SPATIAL VARIABILITY IN WATER QUALITY AND MACROINVERTEBRATE ASSEMBLAGES ACROSS A DISTURBANCE GRADIENT IN THE MARA RIVER BASIN, KENYA

BY

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DECLARATION

DECLARATION BY THE STUDENT

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DEDICATION

I dedicate this work to my lovely wife; Mrs. Lubanga for always believing in me and encouraging me throughout this journey and to my lovely children for their continuous support and believing in me irrespective of all the odds.

ABSTRACT

Across the Afrotropical ecosystems, human activities are increasingly modifying natural flow regimes, nutrient and organic matter loading and processing in streams and rivers, with implications on ecosystem structure and functioning. Macroinvertebrates functional composition data is important in assessing the effects of anthropogenic activities on ecological conditions of rivers and streams. The Mara River Basin has undergone extensive land-use change, but the influences of these changes on water quality and aquatic communities are still not well understood. This study, which was conducted in the months of August 2013 to February 2014, investigated changes in water quality and macroinvertebrate assemblages across a disturbance gradient arising from rural human activities in nineteen sites; grouped into three human-impact categories (reference undisturbed sites (n = 7), moderately disturbed sites (n = 6) and disturbed sites (n = 6). Temperature, dissolved oxygen, total dissolved solids, pH and electrical conductivity were measured *in situ* at each sampling site, and samples were collected for analysis of nutrients and total suspended solids. Sampled macroinvertebrates were identified to the lowest-possible taxonomic level, mostly family level, for analysis of structure (richness and diversity indices) and functional composition. There were significant spatial variations in water quality variables across the disturbance gradient ($p < 0.05$). The highest mean temperature and suspended solids values were recorded at the highly disturbed sites while the lowest values were recorded at undisturbed sites. Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa dominated (70% in abundance) the macroinvertebrate taxa in undisturbed sites with a few taxa (notably *Lepidostoma*, Colembolla and *Leptophlebi*a *sp.*) being restricted to these sites, while Diptera dominated (48% in abundance) the macroinvertebrate taxa at the disturbed sites. Additionally, higher macroinvertebrate diversity and richness indices were recorded at the undisturbed sites. In regard to functional feeding groups, collectors were the numerically dominant taxa at all the site categories with the abundance of shredders being highest at the undisturbed sites. This study adds further evidence that land-use change from forestry to agriculture has a strong influence on the structural and functional composition of macroinvertebrates in the Mara River Basin. Attention should also be given to riparian management and monitoring of in stream activities by people and their livestock. Future studies should focus on restoration of degraded ecosystems and monitoring of restoration processes.

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LIST OF ACRONYMS AND ABBREVIATIONS

AGR- Streams in agriculture land use
ANOVA- One Way of Analysis of Variance
APHA- American Public Health Association
asl- Above Sea Level
CPOM- Coarse Particulate Organic Matter
DO- Dissolved Oxygen
EC- Electrical Conductivity
FFG- Functional Feeding Group
FOR- Streams in forest land use
FPOM- Fine Particulate Organic Matter
IWRM- Integrated Water Resources Management
LVB- Lake Victoria Basin
MFC- Mau Forest Complex
MIN- Minutes
MIX- Streams in mixed land use
MMNR- Maasai Mara National Reserve
MRB- Mara River Basin
OM- Organic Matter
PCA- Principal Component Analysis
RCC- River Continuum Concept
SD- Standard Deviation
SNP- Serengeti National Park
TDS- Total Dissolved Solids
TN- Total Nitrogen
TP- Total Phosphorus
TSS- Total Suspended Solids
WHO- World Health Organization

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Human activities associated with broad-scale changes in natural resource acquisition (e.g. industry, agricultural activities and mining) or urban and industrial growth (human settlements and transport infrastructure) affect terrestrial ecosystems (Foley *et al.,* 2005; Masese *et al.,* 2009a; Minaya *et al.,* 2013; Masese *et al.,* 2014b). Human population growth is a major precursor to land use change by increasing extraction of natural resources in both terrestrial and aquatic ecosystems (Dudgeon *et al.,* 2006, 2010; Steffen *et al*., 2015; Grill *et al.,* 2019). Consequently, aquatic ecosystems have been altered globally by broad-scale changes to rates of natural resources acquisition (forestry, agriculture, and mining), settlements (urbanization) and infrastructural developments (e.g dams, transport infrastructure, etc) (Allan, 2004; Foley *et al*., 2005; Vörösmarty *et al*., 2010; Reid *et al*., 2019). These threats have modified the character of watersheds and degraded rivers, resulting in loss of biodiversity and ecosystem functioning (Vaughn, 2010; Carpenter *et al*., 2011; Tickner *et al*., 2020). Furthermore, degradation of rivers through non-point-sources pollution resulting from increasing agricultural activities (e.g crop farming and livestock grazing) has been recognized as a global problem (Neil *et al*., 2001; Vaughn, 2010; Woodward *et al*., 2012; Leip *et al*., 2015).

In the Afrotropics, human population growth and the subsequent demand for land for settlements, livestock grazing and crop farming to meet increasing food demands pose the greatest challenge to biodiversity conservation and water resources. At the catchment-scale, land-use change is characterized by expansion of croplands and human settlements (including urbanization and road construction), grazing of livestock and introduction of exotic species (Fugère *et al*., 2016; Ogutu *et al*., 2016; Ordway *et al*., 2017; Mapulanga & Naito, 2019). At the local reach-scale, land-use and human activities are characterized by heavy trampling by people and their livestock, excessive water abstraction for irrigation, domestic and industrial use, waste disposal (solid and liquid), damming and introduction of exotic species (Mathooko 2001; Nyenje *et al*., 2010; Minaya *et al*., 2013; McClain, 2013; M'Erimba *et al.*, 2014; Fouchy *et al*., 2019; England, 2019). These activities, at both the catchment- and reach-scale, have been implicated in the deterioration of water and habitat quality, changes in nutrient cycling, organic matter processing and basal food resources for aquatic communities, leading to biodiversity loss and general impairment of ecological integrity of streams and rivers (Masese & McClain, 2012; Masese *et al.*, 2014a, b; Fugère *et al.*, 2018; Mangadze *et al.*, 2019; Tampo *et al.*, 2020).

Understanding how aquatic communities respond to multiple disturbance gradients such as land-use change at both the reach- and catchment-scales is important for aquatic biodiversity conservation and water resource management. In streams and rivers, benthic macroinvertebrates have been recognized as the best indicators of water and habitat quality and overall integrity of streams and rivers (Rosenberg & Resh, 1993; Dickens & Graham, 2002; Masese *et al*., 2014a). In aquatic food webs, macroinvertebrates play a major role in linking basal resources and higher trophic levels by processing allochthonous organic matter and making it available for other aquatic consumers (Vannote *et al*., 1980). The high diversity of macroinvertebrates, broad adaptations to environmental conditions and dependence on diverse sources of energy among different taxa makes them sensitive to all forms and levels of human disturbances in streams and rivers. Thus, land-use changes at the catchment- and reach scale with implication on environmental conditions and basal food resources can have ramifications on the structural composition and functional organization of macroinvertebrate assemblages. Based on this understanding, both structural and functional compositions of macroinvertebrates have been used to assess the ecological condition and ecosystem-level processes in lotic systems (Barbour *et al.*, 1999; Merritt *et al.*, 2017).

In the tropics, mainly Africa, development of biomonitoring indices and programs for streams and rivers still lags behind other regions around the world, but great strides have been made to understand how aquatic communities respond to multiple stressors in streams and rivers. Most studies have utilized macroinvertebrates as bioindicators of ecosystem integrity and human disturbance in streams and rivers (Masese *et al.*, 2013; Mangadze *et al.*, 2019). Based on the Environmental Flow Assessment (EFA) in the Mara River Basin and from the critical indicators used to monitor the ecosystem's health, invertebrates were identified as one of the most sensitive indicator in responding to river quality levels (LVBC & WWF-ESARPO, 2010). The results from the study regarding the macroinvertebrate component showed that the benthic compositions from the upper reaches to lower reaches were highly dependent on the increasing degradation due to anthropogenic activities (Minaya *et al.*, 2013; Masese *et al.*, 2014a). Macroinvertebrates are important indicator species based on their sensitivity to environmental changes and as such are good indicators of an ecosystem's health (Karr & Chu, 2000). As a result of this growing knowledge, biotic indices continue to be developed for different countries for biomonitoring of streams and rivers (Dickens & Graham, 2002; Kaaya *et al.*, 2015; Aschalew & Moog, 2015). However, more data on the effects of human disturbance emanating from rural agricultural land use and human settlements on water quality and aquatic communities are still needed to strengthen existing biomonitoring indices and to contribute to the development of new indices for bioindication. Moreover, most studies have mainly focused on structural indicators of change while a limited number have looked at functional indicators, including the composition of macroinvertebrate functional feeding groups as indicators of human disturbance in streams and rivers.

The Mara River is one of the most important freshwater ecosystems for Kenya and Tanzania. The river has a catchment area of 13,504 Km^2, with Kenya accounting for 65 percent and Tanzania for 35 percent. With the main source of this Trans – Boundary River being the Mau Forest, it flows through diverse landscapes, has a total length of 395 km, and discharges into Lake Victoria through Tanzania. The Maasai Mara River flows through the Serengeti National Park and the Maasai Mara National Reserve; these parks hold an exceptional diversity of animals and represent the stage of the world-famous Serengeti-Mara Ecosystem in which migration of wild beasts takes place from July to October (Subalusky *et al.*, 2017). The importance of this ecosystem is known in providing sustainability of the tourism industry and support of local livelihoods and has made it an important source of revenue.

The Mara River basin, just as many other tropical river catchments, is threatened by encroachment for human settlement, livestock grazing and agricultural activities in the protected forested areas and the other fragile ecosystems (Mati *et al.,* 2008; Masese *et al.,* 2014a). Growing human and animal populations, along with poor and ineffective land management methods on recently deforested lands, have resulted in massive soil erosion and increased sedimentation into the Mara River. Climate variability and change in land-use have both been modelled as prospective changes in the river's flow regime in this river system (Melesse *et al*., 2008; Mango *et al.,* 2011; Kilonzo *et al*., 2014). These changes to the existing natural conditions, as well as the spatial organization of plants and soils in the terrestrial ecosystem, have significant long-term implications for the ecology of the river and the associated ecosystems (Mati *et al*., 2008; Masese *et al.*, 2014a), hence there is need for continuous biomonitoring. This approach of using aquatic bioindicators to evaluate the biotic integrity of stream catchments and associated ecosystems is important to environmental resource managers in identifying degraded areas and therefore call for appropriate measures to restore these ecosystems to achieve greatest needs in the most cost-effective way.

1.1.1 Functional classification of macroinvertebrates

Benthic macroinvertebrate functional feeding group (FFGs) classification is a trait based on morphological as well as the behavioural mechanisms used by these organisms to acquire food materials (Cummins & Klug, 1979). There are five major macroinvertebrate functional feeding groups (FFGs) including; Scrapers/grazers which consume algae and associated material; shredders consuming leaf litter or other Coarse particulate organic matter (CPOM); collector-gatherers collect Fine particulate organic matter (FPOM) from the stream bottom; collector-filterers collect Fine particulate organic matter (FPOM) from the water column; and predators which feed on other consumers in the system (Cummins & Klug, 1979).

1.2 Statement of the problem and Justification

Understanding how stream macroinvertebrate communities respond to multiple land use changes in nature is important because there are multiple stressors operating in the environment. Benthic macroinvertebrate structure and their role in stream ecosystems are shaped by riparian vegetation through the supply organic matter and provision of canopy in streams (Masese *et al.,* 2014b). Some of the influences on riparian quality and integrity of biotic stream ecosystems include the growth and expansion of agricultural and urban areas (Allan, 2004), overgrazing (Kibichi *et al*., 2008; Leip *et al*., 2015), and the introduction of exotic species (Masese *et al*., 2017). Few studies have looked into the response of benthic invertebrates in streams and rivers following conversion of grassland and forested catchments to agriculture, urbanization, industrial activities, mining and other forms of development (Dudgeon, 2006). Anthropogenic alterations on the riparian corridor alter the functional feeding group composition of macroinvertebrates by modifying food availability and causing changes in habitat structure and quality (Dudgeon, 2006; Wantzen & Wagner, 2006). Degradation alters the quality and amount of organic matter in streams, as well as the dynamics of primary productivity (Bambi *et al.,* 2017), in that macroinvertebrates composition from upper reaches to lower reaches are highly dependent on increasing degradation due to anthropogenic activities (Kibichi *et al*., 2008; Raburu *et al*, 2009; Masese *et al.,* 2014a, b). The relative abundance of macroinvertebrate functional groups reflect anthropogenic influences within stream catchments, and can be therefore be good surrogates of ecosystem attributes. However, there still exists insufficient data on the macroinvertebrate functional feeding groups of the Mara River basin, leading to poor environmental management. Therefore, the need for further studies, especially those examining biological attributes of lotic systems are necessary to emphasize the important roles of benthic macroinvertebrates in stream and rivers. This study is important because it aimed at identifying effects of changes in land-use on macroinvertebrate indicators within the Mara river basin that can be used in future monitoring, such as in determining water quality and trophic status sufficient to maintain important ecological processes.

1.3 Study Objectives

1.3.1 General Objective

To investigate spatial variation in the structural and functional composition of macroinvertebrates in response to different levels of disturbance caused by change in land use in the upper Mara River Basin, Kenya.

1.3.2 Specific Objectives

i. To determine the effects of land use in the catchment on water quality in streams in the upper Mara River Basin, Kenya.
ii. To determine the effects of land use in the catchment on abundance, distribution and diversity of macroinvertebrates assemblages in the upper Mara River Basin, Kenya.
iii. To determine the relationships between water quality and the structural composition of macroinvertebrates in the upper Mara River Basin, Kenya.
iv. To determine the relationships between water quality and the functional composition of macroinvertebrates in the upper Mara River Basin, Kenya.

1.4 Hypotheses

H_{01}: There are no changes in water quality with increasing levels of human disturbance in streams in the upper Mara River Basin.

H_{02}: There are no changes in the structural and functional composition of macroinvertebrates instreams in the upper Mara River Basin.

H_{03}: There are no relationships between disturbance (measured by water quality) and structural composition of macroinvertebrates in streams in the upper Mara River Basin.

H_{04}: There are no relationships between disturbance and functional composition of macroinvertebrates in streams in the upper Mara River Basin.

CHAPTER TWO

LITERATURE REVIEW

2.1 Land-use influence on macroinvertebrate structural and functional composition

Aquatic ecosystems, globally and regionally, have been highly modified by human activities resulting in a change in flow regimes, organic matter dynamics, sediment characteristics and composition of aquatic biota (Hughes and Convey, 2010; Minaya *et al.,* 2013; Masese *et al.,* 2014b). Changes in land use from forest to cropland, animal grazing, and human settlements have a significant impact on stream catchments, stream hydrology and ecosystem functioning (Clapcott *et al.,* 2012; Masese *et al.,* 2014b; Piggott *et al*., 2015). Streams in agriculturally dominated catchments are prone to changes in biogeochemistry, habitat homogeneity, increased pollution, canopy reduction, and hydrological changes (Quinn *et al.,* 1997; Allan, 2004; Woodward *et al.,* 2012; Cooper *et al.,* 2013). The majority of these consequences are a result of decreased forest cover in these catchments as well as deforestation in the riparian zones (Woodward *et al.,* 2012; Cooper *et al.,* 2013). Being the interface between terrestrial and aquatic systems, riparian forests have a significant impact on stream ecosystems. They; buffer streams through enhanced infiltration rates, sediment retention, enhanced shade, and delivery of allochthonous food and shelter supplies (Benstead & Pringle, 2004; Bleich *et al.,* 2015). Consequentially, deforestation in stream catchments results in direct and indirect physical, chemical, and biological effects on streams (Gregory *et al.,* 1991; Masese *et al.,* 2009a; Raburu *et al.,* 2009; Masese *et al.,* 2014a, b).

Anthropogenic influences on streams may emanate either from catchment or reach-scale influences and act on different magnitudes as different stressors have varying effects at different scales on stream ecosystem functioning (Roth, 1997; Feld, 2013; Tanaka, 2016). However, predicting biological responses to these stressors is difficult since organisms, and consequently, assemblages can exhibit linear or nonlinear responses to anthropogenic disturbance gradients (Allan, 2004; Masese *et al.*, 2014a). Research indicates the importance of catchment-scale pressures on the local physical habitat condition, condition of water quality and quantity, as well as the condition of these aquatic ecosystems which can be assessed using Multi-metric indices (MMIs) built from multiple biological assemblage attributes (Allan, 2004; Wang *et al*., 2006; Hughes and Convey 2010). The multi-metric technique combines the responses of many assemblage components (e.g., richness, composition, trophic guilds, diversity, and dominance) to anthropogenic stresses. (Hughes and Covey, 2010; Karr, 1999; Hering *et al.,* 2006; Ferreira *et al.,* 2014; 2017). The approach further integrates the response of multiple anthropogenic pressures at both catchment and reach scales (Karr, 1999). The method is advantageous in its use as it can be easily interpreted, can be rapidly developed and is more cost-effective than purely physical and chemical water monitoring (Allan, 2004).

Benthic macroinvertebrates community composition have for long been utilized as bioindicators of stream health and environmental integrity (Bonada *et al.,* 2006; Buss *et al.,* 2015). They also present a wide range of traits and respond differently to aspects such as differential resource availability, pollution and altered environmental conditions (Lange *et al.,* 2014). In many parts of the globe, benthic invertebrate assemblages are used as an indication of land-use impacts in catchments of stream ecosystems as well as a measure of direct disruption in the aquatic environment (Roy *et al.,* 2003; Gabriels *et al*., 2010). These organisms have proven to be an efficient tool in biomonitoring studies as they can incorporate anthropogenic influences across several spatial and temporal dimensions (Rosenberg & Resh, 1993; Bonada *et al*., 2006).

Deforestation has a variety of effects on macroinvertebrates, including increased nutrient and contaminant levels, lower dissolved oxygen concentrations, habitat alterations, higher temperature levels, increased primary production, and hydrological changes (Sponseller *et al.,* 2001; Clapcott *et al.,* 2012; Masese *et al.,* 2014b). Streams are dynamic systems, and discharge patterns and flow regimes can have a direct impact on macroinvertebrate assemblages, either by increasing hydrological heterogeneity in flow regimes or by disrupting macroinvertebrate communities through fluctuating high and low stream water flows (Resh *et al.,* 1988; Townsend *et al.,* 1997). Clearing riparian vegetation for farming increases the susceptibility of these aquatic habitats to surface runoff, which can result in high nutrient concentrations and rapid algal bloom in these systems (Allan, 2004). When the natural riparian vegetation along streams is destroyed for agricultural purposes, water temperature, nutrient content, and sediment intake in streams tend to rise, posing a threat to the ecological integrity of these aquatic ecosystems. This study was therefore set to contribute to this knowledge by investigating changes in macroinvertebrate communities that result from changes in land use in the Mara River.

2.2 Streams and macroinvertebrates

The stream's physical environment imposes several restrictions on organisms as well as the type and quantity of food available (Dallas, 2007). These factors such as topography, lithology, run-off and large woody debris characterize many diverse habitats by shaping these streams and generating different channel forms (Frissel *et al.,* 1986). Physical heterogeneity plays a crucial role in influencing biota (Hynes, 1975), nutrient dynamics (Meyer *et al.,* 1988), algal and macrophyte distribution (Pringle and Hamazaki, 1988), organic matter dynamics, predator-prey interaction, and presence/absence of refugal substrates (Roy *et al.,* 2003). The structure and function of stream ecosystems are shaped by the various interlinked factors and relationships such as resource availability, abiotic and biotic variables in the environment.

In ecosystems, the abiotic environment sets the platform for the evolution of certain traits and related life-history strategies among aquatic biota (Lytle & Poff, 2004). Water velocity for instance is relevant to these communities as they rely on water currents to transport food resources as well in cases of translocation of these organisms. Water current on the other hand may drag individuals, which may be a severe disturbance force owing to periodic variations and substrate dislodgment. In this regard, flow conditions have a large impact on community organization of biota in stream ecosystems (Biggs *et al.,* 2005).

The impact of hydrological disturbances on macroinvertebrate diversity in deforested watersheds can be magnified when compared to forested catchments due to effects such as greater sediment delivery loads and loss of refugia in these systems (Stanley *et al.,* 2010). Despite the fact that these interactions are ubiquitous, not enough research has been done to assess the impacts of hydrological disturbances in relation to land-use change, particularly in tropical areas, given that hydrological patterns vary between catchments with distinct land uses. The majority of research examining variations in ecological responses of aquatic communities to environmental gradients focus on spatial variation, with lesser attention towards examination of temporal variation across the same sites (Booker *et al.*, 2015).

Globally, freshwater ecosystems face threats from several stressors such as pollution and land- use change which shape the macroinvertebrates community in local and catchment scales (Ormerod *et al.*, 2010). In Kenya and within the region, unsustainable land-use being witnessed present other set of environmental challenges (FAO, 2010). At local scales, Mara River is coupled with challenges of land-use change, erosion and sedimentation as a result of flooding and water abstraction. This study aimed at investigating the distribution patterns as well as the diversity of macroinvertebrates in streams of the Mara River within different land-use categories.

2.3 Factors influencing the distribution of macroinvertebrates

Benthic invertebrate communities can differ upstream and downstream in the same stream due to longitudinal gradients in the physical environment imposed by hydrology. The variation in community distribution may also be due to changes in the river quality influenced by land use including intensive agriculture and urbanization, and the allochthonous and autochthonous organic matter input by riparian vegetation (Vannote *et al.*, 1980). The distribution of benthic macroinvertebrates is influenced by a variety of ecological variables. Substrate quality and composition, stream discharge, riparian vegetation quality, height and cover, geographical position (latitude), water velocity, and land use as a proxy for process level impacts (physico- chemical features and the level of pollution in the ecosystem) are among these elements (Giller & Malmqvist, 1998; Allan, 2004). The substrate types play an important role as the main feature of microhabitats where different benthic macroinvertebrates reside (Dallas, 2007). A study done by Iwata *et al*. (2003) in a tropical rainforest found a strong correlation between deforestation and substrate type that affect and influence the abundance, diversity and composition of benthic macroinvertebrates.

Human activities impact natural terrestrial ecosystems, through broad-scale land-use changes linked to natural resource acquisition (forestry, agriculture, and mining), as well as urban and industrial growth (settlements and transport infrastructures) (Foley *et al*., 2005). These changes have the potential to have significant and long-term ecological consequences for river systems (Allan & Flecker, 1993; Fausch *et al*., 2010). Low-order open streams are defined by macroinvertebrate communities that rely on sunlight penetrating through the open canopies for primary productivity (Delong & Brusven, 1998).

Changes in watershed vegetation, particularly in the riparian regions, affects the amount, quality, and seasonality of external resource inputs to streams (sunlight regimes and allochthonous input) (Naiman, 2005a, b). It also has an impact on the environmental stressors' regime through sediment inputs and loading, temperature and physico-chemical water quality parameters which have significant influences on the growth, survival, feeding, and distribution of aquatic communities (Sponseller *et al.*, 2001; Thompson & Townsend, 2004; Richardson, 2008). Reforestation and afforestation have become prevalent activities in recent decades as a means of recovering and/or converting new areas to reduce erosion. The impact of these forestry techniques on the catchments that drain plantations is substantial (Foley *et al*., 2005). In aquatic ecosystems, land use is among the indirect stressor for aquatic biota (Sponseller *et al*., 2001). Therefore, this study aimed at looking at how land-use change from forest to agriculture affect the distribution, diversity and composition of macroinvertebrates in the Mara River.

2.4 Benthic macroinvertebrates as bioindicators

Bioindicators; defined as an assemblage of living organisms sensitive to environmental stressors and are capable of responding in a manner that can be quantified to explain the ecological processes and deduce the prevailing conditions in the particular environment (Allan, 2004). They have been used since the beginning of the last century as an important biomonitoring tool to evaluate river quality and levels of organic waste in rivers.

Biodiversity has long been used to examine complex interactions existing between human activities and landscape management and the consequences arising from these interactions. The responses of the biodiversity to these activities at the landscape level vary, with some creatures responding more quickly and definitely than others (Thompson & Townsend, 2004; Richardson, 2008). Undoubtedly, benthic macroinvertebrates are among the most used bioindicators due to their sensitivity to environmental changes and in providing scientifically defensible evidence of environmental status (Resh, 1995; Barbour *et al*., 1999). However, bio assessments using well-established methodologies are still in a developing stage for some African countries including Kenya.

Macroinvertebrates are superior bioindicators as they are niche-specific and spend most of their life cycle in water bodies giving them the unique ability to trace the human impact over time (Bonada *et al*., 2006). Macroinvertebrate community abundance and diversity can be used to assess ecological changes and impacts that might occur due to the change in land use. It recommends stream protection by maintaining and if it is possible minimizing the urban and agricultural land cover in the catchment (Allan, 2004). Several studies have recognized the significant correlation existing between changing land-use and the accompanying macroinvertebrate communities, showing that total taxa richness, and percentage abundances of Ephemeroptera, Plecoptera and Trichoptera (EPT) decrease while Oligochaeta and Diptera groups increase as the pollution and deterioration in the river quality increases (Barbour *et al.,* 1999; Raburu, 2003; Masese *et al.,* 2009a; Minaya *et al.,* 2013; Masese *et al.,* 2014a).

Benthic macroinvertebrates are valuable pointers of the health of aquatic bodies since they exhibit a wide range of pollution and disturbance sensitivities (Rajele, 2004; Kazanci & Dugel 2010). Stream variables such as breadth, depth, substrate, water velocity, and physico-chemical parameters, are often factors influenced by both natural and human activities, which in turn have significant impacts on the distribution and composition of stream macroinvertebrate communities (Baptista *et al.,* 2007; Arimoro, 2009; Arimoro *et al.,* 2011). Other than their ability to indicate both long-term and short terms changes in the system, macroinvertebrates are popularly utilized for biomonitoring because of their relatively short life spans and easiness of capture (Resh, 2008). In riverine ecosystem food webs, macroinvertebrate populations also play a crucial role. Being an important energy source for higher trophic levels such as fish, they are fundamental to stream health in that, when classified into functional feeding groups they play essential roles in the breakdown of detritus, assimilation of biofilm, and as predators and prey (Erdozain *et al*., 2019). In general, they customarily respond negatively to physical channel alterations and riparian disturbances (Hedrick *et al*., 2013; Paller *et al*., 2014).

In Kenya, several studies have used macroinvertebrates as bioindicators of water quality, a trend that is becoming widespread because it is a cost-effective method.

These studies include; Raburu *et al.* (2009), Masese *et al.* (2009b), Minaya *et al.* 2013, Masese *et al.* (2014a,b) and M'Erimba *et al.* (2014). This study was set to contribute to such knowledge by using macroinvertebrates as bioindicators in the different land use categories within the Mara River catchment.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location of study area

The first to fifth order mid-altitude (1100–3070 m above sea level (a.s.l) streams draining the western slopes of the Mau Escarpment within the Kenyan Rift Valley were used for this study. The trans-boundary Maasai Mara River Basin (MRB) (Kenya/ Tanzania) covers 13,835 km^2 and is located between latitudes 0°21'S and 1°54'S and longitudes 33°42'E and 35°54'E, with Kenya having for 65% and Tanzania for 35%. The Mau Forest Complex is drained by the river, which originates in the Enapuiyapui Swamp on the Mau Escarpment's eastern side (MFC). The MFC is a large tropical wet broadleaf forest that feeds tributaries flowing into Lakes Baringo, Nakuru, and Victoria.

3.1.2 Topography and drainage

The Northern and Eastern parts of the Mara River basin are surrounded by rocky and hilly topography. The MRB's altitude varies from 3070 meters above sea level on the Mau Escarpment to approximately 1100 meters above sea level in the Mara wetland. The climate of the region is characterized by relatively cool temperatures throughout the year, with mean annual figures range from 12^0C to 16^0C. Average minimum temperatures within the middle catchment are in the range of 10^oC to 14^oC, whereas the mean maximum temperatures range from 22^0C to 26^0C. The region experiences bimodal patterns of precipitation with annual precipitation ranging from 1000 to 2000 mm. The basin experiences both the dry and wet seasons. The dry conditions are usually experienced in the months of December–March and July-September. The wet condition is has both the long rains (April–June) and the short rains (October–November). The lower catchment consists of gently sloping plains (Tarus & Nadir, 2020).

The drainage within the MRB is determined by the type and arrangements of the bedrock units in the basin (Mutie, 2006): (i) the two permanent tributaries in the basin, Amala and Nyangores meet at the base of the escarpment to form the upper Mara River. (ii) In the midlands of the basin three key tributaries including the Talek River which originates from the Loita plains and joins the Mara in Maasai Mara National Reserve (MMNR), the Engare Ngito, originating from the Ilmotyookoit ridges, and the Sand River, which joins the Mara at the Kenya-Tanzanian Border in the Serengeti plains.

3.1.3 Geology and soils

On the Kenyan side, majorly on the Amala and the Nyangores sub-basins, there is Mollic Andosols soils which were derived from tertiary volcanic materials (Mati *et al.*, 2008). The steepest slopes of this region have Cambisols whereas in the Northern regions, Humic Nitisols are included. In the Mid-Mara sub-basin, the soils are generally rocky, sandy and are shallow (Ogunah *et al.*, 2016). Mara river basin is dominated by brown clay soils which are waterlogged seasonally (Kilonzo *et al.*, 2014).

3.1.4 Social economic activities

The Mara catchment area is home to approximately 1.1 million people (Kenyan 2019 population census). Majority of this population is located in the upper and mid reaches of the basin while the lower reaches is sparsely populated. Excisions of forests for human development, plantation forest, and tea farming (both small- and large scales) have resulted in the current size of the Mara forest being greatly fragmented and diminished in size (Ogutu *et al.,* 2011). Forest reserves and national parks do, however, conserve certain portions of the forest that are still intact (Lamprey & Reid, 2004). Communities with the basin engage in semi-intensive small-holder farming of tea (as a cash crop), maize, beans, and potatoes (as food crops), and livestock keeping. This has resulted in the disappearance of native riparian flora along these rivers, which is now dominated by the exotic Eucalyptus trees.

Livestock rearing is the second largest contributor to the economy of the Mara; behind agriculture, and consists mainly of cattle, goats, and sheep rearing (Yanda & Majule, 2004). Small and middle scale livestock rearing is carried out within the upper region of MRB, while extensive ranching is carried out in the upper portions of the basin within the group ranches. Small and middle scale livestock rearing consists of pastoral herdsmen, mainly the local Maasai tribesmen, who herd their cattle based on environmental conditions, in search of both adequate grazing grounds and water supplies (Hoffman, 2007).

Tourism is another important economic activity in this region. The MMNR and the Serengeti National Park (SNP) are famous for having the world's largest density of herbivores. These parks also hold a natural wonder (the annual migration of wildebeest). It is estimated that 1.3 million wildebeest, 200,000 zebras and 440,000 gazelles do migrate between the MMNR and SNP. In the mid stretches of the basin on the Kenyan side, the river and its tributaries is estimated to host more than 4,000 hippos (Kanga *et al.,* 2011)

3.1.5 Sampling design

A total of 19 sampling sites were chosen in stream sections classified into three main groups based on watershed disturbance gradients, riparian land use, and reach-scale human effects. The disturbance gradient was based on the land use at the catchment where sites with intact catchment zones characterized by greater than 60% forest cover. Highly disturbed sites had intensive agriculture (both livestock and crop farming) being practised in the catchment while moderately disturbed sites had a mix of both forest catchments and agriculture with none being dominant and exceeding 60% cover. Catchments of each of the study sites were defined and the area upstream of each of these sites determined using the Digital Elevation Model of Kenya (90 m by 90 m), which uses data from the Shuttle Radar Topography Mission. The (a) Undisturbed sites (near pristine sites dominated by forest cover, n = 7), (b) highly disturbed sites (Plate 2) (dominated by agricultural activities; maize and tea farming, and livestock keeping, n = 6), and (c) moderately disturbed sites (Plate 1) (mixed activities within the sites; forest fragments and small-scale agriculture, n = 6) (Figure 1). The sites were selected based on the disturbance level in two main tributaries of the Mara River; Amala and Nyangores (Figure 1). Of the 19 sites, 8 were located along the Amala tributary while 8 along the Nyangores tributary. Three sites were located along the Mara River after the two tributaries have joined (Figure 1).

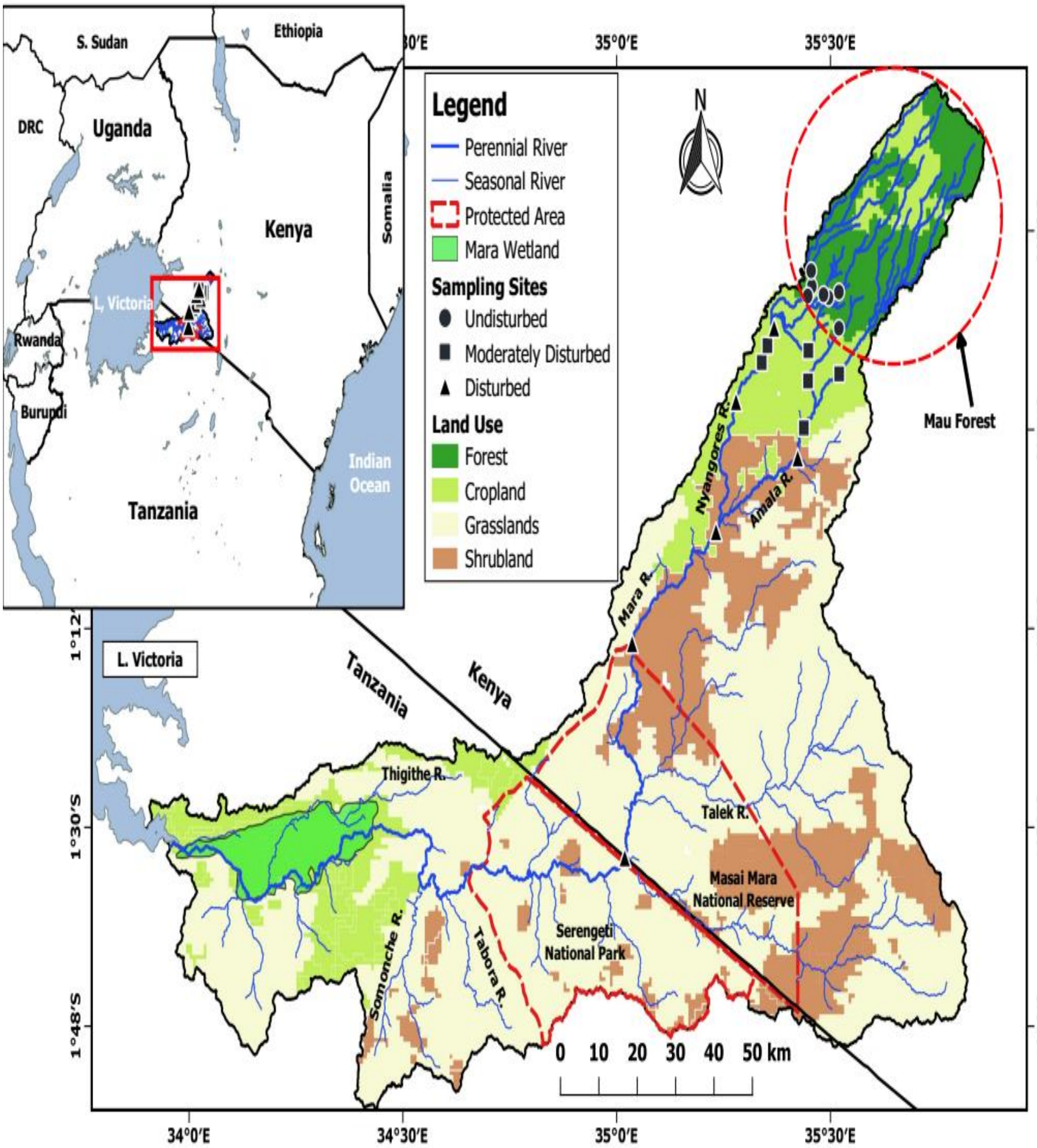

Figure 1: Location of sampling sites along the Mara River Basin, Kenya

3.2 Sampling procedure

3.2.1 Sampling for water physico-chemistry variables

Measurement of physico-chemical water quality variables was done for a period of 6 months from end of August 2013 to early February 2014. At each location, triplicates measurements of pH, dissolved oxygen (DO), temperature, electrical conductivity

(EC), total dissolved solids (TDS), and salinity were measured *in-situ* using a YSI multi-probe water quality meter (556 MPS, Yellow Springs Instruments, Ohio, USA).

Additionally, water samples for the analysis of total nitrogen (TN) and total phosphorous (TP) were collected in two replicates in acid washed 500 mL high density polyethylene (HDPE) plastic bottles and stored in a cooler box in the field using ice packs before being transported to the University of Eldoret laboratory for analysis.

3.2.2 Total suspended solids samples collection

The field procedure for the determination of total suspended solids involved the filtration of water samples at the field through Whatman Glass Fibre Filters (GF/F) of 0.42mm thickness, 0.7 µm pore size and 47mm diameter. Water samples were drawn from the stream and known volumes were filtered through these filters depending on the turbidity levels of the water at each site. Filtration was done to a level where the water could no longer pass through the Glass Fibre Filters (GF/F) with ease. These filters were then wrapped in envelopes made from aluminium and placed in a cool box and thereafter transported to the University of Eldoret laboratory for determination of total suspended solids (TSS).

3.2.3 Macroinvertebrates collection

At each sampling location, a representative stretch of about 100 meters was chosen that contained stream mesohabitats of (at least a riffle, pool, and run) for a segment of one to several kilometres. Sampling was done from the lower reaches of the identified reach stretch and proceeded upstream to minimize the effects of physical disturbance and hence invertebrate drift. A sample consisted of 10 sampling units. Sediments were disturbed to a depth of 5-10 cm.

Field processing of invertebrates involved sorting and removal of large particles such as branches, sticks and stones. These materials are thoroughly washed, overturned and inspected for macroinvertebrates as these organisms may reside on or within sediments, or maybe associated with aquatic vegetation (Phiri *et al.*, 2012).

Samples were taken within 2-5 min, using a dip net (300-µm mesh size), whereby substrate used by macroinvertebrates as habitats were disturbed by foot or by hand and macroinvertebrates allowed to flow with current into the net. The collected samples were thereafter preserved in 75% ethyl-ethanol or 4% formalin solution, and transported to the laboratory for processing.

3.2.4 Measuring of stream and habitat variables

Reach characterisation was done at each sampling point by measuring stream width, water depth, flow velocity, and water discharge over a 100-meter stretch. Measurements of the stream width were taken at several points within the identified reach using a measuring tape. Water depth were randomly measured from several points within the identified reach using a meter rule. Velocity was similarly measured randomly within the identified reach using a mechanical flow meter (General Oceanics; 2030 Flow meter, Miami, Florida). The velocity–area method developed by Wetzel & Likens (2000) was used to compute the stream discharge using water velocity, depth and width in each sampling site.

Discharge (Q) = River cross-sectional area (A) × Velocity (v)

Where: Area = Width * Water depth at each measurement.

3.3 Laboratory analyses

3.3.1 Nutrient analyses

In the laboratory, water column nutrient analyses were determined using standard colorimetric methods (APHA, 2005). Unfiltered water samples were used for TP and TN analyses. For TP, after persulfate digestion, samples were analyzed using the ascorbic acid method with absorbance read at a wavelength of 885 nm (APHA, 2005), while TN was determined using Koroleff method where after persulphate digestion absorbance was read at a wavelength of 220 nm and 275 nm (APHA, 2005). Soluble Reactive Phosphorus (SRP) was analyzed using the ascorbic acid method with absorbance being read ata a wavelength of 885 nm while Nitrate (NO_3) and Nitrite (NO_2) soluble nutrients were analyzed using the Salicylate method with the spectrophotometric absorbance read at a wavelength of 543 nm (APHA, 2005). Ammonium (NH_4) was analyzed through the reaction between sodium salicylate and hypochlorite solutions with the spectrophotometric absorbance of the treated sample being read at a wavelength of 665 nm (APHA, 2005)

3.3.2 Total suspended solids

The glass fibre filters (GF/F) containing the total suspended particulate matter were dried in an oven at 60^{o}C for 72 hours to constant weight and TSS was determined using the equation below:

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

Where:

A= Weight of filter (g) + residue

B= Weight of pre-combusted filter without residue (g)

V= Volume of water filtered (ml)

3.3.3 Sorting, identification and FFG allocation of macroinvertebrates

Macroinvertebrates were preserved in 75% ethanol after being separated from detritus, and thereafter identified to the lowest-possible taxonomic level or morphospecies using keys from numerous guides described by (Day & de Moor, 2002a, b; Day *et al.,* 2002; de Moor *et al.,* 2003a, b; Stals & de Moor, 2007; Merritt *et al.,* 2008). Abundance was estimated as a total count of individuals in each taxon. Once identified, the invertebrates were assigned to their respective functional classes; collectors, scrapers, shredders and predators, using references from literature (Cummins *et al.,* 2005; Merritt *et al*., 2008; Masese *et al*., 2014a).

Plate 1: A stream in a moderately disturbed land use category in the Mara River (Photo: Dr. Frank Masese)

Plate 2: An anthropogenic activity (cutting down of trees and clearing of shrubs for firewood) in the Mara River basin (Photo: Dr. Frank Masese)

3.4 Data analysis

Descriptive statistics (means ±standard deviation) and plots were used to present spatial variation in water quality variables and nutrients at the different land use categories. Before analyses were performed, data was tested for normality using Kolmogrov-Smirnov normality test.

Significant variations in water quality variables and stream size variables among site categories were tested using one-way analysis of variance (ANOVA) followed by Tukey multiple post hoc comparisons of the means where there were significant differences. To reduce the dimensionality of the physico-chemical and stream size variables, Principal Component Analysis (PCA) was used.

Community structure was described in terms of taxon richness, abundance and community indices. Species occurrence (presence-absence) and distribution data were summarized for each study site and means calculated for each site/ disturbance category using the number of taxa (S) and the total relative abundances. Several reach- scale diversity indices were calculated for each study site and means calculated for each site category. Shannon's diversity index (H′) was derived as a measure of diversity (Magurran, 2004), and an associated H′/H′max index (Pielou, 1975) was used as a measure of evenness. The reciprocal form of the Simpson index (1-Ds) (Simpson, 1949) was used as a measure of species richness. Hill's number (i.e., gamma diversity; Hill, 1973) and Fisher's alpha (Fisher *et al.*, 1943) were used as extra measures of macroinvertebrates diversity. Hill's number was calculated as the ratio between H′ and 1/D (Hill, 1973). Margalef's species richness index was also determined as an extra measure of taxon richness.

Functional structure was also described in terms of taxon richness and abundance of the different FFGs at the different study sites and site categories. To determine the key macroinvertebrates responsible for the differences observed among the three site categories attributed to changes in land-use, nutrient levels and water quality, similarity percentages analysis (SIMPER) was used. The percentage contribution of each taxon and FFGs to the overall dissimilarity between the site categories was quantified. SIMPER is a strictly pairwise analysis between two-factor levels (Clarke & Warwick, 2001), and in this case, comparisons were made between undisturbed and disturbed, and disturbed and moderately disturbed sites.

Canonical correspondence analysis (CCA) was used to investigate the relationship between macroinvertebrate structural and functional composition, water quality variables, nutrients and stream size variables across the different disturbance gradients.

All analyses were performed using PAST software (Version 3.21) and Minitab software (version 17) and figures were created in SigmaPlot (Version 12) and MS Office Excel (2016).

CHAPTER FOUR

RESULTS

4.1 Physico-chemical water quality variables and land-use categories

There were significant differences in electrical conductivity, temperature, TDS, TSS, salinity, TN, SRP, NO_3, NH_4, depth and stream discharge ($p < 0.05$) among the different site categories/ disturbance levels, while pH, DO TP and NO_2 were not significantly different ($p > 0.05$) (Table 1). Undisturbed sites had the highest DO levels (7.5 ± 0.23), and lowest mean values of Temperature, TN, conductivity and TDS (Table 1). TN was higher than TP at all sites. Moderately disturbed sites recorded the highest levels of both TP and TN while NH_4, SRP, NO_2 and NO_3 were higher in highly disturbed sites, with undisturbed sites recording the least concentration levels. The highest TSS and nutrients levels were recorded in the disturbed sites, while TDS and conductivity recorded the highest concentration levels at the moderately disturbed sites (Table 1).

Table 1: Means (± SE) variation of physico-chemical variables and stream size variables in the three site categories

	Site categories				
Water/stream variables	**Undisturbed (n = 7)**	**Moderately Disturbed (n = 6)**	**Highly Disturbed (n = 6)**	***F*-value**	***p*-value**
Water physico chemistry					
pH	6.1 ± 0.4^{a}	5.1 ± 0.6^{a}	4.9 ± 0.3^{a}	1.78	0.172
DO (mg/L)	7.5 ± 0.2^{a}	6.7 ± 0.3^{a}	6.9 ± 0.2^{a}	1.91	0.151
Conductivity (µS/cm)	70.5 ± 4.4^{a}	127.2 ± 8.2^{b}	111.8 ± 8.6^{b}	6.21	**0.002***
Temperature (^{o}C)	14.2 ± 0.4^{a}	18.2 ± 0.7^{b}	18.5 ± 0.5^{b}	13.21	**0.001***
TDS (mg/L)	40.5 ± 5^{a}	83.5 ± 8.0^{b}	69.1 ± 6.7^{c}	5.14	**0.007***
TSS (mg/L)	17.3 ± 7.2^{a}	20.9 ± 7.5^{ab}	29.4 ± 6.7^{b}	0.68	**0.049***
Salinity (mg/L)	0.03 ± 0.004^{a}	0.06 ± 0.005^{b}	0.04 ± 0.004^{ab}	4.71	**0.013***
Nutrients					
TP (mg/L)	0.1 ± 0.02^{a}	0.2 ± 0.04^{a}	0.1 ± 0.02^{a}	2.15	0.119
TN (mg/L)	0.4 ± 0.07^{a}	0.8 ± 0.12^{b}	0.7 ± 0.08^{b}	2.85	**0.006***
NO_3 (mg/L)	0.4 ± 0.14^{b}	1.2 ± 0.2^{a}	1.4 ± 0.6^{a}	10.00	**0.002***
NO_2 (mg/L)	0.01 ± 0.001^{a}	0.02 ± 0.01^{a}	0.04 ± 0.01^{a}	3.20	0.068
SRP (mg/L)	0.01 ± 0.001^{b}	0.03 ± 0.01^{a}	0.04 ± 0.01^{a}	12.93	**<0.001***
NH_4 (mg/L)	0.02 ± 0.01^{b}	0.08 ± 0.03^{ab}	0.09 ± 0.09^{a}	4.51	**0.028***
Stream size variables					
Width (m)	4.3 ± 1.0^{a}	10.5 ± 3.2^{a}	9.7 ± 2.6^{a}	2.09	0.157
Depth (m)	0.2 ± 0.05^{a}	0.3 ± 0.09^{b}	0.2 ± 0.01^{a}	3.83	**0.044***
Discharge (m^3/s)	0.2 ± 0.1^{b}	1.4 ± 0.4^{ab}	0.6 ± 0.4^{a}	3.48	**0.054**

*Means that do not share a letter are significantly different, Tukey *post hoc* tests

**p* –values in bold marked with asterisks are significantly different among site categories at $p < 0.05$

There were significant differences in physico-chemical and stream size variables between site categories (PERMANOVA *F* = 5.14, *df* = 2, *p* = 0. 01). The relationships among water quality and stream size variables in the river were summarized by the PCA (Figure 2). PCA (PC 1) axis explained 35.5% of the total dataset variance, while the second PCA axis (PC 2) explained 22.7% of the total variance in water physico-chemistry among site categories (Figure 2). Highly disturbed sites were associated with higher levels of electrical conductivity, turbidity (TSS), temperature and high nutrient levels than both the moderately disturbed and undisturbed sites (Figure 2). Moderately disturbed sites were associated with river depth and discharge while the undisturbed sites were associated with increased DO levels (Figure 2).

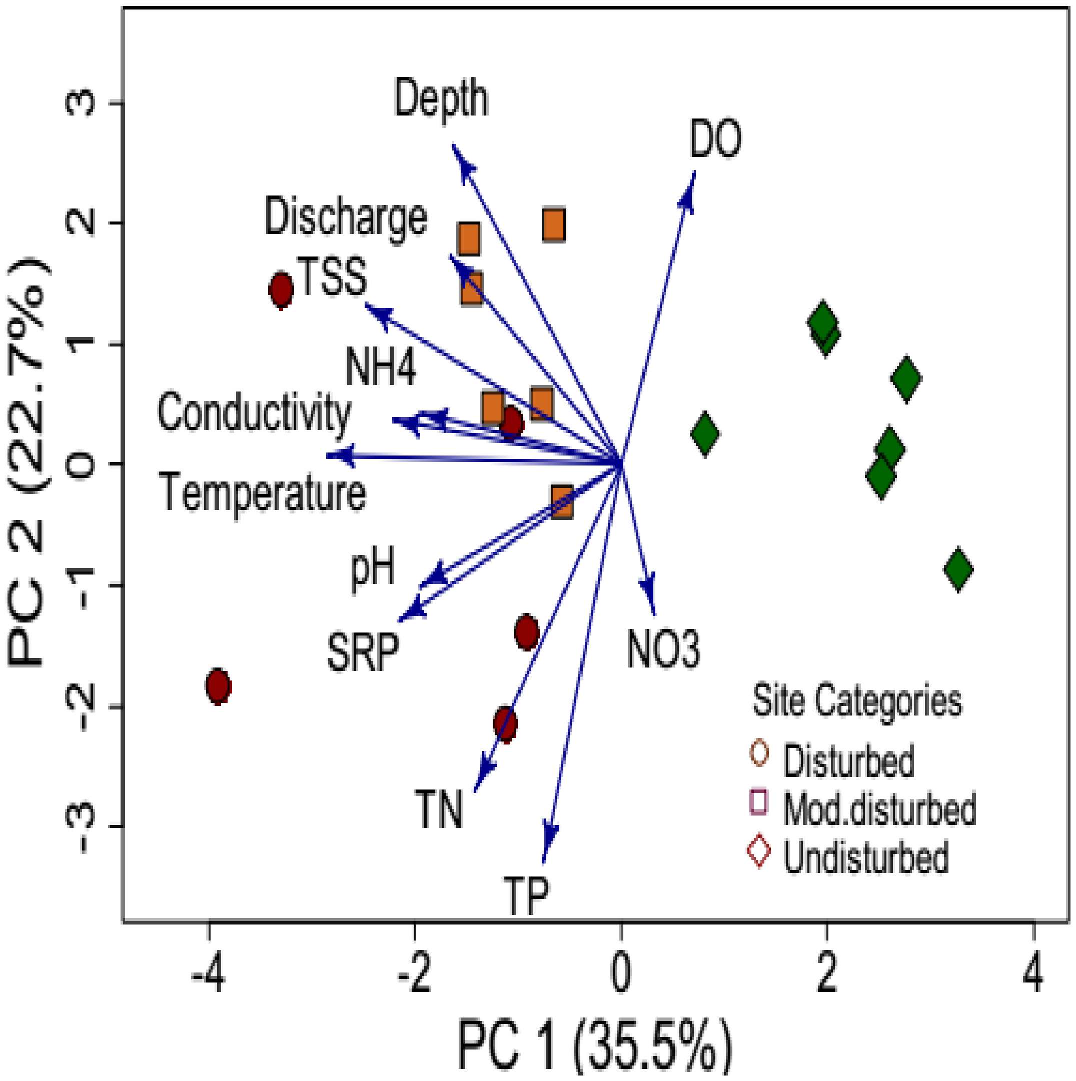

Figure 2: Principal component analysis of physico-chemical variables and nutrients in the Mara River, western Kenya. Disturbed- n = 6, moderately disturbed - n = 6, Undisturbed –n = 7, DO= dissolved oxygen, NO_3= nitrates, TP= total phosphorous, TN= total nitrogen, SRP= soluble reactive phosphorous, TSS= total suspended solids

TN was higher than TP in all the site categories (Figure 3). TP did not vary significantly across the different disturbance categories ($p > 0.05$) while TN varied significantly ($p < 0.05$; Table 1). Moderately disturbed sites recorded highest levels of both nutrients while the undisturbed sites recored the least concentration levels (Figure 3).

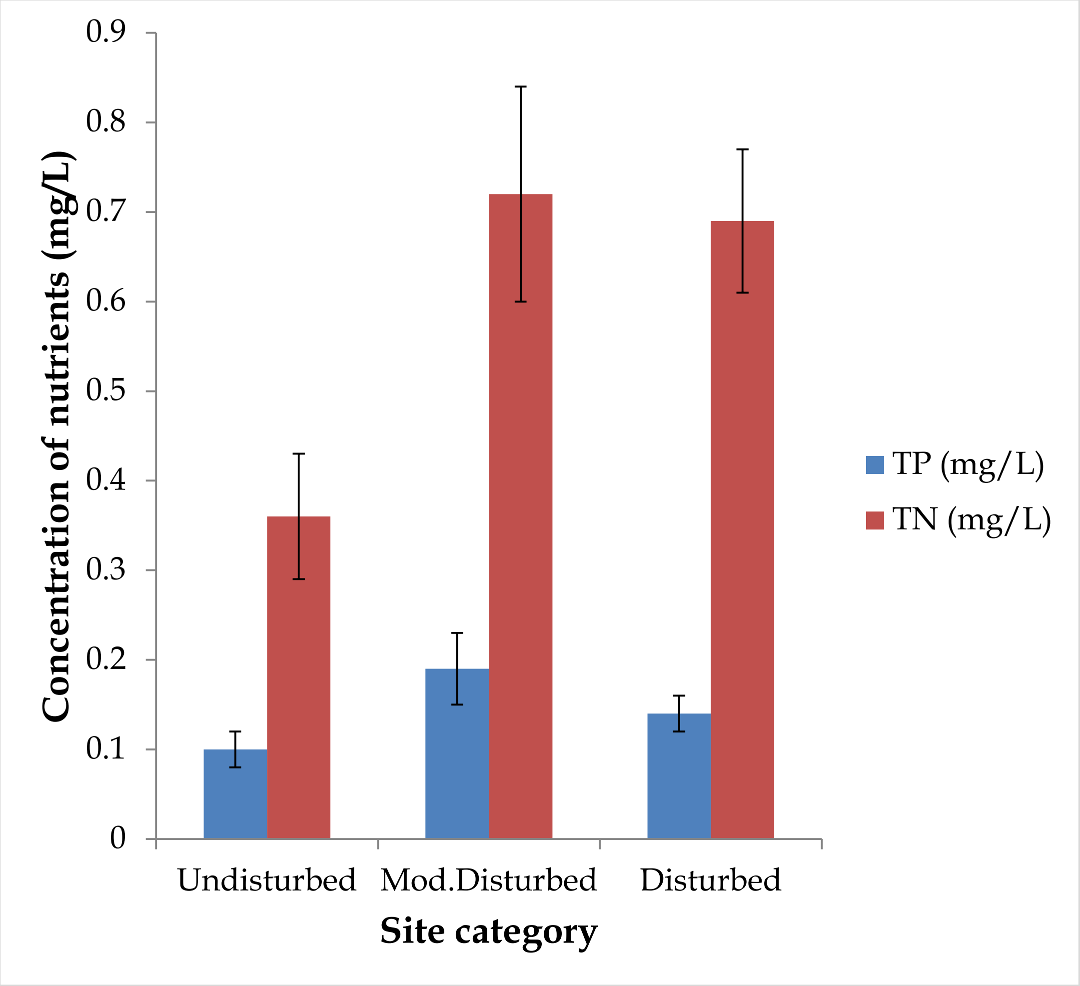

Figure 3: Nutrient concentration in the three site categories in the Mara River, western Kenya. Mod. Disturbed = moderately disturbed, TP= Total phosphorous, TN= Total nitrogen. Error bars represent standard error

Stream order was employed as a measure of stream size along the Mara River. Nutrient levels increased with increase in stream order, from head waters to the mid reaches (Stream order 5) (Figure 4). Both TP and TN were highest at stream order 5 and lowest in the head waters (stream order 2) with TN recording higher concentration levels than TP in all the stream orders (Figure 4).

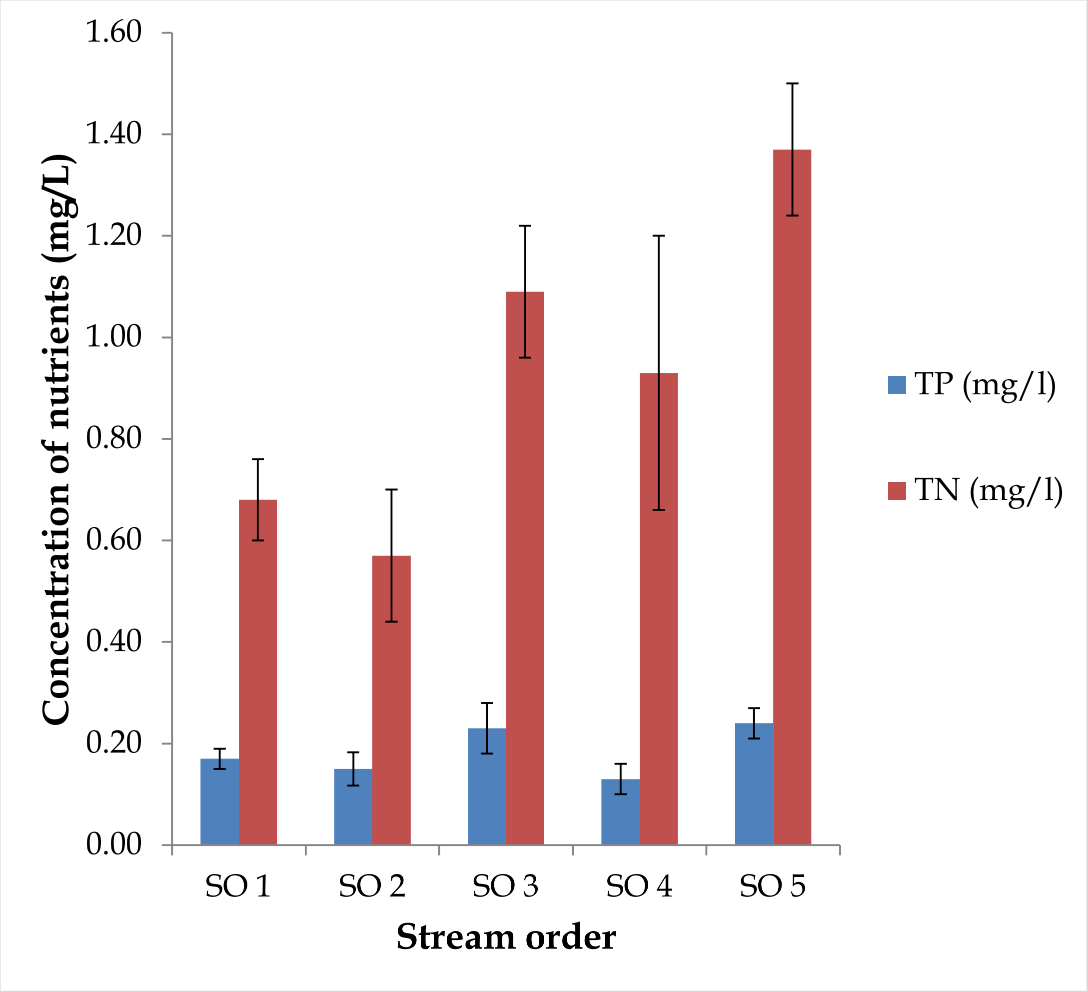

Figure 4: Nutrient variation (TP and TN) along the Mara River. SO = Stream order, TP = Total phosphorous, TN = Total nitrogen

4.2 Community composition of macroinvertebrates

4.2.1 Macroinvertebrate structural composition

A total of 48,848 macroinvertebrate individuals belonging to 21 orders and 70 families were identified. Of these 27311 individuals were collected along the undisturbed sites, 9393 individuals were collected along the moderately disturbed and 12144 individuals were collected along the disturbed sites (Figure 5). The undisturbed site categories had the highest number of macroinvertebrate individuals with the moderately disturbed sites having the least number of individuals (Figure 5).

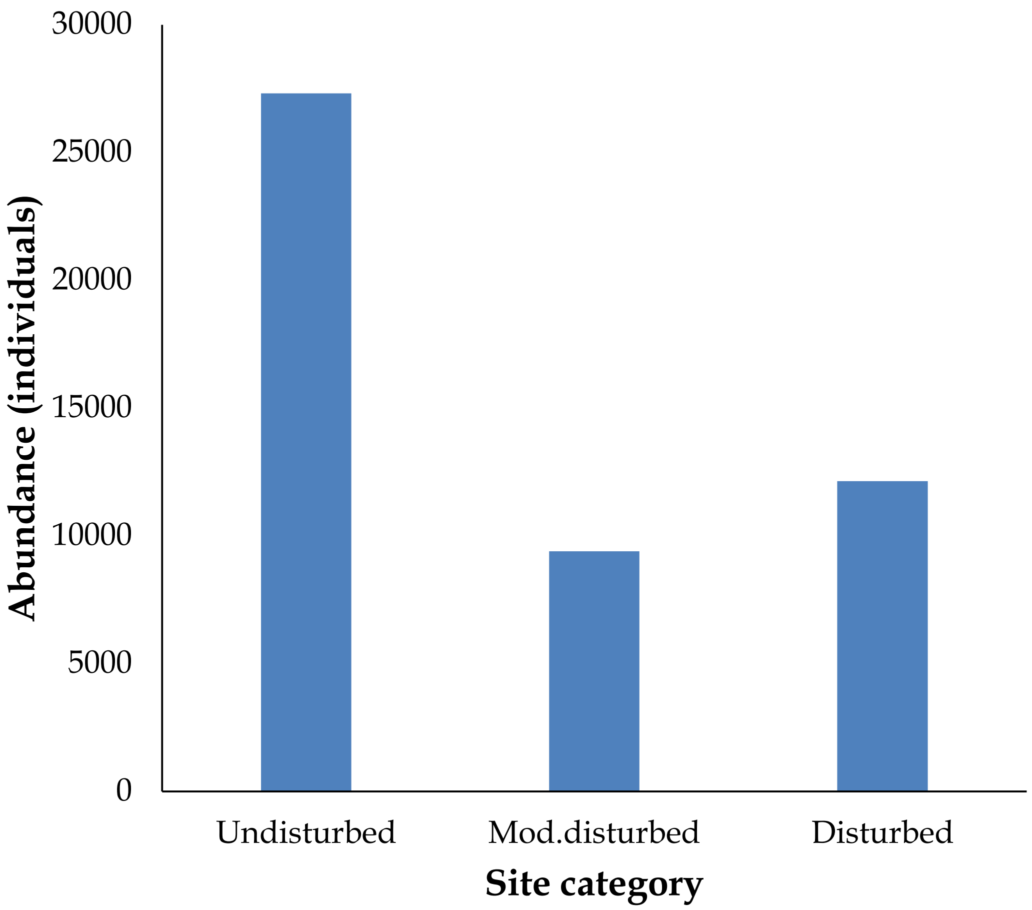

Figure 5: Abundance of macroinvertebrates across the three site categories along the Mara River, western Kenya. Mod.disturbed = moderately disturbed

There was significant difference in the abundance macroinvertebrates across the three site categories (p = 0.006; Table 2). Mann-Whitney pairwise comparisons performed (Appendix 2) after the Kruskal-Wallis test indicated that significant differences existed between undisturbed and the disturbed, and between moderately disturbed and the disturbed sites.

Table 2: Kruskal-Wallis test on macroinvertebrates abundance among the three site categories in the Mara River

Site category	N	Median	Ave Rank	Z
Undisturbed	104	2.5	150	-0.9
Moderately disturbed	104	1	132.1	-3.38
Disturbed	104	6.5	187.4	4.28
Overall	312		156.5	
H = 21.33 DF=2 p = 0.006				

The disturbed land use sites had 16 macroinvertebrate orders identified, 19 in the undisturbed sites and 13 orders from moderately disturbed sites. Orders Arachnida, Bivalvia, Ephemeroptera, Hemiptera, Hirudinae, Lepidoptera, Odonata, Trichoptera and Turbellaria were identified from all the site categories. Orders Coleoptera and Gastropoda were found in the undisturbed and disturbed sites but were absent in the moderately disturbed sites. Order Colembolla was only found in the undisturbed sites (Figure 6). Orders Diptera, Ephemeroptera and Trichoptera were the most predominant orders in all the three site categories (Figure 6).

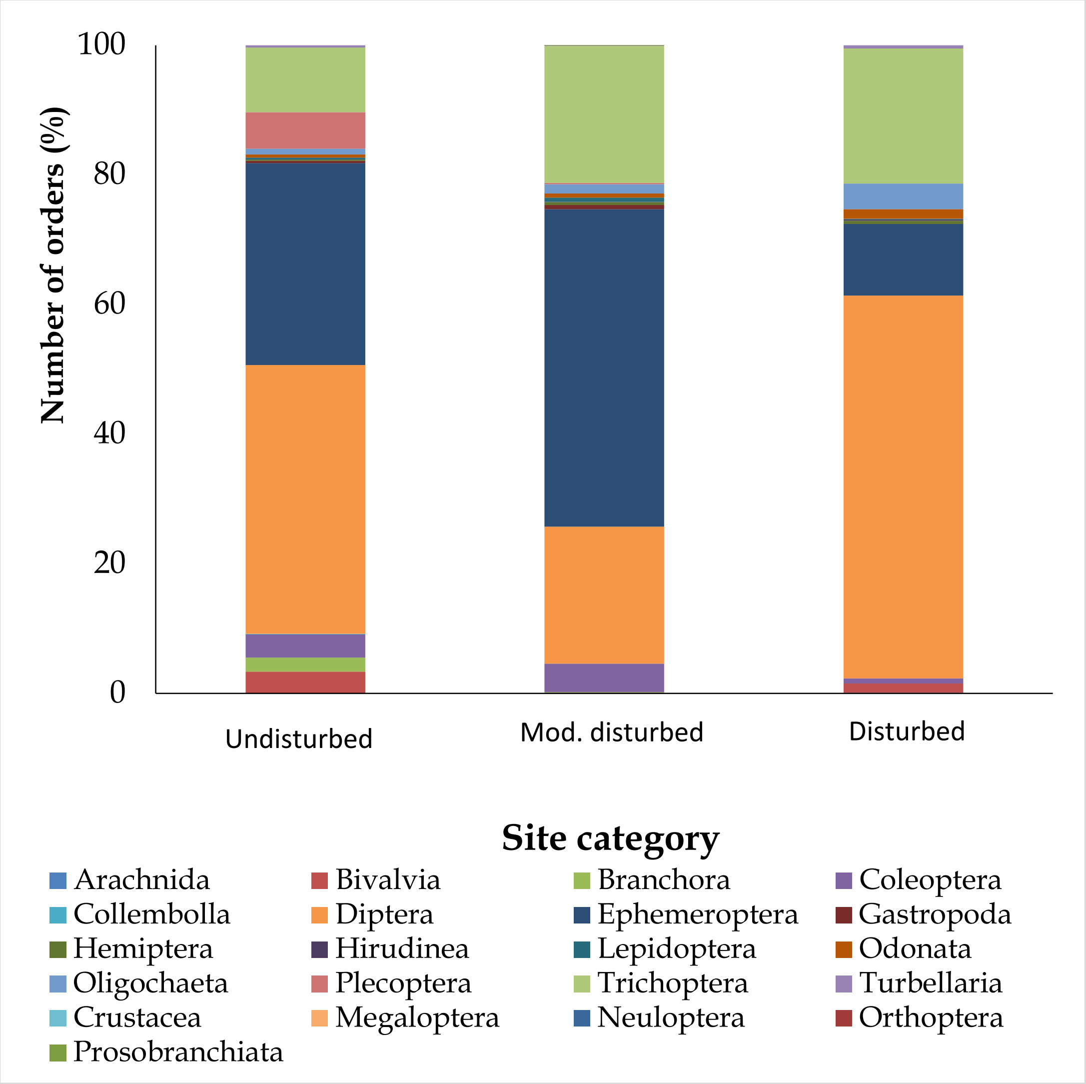

Figure 6: Number of macroinvertebrate orders across the three site categories in the Mara River, western Kenya. Mod. Disturbed = moderately disturbed

Across the three site categories, Ephemeroptera, Plecoptera and Trichoptera (EPT) orders dominated (34% of relative abundance) in the undisturbed sites (Figure 7), while moderately disturbed and disturbed sites were dominated by the other taxa by 49% and 34% of relative abundance, respectively (Figure 7). Coleoptera taxa were more abundant in the undisturbed sites while the Dipterans were more abundant in the disturbed sites (Figure 7). The moderately disturbed sites had the highest abundance of the Hemipterans (17% of relative abundance) compared to the other categories, but were lacking the Coleopterans (Figure 7).

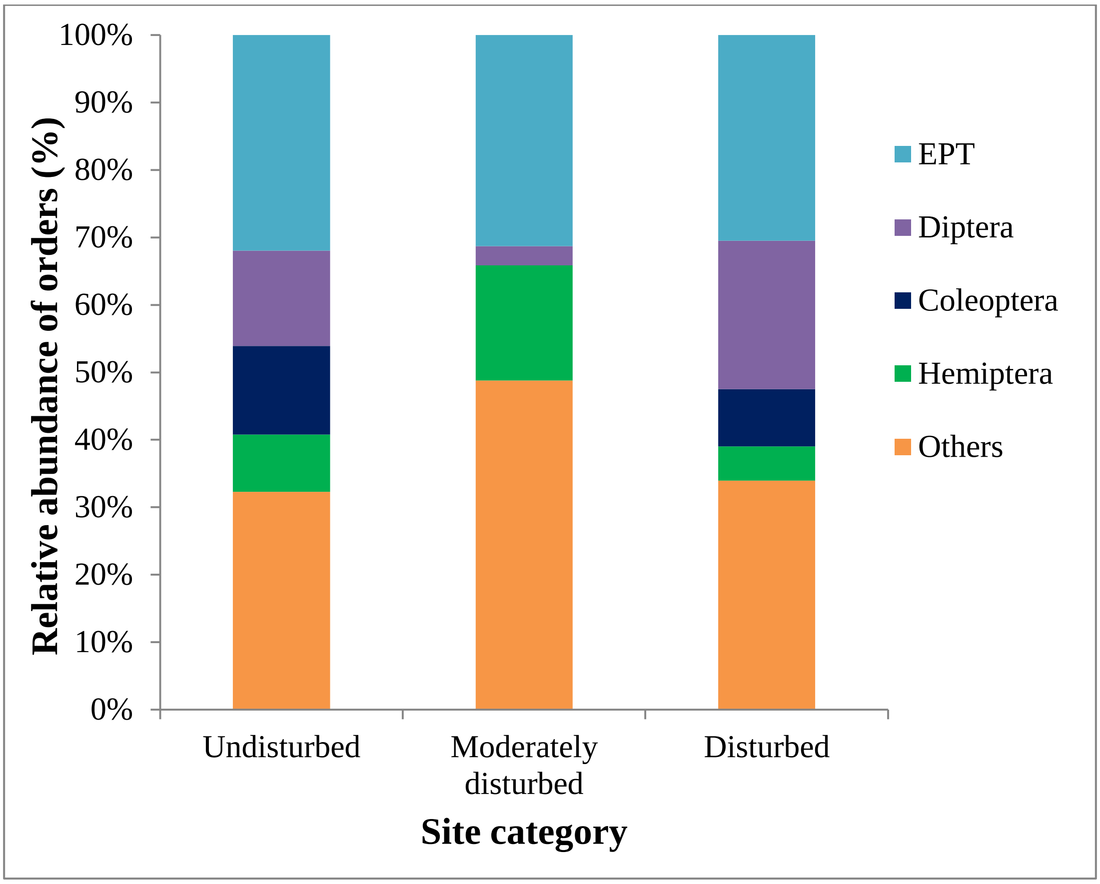

Figure 7: Relative abundance of macroinvertebrate orders across the three land use types in the Mara River, western Kenya. EPT= Ephemeroptera, Plecoptera, Trichoptera

4.2.2 Diversity indices

Diversity indices displayed mixed results with some showing wide ranges, such as taxon richness, dominance, Margalef's species richness index and Fisher's alpha diversity, while the rest showed narrow ranges (Table 3). Shannon diversity index was higher (2.45) in undisturbed sites than in the highly disturbed sites (2.06). Similar trends were obtained using the Simpson index (1/*Ds*), with higher values in undisturbed sites (0.88) compared with the disturbed (0.80) and moderately disturbed sites (0.83). Pielou's evenness index displayed the lowest response across the disturbance gradient with a value of 0.19 at undisturbed sites and 0.20 at both moderately disturbed and disturbed sites. In contrast, Fisher's alpha diversity showed the widest range with the highest value (7.29) at undisturbed sites and the lowest value (5.00) at disturbed sites. Dominance index followed the opposite trend as Fisher's alpha diversity index with the highest value (0.20) at disturbed sites and the lowest value (0.12) at undisturbed sites. Undisturbed sites had the highest number of taxa (60), followed by disturbed sites (51) and lastly the moderately disturbed sites which had the least number of taxa (39) (Table 3).

Table 3: The community diversity indices of benthic macroinvertebrates in streams across a disturbance gradient in the Mara River, western Kenya

Indices	**Undisturbed (n = 7)**	**Moderately disturbed (n = 6)**	**Highly Disturbed (n = 6)**
Taxon richness (*S*)	60	39	51
Number of individuals (abundance)	27,311	9,393	12,144
Dominance (D)	0.12	0.17	0.20
Simpson index (1-D)	0.88	0.83	0.80
Shannon index (H')	2.45	2.31	2.06
Pielou's evenness (*J'*)	0.19	0.20	0.20
Hill's number (gamma diversity)	3.44	2.55	2.49
Margalef's species richness index	5.78	5.47	4.04
Fisher-alpha diversity	7.29	7.09	5.00

4.3.3 Similarities in macroinvertebrate taxa composition in the three disturbance categories

Pair-wise SIMPER's comparisons of macroinvertebrate taxa abundances between undisturbed and disturbed sites identified Simuliidae (26.0%), Baetidae (17.5%), Chironomidae (11.2%) and Hydropsychidae (10.8%) as the major families contributing the greatest dissimilarity between the two categories, with higher abundance in undisturbed sites (Table 4). The same families, Simuliidae (22.7%), Baetidae (13.9%), Chironomidae (13.1%) and Hydropsychidae (13.4%), also contributed the greatest dissimilarity between undisturbed and moderately disturbed sites, with higher abundance at the moderately disturbed sites, other than for Baetidae that had higher abundance in undisturbed sites (Table 4).

Table 4: Top-ranked SIMPER results in the composition of macroinvertebrates taxa mean abundance between undisturbed and disturbed, and undisturbed and moderately disturbed site categories. Undisturbed = 7, moderately disturbed = 6, disturbed = 6

	Mean Abundance			
Taxon	**Highly Disturbed**	**Undisturbed**	**% Contribution**	**% Cumulative**
Simuliidae	362	384	26.01	26.01
Baetidae	202	521	17.54	43.55
Chironomidae	130	246	11.23	54.78
Hydropsychidae	174	321	10.81	65.58
Tricorythidae	40.3	320	7.511	73.09
Heptageniidae	102	187	5.964	79.06
Caenidae	15.7	135	4.095	83.15
Philopotamidae	47.5	72.8	3.449	86.6
Perlidae	1.83	62.6	3.128	89.73
Elmidae	33.8	80.7	2.737	92.47
Scirtidae	3.67	26.6	2.157	94.62
Potamonautidae	0.833	34.9	1.504	96.13
	Moderately disturbed	**Undisturbed**		
Simuliidae	1150	384	22.68	22.68
Baetidae	453	521	13.94	36.62
Hydropsychidae	626	321	13.44	50.06
Chironomidae	444	246	13.08	63.15
Tricorythidae	325	320	10.96	74.11
Heptageniidae	336	187	7.301	81.41
Caenidae	140	135	4.871	86.28
Philopotamidae	89.5	72.8	3.075	89.36
Elmidae	74.3	80.7	2.817	92.18
Perlidae	0	62.6	2.077	94.25
Scirtidae	4.25	26.6	1.494	95.75
Potamonautidae	0.25	34.9	1.199	96.95

4.3 Functional composition of macroinvertebrates

From the 48,848 macroinvertebrates collected, 39032 were collectors, 1554 were predators, 7116 were scrapers, and 1146 were shredders (Table 5).

Table 5: Abundance and distribution of macroinvertebrates taxa and FFGs (Dobson *et al*., 2002; Merritt & Cummins, 2006; Merritt *et al*., 2008; Masese *et al*., 2014a) across the three site categories in the Mara River, western Kenya

Order	Family	FFG	Undisturbed	Moderately disturbed	Disturbed
Bivalvia	Sphaeriidae	Collector	319	144	176
Coleoptera	Amphizoidae	Predator	0	0	2
	Dytiscidae	Predator	0	0	3
	Gryrinidae	Predator	3	10	62
	Lampyridae	Predator	0	0	1
	Sciomyzidae	Predator	0	2	8
	Elmidae	Scraper	108	78	1062
	Psephenidae	Scraper	0	0	2
	Scirtidae	Scraper	208	7	91
	Curculionidae	Shredder	6	0	0
	Helophoridae	Shredder	2	0	0
Collembolla	Collembolla	Collector	4	0	0
Decapoda	Potamonautide	Shredder	224	0	54
Diptera	Chironomidae	Collector	787	1529	2561
	Culicidae	Collector	1	0	4
	Dixidae	Collector	3	0	0
	Ephydridae	Collector	0	0	1
	Psychodidae	Collector	7	0	1
	Simuliidae	Collector	2992	4456	3103
	Stratiomyidae	Collector	2	1	15
	Syrphidae	Collector	0	1	0

	Athericidae	Predator	24	0	39
	Ceratopogonidae	Predator	21	8	11
	Chaoboridae	Predator	0	0	5
	Emphididae	Predator	4	0	0
	Muscidae	Predator	13	5	110
	Tabanidae	Predator	29	0	6
	Tipulidae	Shredder	87	30	95
Ephemeroptera	Baetidae	Collector	2039	1267	4907
	Caenidae	Collector	206	491	1272
	Ephemerellidae	Collector	3	0	179
	Leptohyphidae	Collector	8	0	386
	Oligoneuriidae	Collector	0	0	1
	Tricorythidae	Collector	111	105	4490
	Heptageniidae	Scraper	588	1258	2073
	Leptophlebiidae	Scraper	50	35	74
Hemiptera	Gerridae	Predator	3	13	12
	Hebridae	Predator	0	0	6
	Naucoridae	Predator	0	4	82
	Nepidae	Predator	0	4	12
	Notonectidae	Predator	1	12	8
	Pleidae	Predator	0	0	2
	Veliidae	Predator	13	1	6
	Belostomatidae	Shredder	0	1	0
Lepidoptera	Crambidae	Shredder	26	7	181
Megaloptera	Corydalidae	Predator	0	0	1
Neuroptera	Sisyridae	Predator	0	0	1

Odonata	Aeshinidae	Predator	7	5	10
	Corduliidae	Predator	7	0	2
	Gomphidae	Predator	6	2	43
	Lestidae	Predator	4	110	50
	Libellulidae	Predator	18	9	53
Oligochaeta	Lumbriculidae	Collector	9	308	87
	Tubificidae	Collector	56	80	88
Plecoptera	Perlidae	Predator	471	0	105
Trichoptera	Limnichidae	Collector	0	11	0
	Polycentropodidae	Collector	60	18	8
	Hydropsychidae	Collector	577	1732	4440
	Ecnomidae	Predator	13	39	4
	Hydrophilidae	Predator	0	0	1
	Galastocoridae	Scraper	0	0	1
	Glossosomatidae	Scraper	4	0	34
	Hydroptilidae	Scraper	3	0	36
	Philopotamidae	Scraper	179	250	942
	Sericostomatidae	Scraper	2	7	24
	Lepidostomatidae	Shredder	39	74	172
	Leptoceridae	Shredder	27	13	99
Tricladida	Dugesia	Predator	6	17	7
	Mesostoma	Predator	6	0	0
	Tricladidae	Predator	7	0	0

The undisturbed sites had the highest abundance (27311) while moderately disturbed sites had the least abundance (9393). There was significant difference among the abundance of all functional feeding groups in the three site categories ($F_{(1,\,2)} = 2.050$, $p = 0.0056$). Collectors had the highest number of individuals across the three sites categories while shredders had the least abundance across the three site categories (Figure 8). All the three land use categories were dominated by collectors and scrapers (Figure 8).

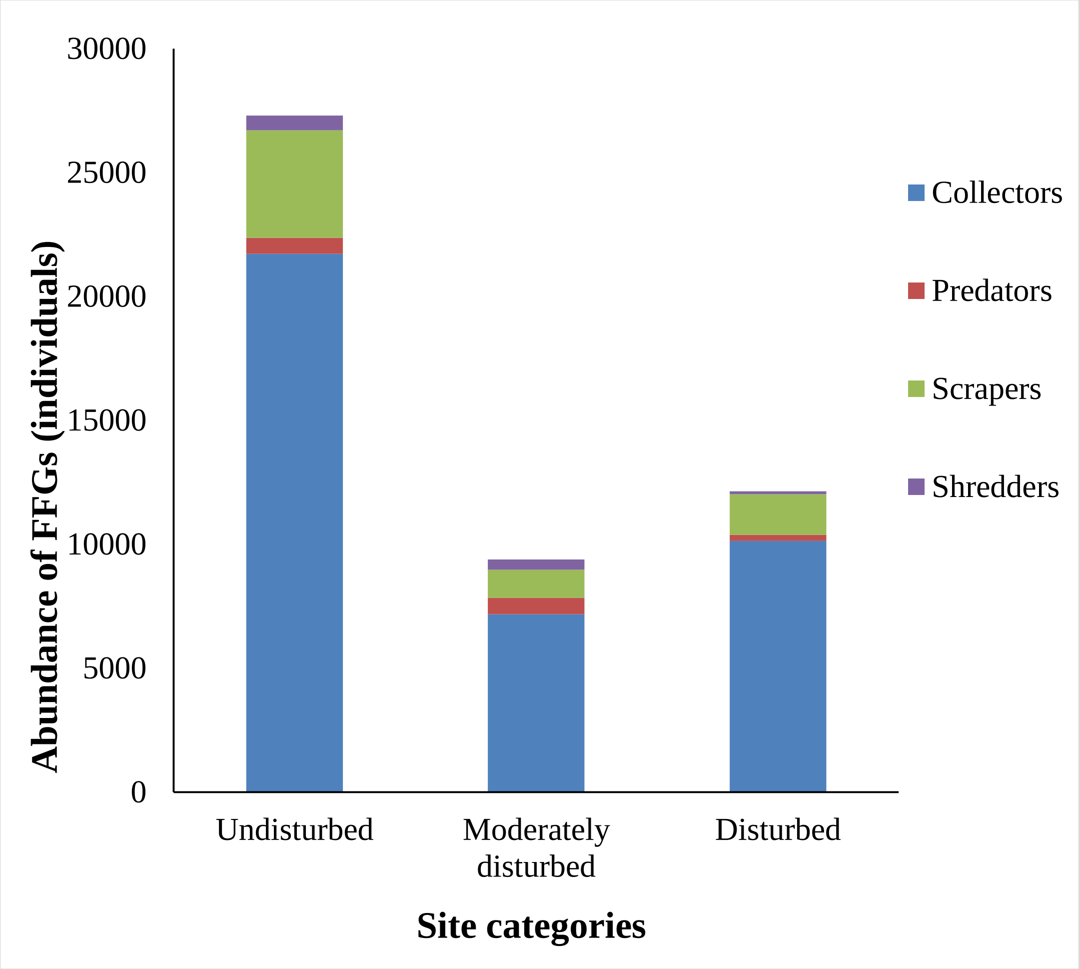

Figure 8: Abundance of macroinvertebrate FFGs in forested, mixed and agricultural land use types along the Mara River, western Kenya

Collectors and scrapers dominated all the site categories (Figure 9). Shredders had the highest relative abundance in the undisturbed sites (4%), and had the lowest relative abundance in the moderately disturbed sites (1%) (Figure 9). Scrapers had the highest relative abundance in the disturbed sites (16%) and were least abundant in the undisturbed sites (Figure 9). Predators dominated the moderately disturbed site category (13%). Although not significant, collectors had the highest relative abundance in the moderately disturbed sites (84%), followed by the disturbed sites (80%) and were least in the undisturbed sites (76%) (Figure 9).

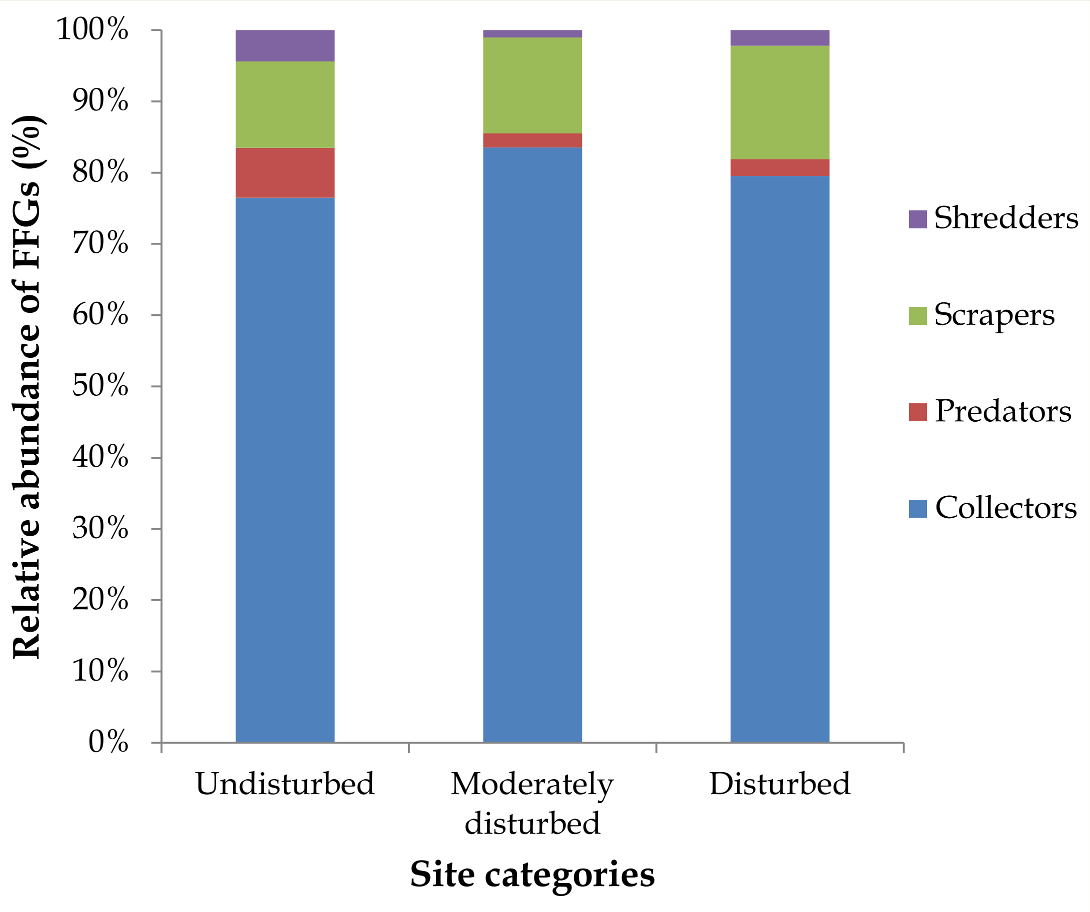

Figure 9: Dominance (%) in abundance of macroinvertebrate FFGs in the three site categories in the Mara River, western Kenya

Across the different site categories, predators had more taxon richness, followed by collectors (Figure 10). Predator taxa richness increased with increase in disturbance from the undisturbed sites (35%) to disturbed sites (47%) (Figure 10). On the contrary, taxa richness of shredders and collectors decreased with increasing disturbance. Highest shredder (16%) and collectors (33%) relative richness were recorded in the undisturbed sites and were lowest at the disturbed sites with 10% and 27%, respectively (Figure 10).

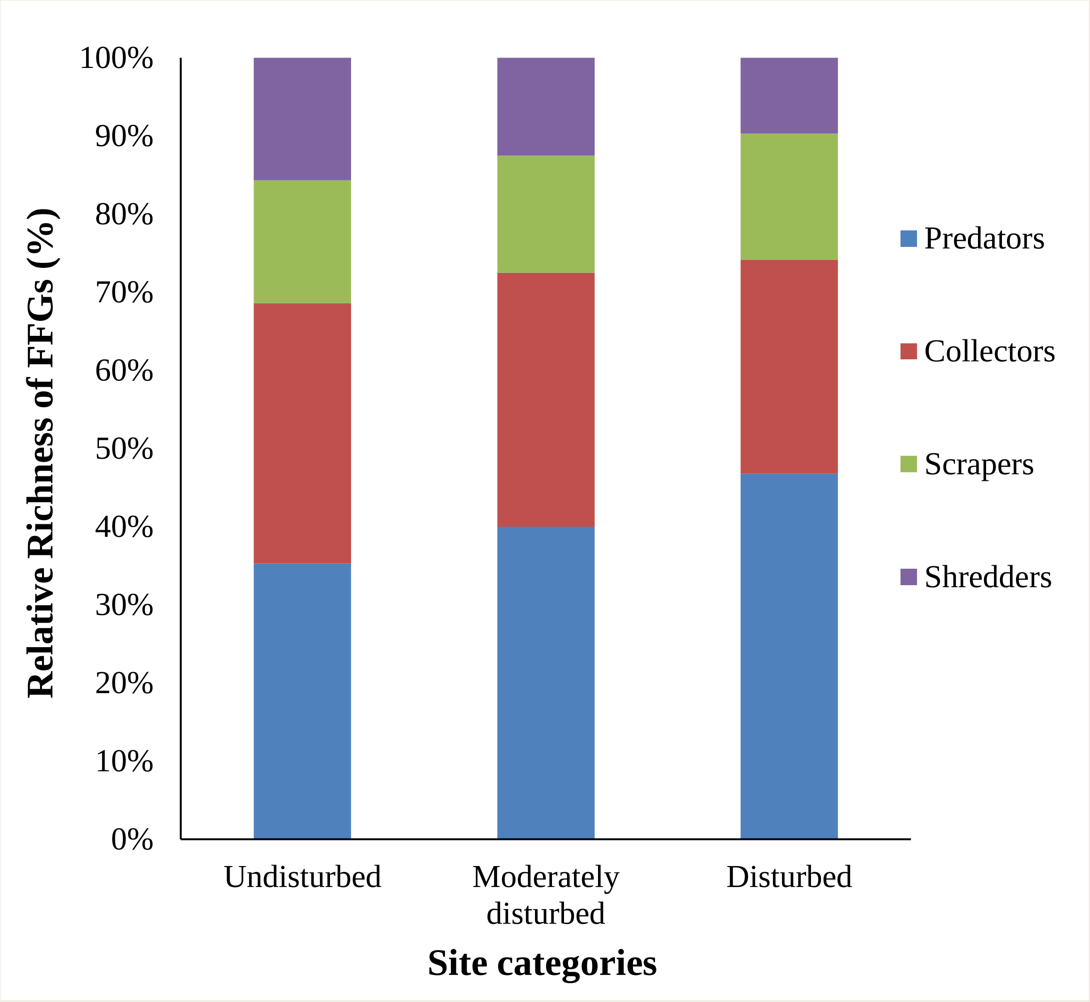

Figure 10: Macroinvertebrate FFGs richness across the three land use types in the Mara River, western Kenya

Macroinvertebrates FFG richness decreased from low order streams (upper reaches) to the lower reaches along the Mara (Figure 11). Upstream reaches had the highest taxa richness while the midstream reaches had the least taxa richness (Figure 11).

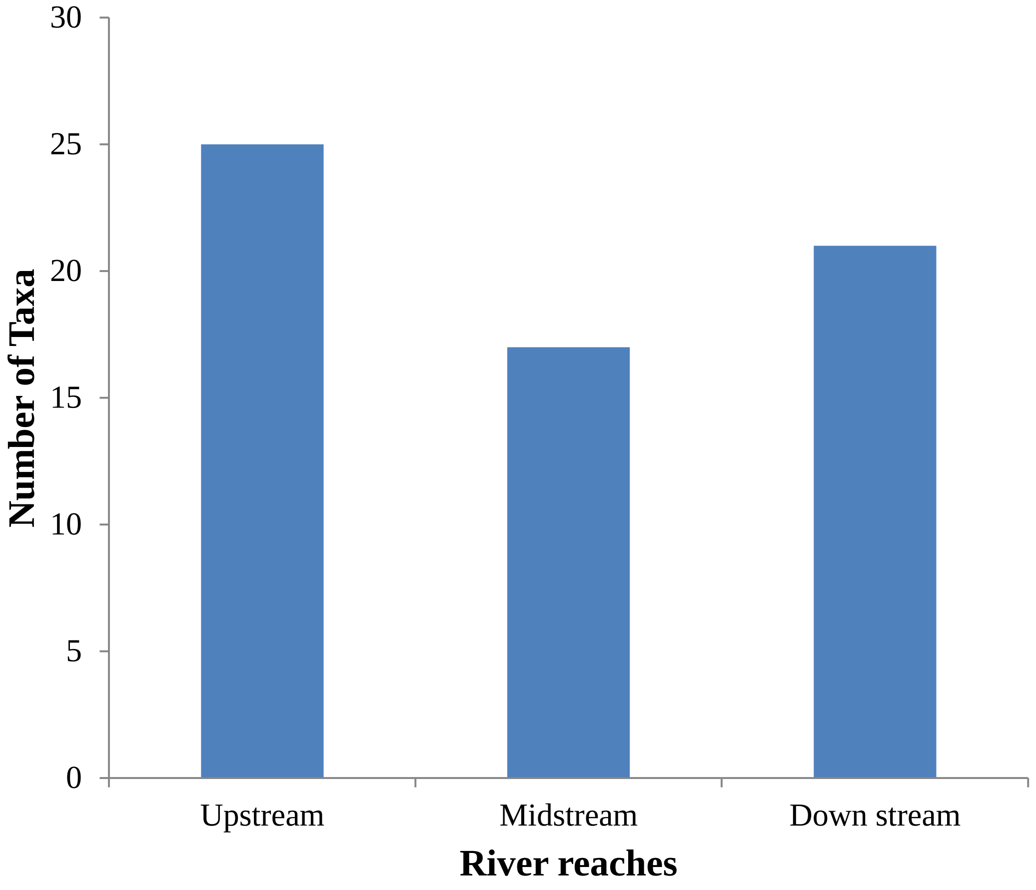

Figure 11: Macroinvertebrate FFGs richness along the Mara River, western Kenya

4.4 Relationships between the structural and functional composition of macroinvertebrates and water quality variables

The CCA triplot between selected variables (water physico-chemical parameters, nutrients and stream size) and macroinvertebrates showed distinct patterns. Thevariables correlated with specific macroinvertebrate assemblages under different levels of disturbance. The first two components explained 66.0% of the total variation with the first principle component accounting for 34.9% and the second principle component 31.1% (Figure 12). Lepidostomatidae, Hydropsychidae, Crambidae, Tipulidae, Potamonautiedae, Leptoceridae and Tricorythidae occurred mainly in undisturbed sites and were associated with low mean water temperature. Increase in temperature, width, TSS and discharge correlated with the occurrence of higher abundances of Baetidae, Libellulidae, Philopotamidae and Simuliidae were found mainly in moderately disturbed sites. Chironomidae were correlated with increased levels of conductivity at the disturbed sites (Figure 12).

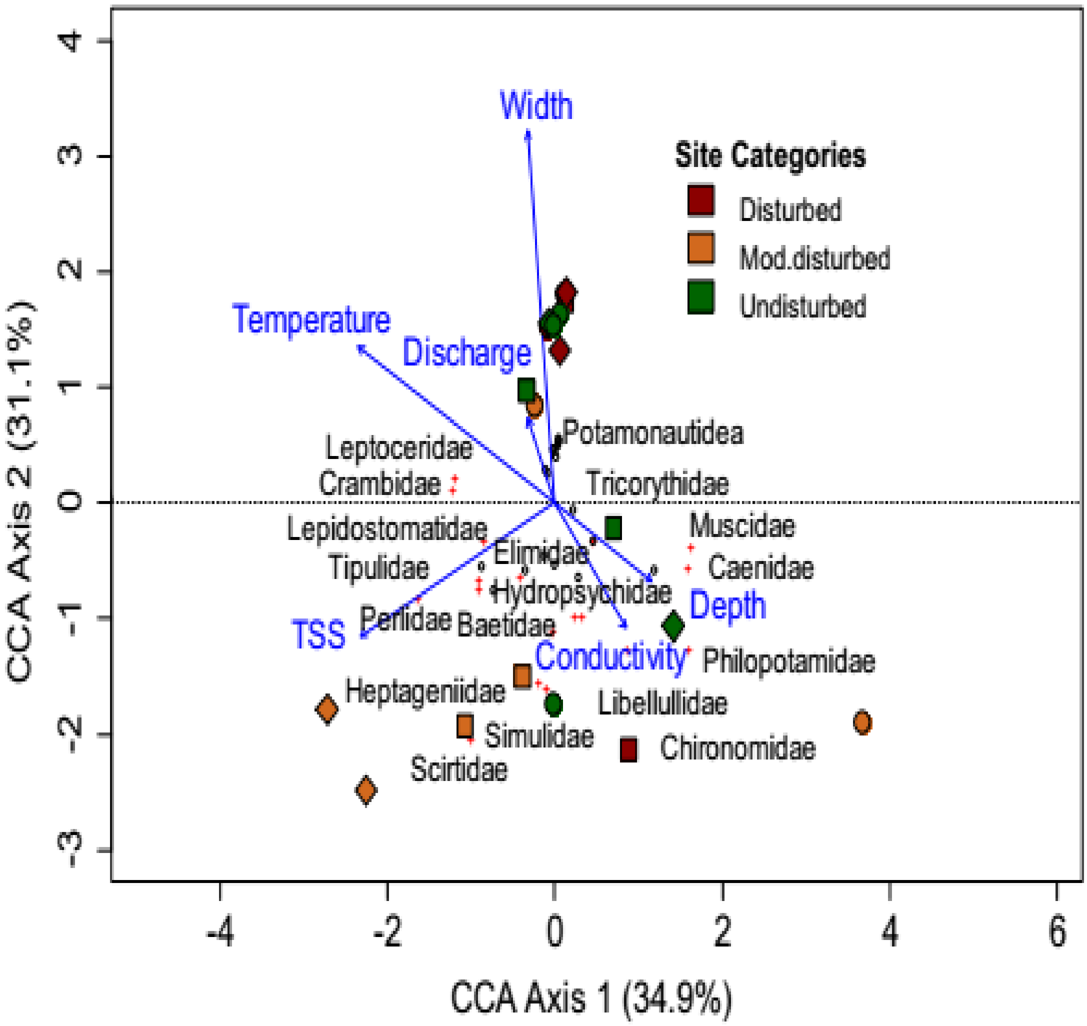

Figure 12: Canonical Correspondence Analysis (CCA) triplot on the association between water quality variables, nutrient concentrations and stream size variables with macroinvertebrates taxa in the three site categories in the Mara River, western Kenya

The canonical correspondence analysis (CCA) ordination of macroinvertebrates FFGs with selected water quality variables, nutrient concentrations and stream sizes variables also displayed distinct separations. The first components explained 34.7% of the total variation in the dataset while the second component accounted for 31.3% (Figure 13). There was a distinct association of shredders with undisturbed sites with lower temperature levels, while collectors were associated with higher temperature, discharge and TSS in moderately disturbed sites. Predators and scrapers were positively associated with increasing levels in conductivity and stream width at disturbed sites though scrapers were negatively associated with increased TSS levels at the disturbed sites (Figure 13).

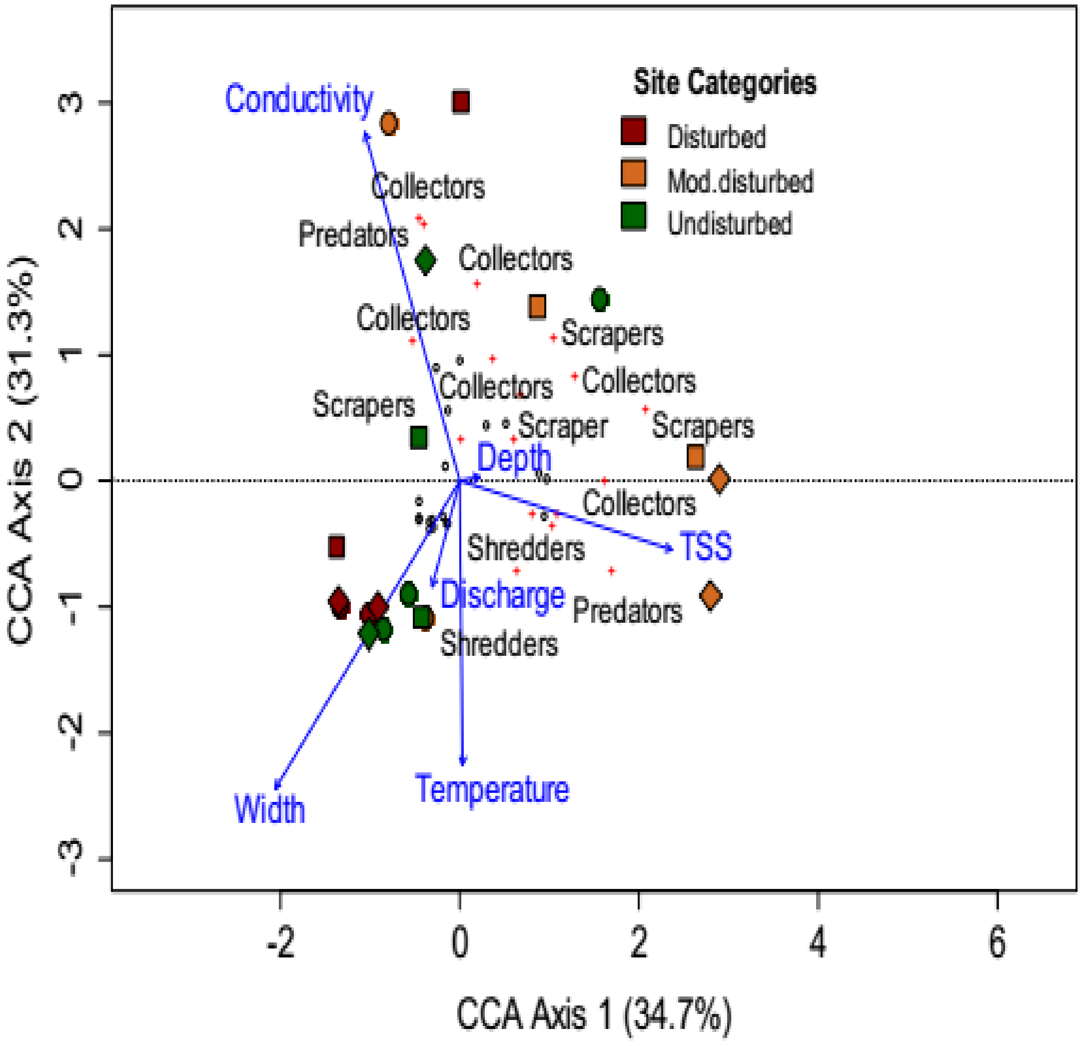

Figure 13: A CCA triplot on the association between water quality variables, nutrient concentrations and stream size variables with macroinvertebrate FFGs in the three site categories in the Mara River, western Kenya

The structural and functional attributes of macroinvertebrates were related to selected water quality variables and nutrients (TP and TN) (Table 6). Total abundance (number of individuals/sample) was positively correlated to pH, TP and TN. Number of shredders strongly negatively correlated with conductivity (-0.99) and temperature (-0.70). The Shredders (%) were also negatively associated with conductivity (-0.98) and temperature (-0.99) while scrappers (%) were favoured by high conductivity (0.82) and temperature (0.90) levels. All those associations were strong ($r > 0.7$) and significant ($p < 0.05$) (Table 6).

Table 6: Pearson correlation analysis among macroinvertebrate community attributes with water quality variables and nutrients. (EC-conductivity, DO- dissolved oxygen TSS-total suspended solids, TP-total phosphorous, TN-total nitrogen)

	Water quality and nutrients variable						
Community attributes	pH	DO (mg/L)	EC (µS/cm)	Temperature (^{o}C)	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Total abundance	**0.98***	0.13	0.77	0.65	0.28	**0.94***	**0.98***
No. total taxa	0.76	0.71	0.21	0.04	-0.37	0.75	0.75
No. Collectors	0.51	0.90	-0.12	-0.28	-0.65	0.50	0.50
No. Scrapers	0.94	-0.25	0.95	0.89	0.62	0.95	0.94
No. Shredders	-0.04	0.53	**-0.99***	**-0.70***	0.93	-0.02	-0.02
No. Predators	-0.80	0.97*	0.58	-0.98	-0.83	-0.81	-0.81
% Collectors	0.56	0.87	-0.06	-0.22	-0.60	0.55	0.54
% Shredders	-0.66	0.69	**-0.98***	**-0.99***	-0.92	-0.68	-0.68
% Scrapers	0.30	-0.93	**0.82***	**0.90***	-0.97	0.32	0.32
% predators	-0.79	-0.68	-0.25	-0.09	0.33	-0.78	-0.78

*Values in bold are significant at $p < 0.05$

4.4.1 Similarities in macroinvertebrate taxa composition in the three disturbance categories

SIMPER's pair-wise comparisons of condition categories based on FFGs identified collectors (74.35 %) and shredders (17.95%) to contribute the greatest dissimilarity between undisturbed and disturbed sites, with higher abundance in undisturbed sites. Again, collectors (72.67 %) and shredders (24.19%) contributed to the greatest dissimilarity between undisturbed and moderately disturbed sites with collectors having a higher abundance in the moderately disturbed sites while shredders had a higher abundance in the undisturbed sites. Collectors (75.13%) and scrappers (23.75%) contributed the greatest dissimilarity between disturbed and the moderately disturbed sites with higher abundance in the moderately disturbed sites. Even though predators contributed the least dissimilarity in both cases, they recorded a high abundance in disturbed sites (Table 7).

Table 7: FFGs-ranked abundance- based SIMPER results in the composition of macroinvertebrates between undisturbed and disturbed, and undisturbed and moderately disturbed site categories. Undisturbed = 7, moderately disturbed = 6, disturbed = 6

	Mean Abundance			
Taxon	**Highly Disturbed**	**Undisturbed**	**% Contribution**	**% Cumulative**
Collectors	934	1727	74.35	62.12
Shredders	180	614	17.95	95.06
Scrapers	14	90	3.97	98.42
Predators	65	19	3.74	83.86
Taxon	**Mod. disturbed**	**Undisturbed**	**% Contribution**	**% Cumulative**
Collectors	3914	1727	72.67	71.68
Shredders	985	614	24.19	98.25
Scrapers	49	90	1.82	99.17
Predators	23	19	1.32	83.72
Taxon	**Highly Disturbed**	**Mod. disturbed**	**% Contribution**	**% Cumulative**
Collectors	934	3914	75.13	72.38
Scrapers	14	49	23.75	85.71
Shredders	180	985	0.14	99.97
Predators	65	23	0.98	99.61

CHAPTER FIVE

DISCUSSION

This study demonstrates that both the structural and functional composition of macroinvertebrates display spatial variability in taxon richness, diversity and relative abundance of the various taxa in response to changes in water quality and nutrient concentrations across a disturbance gradient. The gradient observed in the disturbance levels is defined by both catchment and reach-scale influences. There was an increase in conductivity (EC), water temperature, TSS, TDS and nutrients concentrations (especially dissolved fractions of nitrogen) from values in undisturbed forested sites to high levels in disturbed agricultural sites. There were also differences in the structural and functional composition of macroinvertebrates across the disturbance gradient with highest numbers of taxa recorded in the undisturbed sites. Higher abundance of shredders was recorded in undisturbed sites, while predators increased in both richness and abundance with increasing disturbance. Taxon richness and abundance of scrapers were higher at the moderately disturbed and disturbed sites where water temperature and nutrient concentrations were higher.

5.1 Physico-chemical water quality variables and nutrients

The higher levels of electrical conductivity, temperature, total suspended solids, total dissolved solids and nutrients recorded in moderately disturbed and disturbed sites can be attributed to opening of the canopy, diffuse pollution from agricultural farms and sedimentation caused by agricultural activities such as that serve as livestock watering points and the associated erosion of the river banks. The low temperature at the undisturbed sites can be attributed to shading from the forest cover. These results are similar to studies by Kibichii *et al.* (2007) and Kasangaki *et al.* (2008) which attributed the high values of conductivity, TSS, TDS and temperature to near and in-stream activities such as farming along the riparian zone, livestock grazing, watering and defecating in the river as well as due to the erosion along the river banks. Other studies have also linked the removal of riparian vegetation to changes in stream morphometry and hydrology, substrate characteristics, light and temperature regimes, water physico-chemical features, and organic matter composition (Kaufmann *et al.,* 2009; Masese *et al.,* 2009a; Minaya *et al.,* 2013; Masese *et al.,* 2014a, b).

The low dissolved oxygen levels in the moderately disturbed and disturbed sites could be attributed to the high temperature levels recorded at these sites as well as livestock defecation and urination into these streams, siltation and decomposition of organic matter which have been found to provoke responses in the water chemistry such as the reduction of dissolved oxygen levels (Raburu *et al.,* 2009; Masese *et al.,* 2009a; Minaya *et al.,* 2013; Masese *et al.,* 2020). Similarly, the high TSS and TDS values draining disturbed sites most probably resulted from erosion of unprotected banks and siltation, while the high nutrient levels (TP and TN) could be attributed to the influx of farm inputs (fertilizer and manure) as well as cattle defecation and urination into streams draining these areas (Masese *et al.,* 2017).

5.2 Structural composition of macroinvertebrates

The study recorded a very high number of individuals with a total of 48,848 macroinvertebrate individuals belonging to 21 orders and 70 families. The higher abundance, diversity and richness of macroinvertebrate taxa in undisturbed sites could be explained by the fact that limited human disturbance in these sites favoured a wider range of habitats that could support a diverse macroinvertebrate community. These results concur with similar studies in the region that have indicated higher taxa diversity in forested land-use than in the streams draining other land- uses, such as agriculture, urban and settlements; Kasangaki *et al*. (2006), Kasangaki *et al.* (2008), Masese *et al.* (2009a), Minaya *et al.* (2013), M'Erimba *et al.* (2014). Ephemeroptera, Plecoptera and Trichoptera (EPT) richness and abundance were higher in undisturbed sites than in moderately disturbed and disturbed sites. Undisturbed sites also had the most diverse taxa, richness and evenness.

The higher numbers of sensitive EPT taxa and high macroinvertebrates diversity and richness in these sites could be attributed to habitat diversity and complexity in these sites coupled with good water quality conditions. Several studies reported a decrease in the number of taxa and the relative abundance of sensitive orders such as the EPT while tolerant orders such as Oligochaeta and Diptera increase as the pollution and negative changes in the river quality increases (Raburu *et al*., 2009; Kilonzo *et al*., 2014; Masese *et al*., 2009a, 2014a). However, it is notable that some families among the EPT, such as Baetidae, Caenidae and Hydropsychidae can increase their abundance in organically polluted sites (Masese & Raburu, 2017), and this can compromise the performance of this index as a measure of disturbance.

Species richness differed among the site categories, ranging from 60 taxa in the undisturbed sites to 51 and 39 in the disturbed and moderately disturbed sites, respectively. The small streams in the forested sites had pristine conditions thereby hosting a diverse number of taxa. The diversity indices utilized were mostly in accord when it came to variations in macroinvertebrates diversity and richness among site categories, as depicted by the abundance data (Table 2).

The disturbed and moderately disturbed sites had low Shannon diversity index values (<2.1), indicating extensive deterioration impacting macroinvertebrate taxa in these sites. Disturbed sites were more affected, having depauperate communities dominated by few taxa (particularly Diptera and Hemiptera). Diptera and Hemiptera showed an increased abundance and distribution in these sites, indicating that these taxa are unaffected by ongoing human-induced changes in the environmental and ecological states (Masese & McClain, 2012; Raburu & Masese, 2012). Fisher's alpha diversity revealed clear differences among site categories, implying that it is less sensitive to numerical dominance of invertebrate assemblages by a few dominating taxa and thus better suited in assessing anthropogenic impacts on macroinvertebrate diversity in the region.

Although taxon richness and abundance are influenced by natural factors, anthropogenic activities in the moderately disturbed and disturbed sites likely aggravated the effects observed in this study. Anthropogenic disturbances such as changes in land-use as a result of agriculture (farming and livestock husbandry), deforestation, unpaved road construction and settlements are reported to have an impact on the amount of sediments and runoff entering receiving water bodies during rainstorms (Wang *et al.,* 2003; Donohue & Irvine, 2004; Masese *et al.*, 2017) and therefore negatively affect the water quality in these systems which in turn influence the composition of the resident biota.

5.3 Functional composition of macroinvertebrates

The presence of thick riparian canopy in the undisturbed sites created conditions with plenty of feeding material that supported the high abundance and richness of the shredder functional guild which utilizes leaf litter from these riparian zones as an energy source. Contrastingly, this feeding guild recorded the lowest abundance and richness in the disturbed sites which is a function of stripped canopy cover along riparian zones and therein the lack of litter fall and increased temperature. Shredders are also intimately linked and dependent on to the nature of riparian vegetation (Dobson *et al*., 2002), because of their reliance on allochthonous food resources (Masese *et al*., 2014a) and as well contribute to nutrient cycling and energy transfer to other trophic groups (Boyero *et al*., 2011; Brasil *et al*., 2014).

The abundance and richness of scrapers were higher in the highly disturbed sites which could be attributed to the increased temperatures (due to open canopy) and nutrients (from agricultural farms and input of wastes from livestock) (Masese *et al*., 2020) which supported primary productivity (algal production) which served as an energy source for scrapers. This is in line with an earlier study by Barbee, (2005) which pointed out that the densities of scrapers are determined by the presence or absence of algal biomass and production.

Collectors had the highest number of individuals across the three site categories. The high numbers across the sites could be attributed to the wide array of food resources consumed by this group. Studies have documented the dependence of collectors on the capacity of shredders to disintergrate Coarse Particulate Organic Matter (CPOM) to Fine Particulate Organic Matter (FPOM), which serves as an energy source for collectors and therefore, their abundance is dependent on the availability of shredders in the upstream forested sites in the river continuum. Similar research in tropical regions report the dominance of collectors in all sections of the stream network (Tomanova *et al*., 2006); Jiang *et al*., 2011).

Numerical abundance and taxon richness of predators increased with a shift in disturbance from undisturbed to disturbed site categories. Predators such as Odonata and Hemipterans are more tolerant to pollution (Boyero *et al*., 2009; Favretto *et al*., 2014) and therefore can withstand degraded habitat and water quality conditions. Additionally, the existence of additional tolerant prey species like Oligochaeta allowed these species to dominate in the degraded habitats (Barbee, 2005), consistent with the river continuum concept (RCC) which proposed that the abundance of predators depend on the availability and abundance of prey (Vannote *et al*., 1980).

In order to establish some longitudinal trends, stream order was employed as a measure of stream size along the Mara River. Longitudinal gradients in the nutrients and macroinvertebrates FFGs were established. Nutrient levels increased with increase in stream order, from head waters to the mid reaches. The head waters were forested reaches with minimum to no human interference thereby low levels of TP and TN in the streams. Agricultural activities along the river caused an increase in these levels due to the fertilizers being utilized in the farms. Macroinvertebrates abundance significantly correlated with TP and TN thereby influencing their distribution along the gradient. The RCC (Vannote *et al.*, 1980) addresses changes in the relative abundance of macroinvertebrate FFGs in the longitudinal gradient of streams.

There was change in the distribution, longitudinal abundance and diversity of macroinvertebrates along the Mara River. Stream order 2 and 4 had the least relative abundance while stream order 3 had the highest relative abundance of macroinvertebrates. However, it has been documented that the relative abundance and biomass of macroinvertebrates in tropical streams do not follow the RCC prediction

(Bonada *et al*., 2006); Tamanova *et al*., 2007); Masese *et al*., 2014a). Macroinvertebrates FFG richness also decreased with increase in stream order. Increase in stream order could be related to land-use change from forest to agriculture thereby affecting the distribution of macroinvertebrates.

5.4 Relationships between macroinvertebrate assemblages and water quality variables

The distribution of macroinvertebrate structural and functional assemblages was influenced by physico-chemical water quality variables and nutrients across the site categories. Canonical correspondence analysis (CCA) indicated that specific site categories correlated with specific water quality variables which in turn affected the distribution of the macroinvertebrates. An increase in DO and a decrease in temperature affected Lepidostomatidae, Leptoceridae, Crambidae, Baetidae and Philopotamidae families, which are sensitive to pollution (Masese *et al*., 2014a; Dobson *et al*., 2002), mainly at the undisturbed sites.

Shredders (Lepidostomatidae, Leptoceridae and Crambidae) found in the undisturbed sites (forested area) were favoured by the low temperatures, high DO levels and dense canopy. Studies by Dobson *et al*. (2002), Minaya *et al*. (2013) and Masese *et al*. (2014a) reported similar trends. Increase in TP, TN and conductivity levels positively influenced predators at the disturbed sites concurring with other studies such as by Bojsen & Jacobsen, (2003) which reported collectors and predators to be more tolerant to pollution hence dominating degraded sites.

In the moderately disturbed sites, TSS was established as the main variable affecting the scrapers. This is attributed to greater depths and increased turbidity’s in these sites which prevent light penetration into the water column, thus hindering primary production (algae) which is the main energy source for scrapers. Increase in nutrient levels and reduction in water quality negatively impacted the distribution of sensitive macroinvertebrate taxa. The deteriorating water quality with an increase in disturbance levels, as noted by the increasing levels of TSS, temperature, electrical conductivity, and TDS from undisturbed to disturbed through moderately disturbed sites also have contributed to the low richness and diversity of macroinvertebrate taxa in the disturbed sites.

The replacement of natural vegetation by intensive agriculture (grazing and crop farming) is linked to water quality deterioration and degradation of physical habitat in streams (Bryce *et al*. 2010; Masese *et al*., 2014a). These results are consistent with numerous studies that report the influence of abiotic factors on variation in macroinvertebrate communities (Coucerio *et al*., 2007; Kasangaki *et al*., 2006, 2008; Masese *et al*., 2009a, 2014a).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The patterns in macroinvertebrate assemblage spatial distribution reported in this study demonstrate how variations in water quality in lotic systems affect macroinvertebrate structural and functional composition. Both structural and functional organization of macroinvertebrates display spatial variability in taxon richness, diversity and relative abundance of the various taxa in response to changes in water quality and nutrient concentrations across a disturbance gradient defined by both catchment and reach-scale influences. Specifically, this study shows that even in areas under small-scale agriculture and rural settlements, macroinvertebrates can track even subtle changes in water quality.

The taxon richness and abundance of EPT taxa and Shredder diversity and abundance dominated in the undisturbed (forest) land use sites and decreased with change of water quality variables across the disturbance gradient. Changes in the composition and distribution of macroinvertebrates mainly resulted from small-scale agriculture, livestock grazing and access to streams and rivers for watering. These activities led to deterioration in both habitat and water quality in the streams. This study contributes to further development of biomonitoring indices in the region by identifying taxa that are responsive to human activities in urbanized catchments in the Afrotropics.

6.2 Recommendations

i. Forest cover and riparian zones along the Mara River should be protected for the conservation of the biotic communities in the river.

ii. Classification of the FFG using mouth parts should be done so to be able to classify collectors into filterers and gatherers. Since the study was carried out during the wet season, further studies are needed to understand the roles of seasonality in the distribution of macroinvertebrate communities in this river system.

iii. Future efforts for water quality and biodiversity conservation in streams and rivers should prioritize and strengthen minimizing the impacts of these human activities on these ecosystems.

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APPENDICES

Appendix I: Analysis of Variance table on macroinvertebrate FFG abundance among the three land use sites.

ANOVA					
	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	58047.124	2	9674.521	2.050	.0056
Within Groups	11815196.247	2503	4720.414		
Total	11873243.371	2509			

Appendix II: Mann-Whitney test results for significance among the three land use categories

	Mann-Whitney pairwise comparisons		
	Highly Disturbed	**Undisturbed**	**Moderately disturbed**
Highly disturbed	-	0.0064	0.0014
Undisturbed	0.0094	-	0.1615
Moderately disturbed	0.0042	0.4846	-

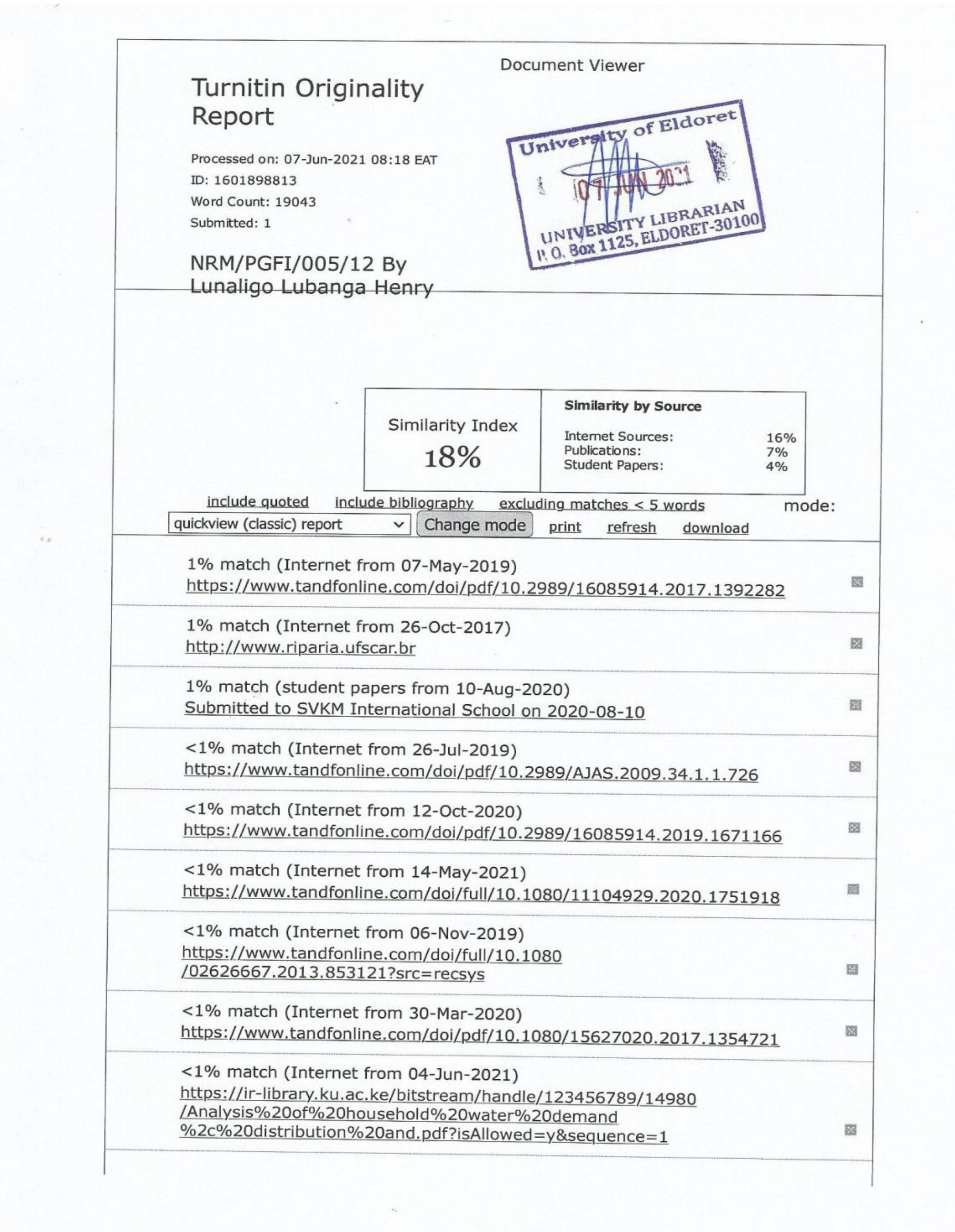
Appendix III: PCA loadings of water quality and nutrients in the three land use (forest, mixed and agriculture) categories

	PC 1	PC 2
TSS	0.20559	-0.7435
pH	-0.34043	0.28358
DO	-0.35637	-0.09576
Conductivity	0.35778	0.052076
Temperature	0.35378	-0.14479
TDS	0.35547	0.11525
Salinity	0.31357	0.43949
TP	0.33289	0.33614
TN	0.3552	-0.12052

Appendix IV: CCA Eigen values and % variation

Axis	Eigenvalue	% variation
1	0.2269	46.62
2	0.12886	26.48
3	0.059607	12.25
4	0.030893	6.348
5	0.01846	3.793
6	0.011462	2.355
7	0.00751	1.543
8	0.002954	0.6071
9	7.28E-07	0.00015

Appendix V: Similarity Report



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