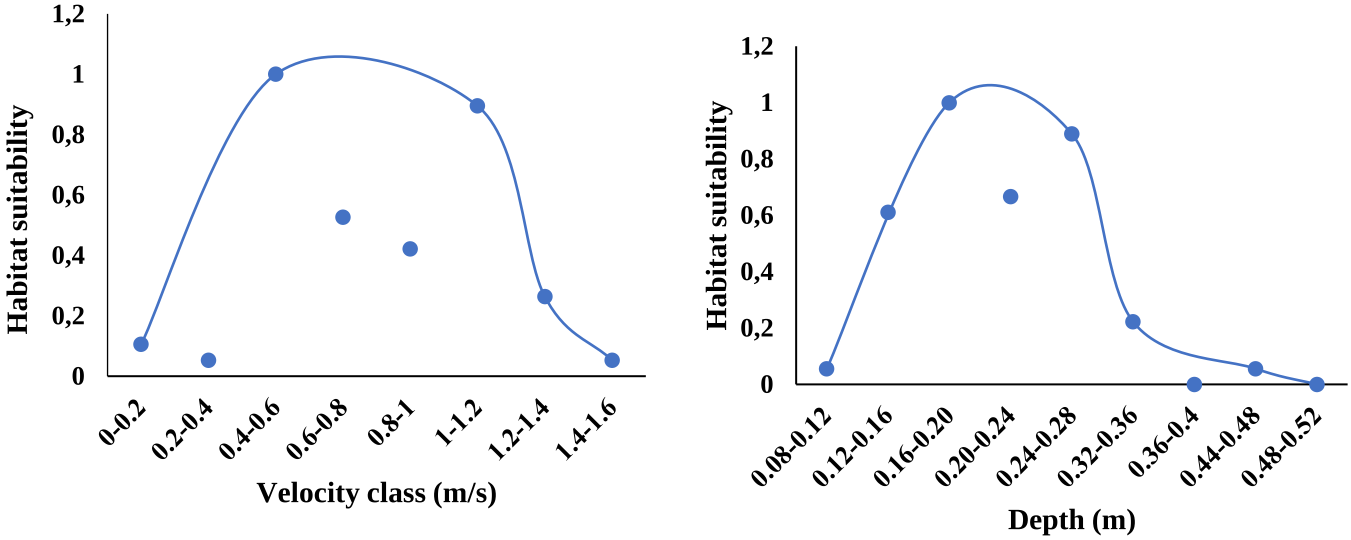


Figure 67:Velocity (left) and depth (right) preferences of *Neoperla* sp.

CHAPTER FIVE

5.0 DISCUSSION

Land use influences on the structural and functional composition of macroinvertebrate communities through the influence of water and habitat quality variables were investigated in Mt Elgon region, Kenya. Deforestation in catchment areas of streams as well as in the riparian zone alter the integrity of streams by increasing erosion, sedimentation, and the resulting degradation of physical habitats and water quality (Chapman and Chapman 2003, Kaufmann *et al.*, 2009). These activities have detrimental effects of aquatic biodiversity residing in streams which depend on these streams for habitat, food and shelter. The influence of these land use shifts and their subsequent influence on macroinvertebrate communities are discussed in the sub-sections below.

5.1 Physico-chemical water parameters

Higher electrical conductivity, temperature, total suspended solids, total dissolved solids and lower pH was recorded in streams within agricultural areas (Table 10). These variables were positively correlated with the percentage of crop cover in the catchment and negatively correlated with altitude. Similar findings were reported by Kasangaki *et al*. (2008), Minaya *et al*. (2013) and Kibichii *et al*. (2007) who documented that despite the narrow temperature range in the tropics, agricultural streams are warmer and with higher electrical conductivity, suspended sediments and dissolved nutrients compared with forest streams.

The lower temperatures in the forested streams is attributed to shading provided by the riparian vegetation which was lacking in most streams in the agricultural areas. Masese *et al.* (2009) documented the importance of forest cover in limiting solar radiation reaching the water and therefore contributing to minimal fluctuations in forested areas. The altitudinal drop, rapids and falls characterizing the streams, allowed re-oxygenation of the water, and can explain lack of variation in dissolved oxygen levels with both altitude and land use change from forestry to agriculture. This is corroborated by findings by Minaya *et al.* (2013), and captures the dynamic nature of tropical streams and rivers influenced by both land use change, and riparian and in-stream activities.

Conductivity responded strongly to land use change from forestry to agriculture. High conductivity recorded in agricultural streams could be a factor of fertilizer and nutrient enrichment from the farms draining the catchment. This water quality significantly correlated with temperature, TDS, salinity, pH, and TSS which were higher in agricultural streams. Sediments transported from the farms to streams in the event of run-off have low pH and are rich in exchangeable cations of Ca^{2+}, Mg^{2+}, Na^{2+}, K^{-}, $SO4^{2-}$,Cl^{-} found in fertilizers being used in the agricultural farms (Muriuki *et al.*, 2013). Additionally, soil tillage mobilizes major ions in the soils and increases their leaching into water bodies where they elevate conductivity levels as discussed by Masese *et al.* (2017).

High TSS and TDS values recorded in agricultural streams most probably resulted from erosion of unprotected banks and siltation. Owing to the sampling done in a rainy season, the runoff from streams were deposited in these agricultural streams, and the water were murky and laden with sediments. Kilonzo *et al.* (2013) conducted a similar study and documented elevated concentrations of nutrients and sediments in streams draining agricultural catchments during the wet season due to run-off from unpaved roads, footpaths and farmlands.

5.2 Spatio-temporal variation in substrate composition

Macrolithal substrate dominated the streams in forested areas while akal substrate dominated in agricultural streams. This prevalence of smaller substrates in the agricultural catchment could be attributed to the anthropogenic activities happening in these areas. Cultivation of the land adjacent to rivers, clearing of riparian and catchment vegetation and the presence of livestock trampling on sediments at these streams increased erosion and sedimentation activities. Total suspended solids which is a measure of siltation rates in streams was lower in forested sites than in agricultural sites. The clear colored water in forested areas also indicated minimum disturbance in these sites. Siltation which was evidenced in the agricultural streams by the high total suspended, as well as the prominent brown colour of water in these streams, also contributed to the high percentage of fine sediments in these streams. This study taking place during rainy season meant higher sediments were being deposited in these agricultural streams as large quantities of sediments were being eroded from cultivated farms and footpaths, and subsequently washed into streams.

5.3 Macroinvertebrate composition and distribution

This study identifies Simuliidae, *Cheumatopsyche*, Oligochaeta, Sphaeriidae, Chironomidae, Lepidostomatidae, *Diplectrona, Baetis*, Tipulidae, Caenidae and *Afronurus* as the most commonly occurring taxa in most of the sites. *Adicella*, Trycorythidae, Libellulidae/Cordulidae and Empididae were limited to agricultural streams and an altitude range of < 2000 m a.s.l. Leptophlebiidae, *Afrocaenis*, Physidae, Dixidae, Pisuliidae, Wormaldia, Glossiphoniidae, Gomphidae, *Trichosetodes*, Prosopistomatidae, *Neoperla* and Dolichopodidae were limited to forested streams in altitudes >2000 m a.s.l. Planorbidae, *Tinodes* and Tabanidae were found at altitudes >2000 m a.s.l but also occurred in agricultural streams. Scirtidae, Limoniidae, *Triaenodes* and *Potamonautes* were highly occurring in forested streams though were found in some agricultural streams.

A study by William and Hynes (1971) in the same region showed that the mountain stream fauna of Mt Elgon was dominated by *Baetis*, *Centroptilum*, *Cheumatopsyche,* Simuliidae and Chironomidae together with considerable numbers of *Dugesia, Oligoneuriidae, Euthraulus, Caenis, Neoperla* and *Hydropsyche* and smaller numbers of *Prosopistoma*. *Potamonautes* sp. were also prevalent at higher altitudes. Taxa among *Neoperla*, *Tinodes*, Philopotamidae, Leptophlebiidae, Prosopistomatidae, Dolichopodidae, Dixidae and Tabanidae were restricted to forested areas. *Baetis,* Hydropsychidae and Simuliidae, which were the most cosmopolitan taxa in the study area, are reported to have short regeneration times and rapid colonization rates, enabling them to cope with fluctuating environments and build up large populations opportunistically (Newbold *et al.*, 1980; Hynes 1975).

Higher mean abundance, richness and diversity were recorded in forested than in agricultural sites. The freshwater crabs (*Potamonautes* sp.) were observed in large numbers at the forested sites, although, but occurred in low numbers at the other sites. Similar observations were made by Kibichii *et al.* (2007) who reported low numbers of Potamonautid crabs in impacted sites. Cumberlidge & Clark (2010) reported the occurrence and endemicity of *Potamonautes elgoni* in the upper reaches of rivers on the highlands of western Kenya and eastern Uganda.

Ephemeroptera, Plecopeta and Trichoptera richness and abundance were higher in forested streams than in agricultural streams. Similar of such studies are documented by M'erimba *et al*. (2014) on highland streams in Kenya. Coleoptera richness was high in forested sites, very low and absent in agricultural streams. Similarly, in the same area, William and Hynes (1971) documented a lot of Helolidae/ Scirtidae larvae in the upstream reaches. This is similar to our study where Scirtidae (*Elodes*) were recorded in high abundance in Kibisi upstream. Raburu *et al*. (2009) and Minaya *et al.* (2013) have discussed the utility of Ephemeroptera, Plecoptera, Trichoptera, Coleoptera and Odonata (COPTE) as a measure of diversity and pollution in Kenyan streams.

The higher diversity of macroinvertebrates in forested areas compared to agricultural areas could be attributed to habitat diversity and complexity in these sites. Streams with minimally disturbed riparian forest are known to contribute branches and large wood to channels that increase habitat complexity and produce habitats that favor increased abundance and diversity of macroinvertebrates (Kaufmann and Faustini, 2012). Sites in forested areas contained more stable substrate (cobbles, pebbles and boulders) in comparison to the less stable substrate types of sand and fine sediments in agricultural areas.

5.4 Influence of water and substrate quality on macroinvertebrates community composition

The influence of substrate type and quality on macroinvertebrate community composition were effected through siltation and erosion. These factors affect macroinvertebrates communities by blocking habitats and limiting the number of organisms residing in these streams. These effects were evident in Kapkateny midstream where MHS samples were taken from sites with differing magnitude of anthropogenic influence. Lower abundances and diversities of organisms were seen in the site with high disturbance ratio from being used as cattle watering point. Kasangaki *et al.* (2006) reported similar scenarios with taxonomic diversity and richness reported to decrease with disturbance. Similar reports appear in the work by Bryce *et al.* (2010) who recognizes that human activities, such as road building, agriculture, mining and logging, increase the delivery of fine sediments to streams where they cause impairment to habitats and aquatic life. Kibichii *et al*. (2007) and Masese *et al.* (2014) also report that with the capacity of fine sediments to be easily mobilized downstream, erosion of land is likely to increase the quantity of fine sediments deposited in pools of impacted sections of the stream. In another study, Allan (1995) observed that the shifting nature of fine sediments in streams makes them less attractive for colonization by invertebrates, therefore always having a smaller number of invertebrates, compared to stable larger particles.

Despite the occurrence in small proportions of bigger sized substrate types of macrolithal, megalithal and mesolithal in some of our investigation sites, diversity and abundances of macroinvertebrate communities was still low. This is explained by Allan (1995) who conceptualizes that in constantly disturbed streambeds, even larger particles are less attractive to colonization because their surfaces are covered by silt. Kibichii *et al.* (2007) and Wood *et al*. (2005) in their work state that the frequently disturbed streambeds meant that only a few taxa tolerant to constantly shifting sediments and bedrock can proliferate in large numbers, while a majority of the taxa occur only rarely. Suspended solids reaching streams can smother the riverbed, flush away substrates and associated invertebrates, and increase the quantity of fine sediments in pools, which can be colonized only by a few specialized taxa (Kibichii *et al.*, 2007).

The changing physico-chemistry of the water in the streams with land use change, as noted for TSS, temperature, electrical conductivity, and TDS (Table 10) also have contributed to the low richness and abundances of macroinvertebrate taxa in the agricultural sites. Replacement of native vegetation by pasture and intensive agriculture is associated with degradation of water quality and degradation of physical habitat (Bryce *et al*. 2010).

5.5 Patterns of macroinvertebrates functional feeding groups

Non-Metric Multidimensional Scaling indicated that forest cover, coarse particulate organic matter and altitude were the predictor variables influencing the invertebrate assemblages in the forested streams. This corresponds to the high biomass levels of shredders recorded in the streams. The relative abundances of macroinvertebrates functional feeding groups (FFGs) have been used as functional indicators of streams and rivers (Cummins *et al*., 2005; Barbour *et al*., 1999). Shifts in land use from forested to agricultural typically reduce habitat complexity and affect organic matter dynamics (Mbaka *et al*., 2015; Masese *et al*., 2014). This was reflected in the reduction in richness, abundance and biomass of shredder communities and subsequent increase in the abundance of filtering collectors in agricultural areas.

This study documented interesting longitudinal trends in FFGs. Whereas abundance data showed no clear trend in the distribution of shredders from upstream sites to downstream sites, biomass data presented a different picture. Shredder biomass decreased from upstream to downstream sites while the biomass of total collectors (filtering and gathering collectors) increased from upstream to downstream. Both scraper biomass and abundance were higher in the downstream sites (between altitudes of 1624-1701 m a.s.l, average width sizes of 3.29 $\pm$ 1.7 m and average depths of 0.26 $\pm$ 0.1 m). These sites which were characterized by agriculture as the main land use were open allowing light penetration required for establishment of primary productivity which supports scraper functional guild.

The shredder biomass which differed significantly from the other functional feeding groups was contributed significantly by crabs of the genus *Potamonautes* reported to be highly abundant in East African Highland streams (Masese *et al*., 2014; Dobson *et al.*, 2002). The present study found the highest occurrence of crabs in Kapkateny tributary site (4B) which had substrate comprising of 55% detrital components and 40% macrolithal substrate. This site was located upstream in a forested catchment. In his study, Masese *et al.* (2014) found the occurrence of these crabs hiding under rocks and in crevices in the riparian zone while Kibichii *et al.* (2007) reported the occurrence of crabs being in sites with closed canopy sites. Their role in the utilization of detrital and CPOM component places them in an important niche in the tropical streams and calls for the conservation of tropical streams with riparian vegetation and forested catchments due to their important role as a habitat for *Potamonautes* sp.

While spatial and longitudinal trends in this study are interesting, there has been a lot of discussion whether tropical streams fit into existing models of river functioning such as the RCC (Vannote *et* *al.,* 1980). The RCC address changes in the relative abundance of macroinvertebrate FFGs in the longitudinal gradient of streams. However, it has been noted that relative abundance and biomass of shredder does not show similar trends (Masese *et al*., 2014), as also noted in this study. Bonada *et al.* (2006) had earlier noted that structural and functional indicators are not necessarily concordant, highlighting the need to consider both during bioassessment. Tamanova *et al*. (2007) further offers plausible reasons why the distribution in their work did not 'fit' the RCC concept being the influence of working with relative abundances. Masese *et al.* (2014) pointed out that the assignment of functional feeding groups to families as opposed to species being another of the reasons for the earlier discussions on the distributions of functional feeding groups in tropical streams. It is important to note that in this study the assignment of functional feeding groups was done on the genus level.

5.6 Scale-influences on macroinvertebrate structure

Kapkateny Midstream sites presented an interesting picture on the importance of local scale influences overriding catchment scale influences on macroinvertebrate communities. Kimurio Midstream 2nd MHS (4E) though found in an agricultural area had a higher abundance, richness and diversity of macroinvertebrates. This could be attributed to the prevailing local conditions in the area. The site was characterized by macrolithal substrate, partly hidden from disturbances of cattle trampling and the associated natural forest on one bank with the left bank having planted Eucalyptus trees which increased its habitat complexity. Kapkateny midstream 1st MHS (4C) on the other hand had the lowest taxonomic abundance and richness (Figure 61). Kapkateny midstream 1st MHS was frequented by animals drinking from the stream. This two sites sampled in the same stream, reach and sampling time however had different local conditions which reflects on the fact that large scale influences of land-use can be dominated by local impacts as discussed by Minaya *et al.* (2013) and shows how disturbance and poaching of macroinvertebrates at the site scale is an essential small scale factor. Hughes *et al.* (2010) and Kaufmann and Faustini (2012) report that at the site scale, physical-habitat complexity (structural cover, substrates, and water flow) influences assemblage composition, richness, and temporal stability and ecological processes. Similarly, the work by Minaya *et al.* (2013) upon testing scale effects on macroinvertebrates assemblages documented that they reacted more sensitively at the reach scale than at the catchment-scale, suggesting a stronger influence of local habitat conditions as seen in this study.

5.7 Habitat preferences of macroinvertebrate taxa

In our study, indicator species analysis showed that *Tinodes*, *Potamonautes* sp, Sphaeriidae, Tipulidae, Limoniidae, Scirtidae, *Triaenodes*, *Diplectrona* and *Wormaldia* were significantly occurring in streams in forested areas and in high altitude (above 2200 m a.s.l). Percentage forest cover and altitudinal class were highly and significantly correlated (0.91*, p= 0.05), and therefore it was hard to separate the individual influences of the two drivers in predicting the occurrence of these taxa. Importantly, however, is that the indicator analysis presented taxa that were limited to forested catchments in high altitudes. Taxa occurring at such sites are often sensitive to factors of temperature, oxygen content, substrate types and detrital food availability. Kibichii *et al.* (2007) found that species limited to forested streams were often sensitive to sedimentation.

The distribution of *Neoperla* (Perlidae) was limited to forested catchments in altitudes above 2200 m a.s.l. This species preferred water depths of 0.02-0.28 m and velocities in the range 0.2-1.2 m/s. Perlidae have been reported elsewhere to be sensitive to higher temperature regimes (Kasangaki *et al.*, 2006; Quinn & Hickey, 1990). Coldwater organisms are generally known to be more sensitive to environmental changes (Griffiths *et al.*, 2001), thereby expected to respond quickly to environmental disturbances and therefore can be used a good indicator taxon.

Similarly, *Potamonautes* sp. was limited to forested catchments due to the availability of detrital food owing to their detritivorous nature. Thirion (2016) reported that commonly occurring potamonautid crabs occurred at all velocity conditions with no obvious preference for a specific type of flow. In my study, *Potamonautes* sp. was found in water depths in the range of 0.08-0.2 m and velocity ranges of 0.2-0.6 m/s. They also occurred in large numbers in streams with woody debris, irrespective of substrate type. The above observation suggests that food items such as leaf litter and woody debris of high quality that support their shredder-feeding behaviour dominated in forested sites and favoured the occurrence of *Potamonautes* sp.

Oligoneuriopsis sp. was abundant in streams with megalithal substrate type, depth range of 0.12-0.28 m and velocities in the range of 0.4-1.2 m/s. William & Hynes (1971) and Thirion (2016) findings are similar to the ones in this study. Thirion (2016) describes *Oligoneuriopsis* as a highly sensitive taxa found in altitudes above 1890 m a.s.l, with a preference for very fast flowing water and highly associated with megalithal substrate with high velocities of up to 1.2 m/s.

CHAPTER SIX

6.0 Conclusion and Recommendation

This thesis investigated the structural and functional responses of macroinvertebrate communities to changes in land use in Mt Elgon, Kenya. The study had four hypotheses. For the first hypothesis, the levels of total dissolved solids (TSS), total suspended solids (TDS), temperature, pH, electrical conductivity (EC), dissolved oxygen (DO) and salinity were hypothesized to be higher in the streams in agricultural areas than those in forested areas. This hypothesis was confirmed by the results that showed that with the change in land use from forest to agriculture, physico-chemical water quality parameters deteriorated indicated by the high levels of TSS, TDS, temperature, salinity and EC in agricultural areas. Dissolved oxygen and pH were however not significantly different between the two land use types.

The second hypothesis predicted the reduction in sediment size composition in agricultural streams in comparison to forested streams. This prediction was confirmed in the study. The results gave a good indication of this change as shown by the dominance of akal in agricultural streams while macrolithal dominated in forested streams. The percentage of fine substrate was higher in agricultural streams than in forested streams.

In the third hypothesis, the diversity, abundance and biomass of macroinvertebrate communities was predicted to be lower in agricultural areas and higher in forested streams. This hypothesis was not rejected as streams in forested areas recorded higher taxonomic richness, abundance and biomass.
The fourth objective predicted the reduction in abundance and biomass of shredders with the shift in land use from forested to agriculture. This hypothesis was confirmed with forested sites recording high biomass levels of shredders contributed significantly by crabs. Abundance of shredders in forested streams though higher than in agricultural streams was not significant.

The results show that land use change from forest to agriculture was a major driver of changes in both physico-chemial water quality and habitat quality, which significantly influenced the diversity and distribution of macroinvertebrate taxa. From this work, it can be deduced that conversion of stream catchments from forested to agricultural have adverse effects on stream ecosystems integrity. The change in water and habitat quality and the subsequent shift in macroinvertebrate composition shows the need to conserve these catchments. *Potamonautes elgoni* endemic to Mt Elgon region are seen to occur mostly in forested areas with major reduction in their biomass reflected in the shift of land use from forest into agriculture; which corresponds with the reduction in food resources owing to their detritivore nature. If the trend in the conversion of forests into agricultural lands in the area continues, the populations of these species in the region will be under threat. This work therefore unveils the need for conservation of the forested regions as well as the riparian areas of Mt Elgon catchment and calls for and adoption of trade-offs in agriculture in the area for biodiversity conservation.

With the study carried out during the wet season, further studies are needed to understand the roles of seasonality in the distribution of macroinvertebrate communities in this region as seasonality was seen to have influenced macroinvertebrate community assemblages in other regions (Touma *et al*., 2011; Masese *et al.,* 2014). This study design also did not incorporate the effects of differing land uses occurring within the same altitudinal range influencing the distribution of macroinvertebrate communities. An in-depth study investigating this is recommended. Similarly, a study looking into the separate effects of longitudinal and land use influences on macroinvertebrate communities that was not clearly reflected in the study design of this work.

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APPENDICES

Appendix 1: Images of different taxa of the Hydropsychidae family (photos: Courtesy of Wolfram Graf)

Cheumatopsyche A

Dorsal view **Ventral view**

Cheumatopsyche B

Cheumatopsyche C

Diplectrona

Thoracic region

Limb

Dorsal view

Ventral view

Appendix 2: Kruskal-Wallis test; abundance of functional groups with agricultural and forested land uses

Null Hypothesis	Test	Sig.	Decision
The distribution of CF is the same across categories of LU.	Independent-Samples Kruskal-Wallis Test	.047	Reject the null hypothesis.
The distribution of CG is the same across categories of LU.	Independent-Samples Kruskal-Wallis Test	.001	Reject the null hypothesis.
The distribution of PRD is the same across categories of LU.	Independent-Samples Kruskal-Wallis Test	.003	Reject the null hypothesis.
The distribution of SCR is the same across categories of LU.	Independent-Samples Kruskal-Wallis Test	.009	Reject the null hypothesis.
The distribution of SHR is the same across categories of LU.	Independent-Samples Kruskal-Wallis Test	.003	Reject the null hypothesis.
The distribution of CPOM (g/m2) is the same across categories of LU.	Independent-Samples Kruskal-Wallis Test	.013	Reject the null hypothesis.

Appendix 3: Pearson correlation between macroinvertebrate indices and physico-chemical water parameters

		POM (mg/l)	Av. Width (m)	Discharge (M^3/s)	Velocity (m/s)	CPOM (g/m^2)	TSS (mg/l)	Av.Depth (m)	Conductivity (μs/cm)
	N	21	21	21	21	21	21	21	21
Total Abundance	Pearson Correlation	-.373	-.033	-.112	-.031	.594**	-.373	-.143	-.414
	Sig. (2-tailed)	.087	.885	.621	.891	.004	.088	.526	.056
Total Taxa richness	Pearson Correlation	-.591**	.211	.099	-.076	.615**	-.591**	.021	-.616**
	Sig. (2-tailed)	.004	.346	.662	.738	.002	.004	.926	.002
Shredder Abundance	Pearson Correlation	-.500*	-.161	-.158	-.238	**.653****	-.500*	.125	-.341
	Sig. (2-tailed)	.018	.473	.482	.286	**.001**	.018	.578	.120
Predator Abundance	Pearson Correlation	-.612**	.055	.001	-.273	.682**	-.611**	-.115	-.666**
	Sig. (2-tailed)	.002	.809	.995	.218	.000	.003	.611	.001

		POM (mg/l)	Av. Width (m)	Discharge (M^3/s)	Velocity (m/s)	CPOM (g/m^2)	TSS (mg/l)	Av.Depth (m)	Conductivity (µs/cm)
Collector abundance	Pearson Correlation	-.327	-.035	-.123	-.015	.537**	-.327	-.182	-.383
	Sig. (2-tailed)	.137	.877	.585	.946	.010	.138	.417	.078
Non-Shredder Abundance	Pearson Correlation	-.355	-.023	-.106	-.015	.575**	-.354	-.159	-.409
	Sig. (2-tailed)	.105	.921	.640	.946	.005	.106	.481	.059
Scraper Abundance	Pearson Correlation	-.275	.225	.379	.332	.691**	-.275	.641**	-.207
	Sig. (2-tailed)	.216	.315	.082	.131	.000	.216	.001	.354
No of shredders	Pearson Correlation	-.630**	.137	.088	-.179	.558**	-.630**	.101	-.650**
	Sig. (2-tailed)	.002	.545	.696	.426	.007	.002	.655	.001
No of collectors	Pearson Correlation	-.373	.267	.156	.199	.402	-.372	-.019	-.433*
	Sig. (2-tailed)	.087	.229	.487	.375	.064	.088	.932	.044
No of predators	Pearson Correlation	-.573**	.120	-.038	-.224	.639**	-.573**	-.020	-.566**
	Sig. (2-tailed)	.005	.594	.867	.315	.001	.005	.929	.006
No of Scrapers	Pearson Correlation	-.222	.046	.125	-.029	.291	-.222	-.004	-.183
	Sig. (2-tailed)	.321	.839	.580	.898	.188	.321	.987	.415
% Shredders	Pearson Correlation	-.127	-.079	.126	-.073	.255	-.128	**.544****	-.002
	Sig. (2-tailed)	.572	.727	.575	.746	.251	.570	**.009**	.994
%Scrapers	Pearson Correlation	.350	.058	.268	.302	-.184	.350	.316	.292
	Sig. (2-tailed)	.110	.797	.228	.172	.413	.111	.152	.187
%Predators	Pearson Correlation	-.156	.152	.298	-.049	.047	-.156	.205	-.167
	Sig. (2-tailed)	.489	.500	.177	.829	.835	.489	.360	.458
%Collectors	Pearson Correlation	-.165	-.066	-.332	-.177	.032	-.165	**-.480***	-.162
	Sig. (2-tailed)	.463	.769	.131	.431	.887	.464	**.024**	.472