IMPACTS OF CANOPY COVER VARIATIONS AND ORGANIC MATTER DYNAMICS ON BENTHIC INVERTEBRATE COMMUNITY ALONG NJORO RIVER, KENYA

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A Thesis Submitted To The Graduate School In Partial Fulfillment For The Requirements Of The Degree Of Master Of Science In Environmental Science Of Egerton University

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DEDICATION

Dedicated to my late dad Sospeter Mbaka, mom Naomi Mbaka, sisters, and brothers w
inspirations and selfless support was a major motivation in my academic endeavours.

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ABSTRACT

An investigation to establish the relationship between benthic macroinvertebrate density, diversity and biomass and canopy cover intensities as well as benthic organic matter in the Njoro River, Kenya, was undertaken from January to April 2009. It was hypothesized that reduction in canopy cover through small scale tree harvesting could substantially alter the macroinvertebrate community density, biomass and diversity as well as organic matter quantities in the stream and on the banks. This research, therefore, aimed at establishing the relationship that exists between canopy cover, organic matter and benthic macroinvertebrate density, diversity and biomass in the Njoro River, Kenya. Canopy cover at each site was estimated by assessing the shaded area which was then expressed as a percentage of the entire area. Sites designated as Njoro Upstream (> 90 % plant cover), Mugo (> 50 % plant cover), Tree tops (> 60 % plant cover) and Mill House (< 1 % plant cover) were chosen along Njoro River and were approximately 1 km apart. Samples were collected four times during the dry season from four sites. Ten benthic samples for macroinvertebrate and organic matter determination were collected from every site using a Hess sampler during each sampling occasion. Additional samples were taken from the banks of each site using a 0.25 m^2 quadrat to quantify the coarse particulate organic matter (CPOM) held on the banks. Significant differences were evident among the sites in the Njoro River in terms of the amount of CPOM held in the wet zone (One way Anova, $F_{(3, 12)} = 18.48$, $p < 0.05$). Mugo site had the highest (1.19 ± 0.09 gm^{-2}) amount of CPOM in the wet zone whilst Mill House site had the lowest (0.19 ± 0.05 gm^{-2}). Treetops site had the highest (70.21 ± 9.37 gm^{-2}) amount of CPOM on the banks whilst Mill House site had the lowest (9.11 ± 1.56 gm^{-2}). These differences could be attributed to human and livestock influences on the riparian vegetation at these sites, the impact being so great at Mill House, a site that had the least canopy cover. Differences in retentive structures between Mugo and Mill House could have resulted in the high CPOM amounts held in the wet zone of Mugo site which had diverse CPOM retentive structures. Tree-tops site had the highest mean macroinvertebrate diversity (1.64 ± 0.07) whilst Mill House site had the lowest (1.21 ± 0.11) mean macroinvertebrate diversity. Significant difference in macroinvertebrate diversity was evident in the Njoro River (One way Anova, $F_{(3, 12)} = 7.37$, $p < 0.05$). Mugo site had the highest mean macroinvertebrate biomass and density whilst Mill House site had the lowest mean macroinvertebrate biomass and density. These differences could probably be as a result of differences in the nature of plants that grow along the river banks. Pearson correlation analysis indicated significant positive correlation between canopy cover and macroinvertebrate diversity. Similarly, there was significant positive correlation between CPOM and macroinvertebrate density ($R^2 = 0.85$, $p < 0.05$, $n = 160$), diversity ($R^2 = 0.77$, $p < 0.05$, $n = 160$) and biomass ($R^2 = 0.71$, $p < 0.05$, $n = 160$). It can be concluded that canopy cover and benthic organic matter had a positive influence on macroinvertebrate density, diversity and biomass.

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Inland aquatic ecosystems integrate all the atmospheric and terrestrial processes that occur in their catchments and are thus considered among the natural environments most sensitive to anthropogenic disturbances (Mcknight *et al.*, 1996; Abuom, 2003). These disturbances include logging (David *et al.*, 2006; Damon, 2006; Ludwig *et al.*, 2007; Tiegs *et al.*, 2008), trampling of the streambed by animals and human beings (M'Erimba, 2004), and sedimentation (Abuom, 2003; Juliano & Susan, 2008), among others. Currently, anthropogenic disturbances are widespread in nearly all inland aquatic ecosystems in the world. Many inland water systems in Kenya have undergone severe riparian vegetation destruction as a result of human encroachment. Watershed development and land-uses have resulted in the impairment of many of the functions and values provided by healthy riparian corridors due to canopy cover removal. Studies show that ecosystem impairment begins at very low levels of development and continues as watersheds become more heavily urbanized (Horner & May, 1999).

Riparian vegetation removal could lead to changes in hydrology, geomorphology, sediment transport, nutrient dynamics, carbon budgets and stream habitats (Davies *et al.* 2005). Secondary impacts include declines in diversity and production of macroinvertebrates (Death, 2002; Entrekin *et al.*, 2008), fish and other organisms, as well as changes in community composition, growth rates, reproductive success and behaviour of aquatic biota. Davies *et al.* (2005) has shown that reduction in canopy cover as a result of riparian vegetation removal could lead to increased in-stream insolation and temperatures which could in turn cause changes in macroinvertebrate density, diversity and biomass and water quality through increased primary production.

Reduced canopy cover which results from decline in density of the riparian vegetation could greatly change the structure and functioning of stream ecosystems as a result of reduced organic matter (Magana, 2000 & 2001) and woody debris input which provide food (Basaguren *et al.*, 2007) and habitat to stream dwelling invertebrates (Death, 2002). Studies by Dobson *et al.* (2003) in a tropical stream have established that shaded stream channels are heavily dependent upon detritus derived from the adjacent terrestrial environment for their energy resources.

Headwater streams can store significant quantities of organic material (Mathooko, 1995 a; Gomi *et al.*, 2002) and are significant sources of allochthonous carbon for downstream reaches (Kiffney *et al.*, 2000). Woody debris is a critical physical component of streams because it traps sediments and dissipates flow energy. Verry *et al.* (2000) established that woody debris in stream channels provides habitat and shelter for aquatic organisms against predators and floods. In large channels, wood triggers the accumulation of spawning gravel, creates backwaters, and causes pools to form (Gomi *et al.*, 2002).

An important function of the riparian vegetation, particularly in headwater streams, that has been interfered with through canopy cover removal is the input of leaves (Magana, 2000) and pine needles which slowly decay and become a valuable food source for invertebrates (Batzer *et al.*,2000). As a result of canopy cover removal, sunlight penetrates the forest canopy and filamentous green algae and rooted aquatic plants become more common. In such streams, a general shift from a macroinvertebrate community dominated by allochthonous processing macroinvertebrates (shredders and detritivores) to one more typical of coarser bed streams with increased representation of mayflies and stoneflies has been noted (Davies *et al.*, 2005).

Riparian vegetation destruction causes loss of bank stability and reduces shading of the stream causing an increase in temperature thus reduced oxygen concentration in the water; only stream biota adapted to low oxygen concentrations will be found in such areas. Mellina *et al.* (2002) demonstrated that slight temperature increases results in a shift in macroinvertebrate community structure to species that tolerate the increased temperatures. Furthermore, riparian vegetation destruction interferes with moderation of downstream flood peaks through upstream storage of water. Riparian vegetation destruction leads to increased sediment input into streams. This sediment may decrease or increase the interstitial space thus influencing the distribution of biota within the substrates (Mathooko, 1999). Changes in stream macroinvertebrate assemblages associated with riparian vegetation destruction have been attributed to changing light and temperature regimes, nutrient levels, substrate particle size distribution, and available food sources (Berit & Dean, 2003). The impacts of riparian vegetation destruction on the benthic macroinvertebrates and organic matter inputs into aquatic ecosystems have received very little scientific attention in the tropics.

Typical of the semi-arid basins in the Rift Valley of Kenya, the Njoro River watershed has been undergoing a new phase of rapid land use change in the uplands portion of the watershed, and continued significant growth in both rural and urban populations and associated economic activities. Considerable negative environmental impacts are occurring, in particular to the quality and quantity of river water. Increased erosion, nutrient and sediment loadings, and human and animal pollution, along with damage to the integrity of the riparian corridor have been observed (Shivoga *et al.*, 2002).

The Njoro River is one of the streams, which experiences anthropogenic type of disturbances, which occur on small scale but on daily basis. These activities have been described in detail by M'Erimba (2004). Almost every anthropogenic activity, to some extent, affects the biophysical environment, often destroying the existing equilibrium or accelerating natural rates of change (Abuom, 2003).

Riparian vegetation destruction has profound negative effects on the ecology of the benthic macroinvertebrates especially their density, diversity (M'Erimba, 2004; M'Erimba, *et al.* 2007) and biomass distribution. Benthic macroinvertebrates are important since they are widely used in biomonitoring as well as their important role in aquatic ecosystems food chains in transfer of energy to higher trophic levels and in nutrient recycling. As a type of disturbance, logging poses a threat to the biodiversity of river ecosystems. Previous research in the Njoro River have concentrated more on the distribution of organic matter as well as macroinvertebrates, litter processing and microbiology while ignoring the relationship between canopy cover removal and quantities of benthic organic matter, macroinvertebrate density, diversity, and biomass distribution. It is therefore the principle aim of this study to investigate the relationship between canopy cover and the macroinvertebrate community density, diversity and biomass distribution, as well as coarse particulate organic matter (CPOM) in the Njoro River. It will generally serve as a basis in the future planning and management of tropical streams.

1.2 Statement of the Problem

During the last 20 years, the Njoro watershed has undergone rapid population growth with associated negative impacts to the riparian vegetation. The watershed of about 280 km^2 has over 300,000 people. The riparian vegetation has undergone various modifications by man through tree harvesting for charcoal, building and timber among other uses. As a result, there is reduced

canopy cover along the river. Canopy cover removal could greatly reduce macroinvertebrate density, diversity and biomass through reduced organic matter inputs which serve as their food and habitat. Reduction of macroinvertebrate density, diversity and biomass could result to loss of some of the vital roles played by macroinvertebrates in lotic systems such as improving water quality through processing of organic matter, as food for other organisms and as indicators of ecological conditions in aquatic ecosystems. Canopy cover removal through riparian vegetation destruction is known to negatively affect benthic macroinvertebrate density, diversity and biomass in temperate rivers. However, there is scant information for tropical rivers. This research therefore aimed at establishing the relationship between macroinvertebrate diversity and biomass in relation to canopy cover and organic matter in the Njoro River.

1.3 Study Objectives

1.3.1 Broad Objectives

This research aims at establishing the relationship between benthic macroinvertebrate community density, diversity and biomass in relation to canopy cover and organic matter quantities in the Njoro River.

1.3.2 Specific objectives are to:

a) Investigate the relationship between organic matter, canopy cover and macroinvertebrate diversity and biomass in the Njoro River.
b) Assess density variations of functional feeding guilds of macroinvertebrates in relation to organic matter and canopy cover in the Njoro River.

1.4 Research Hypotheses

H_o: There is no significant relationship between organic matter, canopy cover and macroinvertebrate diversity and biomass in the Njoro River.

H_o: There is no significant relationship between organic matter, canopy cover and the various macroinvertebrate feeding guilds densities.

1.5 Justification of the study

Benthic macroinvertebrates play an important role in stream ecosystems since they are involved in nutrient cycling, as engineers of the stream structure and as bio- indicators. They also have the

ability to improve water quality through breakdown of organic matter as well as food subsidy for larger organisms like fish. Despite the crucial role played by macroinvertebrates in lotic systems, destroying riparian vegetation could lead to a decline in macroinvertebrate density, diversity and biomass due to decline in allochthonous organic matter that serve as their food. The responses of the benthic macroinvertebrate communities to canopy cover removal in the Njoro River therefore need an investigation in order to understand the need to conserve the riparian vegetation. The findings of this study are worthwhile to the stakeholders of the Njoro River watershed, since the results will provide baseline information that can be used in the formulation of management programmes of the watershed for the sustainable use of the riparian vegetation.

1.6 Definitions of terms

Allochthonous sources of energy: They are energy sources derived from outside the lotic system i.e. from the terrestrial environment e.g. leaves and twigs.

Autochthonous sources of energy: They are energy sources derived from within the lotic systems. During photosynthesis for example, primary producers form organic carbon compounds out of carbon dioxide and inorganic matter.

Benthic macroinvertebrates: Freshwater benthic macroinvertebrates, or more simply benthos are animals without backbones that are larger than half a millimeter. These animals live on rocks, logs, sediment, debris, and aquatic plants during some period in their life.

Biomass: This refers to the living and recently dead biological materials from plants and animals. It is measured per unit area.

Biomonitoring: This is the science of inferring the ecological condition of an area by examining the organisms that live there. It is often used to assess water quality of rivers, lakes, and wetlands.

Canopy cover: This is the vertical projection of plant foliage onto a horizontal surface.

Coarse benthic particulate organic matter: This is organic matter which is > 1mm in size and within the stream.

Disturbance: This is something that causes a community or ecosystem characteristics, such as species diversity, nutrients output, vertical or horizontal structure to exceed or drop below its common (homeostatic) range of variation.

Diversity: This refers to the number of different species in a particular area weighted by some measure of abundance such as number of individuals or biomass.

Humid zones: These are land/river ecotones beyond the bank full line characterized by the presence of a belt of riparian vegetation, and whose direct contact with the stream ecosystem is restricted to flood events.

Lotic ecosystems: This is any spring, stream, or river. Lotic ecosystems are characterized by the interaction between flowing water with a longitudinal gradation in temperature, organic and inorganic materials, energy, and the organisms within a stream corridor.

Riparian vegetation: Plant communities along the river margins are called riparian vegetation. Riparian vegetation may be natural or engineered for soil stabilization or restoration.

Stream health: Meyer (1997) defined a healthy stream as an ecosystem that is sustainable and resistant, maintaining its ecological structure and function over time while continuing to meet societal needs and expectations.

Streamside forests/riparian buffers: Streamside forests/riparian buffers are vegetated areas around the stream channel. They are complex ecosystems vital to the protection of the streams and rivers. They are crucial to the enhancement and protection of the water resources. Hydrophilic plants characterize these areas.

Watershed: This is an extent of land where water from rain or snow melt drains down hill into a body of water such as a river, lake, estuary, wetland, sea or ocean.

Wet zones: These are the channel areas covered by water at time of observation.

Woody debris: This refers to dead trees, either standing or fallen, as well as the remains of branches on the ground in forests.

1.7 Scope of the study

The study focused on the relationship between macroinvertebrate density, diversity and biomass distribution, and canopy cover and organic matter distribution in the Njoro River. The study was conducted on four sites located in the middle reach of the Njoro River.

1.8 Assumptions of the study

In this study, it was assumed that physical conditions in the study sites offered excellent conducive environment for thriving of benthic macroinvertebrates. The in-stream conditions deviate from natural to degraded as a result of human interference with the riparian vegetation. It was also assumed that removal of vegetation cover could alter the patterns of organic matter inputs, which could in turn affect benthic macroinvertebrates density, diversity and biomass.

1.9 Limitations of the study

The depth of the study was limited since macroinvertebrates were to be identified to family level. The study was limited to the low water flow when macroinvertebrates were thought not to be influenced by high water levels. Finally, the numbers of samples per site were limited to ten per sampling occasion due to the fact that there were no quick and satisfactory methods of separating macroinvertebrates from silt and debris.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction: Benthic macroinvertebrates and their role in rivers

Benthic macroinvertebrates represents an extremely diverse group of aquatic animals, and the large numbers of species possess a wide range of responses to stressors such as organic pollutants, sediments and toxicants (Cao *et al.*, 1996; Moeykens, 2009). Unlike fish, benthos cannot move around much so they are less able to escape the effects of sediment and other pollutants that diminish water quality. The long life cycles of benthos are between six months and two years for worms, up to five years for dragonflies or even twelve years for large fresh water shells. This allows studies conducted by aquatic ecologists to determine any decline in environmental quality (Cao *et al.*, op.cit.). This information helps resource managers to determine which rivers and streams have good habitat quality and should be protected. The benthos also can help identify those rivers and streams showing signs of stress. Resource managers can then apply management action that will improve environmental quality, such as storm water control in urban areas and best practices on farmlands to control nutrient runoff (Kar & Chu, 1998; Moeykens, 2009).

Benthic macroinvertebrates is an important part of the aquatic food chain, especially for fish. Many invertebrates feed on algae and bacteria, which are on the lower end of the food chain. Some shred and eat leaves and other organic matter that enters the water. Because of their abundance and position as "middle men" in the aquatic food chain, benthos plays a critical role in the natural flow of energy and nutrients. As benthic invertebrates die, they decay leaving behind nutrients that are re-used by aquatic plants and other animals in the food chain (Kar & Chu, 1998).

Autumn-shed leaves are the major source of organic matter to small woodland streams (Cordora *et al.*, 2009). A group of stream invertebrates, collectively known as shredders, have an important role in leaf processing and in controlling the availability of this energy input to other stream organisms (Anderson & Sedell, 1979). Although shredder production may account for only a small portion of the energy flow in woodland streams (Anderson & Sedell, 1979), shredders ingest, and in so doing alter the size, distribution, and nutritional quality of a large fraction of the leaf input to these ecosystems (Anderson & Sedell, 1979). They increase leaf

decomposition, production of fine particulate organic matter (FPOM) and thus the availability of organic matter to collector organisms (Eggert & Wallace, 2003), and transport of particulate and dissolved organic matter at base flow and thus its availability to downstream communities (Allan, 1995).

2.2 Riparian vegetation

The riparian zone, defined as an ecological complex, is all land directly adjacent to a watercourse including flood plains and wetlands (Parsons, 1991). Riparian lands can also include intermitent streams gullies and dips which sometimes run with water (Nakasone *et al.*, 2003). The vegetation ranges from emergent aquatic and semi-aquatic plants through to terrestrial under storey and canopy species (Parsons, 1991). Further, the zone can be seen as an interface between terrestrial and aquatic systems and is described as a series of ecotones between these systems (Mengis *et al.*, 1999). The high level of interaction between the riparian zone and its respective watercourse (particularly in the case of rivers and streams) makes defining an ecosystem boundary difficult. The riparian zone can be seen as an extension of the river continuum, with 'energy driver association' acting upon the in-stream biology (Mengis *et al.*, 1999). Riparian vegetation provides aquatic communities with allocthonous input for the food chain (Fuchs *et al.*, 2006). The debris also provides building material for macroinvertebrates such as trichopterans to produce their protective cases (Fuchs *et al.*, 2006).

2.3 Status and enforcement of riparian zones in Kenyan rivers

In Kenya, rivers are public resources and accessible to anybody at anytime. The Land Act (Cap 307, section 13 and 3) states that the riparian zone, including the vegetation which grows along the river, is government property (Lelo, 2005). The official size of the strip of government-owned riparian land is marred in confusion. It is not standard and varies according to the width of the river according to a non-conventional calculation whereby the riparian area on each side of the river is to be set equal to two times the width of the river (Lelo, op. cit.). By law, the two pieces of land on both sides of the river, referred to as the riparian zone, are to be left intact. However, in most cases due to the enormity of the task of definition and enforcement, management of the riparian zone is left to the interpretation of the individuals owning land adjacent to the river (Lelo, 2005). In practice, this leads to many land owners clearing the vegetation and using the land right up to the edge of the river (Lelo, 2005).

Many sections of the riparian areas of the Njoro River are devoid of riparian vegetation. Farmers adjacent to the river and outsiders cut down trees and clear vegetation in the riparian zone for medicinal herbs, firewood and fodder (Mathooko & Kariuki, 2000; Shivoga, 2002). Mathooko & Kariuki (2000) estimated that approximately 55% of the riparian vegetation could be used for herbal medicine and 11% as food. All these demands though carried on small scale but intensively, have extensively affected the vegetation cover at some areas along the banks of this river, making them prone to soil erosion from the run off as well as reduced litter inputs into the stream (Mathooko & Kariuki, 2000). Studies suggest a possible correlation between rapid deforestation in the upper zone starting in the early 1990's and the decline both in water quality and stream flow during dry periods (Shivoga, 1999). At least four land uses are significant, which have a bearing on the riparian vegetation in the Njoro River. Starting at the top of the watershed, the upper zone is predominantly forested with indigenous plant species (Mathooko & Kariuki, 2000).This opens to new settlements on recently felled plantation forests, characterized by temporary structures and small scale subsistence farms (Shivoga *et al.*, 2002). This landscape is still littered with tree stumps. Most of the new settlers were originally pastoralists but are now practicing agro-pastoralists (Shivoga *et al.*, 2002). This gives way to a third zone, of older and more permanently settled small and large-scale farms. Besides subsistence farming, these farmers also keep dairy animals and grow wheat as a cash crop (Shivoga *et al.*, 2002). Smaller farms are interspersed with a few remaining large scale farms from the colonial era, including Egerton University's commercial farm. Urban centers are the fourth type of land use, mainly in the middle and lower zone, including Egerton University Campus, Njoro Township, and large parts of Nakuru Municipality. These zones consist of more densely populated settlements, industries, and commercial activity (Shivoga *et al.*, 2002).

2.4 Canopy cover in relation to organic matter distribution in rivers

Plant litter originating from the riparian vegetation along headwater streams is recognized as the major source of energy for heterotrophic biota (Cummins, 1974) as light availability for primary production is substantially limited by the extensive canopy cover (Vannote *et al.*, 1980). With increasing stream size, leaf litter inputs from the riparian vegetation decrease per unit area of the stream. Downstream, a major source of food comes from coarse particulate organic matter (CPOM :> 1 mm) that has been fragmented upstream by biotic and abiotic processes (Mathooko *et al.*, 2000). Further downstream, fine particulate organic matter (FPOM: < 1 mm) dominate the

system. Banks on both sides of a river are important storage and pre-processing zones for plant CPOM that falls asynchronously on them before it ultimately enters the streams (Mathooko *et al.*, 2000).

The linkage of terrestrial and aquatic systems is very strong and stream ecosystems normally receive organic matter inputs, periodically or continuously, from the riparian vegetation bordering them. Bunn *et al.* (1999) strongly argues that leaf detritus entering the stream from terrestrial sources provides the main source of energy in forested streams. Studies by Dobson *et al.* (2002) have established that shaded stream channels are heavily dependent upon detritus derived from the adjacent terrestrial environment for their energy resources. Riparian forests provide food for stream organisms in the form of twigs, branches, bark, leaves, nuts, fruits, flowers, and insects falling from the forest cover. The organic matter gets into stream ecosystems as aerial drift or bank runoff (Mathooko *et al.*, 2000). This organic material is slowly broken down by aquatic microorganisms and stream invertebrates, which form the base of the food chain for larger aquatic organisms such as fish (Reed & Carpenter, 2002). Leaves in the wet zone represent current sources of detritus at the site of retention and also for the different downstream reaches, whilst those on the humid zones represent potential energy subsidy for the stream ecosystem (Mathooko *et al.* 2000). Once in the stream channel, the leaf litter can either be entrained by the water current or retained in the humid zone (Mathooko *et al.* op.cit).

2.5 Canopy cover in relation to macroinvertebrate density, diversity and biomass in rivers

A major influence of riparian vegetation on streams is its shading effect. Shading lowers the amount of light reaching the stream benthos, therefore reducing the amount of light available for algae and macrophytes to utilize in photosynthesis (Hill & Dimick, 2002). It has been shown that reduced incidence light results in lower algal biomass (Sabater *et al.*, 2000, Mosisch *et al.*, 2001). Algal densities, biomass and diversity have been found to be much higher in un-shaded streams than in shaded streams (Kjeldsen, 1996). The degree of shading on the stream is critical since productivity of algae decreases as shade increases though not in a linear fashion (Quinn *et al.*, 1997). Such decreased algal growth has been found to be associated with a decrease in invertebrate density, diversity and biomass. Streams with coniferous riparian vegetation have been found to have lower benthic invertebrate density, diversity and biomass than streams with

deciduous vegetation, due to a greater density of canopy and heavier shading which reduces autochthonous production (Whiles & Wallace, 1997).

Exclusion of woody debris through deforestation decreases density, diversity and biomass of benthic fauna (Dana & Clifford, 2006). The presence of woody debris within a stream increases retention of deciduous leaves and coniferous needles (Pretty & Dobson, 2004), thus increasing the amount of detritus available for macroinvertebrates. In the contrary, studies around the world have shown that invertebrate density, biomass and diversity are higher in sections of streams with open canopies than in forested sections, perhaps as a result of increased autochthonous production (e.g. Keithh & Winsorh, 2006; Vandeneeden & Turner, 2008). Murphy & Hall (1981) reported that density and biomass of invertebrates was generally higher in low-order streams flowing through clear-cuts than in streams of similar size flowing through old-growth forests due to increased autochthonous production.

Quantifying the influence of energy and materials from the terrestrial/aquatic interface along riparian zones is crucial for improving the understanding of river ecosystem structure and function (Hall *et al.*, 2006; Tiegs *et al.*, 2009). In addition to maintaining microclimate conditions of streams and stabilizing river banks, riparian zones supply stream biota with allochthonous inputs that comprise an important source of energy for stream food webs, especially in small, forested streams (Dana & Clifford, 2006; Tiegs *et al.*, 2009) or in large, turbid or deep rivers where autotrophic production is limited (Wallace *et al.*, 1997; Hall *et al.*, 2006). Changes in organic matter inputs to streams as a result of logging activity have been shown to have ecological consequences in streams of harvested catchments (Wallace *et al.*, 1997; Entrekin *et al.*, 2008). Experimental removal of benthic organic matter (BOM) inputs has been shown to reduce invertebrate density, diversity and biomass and alter stream food webs (Eggert & Wallace, 2003; Hall *et al.*, 2006).

2.6 Macroinvertebrate functional feeding groups in relation to canopy cover and organic matter in rivers

Streams with no shading have been found to contain higher invertebrate density, with greater numbers of collector-gatherers, filter-feeders, shredders, piercers and predators, than shaded streams which in turn exhibit greater numbers of shredders (Friberg, 1997; Ernst *et al.*, 2008).

Organic matter in the form of leaves is known to act as the main food source for many detritivorous invertebrates (Heino, 2005). Shredder density has been shown to be positively correlated with the amount of CPOM present in a system (Friberg, 1997). While Shredders consume CPOM, collectors consume FPOM. Collectors are divided into collector-gatherers which use deposited FPOM, while collector-filterers strain suspended FPOM from the water (Friberg, 1997). Hildrew *et al.* (1991) reported a significant positive linear relationship between benthic detritus and shredders, and collector-gatherers. Further, invertebrate densities and detritus amount were positively related for most invertebrates in studies by Egglishaw (1964) and Minshall & Minshall (1977). However, Townsend & Hildrew (1984) reported that only shredders increased in highly retentive areas. Conversely, no relationship could be determined by Petersen & Cummins (1974).

Logging practices which alter the normal flow of organic detritus into streams shifts the trophic structure and relative densities of invertebrate feeding guilds (Heino, 2005.). Logging decreases the quantities of CPOM inputs and changes the kind of inputs causing changes in the shredders and collectors density (Heino, 2005). Leaf litter exclusion experiments have shown a decrease in density and biomass of macroinvertebrates (Wallace *et al.*, 1999; Yamamuro & Lamberti, 2008). In extreme cases, leaf litter exclusion experiments have resulted in the loss of species (Eggert & Wallace, 2003).

2.7 Conceptual framework

Physical, chemical, evolutionary, and ecological processes interacted to produce rivers and their landscapes, including the local and regional biota. Humans through their activities have stressed the systems by altering physical habitat, modifying seasonal water flow, changing the system's food base, changing stream organisms' interactions, and contaminating the water with chemicals. Catchment disturbance through logging may impact negatively on the riparian corridors of streams as well as exert influence on in-stream processes through canopy cover removal. Effects on humid zones of a river as a result of canopy cover removal could include less organic matter on banks, increased soil erosion, and unstable banks (Figure 1). This may lead to reduced energy inputs into a stream through reduction in benthic coarse particulate organic matter, increase or reduction in autochthonous production due to increase in light and suspended sediments respectively, and reduced habitat complexity due to reduced woody debris input.

The compounding effects of these two extremes could lead to loss of the stream health as a result of altered physical habitat for the biota (fish, macroinvertebrates, algae and macrophytes). This loss of stream health could in turn result in decrease in benthic macroinvertebrate density, diversity and biomass. Reduced macroinvertebrate density, diversity and biomass could in turn affect in-stream processes such as processing of organic matter and nutrient cycling which could in turn jeopardise the stream health.

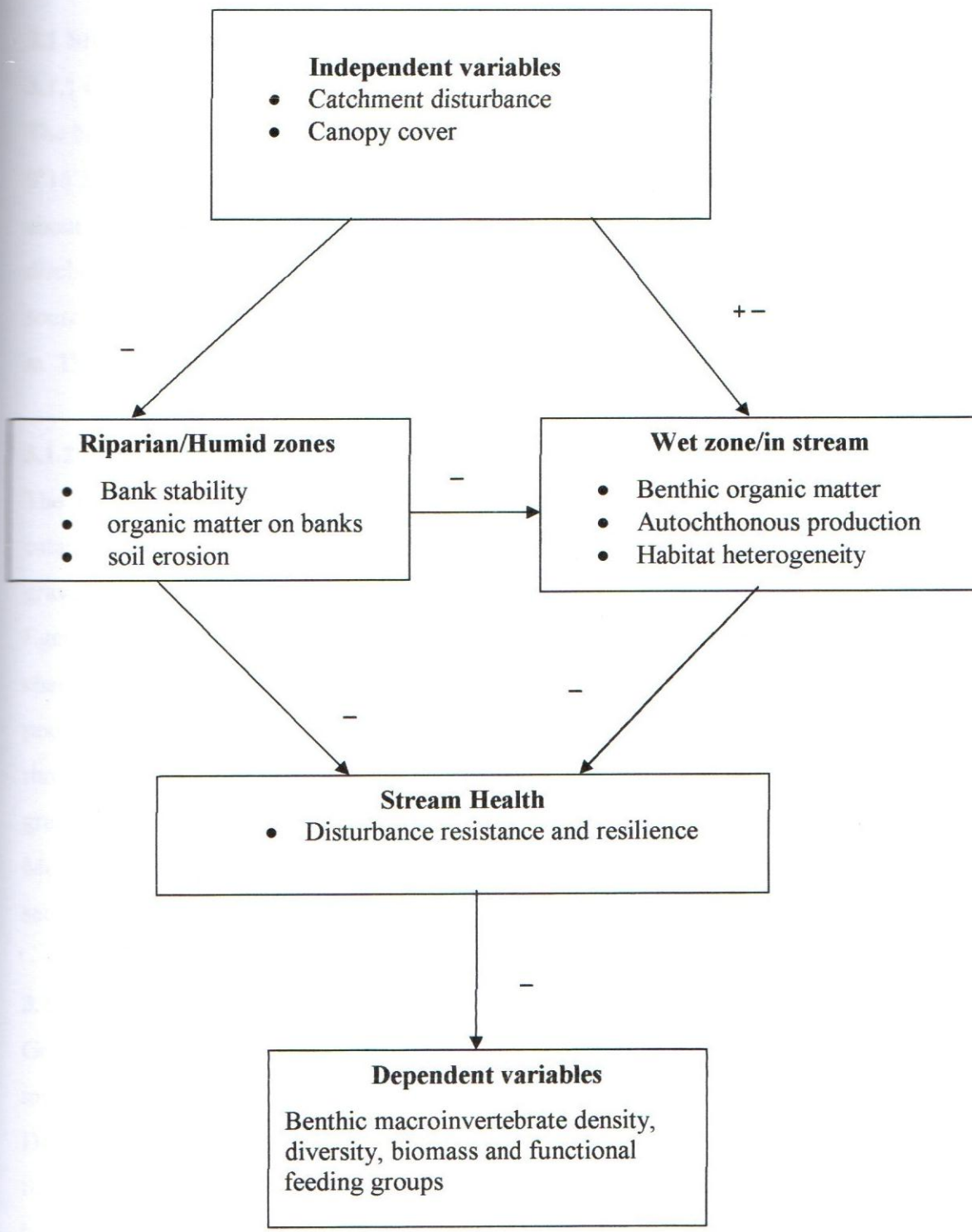


Figure 1: Conceptual framework (- means negative effect while + means positive effect).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

3.1.1 Catchment and location

The Njoro River (Fig. 2) has a catchment of approximately 200 km^2 straddling between latitude 0°15'S, 0°35'S and longitude 35°50'E, 36°05'E. It originates from the Mau Hills at an altitude of about 2880 metres above sea level (m.a.s.l.) to about 1750 m.a.s.l. at the mouth where it discharges into Lake Nakuru, a Rift valley soda lake. The river is 55 km in length from the source to the mouth. Little Shuru (its main tributary) joins the river at an altitude of about 2293 m. The soils in the catchment are predominantly volcanic clay loam.

3.1.2 Channel morphology and sediments

The main channel is dominated by rocky bottom formations, including a high frequency of cataracts in the upper reaches around Logoman area. Downstream of Runguma and beyond gravel and cataracts dominate the bed sediments. The middle course of the Njoro River at the Egerton University area is at an altitude ranging between 2220 and 2240 m.a.s.l. and is characterized by typical pool- riffle sequences, with soft substratum and bedrock cataracts in the pool and riffle sections, respectively. Towards Lake Nakuru (mouth), the river bed meanders through Acacia forest with very little debris dams. Generally, the proportion of the fine sediment grains (median grain size < 1 mm) ranges between 80 and 90 % (Shivoga, 1999; Mokaya, 2000; Muia, 2001) and becomes finer from the headwaters towards the mouth (Bretschko, 1996). The sediments are generally poorly sorted with sorting coefficients (S_o) of about 2.5.

3.1.3 Rainfall and water discharge

Generally, the rainfall patterns in the Njoro area show a characteristic bimodal distribution, with much of the rain falling between April and November. Dry periods normally occur between December and March while wet seasons are observed between April and November. However, this pattern could be drastically altered by weather phenomena. For instance, *El Ñino* occurred between 1997 and 1998 and was followed by a long dry period *(La Ñina)* between March 1999 and March 2000 thus altering the usual climatic pattern. In the upper and middle reaches of the Njoro River, there is permanent discharge though reduced during the dry season. However,

drying up of the river in the lower reaches has been observed in the *La Ñina* of 2000 (Mathooko *et al.*, 2005). It is in the lower reaches up to Lake Nakuru where the river becomes intermittent, flowing only during high flow periods.

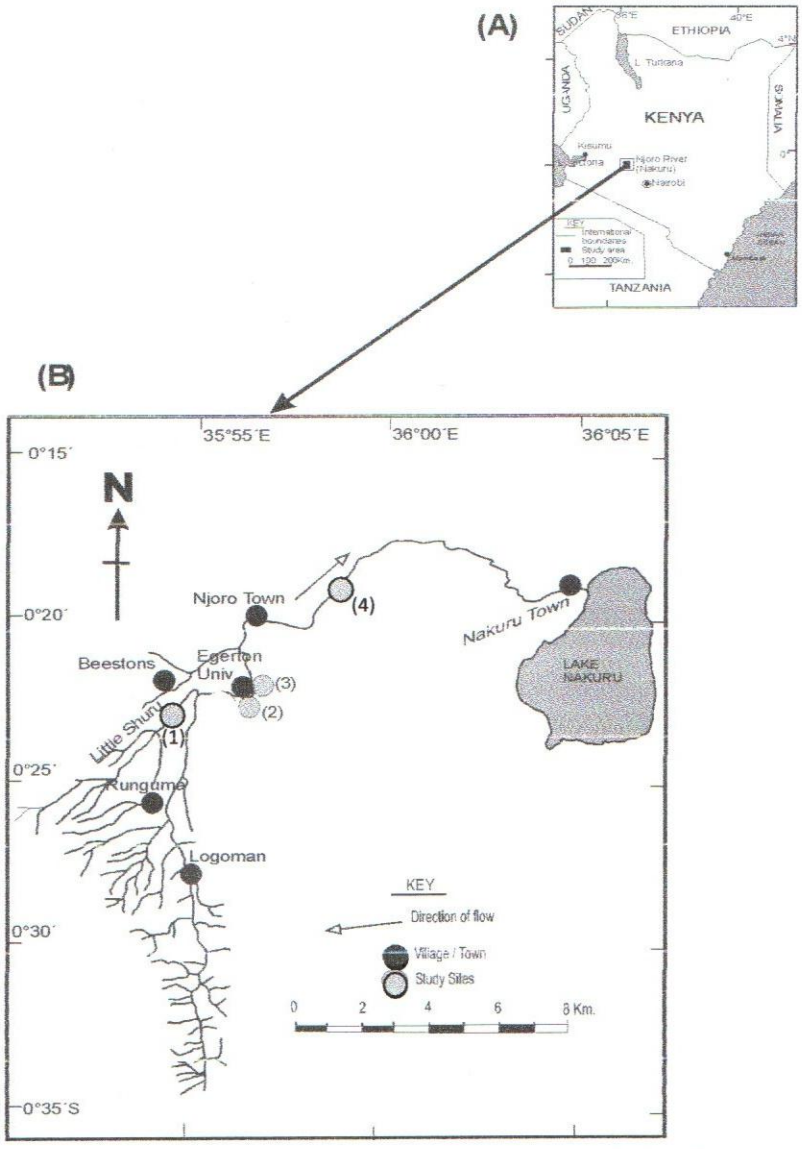


Figure 2: The Njoro River and the study sites. (A) Location of the Njoro River in Kenya, (B) the Njoro River: study sites (1) heavily shaded, (2) medium shaded (3) moderately shaded and (4) least shaded. Figures A and B were redrawn from the Survey of Kenya maps, sheet: No. 118/4, 119/3 and 132/2, edition 8-D.O.S. 1974.

3.1.4 Riparian vegetation

The upper reaches of the river (2300-2600 metres above sea level) are covered by montane *Juniperus procera*, *Olea europaea spp.* and *Olinia usambarensis* (Mathooko & Kariuki, 2000). The uppermost region is open moorland, which is heavily grazed by livestock. The area between Logoman and Runguma is mainly covered by a dense natural montane forest, mainly the *J. procera* community. Downstream of Runguma, a large artificial forest of mainly *Cupressus lusitanica, Pinus patula, Pinus radiata* and *Grevillea robusta* is found. In the herb layer, *Carex johnstonii, Cyanthula polycephala* and *Asparagus africanus* are typical (Mathooko & Kariuki, 2000).

The most dominant tree in the middle reaches around Egerton University is *Syzygium cordatum*. Other trees like *Pittosporum abyssinicum* and *Hibiscus diversifolius* are codominant. The Kikuyu Grass, *Pennisetum clandestinum*, mostly dominates the grass layer. It is at this area where vegetation is greatly disturbed as a result of intensive agriculture and cattle and people trampling. The riparian forest downstream of Egerton University is scattered and dominated by *Acacia abyssinica* that spreads to the river banks (Mathooko & Kariuki, 2000). Towards Lake Nakuru National park, *Acacia xanthophlea* dominates all other trees, with smaller stands of *Dombeya burgessiae* and *Croton megalocarpus* being evident. Many weeds such as *Bidens pilosa, Galinsoga parviflora, Tagetes minuta* and *Solanum incanum* form the herb layer.

3.2 The Njoro River study sites

Four study sites with similar topography, hydraulic characteristics, sediments but differing in the riparian vegetation intensities, were chosen in the middle reach of the Njoro River. The study sites were Njoro-upstream (Heavily shaded), Treetops (Medium shaded), Mugo (Moderately shaded) and Mill House (Least shaded). The sites were approximately 5 kilometres apart and were purposively chosen based on the intensity of the riparian vegetation cover. In the context of this study, sites whose vegetation cover was > 90 % were described as heavily shaded, 51 ≤ 90 %, medium shaded; 10 ≤ 50%, moderately shaded; and ≤ 10 % least shaded sites.

3.2.1 Mill House: (S 00° 18′ 34′′, E 35° 59′ 11′′; least shaded site)

Mill House site is at an altitude of about 2044 m.a.s.l. The site was a pool, 95 m long, 23.5 m wide with an average depth of about 0.31 m during the dry period. Bed sediment was mainly

rock and there was a huge *Syzygium cordatum* tree on the right bank. Riparian vege provided less than 1 % canopy cover (plate 1) at the site with the herbaceous layer bein dominant growth form on both banks. The left and right orographic banks border the leading to Nakuru town and a small scale farm, respectively. The left orographic river ba devoid of vegetation in the downstream end (plate 2) while the upstream end is dominated b herbaceous layer comprising of *Senecio montuosum, Ocimum grattisimum, Solanum inca Vernonia grattisiana*, and *Aspilia mossambicensis.* The right bank is dominated by *Justicia Ocimum grattisimum, Solanum incanum, Senecio petitiamus, Hibiscus diversifolius, didymobotrya and Lantana camara.*

The site lacks any coarse particulate organic matter (CPOM) retentive structures a accessible from the left orographic bank by animals and human beings. The average width riparian vegetation buffer strip in this site was 8 m in the right bank and 1.5 m in the left ban

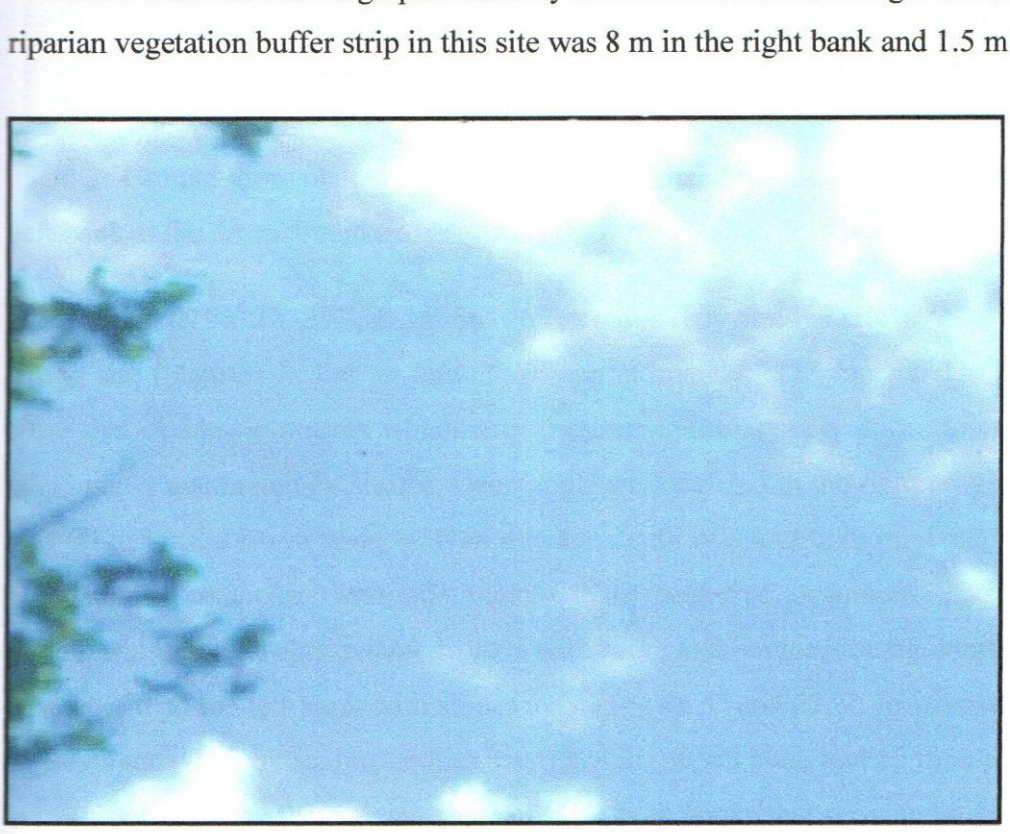


Plate 1: Aerial photograph of Mill House site canopy cover.

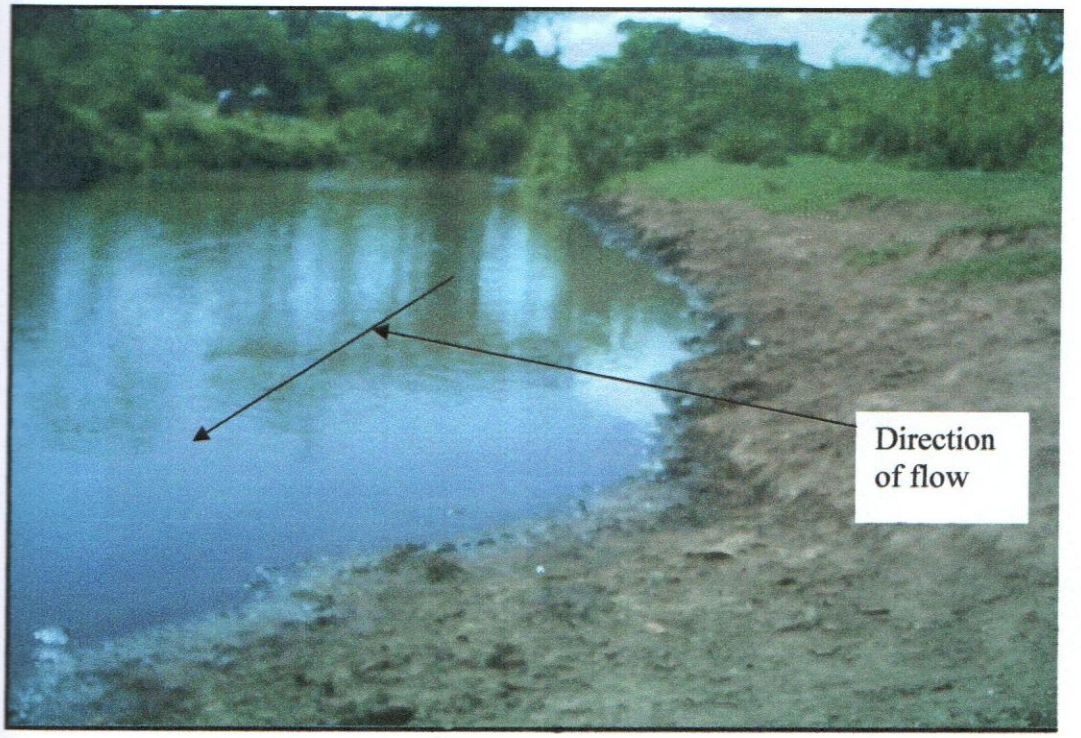


Plate 2: Ground view photograph of Mill House site. The site has bare ground on the left bank at the downstream end.

3.2.2 Mugo (S 00° 22′ 39″, E 35° 56′ 06″; moderately shaded site)

Mugo site (plate 3) lies at an altitude of approximately 2255 m.a.s.l. The site is an extensive riffle that divides into arms which later coalesce approximately 30 m downstream, forming an islet mainly dominated by shrubs. Deep pools are localized in the right orographic bank. The site was 60 m long, 17.6 m wide with an average depth of about 0.76 m. Tree roots, woody debris, boulders and branches were the main CPOM retentive structures. The percentage CPOM retentive structure is approximately 70% with rocks and boulders being dominant. The right bank is steeper than the left bank with slopes averaging 36.5° and 23.3°, respectively (Magana, 2000). The average width of the buffer strip was 12 m in the left bank and 10 m in the right bank. Mugo is heavily shaded by the riparian vegetation on both banks that provide 50 % canopy cover, with *Syzygium cordatum* intertwined with climbing plants being the most dominant growth form. Other growth forms that are co-dominant at this site include *Achyranthes aspera, Cyanthula cylindrica, Basella alba, Zelineria scabra, Crotalaria agatiflora, Vernonia newii, Hibiscus fuscus, Senecio montuosum, Pittosporum abyssinicum, Grewia forbesii, Acacia mearnsii* and *Hibiscus diversifolius.*

(a)



(b)

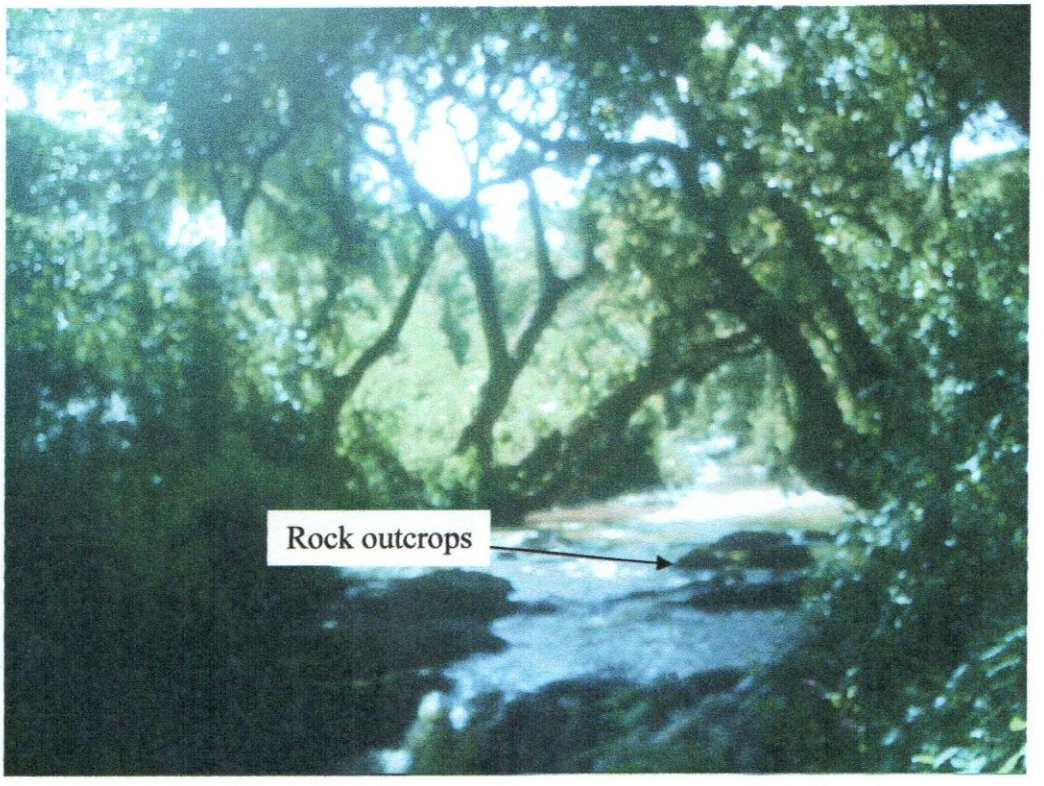


Plate 3: Photograph of Mugo site canopy cover (a) and (b) Ground view with visible rock outcrops.

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3.2.3 Tree-tops (S 00° 22′ 32″, E 35° 55′ 41″; medium shaded site)

Tree-tops site (Plate 4) lies at an altitude of about 2260 m.a.s.l. The site is characterized by rock outcrops in the mid stream. Deep pools are localized in the upstream end of the site where the bottom is characterized by recent deposits of fine sediments mixed with fist size cobbles. The site was 55 m long, 13.5 m wide with an average depth of 0.9 m. Rock out crops are the main CPOM retentive structures. The percentage of the CPOM retentive structures at this site is approximately 30%. The right and left banks border Njokerio settlement and Egerton University, respectively. Tree-tops is heavily shaded by riparian vegetation on both banks that provide 64 % canopy cover, with *Syzygium cordatum* intertwined with climbing plants (plate 4 and 5) being the most dominant growth form. Other growth forms that are co-dominant in this site include *Pentas lanceolata, Olea europea, Rhynchosia holstii, Rhus natalensis, Ipomoea wightii, Senecio siringiflora, Hibiscus diversifolia, Euphorbia fischeri, and Fauria saligria.* The width of the riparian vegetation buffer strip was 22 m in the left bank and 19.5 m in the right bank.



Plate 4: Aerial photograph of Tree Tops site canopy cover.



Plate 5: Ground view photograph of Tree Tops site showing riparian vegetation.

3.2.4 Njoro upstream (S 00° 22′ 36′′; E 35° 54′ 50′′; heavily shaded site)

Njoro upstream site (Plate 6) lies at an altitude of about 2321 m.a.s.l. The site was a shallow pool with a huge *Rhus natalensis* tree at the downstream end. The right and left orographic river banks border small scale farms. Rock outcrops are located on the right orographic bank. The site was 50 m long, 7.4 m wide with an average depth of about 0.5 m. Tree roots, woody debris, boulders and branches were the main coarse particulate organic matter retentive structures. The percentage CPOM retentive structures were approximately 50%. Tree roots and woody debris were the most dominant CPOM retentive structures. Njoro upstream is heavily shaded by the riparian vegetation on both banks that provide 92 % canopy cover, with *Ipomoea wightii* intertwined with *Crotalaria agatiflose* being the most dominant growth form. Other growth forms that are co-dominant at the site include *Heteromorpha trifoliata, Senecio petitiamus, Crotalaria agatiflose, Cyanthula cylindrica, Hibiscus diversifolia, Euphorbia fischeri,* and *Vernonia lasiopus.* The average width of the buffer strip in the right bank and left bank was 7.5 and 8.5 m, respectively.

(a)



(b)



Plate 6: Photograph of Njoro upstream site canopy cover (a) and (b) Ground view showing herb layer overlying the river.

every site during the dry season. Conductivity was measured with a WTW-LF 90 conductivity meter. Dissolved oxygen and percentage saturation were determined using a WTW-OX 192 oxygen meter whereas pH and water temperature were determined using a combined WTW-OX 91 meter.

3.3.1 Sediments

Three random sediment samples for grain size analysis were collected only once at every site along the Njoro River in February 2009. Sediment samples were taken at a depth of about 10 cm using a Perspex tube with an internal diameter of about 6 cm. Substrate characterization was done as described by Müller (1964) where each sediment sample was wet sieved for 10 minutes through a nest of sieves with mesh – sizes ranging between 0.063 - 10 mm. The resultant fractions were oven dried at 60^0 C for 72 hours and then weighed to obtain weight in dry mass (% DM) for each grain size class. The particle diameter at 25%, 50%, and 75% quartiles were read from a curve drawn on semi-log paper. The sorting coefficients were computed using the Füchtbauer (1959) and Müller (1964) expression:

$$S_o = \sqrt{Q3/Q1}$$

where S_o = sorting coefficient, $Q_3 = 3^{rd}$ quartile, and $Q_1 = 1^{st}$ quartile.

$S_o > 1$ means that the sediments are badly sorted and $S_o = 1$ means that the sediments are perfectly sorted (Table 1).

Table 1: Range of sorting coefficients as described by Füchtbauer (1959).

Sorting coefficient	*Description*
1.00-1.23	Very well sorted
1.23-1.41	Well sorted
1.41-1.74	Medium
1.74-2.0	Badly sorted
> 2.0	Very badly sorted

Stream discharge was estimated by measuring water velocity in a selected stream cross section. Water velocity was determined using a current meter and stream discharge was eventually computed as follows (Fig 3.).

Discharge (Q) = $W_1D_1V_1+W_2D_2V_2+$.....$W_nD_nV_n$

where W1-W7 is width in metres, D1-D7 is the depth of the vertical in metres, V is the average velocity at each vertical (m/s) and Q is the discharge in m^3/s (Gordon *et al.*, 1993).

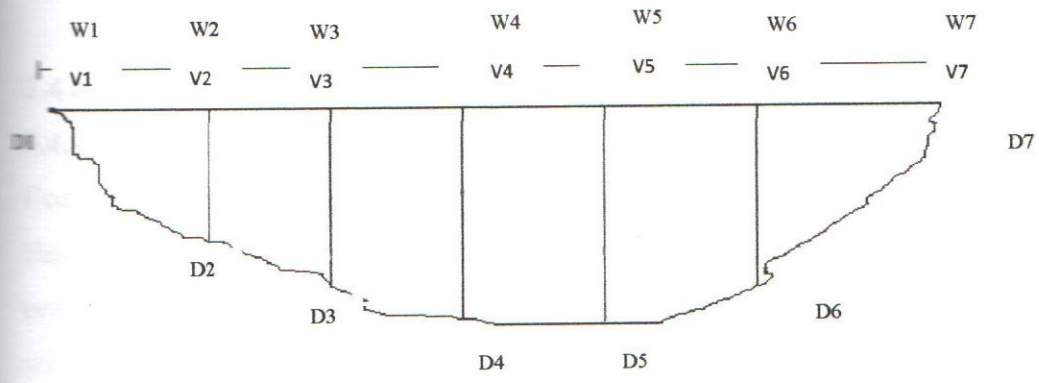


Figure 3: An illustration of a stream cross section for discharge measurement.

3.3.3 Canopy cover

The canopy cover intensity in each site was assessed at noon when the sun is overhead. Each site was demarcated using pegs and the total area assessed by multiplying the length and the width in order to get the total area of the stream segment under consideration (Fig. 4). The un-shaded area was then assessed (using geometric formations such as squares, triangles, circles and rectangles) and deducted from the total area to get the shaded area, which was then expressed as a percentage of the entire area as indicated in formula (Eqn. 1).

% canopy cover = ((Total area (L ×W) – un-shaded area) ÷ Total area (L×W)) × 100.....Eqn 1.

where L = length in meters, W = width in meters and % canopy cover is the shaded area expressed as a percentage of the total area.

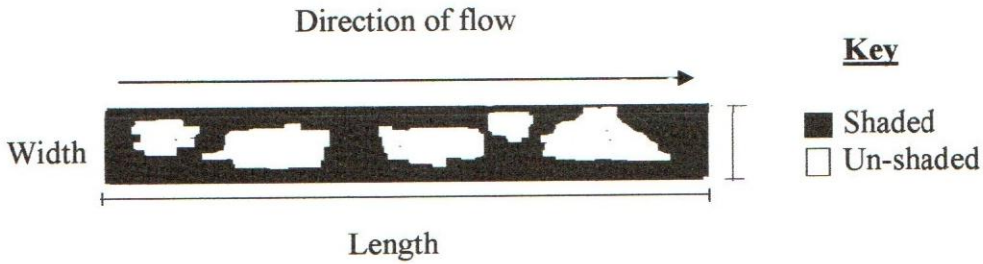


Figure 4: An illustration of a stream segment for canopy cover estimation.

3.4 Coarse Particulate Organic Matter (CPOM)

3.4.1 Collection of coarse particulate organic matter in the wet zone

Coarse particulate organic matter (CPOM) samples were randomly collected using a modified Hess sampler (effective area: 0.029 m^2). Sampling always commenced from downstream at every site, moving upstream to minimize the disturbances while sampling. Sediments enclosed within the working area of the Hess sampler were disturbed by hand for about one minute to a depth of about 10 cm. The samples thus collected were put in well-labelled polythene bags. A total of 10 samples per site were collected during each sampling occasion. The samples were taken to the laboratory for further processing.

In the laboratory, each sample was elutriated to separate organic material from accompanying inorganic materials (e.g. silt) by suspending the material repeatedly in a container (bucket) filled with water, and then sieving out the organic matter (Dudgeon, 1982). Coarse particulate organic matter (CPOM) obtained was further separated into leaves, twigs, fruits and miscellaneous (other unidentifiable material). All the resultant fractions were dried separately in pre-weighed aluminum cups at 60^0C for 24 hours and then weighed to obtain dry mass (DM) estimates, and then ashed at 500^0C for 4 hours to obtain ash free dry mass (AFDM).

3.4.2 Collection of coarse particulate organic matter (CPOM) on the dry zones

Coarse particulate organic matter on the dry zones was quantified by collecting five random samples during every sampling occasion from the left and right banks using a quadrat (area: 0.25 m^2). All the CPOM enclosed within the quadrat were picked by hand and placed into well

3.5 Collection of benthic macroinvertebrates

Random benthic samples for quantifying macroinvertebrate abundance, biomass and diversity were collected using a modified Hess sampler (effective area: 0.029 m^2). Sediments enclosed within the effective sampling area were disturbed by hand for about one minute to a depth of about 10 cm. The material that drifted into the net was removed by hand, put in a well labelled polythene bag and preserved in 4% formalin. In total, ten benthic samples were collected per site during the four sampling occasions. In the laboratory, all samples were washed through a series of sieves (1 mm, 0.5 mm & 63 µm) to separate extraneous materials from animals. Animals were sorted under a dissecting microscope (x 400), identified and enumerated. The macroinvertebrates were assigned to four major functional feeding groups; shredders, predators, filterers and collectors according to (Meritt & Cummins, 1978 and Dudgeon, 1994).They were later placed in pre-weighed crucibles and dried at 60°C for 24 hours after which they were ashed at 500°C for four hours to obtain ash free dry mass (AFDM).

3.6 Determination of benthos Taxon similarity index, diversity and richness

Taxon diversity was determined using the Shannon-Wiener diversity index (H') (Shannon & Wiener, 1949, eqn. 1):

$$H' = -\sum_{i=1}^{n} Pi \ln Pi \quad \text{.....Eqn. 1}$$

where H'= information content of a sample (bits/individual) = index of taxon diversity, n is the number of taxa and the quantity p_i is the proportion of individuals of the i^{th} taxon. This index takes into account both the numbers of taxa and their relative abundance. Further, index of dominance (C) was determined according to Simpson (1949, eqn 2):

$$C = \sum \left(\frac{n_i}{N} \right)^2 \quad \text{.....Eqn. 2}$$

where ni/N is the proportion of each taxon to the total abundance.

Similarity in the taxon abundance on the sites with open canopy versus sites with closed canopy was quantified using the proportionality similarity index (PSI) (Schoener, 1968, eqn 3):

$$PSI_{xy} = 1 - 0.5\sum_{i=1}^{s} / P_{xi} - P_{yi} /) \quad \text{.....Eqn. 3}$$

where p_{xi} and p_{yi} are the proportionality abundance of taxa in samples x and y. Values range from 0 (no species in common) to 1 (identity and relative species abundance identical).

Taxon richness was calculated using Margalefs Index (D) (Clark & warwick, 1994, eqn 4)

$$D = \sum\left(\frac{S-1}{Log_{10}N}\right) \quad \text{.....Eqn. 4}$$

where S is the total number of taxa and N is the total number of individuals.

3.7 Data analysis

The data was analyzed using the Statistical Package for Social Sciences (SPSS® Version 11.5 for Windows, 2000). One way analysis of variance (ANOVA) was applied to test the differences in mean density, diversity and biomass of macroinvertebrates, and organic matter quantities among the sites. Before applying the parametric tests, the data was tested for homogeneity of variances using F-max test (Sokal & Rohlf, 1995). This test is meant to decide if the difference between two or more sample variances is so small that it may be ignored. The data that did not meet this assumption was transformed as $\log_{10}(x+1)$. Least Significant Difference test (LSD, $\alpha = 0.05$) was applied for multiple comparisons of means whenever analysis of variance resulted to significant F-values. Pearson correlation analyses were applied to determine the relationship between macroinvertebrate density, diversity and biomass, and canopy cover and benthic organic matter quantities. T- test was applied to test the differences between the mean density of coarse particulate organic matter on the left and right banks (pooled data) between the sites.

4.1 Introduction

There was a general increase in water temperature and conductivity with time and space in all sites. However, water level decreased with time in all sites. Sediments were poorly sorted in all sites and were characterized by fine sediments apart from Tree tops where fine sediments were mixed with fist sized cobbles. The highest organic matter content was recorded at Tree tops whilst the lowest was recorded at Mill house. Organic matter categories collected in the dry and wet zones included leaves, twigs, fruits and other un-identifiable detritus. Twigs fraction was not common in the dry zone as in the wet zone. More organic matter was collected from the left bank than from the right bank. When the data was pooled, the dry zones retained more organic matter than the wet zone. The highest canopy cover intensity was recorded at Njoro upstream whilst the lowest was recorded at Mill House. Macroinvertebrate density, diversity and biomass tended to increase with canopy cover.

4.2 Water quality status

4.2.1Water temperature

Water temperature in the Njoro River did not differ significantly among the sites (one way ANOVA, $F_{(3, 15)} = 0.93$, $p > 0.05$). The highest mean temperature was recorded at Mill House (21.99 ± 1.54 °C) while the lowest was recorded at Tree-tops (19.25 ± 1.19 °C). The mean temperature was 20.22 ± 0.63 °C pooled data.

4.2.2 Water chemistry

(a) Conductivity

Stream conductivity differed significantly among the sites (one way ANOVA, $F_{(3, 15)} = 8.33$, $p < 0.05$). Post hoc analysis indicated significant differences between Tree-tops and Njoro-upstream, Mill House and Mugo, and Mill House and Njoro-upstream (Least significant difference (LSD test, $\alpha = 0.05$). The highest mean conductivity was recorded at Mill House (282.96 ± 6.83 µs/cm) while the lowest was recorded at Njoro-upstream (145.04 ± 18.13 µs/cm). The pooled data mean conductivity was 198.74 ± 17.50 µs/cm.

(b) pH

The water pH did not differ significantly among the sites (one way ANOVA, $F_{(3, 15)} = 0.29$, $p > 0.05$). The lowest pH was recorded at Mugo (7.26 ± 0.25) while the highest was recorded at Tree-tops (7.60 ± 0.35).

4.3 Substratum characteristics

The proportion of the fine grains (grain size < 1 mm) determined for the sediments of the Njoro River sites ranged between 22 and 96 %. The sediments for all sites were generally poorly sorted with sorting coefficients (S_o) ranging between 2 and 3 (Table 2).

Table 2: Sediment size distribution and sorting coefficients in the Njoro River. % $\bar{x}$ ± SE, n = 3. Q_{25} = 25 % smaller, 75 % large; Q_{50} = 50 % smaller, 50 % larger (median); Q_{75} = 75 % smaller, 25% larger by size in mm, S_o = sorting coefficient.

Variable	Njoro-upstream	Tree-tops	Mugo	Mill House
% < 1 mm	92.94	21.67	96.21	96.00
± SE	*0.51*	*0.82*	*1.27*	*0.74*
Q_{25}	0.06	1.46	0.09	0.12
± SE	*0.02*	*0.01*	*0.03*	*0.05*
Q_{50}	0.32	8.00	0.22	0.39
± SE	*0.16*	*0.50*	*0.09*	*0.05*
Q_{75}	0.58	9.33	0.59	0.60
± SE	*0.10*	*0.33*	*0.20*	*0.26*
S_o	3.12	2.53	2.71	2.25
± SE	*0.21*	*0.05*	*0.32*	*0.06*

4.4 Discharge

The water discharge differed significantly among the sites (one way ANOVA, $F_{(3, 15)} = 4.82$, $p < 0.05$). Post hoc analysis indicated significant differences between Njoro-upstream and Mugo, and Mugo and Mill House (Least significant difference (LSD test, $\alpha = 0.05$). The highest mean discharge was recorded at Mugo (1.66 ± 0.48 $m^3 s^{-1}$) while the lowest was recorded at Mill House (0.75 ± 0.31 $m^3 s^{-1}$). The average mean discharge measured for the Njoro River was 0.95 ± 0.17 $m^3 s^{-1}$ pooled.

4.5 Canopy cover characteristics

Canopy cover intensities differed significantly among the sites (one way ANOVA, $F_{(3, 15)} = 11.78$, $p < 0.05$). The highest canopy cover intensity was recorded at Njoro-upstream (92 %) while the lowest was recorded at Mill House (0.70 %). Details of physical and chemical variables measured at the Njoro River are given in Table 3.

Table 3: Physical and chemical variables measured in the Njoro River study sites between January 2009 and April 2009. Values are means ± Standard Error, n = 12.

Stream variables	Njoro–upstream	Tree–tops	Mugo	Mill House
Temperature (°C)	19.96	19.25	19.66	21.99
± SE	*0.36*	*1.19*	*1.57*	*1.54*
Conductivity (µS/cm)	145.04	214.82	152.15	282.96
± SE	*18.13*	*39.93*	*4.13*	*6.83*
Dissolved oxygen (mg/l)	10.02	11.27	11.18	11.53
± SE	*0.29*	*0.16*	*0.17*	*0.12*
% Oxygen saturation	115.45	134.99	138.05	153.33
± SE	*13.16*	*7.19*	*5.85*	*1.82*
pH	7.30	7.60	7.26	7.74
± SE	*0.28*	*0.35*	*0.25*	*0.36*
Velocity (m/ s)	0.18	0.28	0.34	0.16
± SE	*0.04*	*0.22*	*0.12*	*0.07*
Discharge (m^3/ s)	0.94	1.06	1.66	0.75
± SE	*0.09*	*0.31*	*0.24*	*0.86*
Canopy cover (%)	92.00	64.00	50.00	0.70
± SE	*0.00*	*0.00*	*0.00*	*0.00*

4.6 Coarse Particulate Organic Matter (CPOM).

4.6.1. Coarse particulate organic matter collected from the wet and dry zones of the Njoro River

a) Coarse particulate organic matter collected from the dry zones of the Njoro River

The amount of coarse particulate organic matter (CPOM) collected from the banks of the Njoro River ranged between 9.11 and 70.21 AFDM g. m^{-2} (Fig. 5). The difference in the amounts of

AFDM obtained from CPOM collected among the four sites in the Njoro River, i.e. Njoro - upstream (Heavily shaded) , Tree-tops (Less shaded), Mugo (moderately shaded) and Mill House (least shaded) was significant (One way ANOVA, $F_{(3, 15)} = 15.94$, $p < 0.05$). Post hoc analysis indicated significant differences between Njoro-upstream and Tree-tops, Tree-tops and Mugo, Tree-tops and Mill House, and Mugo and Mill House (Least significant difference test (LSD test, $\alpha = 0.05$). The order of the amount of CPOM collected from the banks was Tree-tops (Medium shaded) > Mugo (Moderately shaded) > Njoro-Upstream (Heavily shaded) > Mill House (least shaded).

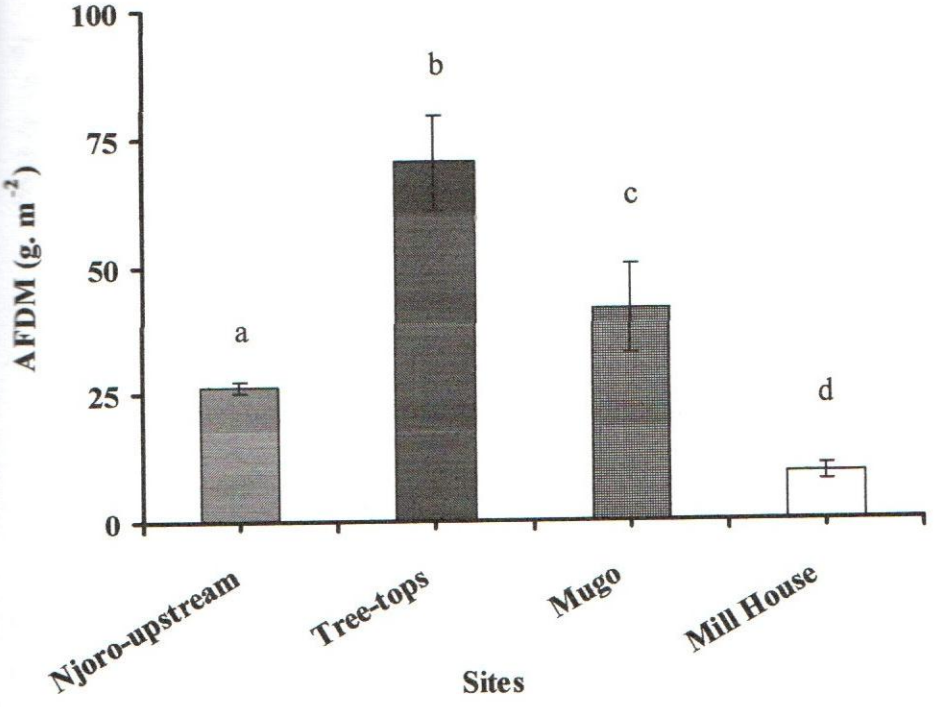


Figure 5: Quantities of coarse particulate organic matter collected from the banks of the study sites in the Njoro River. Vertical lines are ± SE, n = 40.Means followed by the same letter are not significantly different from each other.

When the left and right banks were considered, the amount of CPOM collected from the left bank of the Njoro River was significantly higher than the amount collected from the right bank ($t = 2.84$, $d.f = 15$, $p < 0.05$). The right bank had 30.16 ± 5.39 AFDM g. m^{-2} whilst the left bank had 42.80 ± 7.80 AFDM g. m^{-2}. When the amounts per site of AFDM determined from the CPOM collected from the banks were considered (Fig. 6), the right bank was found to hold

significantly higher amounts of CPOM than the left bank at Mill House, the least shaded site ($t = 4.24$, $d.f = 3$, $p < 0.05$). There was no significant difference in the amounts of AFDM collected from both banks at Njoro-upstream, the heavily shaded site ($t = 2.62$, $d.f. = 3$, $p > 0.05$).

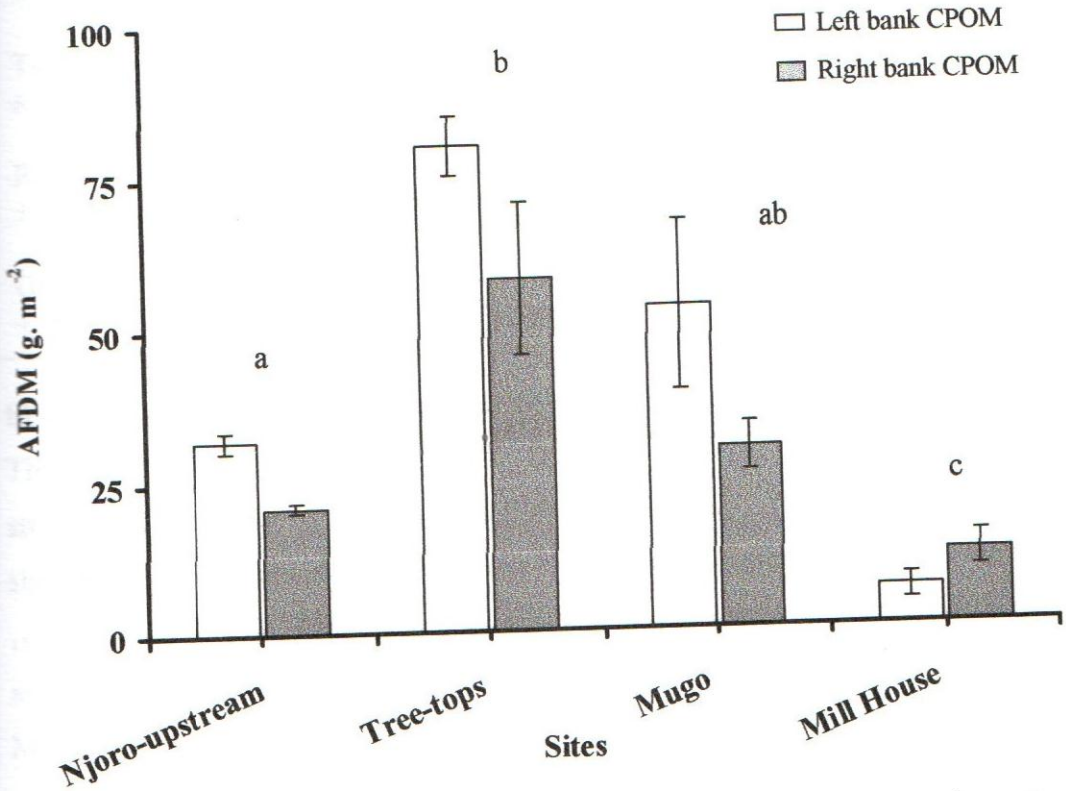


Figure 6: Distribution of ash free dry mass of the coarse particulate organic matter collected from the left and right banks at the sites in Njoro River. Vertical lines are ± SE, n = 40. Means followed by the same letter are not significantly different from each other.

The dry zones of the Njoro River held CPOM categories such as leaves, fruits, twigs and other unidentifiable detritus. Twigs fraction was not common in the dry zone as in the wet zone. Leaves and twigs dominated in all the sites in the Njoro River (Table 4).

Table 4: Various categories of CPOM ash free dry mass collected in the dry zone of the Njoro River sites. Bolded values are means ± Standard Error, n = 40. Values in grams per m^2. Probability level: * $P < 0.05$, ^{ns} not significant.

CPOM	Njoro–upstream	Tree tops	Mugo	Mill House	*F*- value
Leaves	40.14	111.29	61.48	14.76	55.87*
± SE	*4.52*	*9.07*	*8.14*	*2.06*	
Twigs	25.94	68.81	60.72	13.35	69.25*
± SE	*4.45*	*9.52*	*8.28*	*2.91*	
Fruits	18.75	66.42	18.31	1.30	45.07*
± SE	*2.88*	*8.33*	*2.69*	*0.43*	
Others	20.16	34.30	25.41	7.05	38.08^{ns}
± SE	*4.13*	*7.75*	*2.72*	*1.18*	

b) Coarse particulate organic matter collected from the wet zones of the Njoro River

The amount of ash free dry mass (AFDM) in the coarse particulate organic matter (CPOM) in the stream bed of the Njoro River ranged between 0.19 and 1.19 AFDM g. m^{-2} (Fig. 7). There were significant differences in the CPOM ash free dry mass among the sites (One way ANOVA, $F_{(3, 15)} = 18.48$, $p < 0.05$). Post hoc analysis indicated significant differences between Njoro-upstream and Mugo, Njoro-upstream and Mill House, Tree-tops and Mugo, Tree-tops and Mill House, and Mill House and Mugo (Least significant difference (LSD test, $\alpha = 0.05$).

The various plant materials collected at the bed sediments of the Njoro River included leaves, fruits, twigs and other unidentifiable detritus (Table 5). In all sites, twigs dominated other plant particulate organic matter categories in the Njoro River except at Mill House site where leaves dominated. "Others" category of CPOM also contributed a substantial amount of coarse particulate organic matter (CPOM) in the Mugo site.

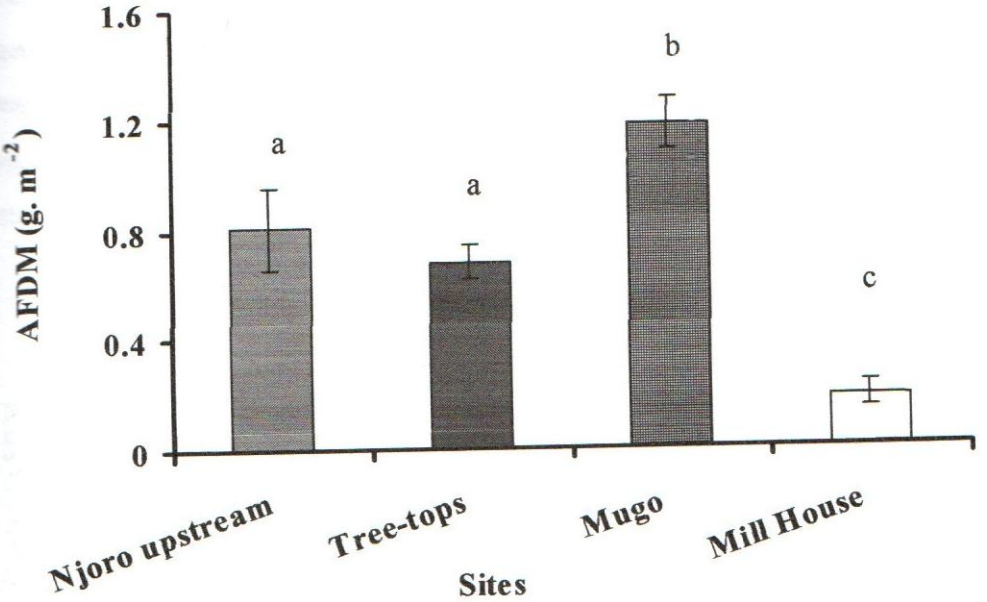


Figure 7: Organic matter retained on the stream bed of the Njoro River sites. Vertical lines: ± SE, n = 40. Means followed by the same letter are not significantly different from each other.

Table 5: Various categories of CPOM ash free dry mass (AFDM) collected in the wet zone of the Njoro River sites. Bolded values are means ± Standard Error, n = 40. Values are in grams per m^2. Probability level: * $P < 0.05$.

CPOM	Njoro–upstream	Tree tops	Mugo	Mill House	*F*-value
Leaves	0.82	0.80	1.29	0.49	43.98*
± SE	*0.11*	*0.06*	*0.14*	*0.08*	
Twigs	1.22	0.89	1.60	0.28	76.12*
± SE	*0.22*	*0.11*	*0.22*	*0.04*	
Fruits	0.46	0.38	0.79	0.22	19.09*
± SE	*0.11*	*0.06*	*0.09*	*0.03*	
Others	0.73	0.66	1.05	0.32	87.69*
± SE	*0.13*	*0.11*	*0.18*	*0.05*	

4.6.2 Canopy cover in relation to coarse particulate organic matter in the dry and wet zones in the Njoro River

Pearson correlation analysis indicated significant positive correlation between canopy cover and organic matter collected from the wet zones. Similarly, a significant positive correlation was established between canopy cover and organic matter collected from the dry zones (Fig. 8a, b).

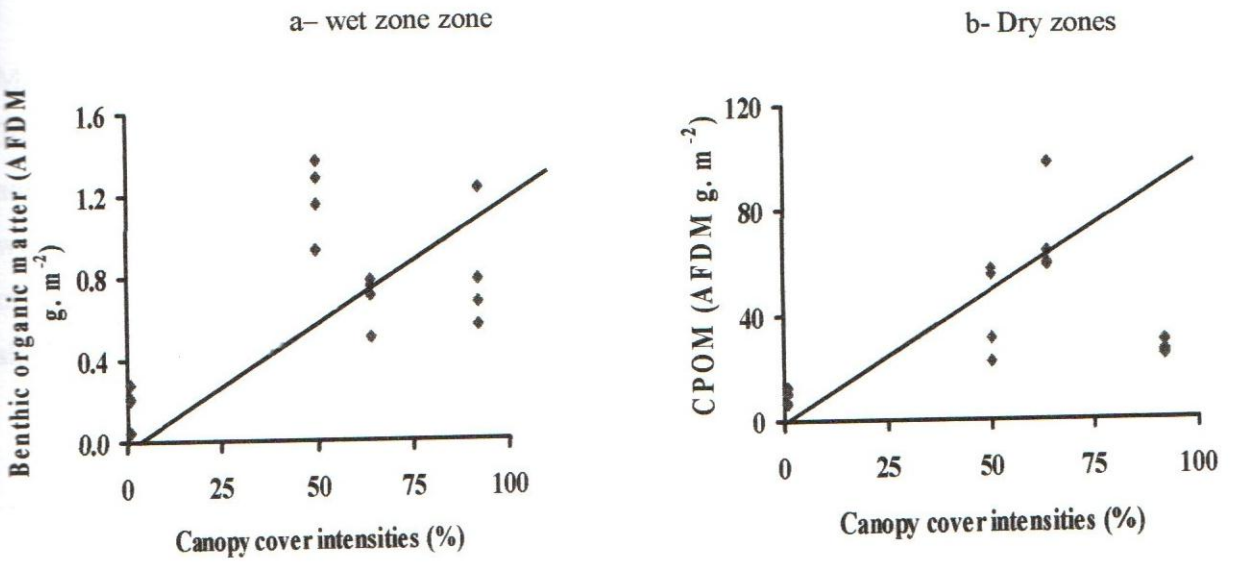


Figure 8: Canopy cover intensities in relation to (a) benthic organic matter and (b) CPOM collected from the dry zones in the Njoro River. Relationship equations: (a) Benthic organic matter = 0.37 + 0.07 [canopy cover intensities], $R^2 = 0.62$, $p < 0.05$, $n = 160$; (b) CPOM = 20.38 + 0.32 [canopy cover intensities], $R^2 = 0.79$, $n = 160$.

4.7 The structure and composition of benthic macroinvertebrates

A total of 13 groups were collected from the Njoro River (Fig. 9). Ephemeroptera, oligochaetes, chironomids, and bivalves were the dominant groups, contributing more than 85 % of the total macroinvertebrates in the Njoro River. Oligochaeta dominated the community with over 42 % of all the macroinvertebrates collected. Bivalvia, ephemeroptera and chironomidae contributed 20, 10 and 14 %, respectively. Other groups constituted 14 %. Post hoc analysis indicated significant differences between Mugo and Mill House (Least significant difference test (LSD test, $\alpha = 0.05$). There were significantly more Oligochaetes in the Mugo site than in the other sites (One way

The densities of the four dominant macroinvertebrate groups in the sites of the Njoro River are presented in Figure 10. Oligochaetes dominated all other groups of macroinvertebrates at Mugo, the moderately shaded site. Bivalves were second in dominance followed by chironomids. Oligochaetes and bivalves also contributed a significant proportion of the macroinvertebrates collected from the other sites in the Njoro River.

Macroinvertebrate densities collected in the sediments of the Njoro River sites ranged between 36.71 and 786.25 ind. m^{-2} (Fig. 11). The differences in the densities of macroinvertebrates among the sites were insignificant (One way ANOVA, $F_{(3, 15)} = 4.27$, $p > 0.05$). More organisms were collected from Mugo than from the other sites in the Njoro River. The order of magnitude of macroinvertebrate densities was Mugo (moderately shaded) > Njoro-upstream (heavily shaded) > Tree-tops (medium shaded) > Mill House (least shaded).

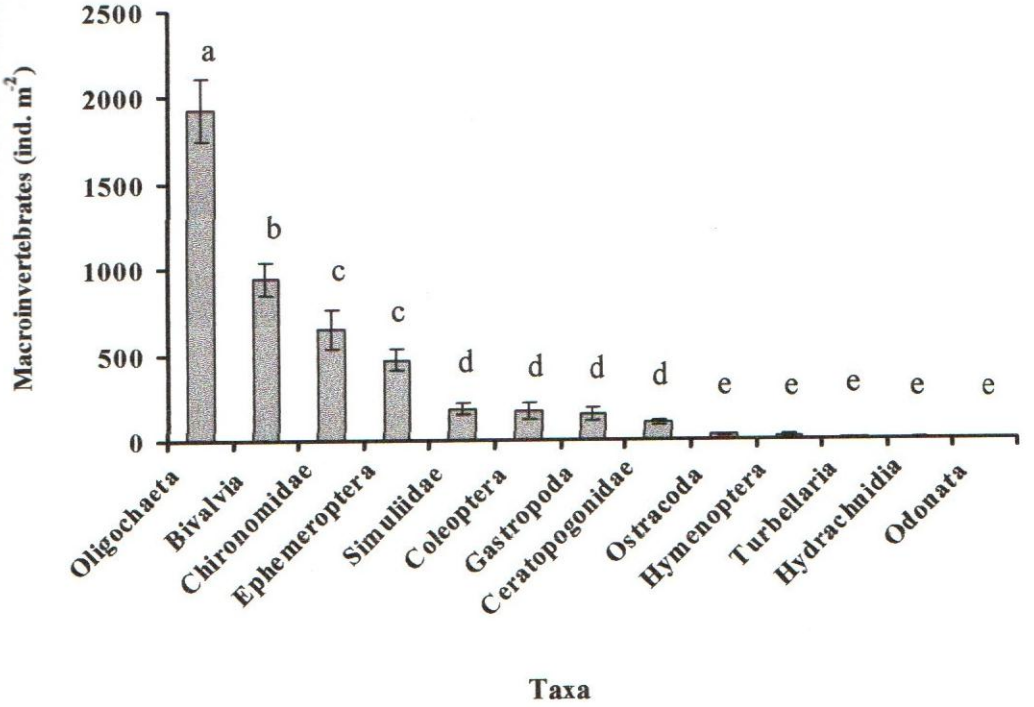


Figure 9: Taxonomic groups of macroinvertebrates collected in the Njoro River sites. Vertical lines are ± SE, n = 160. Means followed by the same letter are not significantly different from each other.

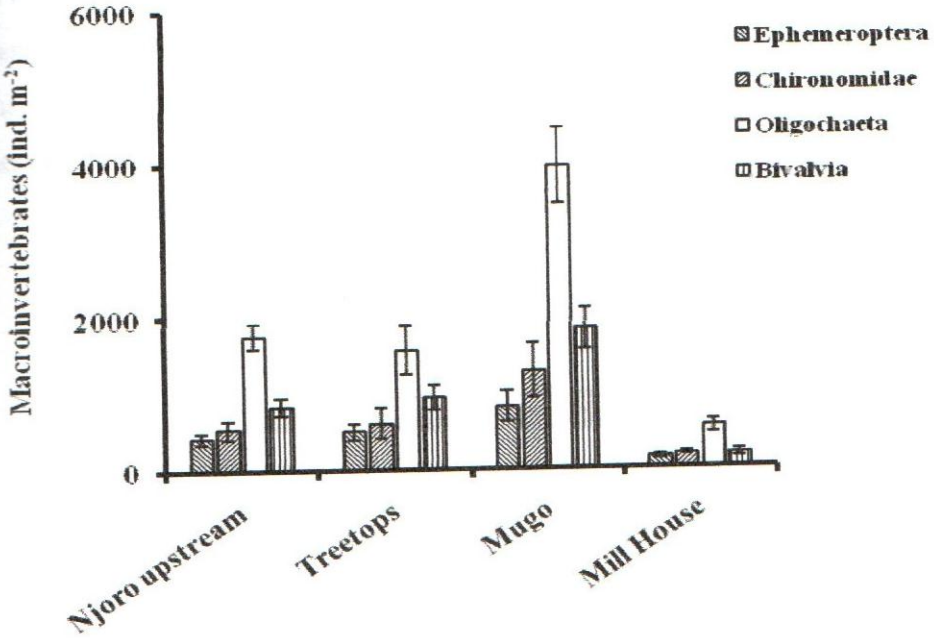


Figure 10: Densities of the major taxonomic groups in the Njoro River sites: Vertical lines are ± SE, n = 40.

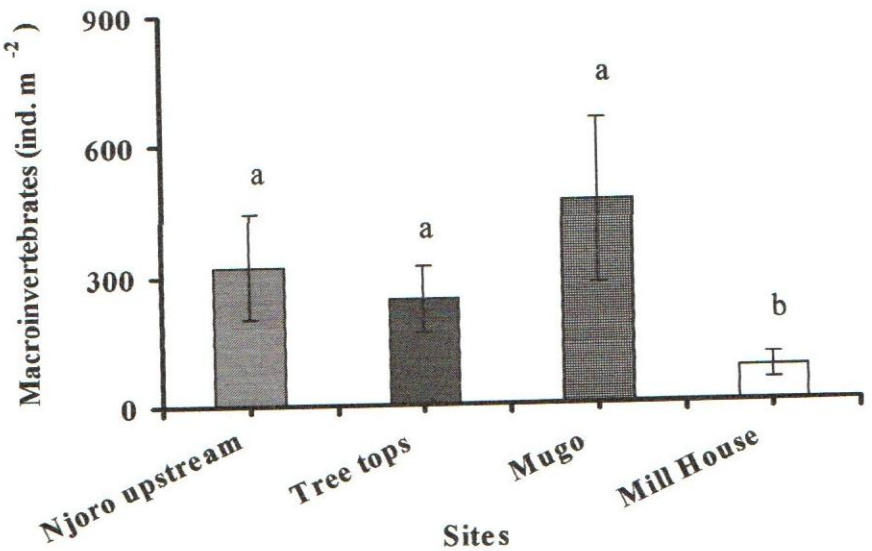


Figure 11: Densities of macroinvertebrates in the Njoro River sites. Vertical lines are ± SE, n = 40. Means followed by the same letter are not significantly different from each other.

4.8 Canopy cover and benthic organic matter in relation to macroinvertebrate densities.

There was insignificant positive correlation between canopy cover and macroinvertebrate densities. However, there was significant positive correlation between benthic organic matter and macroinvertebrate densities (Fig 12a, b).

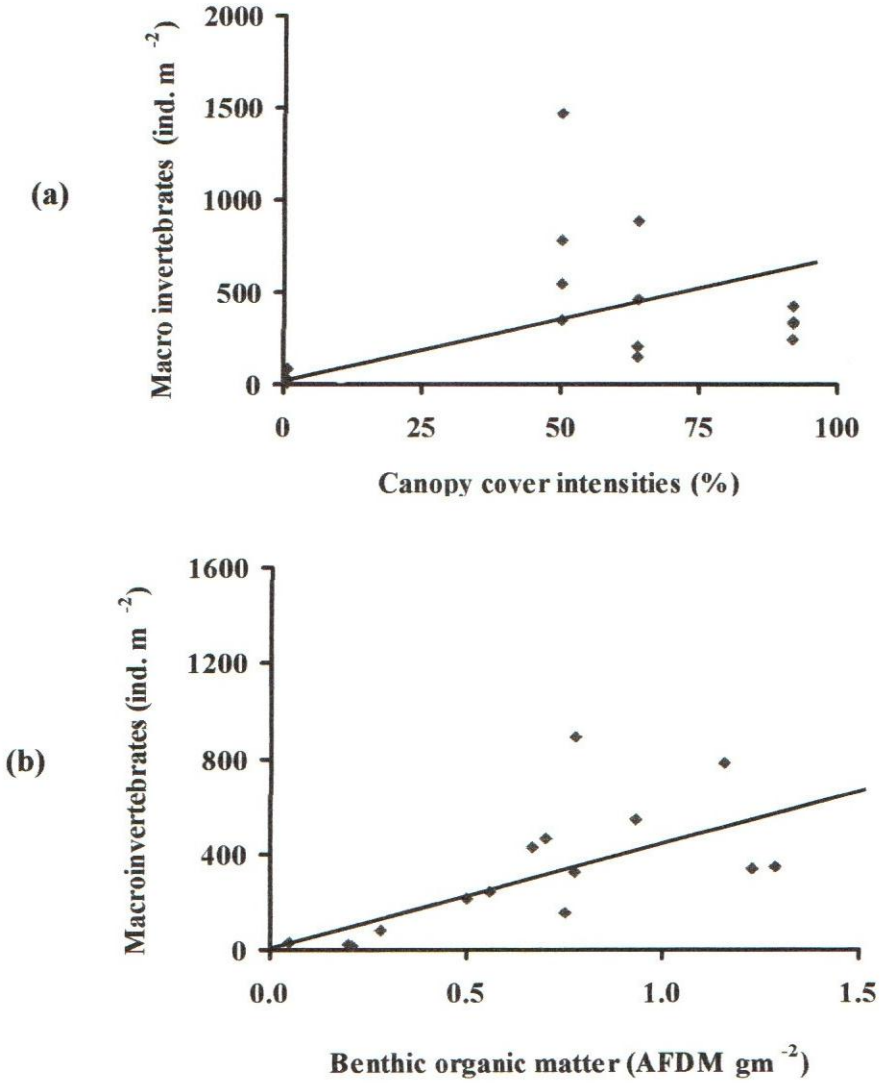


Figure 12: Relationship between (a) Canopy cover and (b) benthic organic matter with macroinvertebrates density in the Njoro River. Relationship equations: (a) Macroinvertebrates = 212.61 + 3.57 [canopy cover intensities], $R^2 = 0.26$, $p > 0.05$, $n = 160$; (b) Macroinvertebrates = - 90.03 + 680.81 [Benthic organic matter], $R^2 = 0.85$, $p < 0.05$, $n = 160$.

4.9 Major taxon densities in relation to benthic organic matter and canopy cover

Figure 13 shows the relationships between the four dominant macroinvertebrate groups and benthic organic matter collected from the bed sediments in the Njoro River. There were significant positive correlations between benthic organic matter and Oligochaeta, Bivalvia, Ephemeroptera and Chironomidae densities.

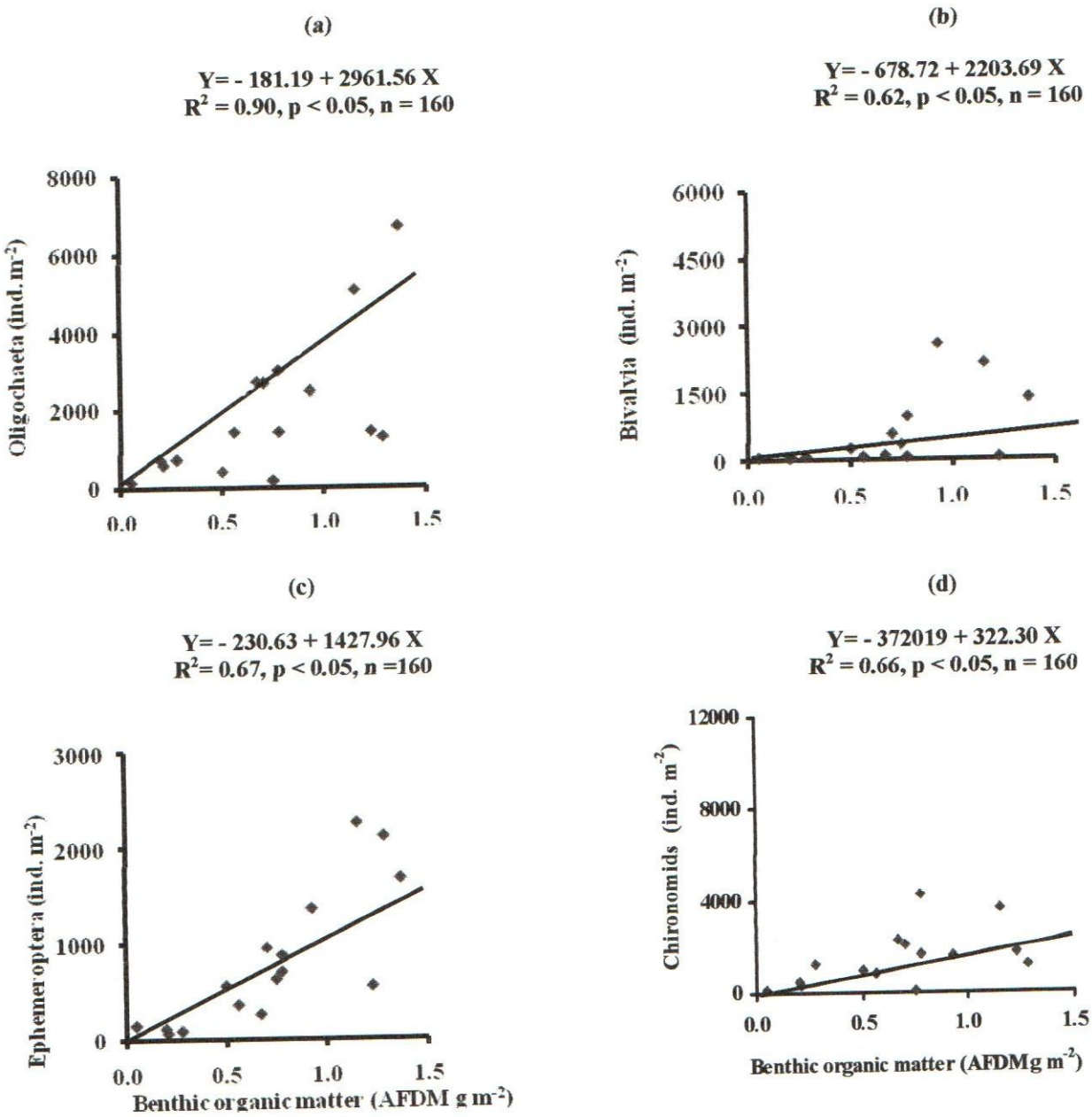


Figure 13: Oligochaeta (a), Bivalvia (b), Ephemeroptera (c) and Chironomidae (d) densities in relation to benthic organic matter in the bed sediments of the Njoro River.

The site with moderate canopy had unexpectedly the highest densities for the taxonomic groups whilst the least shaded site had the lowest densities for the taxonomic groups. Pearson correlation analysis indicated insignificant positive correlation between canopy cover and Oligochaeta, Bivalvia, Ephemeroptera, and Chironomidae densities (Fig. 14). Organic matter had more influence on the macroinvertebrate taxonomic groups than canopy cover.

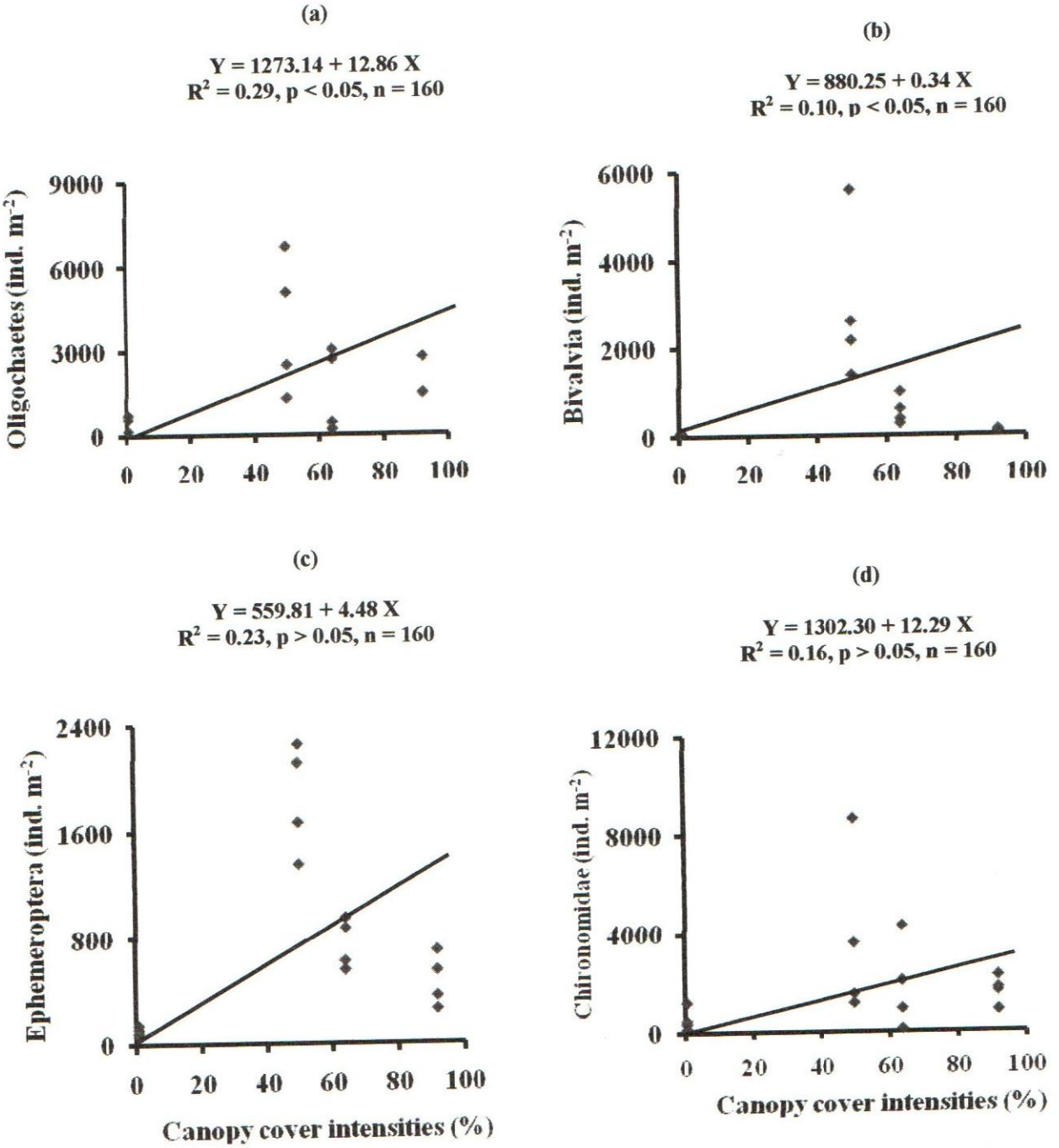


Figure 14: Oligochaeta (a), Bivalvia (b), Ephemeroptera (c) and Chironomidae (d) densities in relation to canopy cover in the Njoro River.

4.10 Taxon similarity index, diversity and Taxon richness

Tree-tops had the highest taxon richness in comparison to the other sites in the Njoro River (Table 6). Maximum diversity occurred at Mugo, the moderately shaded site, in the Njoro River. At Mugo, macroinvertebrates were dominated by one taxon mainly the oligochaetes as indicated by the high index of dominance (C) values. Taxon similarity index ranged between 0.29 – 0.87 at the sites in the Njoro River (Table 7). Macroinvertebrates were more similar between Tree-tops Njoro-upstream and Mill House sites than they were to Mugo and Mill House.

Table 6: Taxon characteristics determined at the sites in the Njoro River. Bold numbers are means ± Standard Error, n = 40.

	Njoro upstream	Tree tops	Mugo	Mill House
Taxon richness (D)	2.80	3.24	2.99	2.32
± SE	*0.17*	*0.13*	*0.15*	*0.11*
Taxon diversity (H')	1.44	1.64	1.59	1.21
± SE	*0.05*	*0.07*	*0.02*	*0.11*
Maximum diversity (H'_{max})	1.84	1.99	2.22	1.68
± SE	*0.03*	*0.06*	*0.22*	*0.09*
Index of dominance (C)	0.25	0.37	1.18	0.11
± SE	*0.01*	*0.02*	*0.06*	*0.01*

Table 7: Proportionality similarity indices (PSI) of macroinvertebrates in the Njoro River sites.

Mugo	Tree tops	Mill House	Njoro upstream
Mugo	0.52	0.29	0.45
Tree– tops		0.72	0.87
Mill House			0.84

4.11 Macroinvertebrate diversity and biomass in relation to canopy cover

In the Njoro River, the highest mean macroinvertebrate diversity (H') was recorded at Tree-tops (1.64 ± 0.07) while the lowest was recorded at Mill House (1.21 ± 0.11) (Fig. 15). Macroinvertebrate diversity differed significantly among the sites in the Njoro River (One way ANOVA, $F_{(3, 15)} = 7.37$, $p < 0.05$). Diversity tended to increase with increased canopy cover. Post hoc analysis indicated significant differences between Mill House and Njoro-upstream, Mill House and Tree-tops, and Mugo and Mill House (Least significant difference test (LSD test, $\alpha = 0.05$). Pearson correlation analysis indicated significant positive correlation ($R^2 = 0.77$, $p < 0.05$, $n = 160$) between canopy cover and macroinvertebrate diversity.

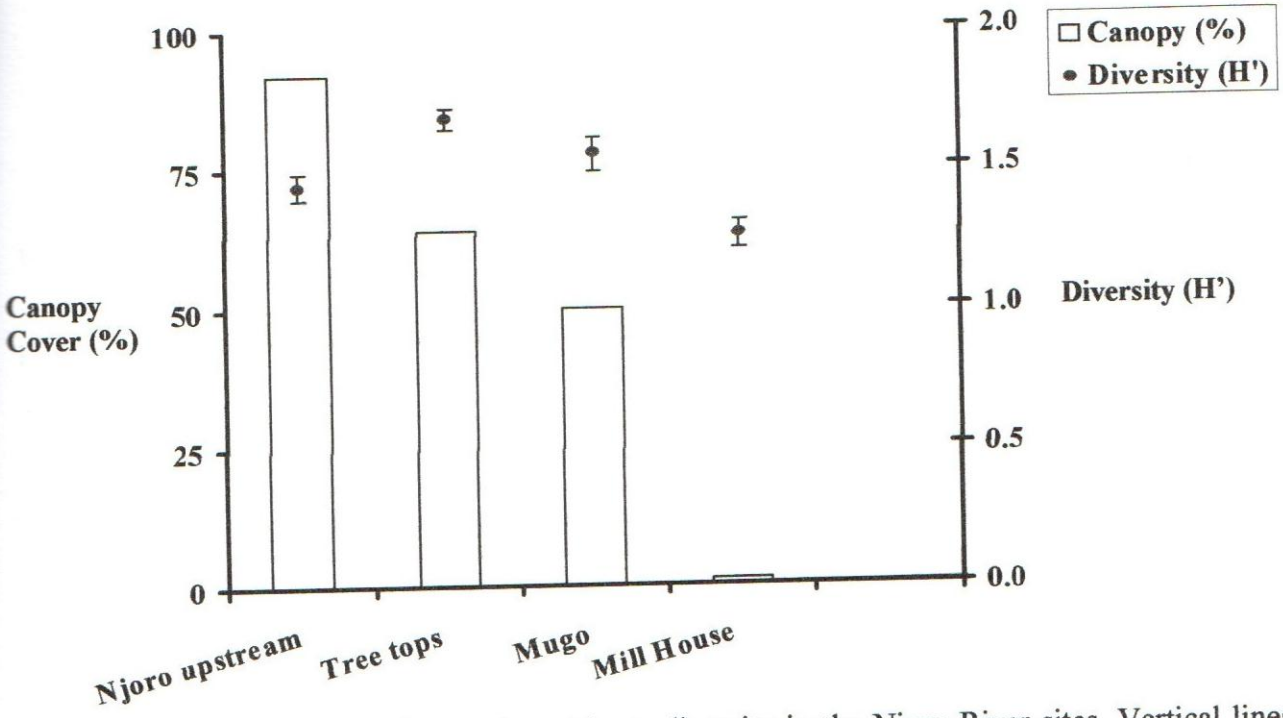


Figure 15: Canopy cover and macroinvertebrate diversity in the Njoro River sites. Vertical lines are ± SE, n = 40.

In the Njoro River, the mean macroinvertebrate biomass ranged between 0.06 ± 0.01 and 0.50 ± 0.15 AFDM g. m^{-2} (Fig. 16). Macroinvertebrate biomass differed significantly among the sites in the Njoro River (One way ANOVA, $F_{(3, 15)} = 5.63$, $p < 0.05$). Post hoc analysis indicated significant differences between Njoro-upstream and Mugo, Tree-tops and Mugo, and Mugo and Mill House (Least significant different test (LSD test, $\alpha = 0.05$). Pearson correlation analysis indicated insignificant positive correlation ($R^2 = 0.40$, $p > 0.05$, $n = 160$) between canopy cover

and macroinvertebrate biomass. The relationship equation was Macroinvertebrate diversity (H') = 1.31 + 0.03 (Canopy cover intensities).

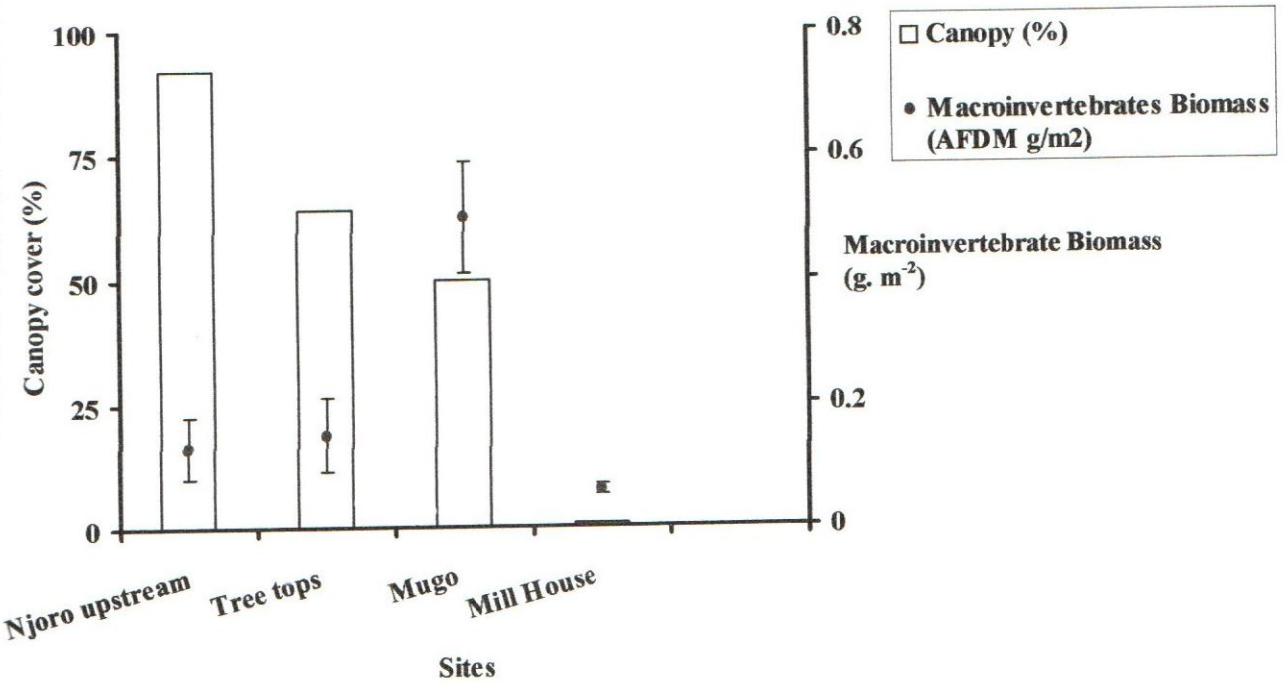


Figure 16: Canopy cover and macroinvertebrate biomass in the Njoro River sites. Vertical lines are ± SE, n = 40.

The biomass of the four dominant macroinvertebrate groups in the sites of the Njoro River is presented in Figure 17. Oligochaetes had the highest biomass at Mugo followed by bivalves, Ephemeroptera, and chironomids. Bivalves and oligochaetes also contributed significantly to the biomass of the macroinvertebrates collected from the other sites in the Njoro River.

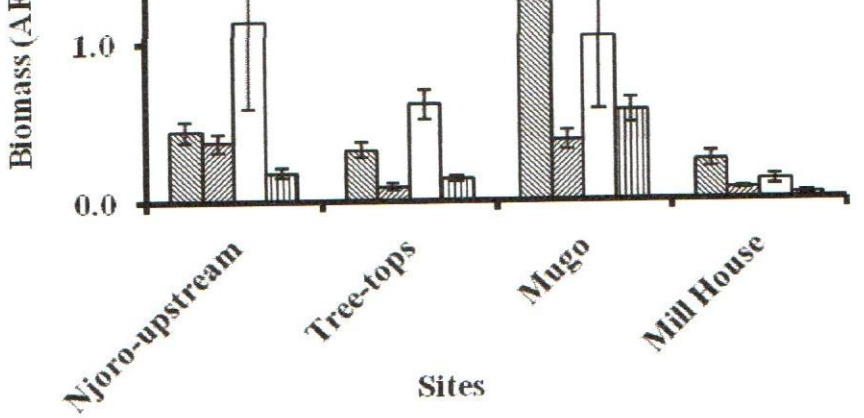


Figure 17: Biomass of the major taxonomic groups in the sites in the Njoro River. Vertical lines are ± SE, n = 40.

4.12 Macroinvertebrate diversity and biomass in relation to coarse particulate organic matter

Figure 18 depicts the amount of CPOM collected from the bed sediments in relation to macroinvertebrate diversity and biomass respectively. There was significant positive relationship between benthic organic matter and macroinvertebrate diversity ($R^2 = 0.81$, $p < 0.05$, n =160). Similarly, there was also significant positive correlation between benthic organic matter and macroinvertebrate biomass ($R^2 = 0.71$, $p < 0.05$, n =160).

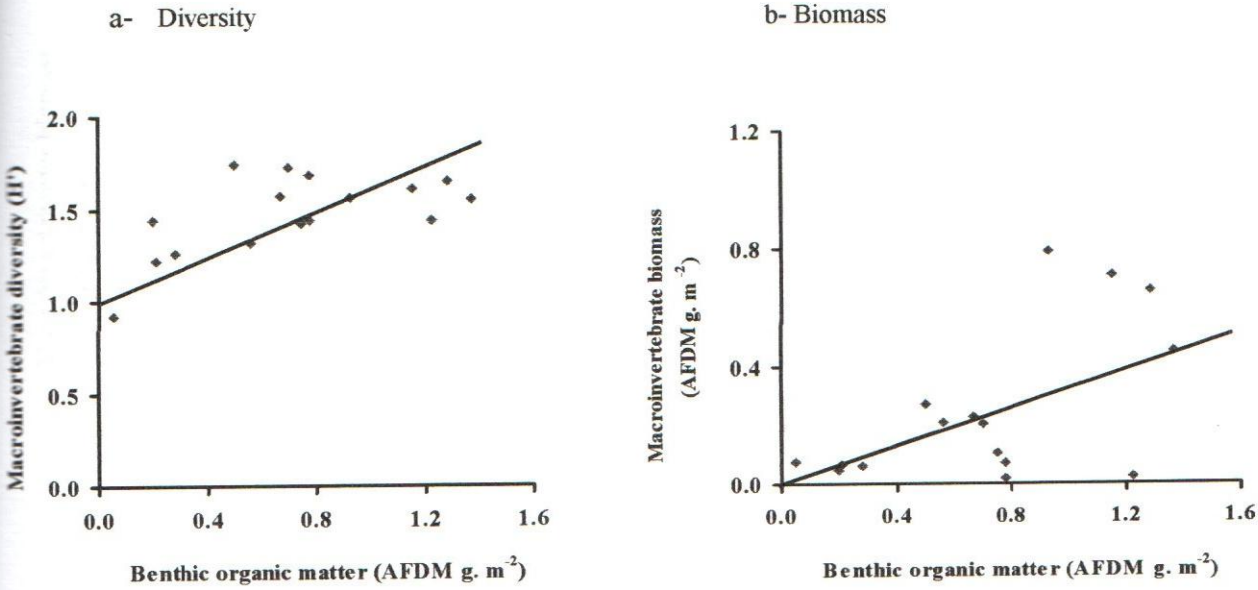


Figure 18: Macroinvertebrate (a) diversity and (b) biomass in relation to coarse particulate organic matter content in the Njoro River. Relationship equations: (a) Macroinvertebrate diversity = 1.25 + 0.32[Benthic organic matter], $R^2 = 0.81$, $p < 0.05$, n =160; (b) Macroinvertebrate biomass = - 0.19 + 0.38 [Benthic organic matter], $R^2 = 0.71$, $p < 0.05$, n = 160.

a) Macroinvertebrate biomass and diversity in relation to various CPOM categories in the Njoro River

There existed no significant relationship between macroinvertebrate biomass and twigs and fruits. However, there was significant positive correlation between macroinvertebrate biomass, un-identifiable detritus and leaves (Fig. 19).

Further, there were significant positive correlations between macroinvertebrate diversity, leaves and un-identifiable detritus. However, there existed no significant relationship between macroinvertebrate diversity, twigs and fruits (Fig. 20).

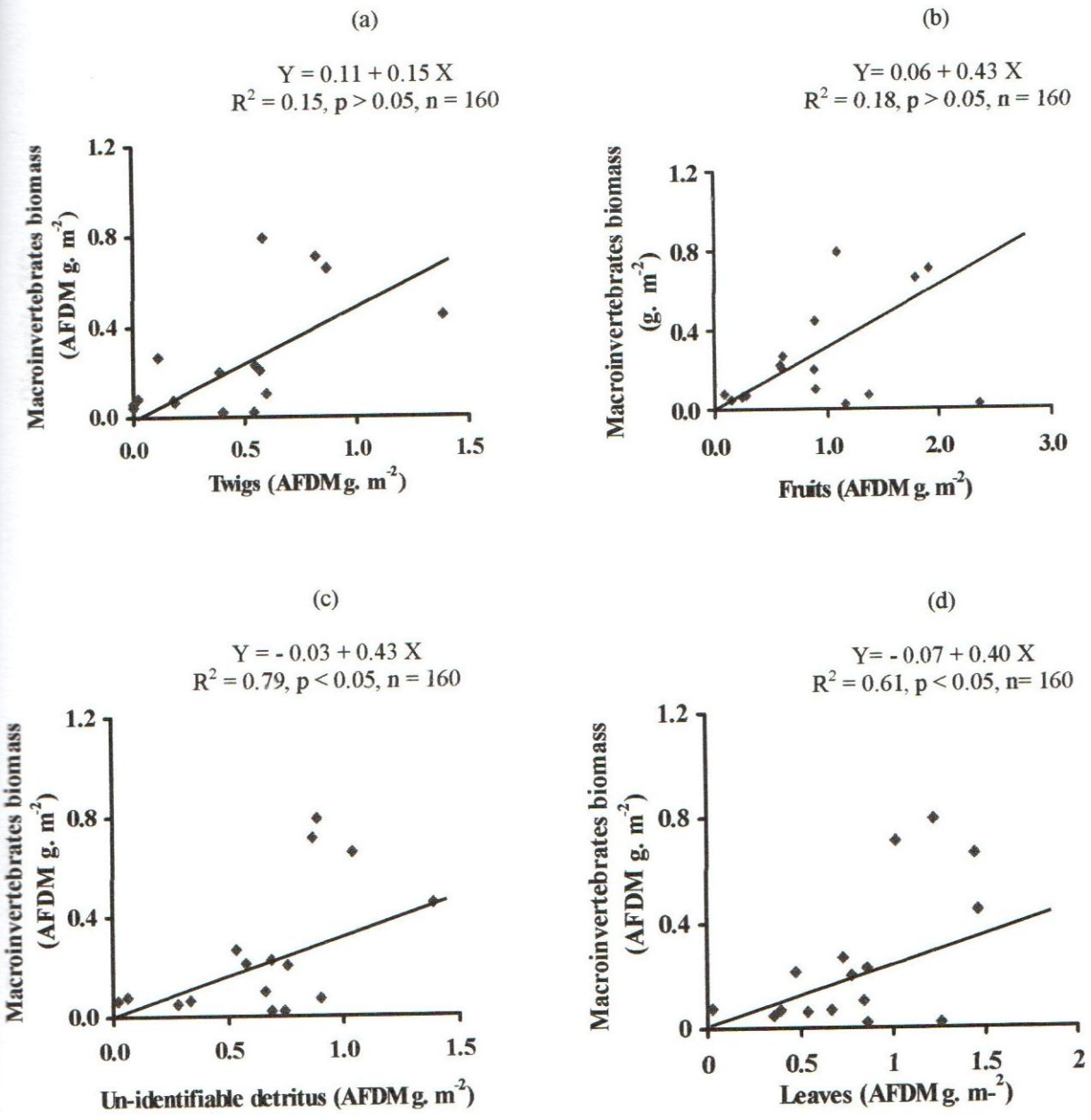


Figure 19: Macroinvertebrate biomass in relation to (a) twigs, (b) fruits, (c) un-identifiable detritus and (d) leaves in the Njoro River.

Equations:

a) Macroinvertebrates biomass = 0.11 + 0.15 [Twigs], R^2 = 0.15, p > 0.05, n = 160.

b) Macroinvertebrates biomass = 0.06 + 0.43 [Fruits], R^2 = 0.18, p > 0.05, n = 160.

c) Macroinvertebrates biomass = 0.03 + 0.43 [un-identifiable detritus], R^2 = 0.79, p < 0.05, n = 160.

d) Macroinvertebrates biomass = -0.07 + 0.40 [Leaves], R^2 = 0.61, p < 0.05, n = 160.

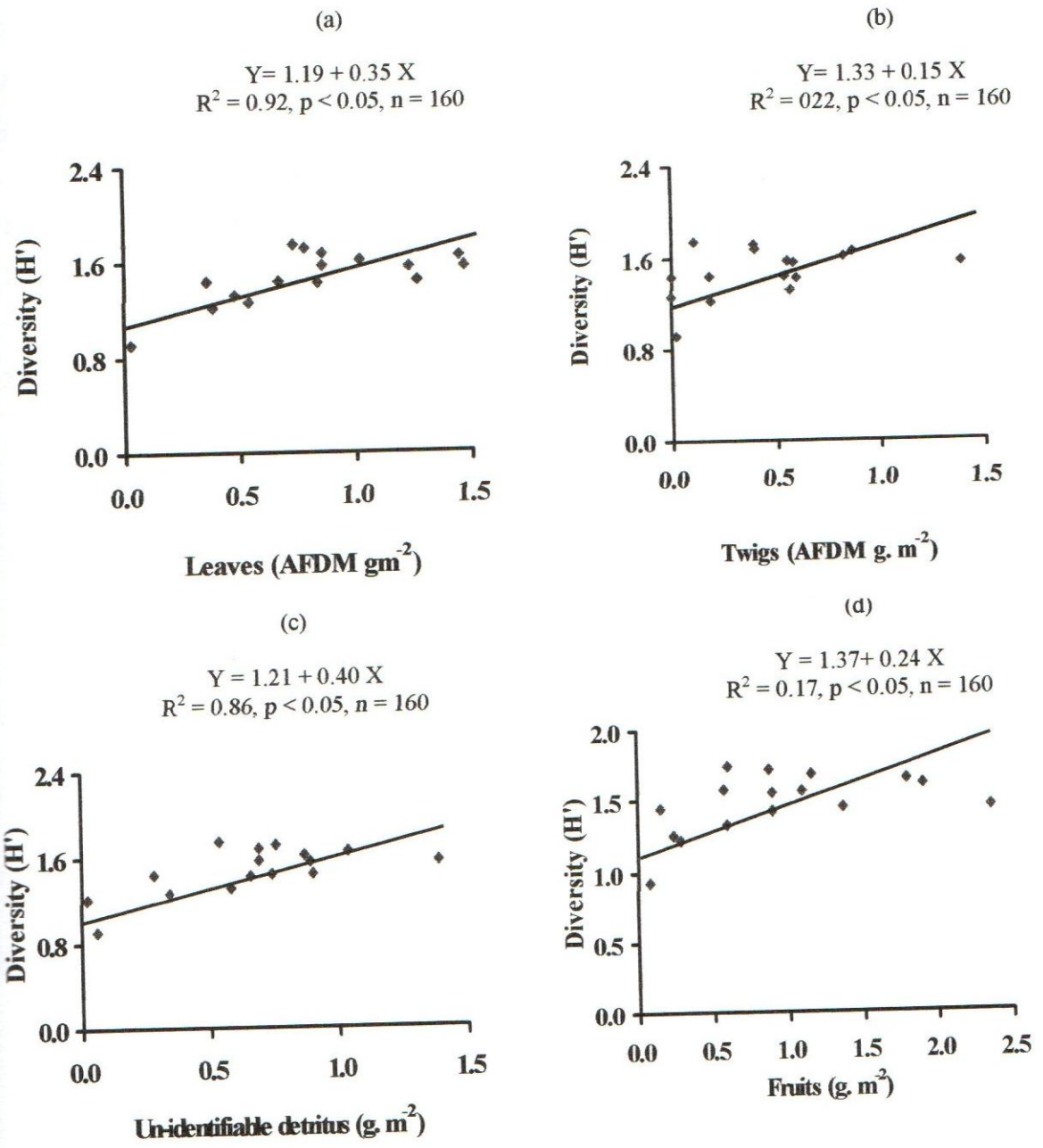


Figure 20: Macroinvertebrate diversity in relation to twigs (a), fruits (b), un-identifiable detritus (c) and leaves (d) in the Njoro River.

Equations:

a) Diversity (H') = 1.19 + 0.35 [Leaves], $R^2 = 0.92$, $p < 0.05$, $n = 160$.

b) Diversity (H') = 1.33 + 0.15 [Twigs], $R^2 = 0.22$, $p > 0.05$, $n = 160$.

c) Diversity (H') = 1.21 + 0.40 [un-identifiable detritus], $R^2 = 0.86$, $p < 0.05$, $n = 160$.

d) Diversity (H') = 1.37 + 0.24 [Twigs], $R^2 = 0.17$, $p > 0.05$, $n = 160$.

4.13 Macroinvertebrate functional feeding guilds densities in relation to benthic organic matter quantities and canopy cover intensities in the Njoro River

(a) Macroinvertebrate functional feeding guilds densities

A total of four functional feeding groups of macroinvertebrates were identified in the Njoro River. They included scrapers, filtering-collectors, gathering-collectors, and predators (Figure 21). The gathering -collectors were the most abundant followed by predators, filtering-collectors and scrapers (grazers). The gathering-collectors also dominated the other feeding guilds in all sites (Figure 22).

The highest mean scraper density was recorded at Tree-tops (1090.51 ± 772.57 ind. m^{-2}) while the lowest was recorded at Njoro-upstream (119.83 ± 68.71 ind. m^{-2}). The overall mean scraper density was 463.50 ± 212.92 ind. m^{-2}. There was no significant difference in the scraper density among the sites (One way ANOVA, $F_{(3, 15)} = 1.26$, $p > 0.05$). Further, the highest gathering-collectors mean density was recorded at Mugo (6491.36 ± 2391.53 ind. m^{-2}) while the lowest was recorded at Mill House (1031.03 ± 235.87 ind. m^{-2}). The mean density of gathering-collectors was 3412.28 ± 800.79 ind. m^{-2}. Post hoc analysis indicated significant differences between Mugo and Mill House (Least significant difference test (LSD test, $\alpha = 0.05$). There was significant difference in the gatherers abundance among the sites (One way ANOVA, $F_{(3, 15)} = 2.67$ $p < 0.05$).

The highest filtering-collectors mean density was recorded at Mugo (1999.79 ± 743.08 ind. m^{-2}) while the lowest was recorded at Mill House (218.96 ± 96.52 ind. m^{-2}). When the data was pooled, the mean filtering-collectors density was 1135.51 ± 247.18 ind. m^{-2}. There was significant difference in the filterers density among the sites (One way ANOVA, $F_{(3, 15)} = 3.08$, $p < 0.0$). Post hoc analysis indicated significant differences between Mugo and Mill House (LSD test, = 0.05). Similarly, the highest predators mean density was recorded at Mugo (2936.04 ± 13494 ind. m^{-2}) while the lowest was recorded at Mill House (409.23 ± 193.92 ind. m^{-2}). The mean density of predators from pooled data was 1530.29 ± 427.27 ind. m^{-2}. There was no significant difference in the predators density among the sites (One way ANOVA, $F_{(3, 15)} = 1.75$, $p > 05$).

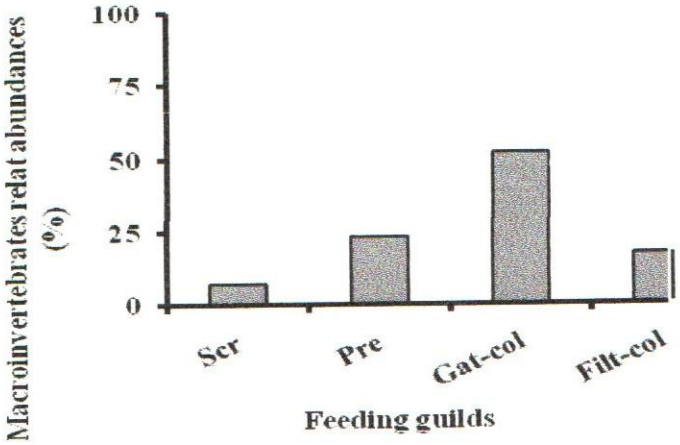


Figure 21: The relative abundances for the functional feeding guilds in the Njoro River: Scrapers (Scr); Predators (Pre); Gathering collectors (Gat-col); and filtering collectors (Filt-col).

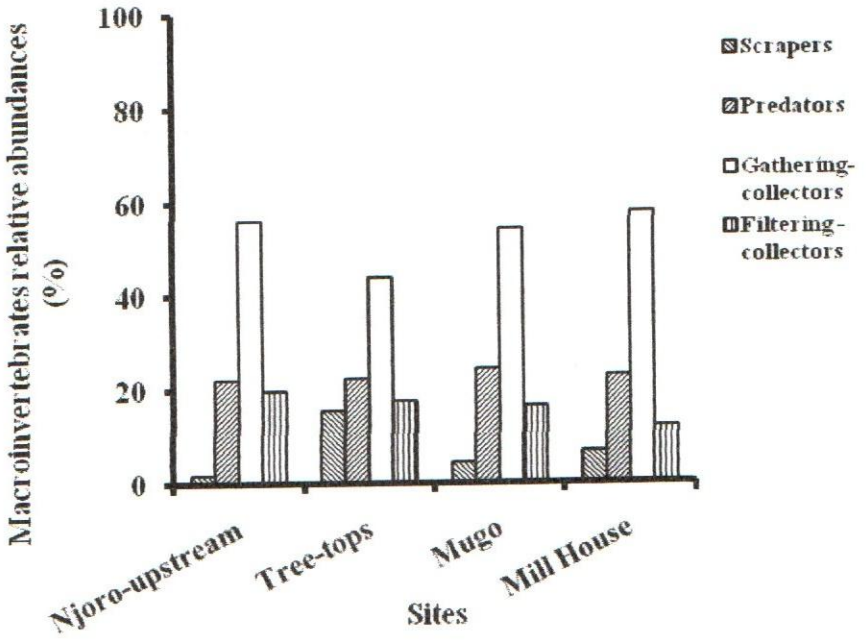


Figure 22: The relative abundances of the functional feeding guilds in the Njoro River sites.

(b) Macroinvertebrate functional feeding group densities in relation to benthic orga matter and canopy cover in the Njoro River

There was significant positive relationship between benthic organic matter and gatheri collector, filtering-collector and predator densities. However, there was insignificant posit relationship between benthic organic matter and scrapers densities (Fig. 23 and 24). Similar there were insignificant positive correlations between canopy cover and scraper, filterin collector, gathering-collector and predator densities (Fig 25 and 26).

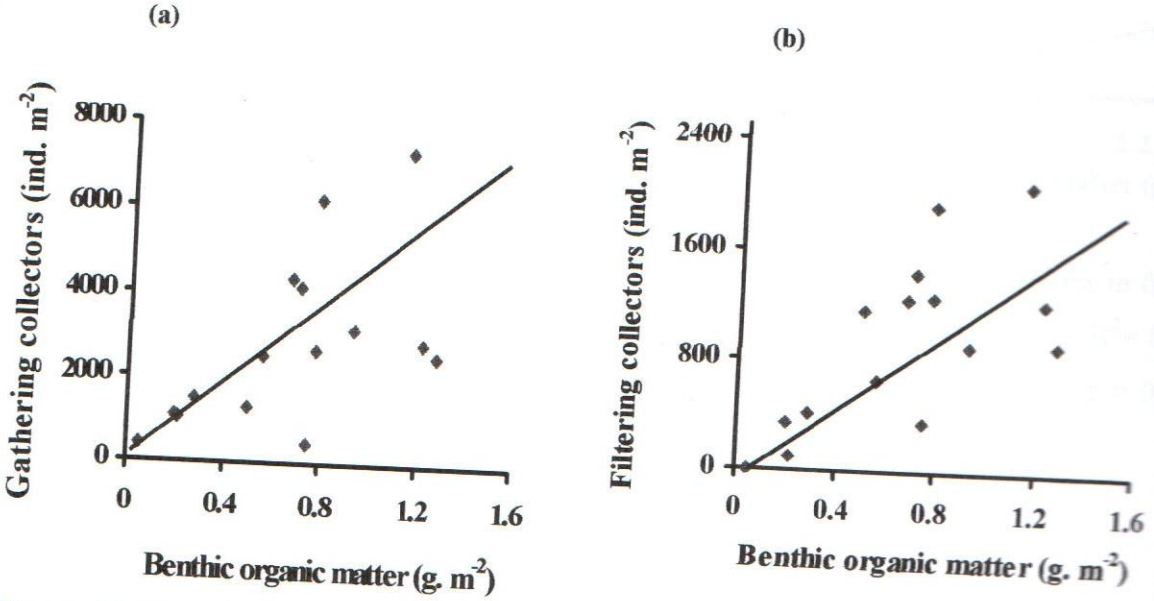


Figure 23: Benthic organic matter in relation to (a) gathering-collector, and (b) predator densities in the Njoro River. Relationship equations: (a) Gathering collectors = -292.07 + 5177.37 [Benthic organic matter], $R^2 = 0.71$, $p < 0.05$, $n = 160$; (b) Filtering collectors = -103.05 + 1731.07 [Benthic organic matter], $R^2=0.83$, $p < 0.05$, $n = 160$.

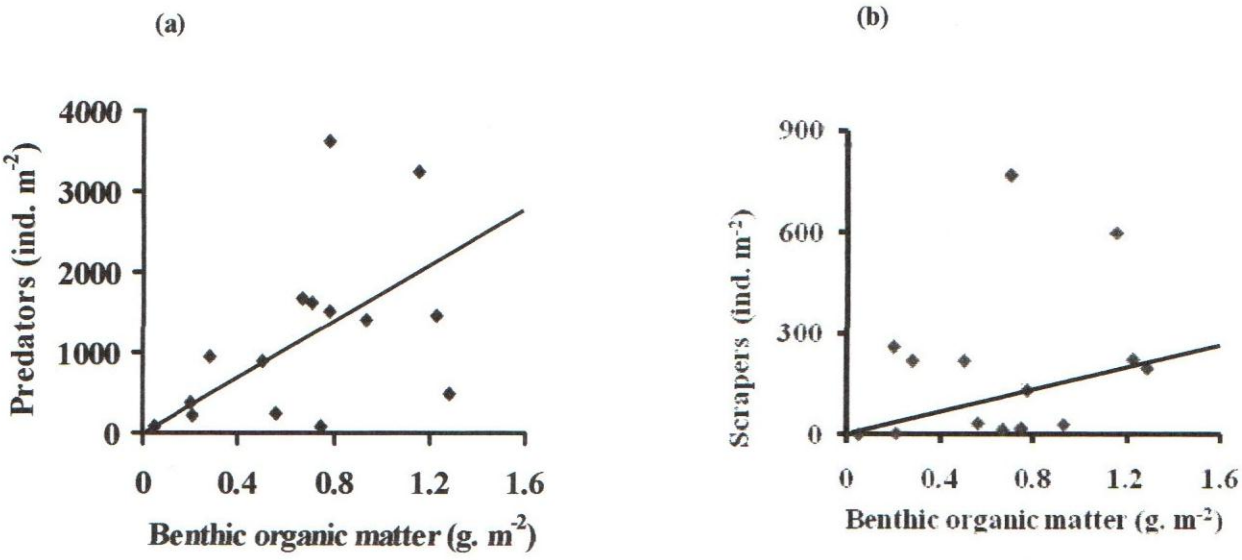


Figure 24: Benthic organic matter in relation to (a) predator and (b) scraper densities in the Njoro River. Relationship equations: (a) Predators = 23.91 – 1.79 [Benthic organic matter], R^2= 0.61, $p < 0.05$, n = 160; (b) Scrapers = 88.13 + 524.64 [Benthic organic matter], R^2 = 0.10, $p > 0.05$, n = 160.

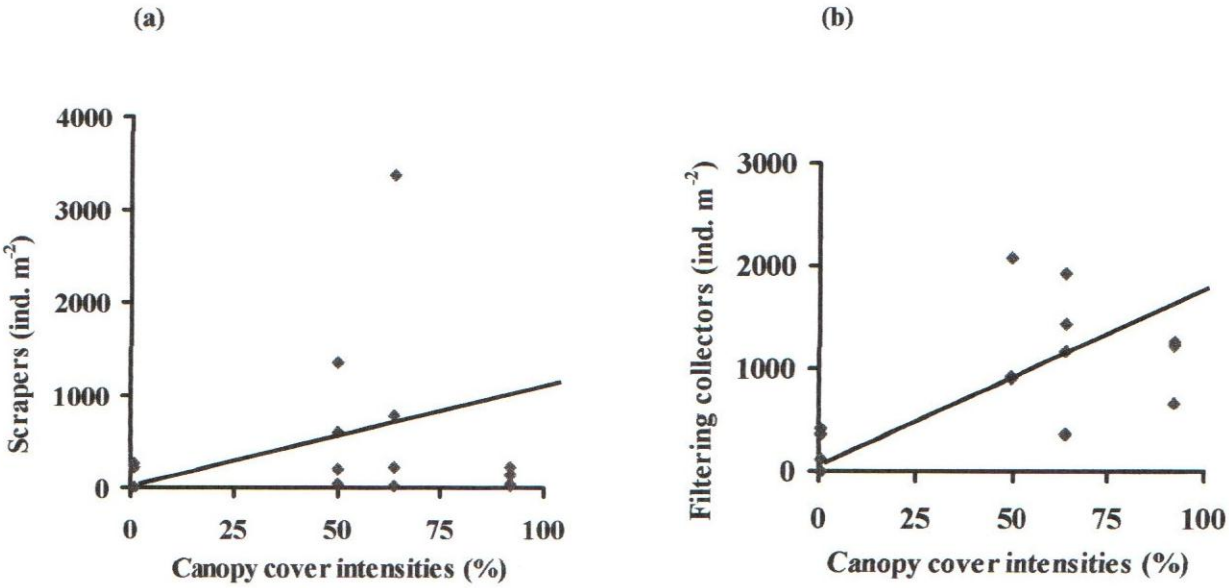


Figure 25: Canopy cover in relation to (a) scraper and (b) Filtering collector densities in the Njoro River. Relationship equations: (a) Scrapers = 340.14+ 2.89 [canopy cover intensities], R^2= 0.16, $p > 0.05$, n = 160; (b) Filtering collectors = 604.28 + 10.28 [canopy cover intensities], R^2= 0.13, $p > 0.05$, n = 160.

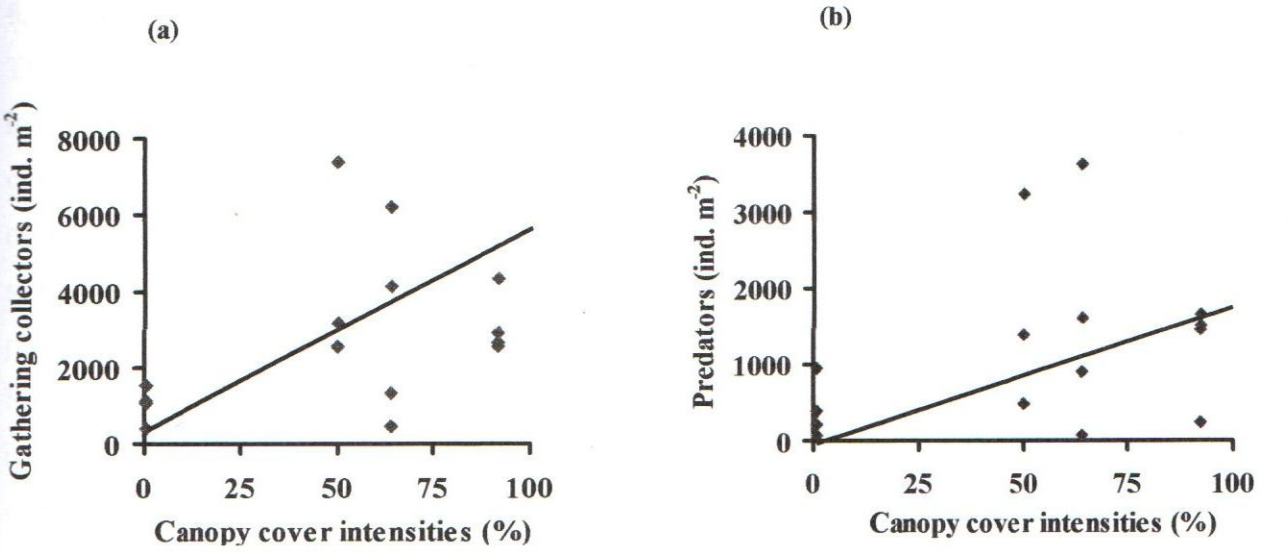


Figure 26: Canopy cover in relation to (a) gathering- collector and (b) predator densities in the Njoro River. Relationship equations: (a) Gathering collectors = 2244.34 – 22.60 [canopy cover intensities], R^2= 0.26, $p > 0.05$, n = 160; (b) Predators = 1026.59 + 9.75[canopy cover intensities], R^2= 0.19, $p > 0.05$, n = 160.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

The riparian ecotone contains ecological processes and habitats that provide refugia for invertebrates (Collier & Smith, 1998). Head water streams are highly dependent upon riparian canopy cover that provides shade, moderates microclimate, and provides the majority of the energy input into the stream in the form of allochthonous materials (Wallace *et al.*, 1997). In-stream invertebrate populations are influenced through multiple trophic levels by the riparian plant communities growing in their immediate upstream surroundings (Wallace *et al.*, 1997). Removal of riparian over-story reduces inputs of organic material, decreases stream shading and increases water temperature through increased insolation (Meehan, 1996; Jayawardana, 2006; Christina *et al.*, 2008) thereby reducing macroinvertebrate diversity and biomass. In addition to reducing organic material inputs, canopy removal may also lead to hydro-geological alterations that tend to degrade the physical habitat for invertebrates (Collier & Smith, 1998).

5.2 Effects of canopy cover on physical-chemical parameters

Mill House had the highest in-stream mean water temperature and dissolved oxygen content in comparison to Njoro-upstream, Mugo and Treetops. The most probable reason for the high water temperature at Mill House could be due to removal of stream riparian vegetation by the surrounding communities leading to increased sunlight penetration into the river. Riparian vegetation surrounding streams increase stream shading hence mitigating water temperature changes (Mellina *et al.*, 2002). Riparian vegetation removal reduces stream shading leading to increased water temperature thus reduced oxygen content in stream water (Mellina *et al.*, 2002). Contrary to the expectations, dissolved oxygen content was highest at Mill House as compared to the other sites in the Njoro River. The high dissolved oxygen content at Mill House could be due to reduced oxygen uptake through biological oxidation as the site had the lowest benthic organic matter content. Decomposition in the aquatic ecosystems usually consumes by far a large volume of oxygen than consumed by both plants and animals (Wetzel, 1983).

pH was higher at Mill House as compared to Mugo. The high organic matter content at Mugo could have led to high biological oxygen demand and increased carbon dioxide production which could have led to low pH values. Primarily, photosynthesis and decomposition determine the

spatial and temporal distribution of inorganic carbon and hence pH (Bootsma & Hecky, 1993). In all sites, there was a general increase in conductivity with time from January to April. This increase in conductivity followed a decline in river water level in all sites. The decline in water level in the river could be one reason that might have caused drastic increase in conductivity values through concentration of dissolved ions. This finding agrees with that of Ford & Naiman (1989) that conductivity fluctuations in a given water body is strongly influenced by the nature of the inflowing water and its periodicity. The decrease in water volume causes concentration of conducting ions resulting in an increase in conductivity (Shivoga, 1999).

5.3 Effects of canopy cover on Particulate Organic Matter (POM) inputs into the dry zones

Mill House (the least vegetated site) had significantly lower amounts of Coarse Particulate Organic Matter (CPOM) in the dry zone than the other sites in the Njoro River. Mill House is greatly affected through removal of stream riparian vegetation by the surrounding communities for building materials as well as fire wood. Destruction of riparian vegetation at this site has greatly reduced the canopy cover and consequently the organic matter content in the dry zone. Loss of riparian vegetation through small scale tree harvesting may lead to reduction in canopy cover and in turn this might lead to reduction in allochthonous organic matter input into streams (Reed *et al.*, 1994). Tree tops had the highest mean organic matter content in the dry zone. This can be attributed to the high density of *Syzygium cordatum* trees in this site. Magana (2000) working in Njoro River found that *Syzygium cordatum* trees contribute more than 60 % of litter inputs in the dry zones of the Njoro River. Further, the riparian vegetation buffer strip was widest at this site hence more CPOM inputs into the dry zone. Investigations in the Sagana River, a tropical stream, in Kenya, by Mwangi (2000) revealed that sites which are "closed canopied" contributed large amounts of CPOM than "open canopied" sites. A similar trend was reported in the Njoro River by Magana (2000, 2001) and M'Erimba (2004). Sites that are less vegetated have also been reported to receive less amounts of CPOM in comparison to heavily vegetated ones in temperate streams (Moser, 1991; David *et al.*, 2006; Peter *et al.*, 2008).

When the left and right river banks were considered, the amount of CPOM collected from the left bank of the Njoro River was significantly higher than the amount collected from the right bank. The low organic matter content in the right bank could be attributed to massive riparian vegetation destruction by the surrounding community whilst the left bank bordered Egerton

University and was more protected. It is therefore not surprising to note that the buffer strip was wider on the left bank than on the right bank for all sites apart from Mill House. Loss of riparian vegetation through small-scale tree harvesting may lead to reduction in canopy cover and in turn this might lead to reduction in allochthonous organic matter input in streams (Magana, 2000; Magana, 2001).

When the amounts per site of AFDM determined from the CPOM collected from the banks were considered, the right bank held significantly higher amounts of CPOM than the left bank at Mill House, the least shaded site. The left bank is devoid of riparian vegetation in the downstream end. Further, the buffer strip was wider on the right bank than on the left bank. There was no significant difference in the amount of AFDM determined from the CPOM obtained from both banks at Njoro-upstream. There is dense herbaceous vegetation on both banks at Njoro-upstream. This finding is similar to that of M'Erimba (2004) who found no significant difference in the CPOM content on the left and right banks at Mugo site while working in the same river. The dry zones retained significantly higher amounts of CPOM than the wetted stream channel. This observation is in agreement with the findings of previous studies in the Njoro River (e.g. Mathooko, 1995; M'Erimba, 2004; M'Erimba *et al.*, 2007), which reported higher plant CPOM on the banks as compared to the wetted zones. Similarly, Gurtz *et al.*, (1987) reported higher amounts of CPOM on the banks, as opposed to the stream channel, of Kings Creek, U.S.A. The explanation offered by these authors was that woody materials entrained during storm flow are moved to the stream banks and again water currents tend to transport materials downstream in the wetted zone.

There were significant differences in AFDM determined from the CPOM categories among the sites apart from the un-identifiable detritus category. Tree tops had the highest leaves, twigs, fruits and un-identifiable (others) detritus content whilst Mill House had the lowest. The most probable reason for this finding could be due to factors such as differences in the nature of riparian vegetation. Mill House site was mainly dominated by the herbaceous layer whilst Tree tops was dominated by *Syzygium cordatum*. *Syzygium cordatum* trees contribute more than 60 % of litter inputs in the dry zones of the Njoro River and provides 45 % canopy cover (Magana, 2000).

5.4 Effects of canopy cover on Particulate Organic Matter (POM) inputs into the wet zon

Mugo had significantly higher Coarse Particulate Organic Matter (CPOM) content in the b sediments as compared to the other sites. The most plausible explanation for this finding the was increased presence of retentive structures at this site. Boulders, rock cataracts and tree roo were more in this site than in all the other sites. On the other hand, Mill House had the lowe CPOM content in the bed sediments. The most probable reason for this finding there was due lack of retention structures at this site. The accumulation of CPOM in the wet zones is large determined by the frequency of retentive structures (Morara *et al.*, 2003; M'Erimba, 200 Niklas, 2005; M'Erimba *et al.*, 2007). Mathooko *et al.* (2001 a, b) observed that sites in t Njoro River, Kenya with less retentive structures, such as boulders, tree roots and debris dam held lower amounts of plant CPOM than sites with numerous retentive structures. Anoth reason that could explain the low organic matter content at Mill House is tree canopy damag Tree canopy damage leads to low organic matter content in the dry and in the wet zones. Cliffo *et al.* (2005) working on North Eastern U.S. streams reported that tree canopy damage led reduction in organic matter inputs in the dry and wet zones.

There were significant differences in AFDM determined from the CPOM categories among th sites apart from the un-identifiable detritus category. Mugo had the highest leaves, twigs, frui and un-identifiable (others) detritus content whilst Mill House had the lowest. The most probabl reason for this finding could be due to differences in occurrence of retentive structures betwee the sites. Mugo had diverse retentive structures as compared to Mill House which had n retentive structures. Sites with more retentive structures retain the highest amount of litter tha sites with less retentive structures (Morara *et al.*, 2003).

5.5 Effects of canopy cover on benthic macroinvertebrate density, diversity and biomass

The least shaded site (Mill House) had high mean water temperature, low benthic organic matte content and macroinvertebrate diversity and biomass. The most apparent explanation for the low macroinvertebrate diversity and biomass at this site could be due to low benthic organic matter a the site. Allochthonous organic matter is an important source of food for detritus processing macroinvertebrates and its reduction could lead to low macroinvertebrate biomass and diversity. These results concur with those of Brenda *et al.* (2005), who found that removal of canopy cover during harvest operations and subsequent removal of most of the woody debris and organic

matter from the stream channel led to elevated water temperatures and low macroinvertebrate community diversity and biomass.

Pronounced declines in mayfly density and an increase in Oligochaeta and Chironomidae were noted at Mill House and this observation agrees with the findings by Brenda *et al.*, (2005) who noted pronounced increase in Oligochaeta, Chironomidae, Mollusca, and more tolerant species of caddisflies such as *Oxyethira albiceps* in clear-cuts in two North New Zealand streams. The most feasible explanation for the decline in the macroinvertebrates density and diversity at Mill House could be due to the high mean water temperature recorded at the site. Mellina *et al.* (2002) reported that slight temperature increases could result in a shift in macroinvertebrate community structure to species that tolerate the increased temperature. Also, the nature of sediments could have an effect on the macroinvertebrate community structure. Fine organic sediments dominated all the sites forming more than 90 %. Fine sediments encourage oligochaetes and chironomids (Dumnika, 1994).

Higher macroinvertebrate diversity and biomass were recorded at Mugo as compared to Mill House. Similarly, the benthic organic matter content was higher at Mugo than at the other sites in the Njoro River. The high macroinvertebrate diversity and biomass at Mugo can be attributed to the high organic matter content recorded at the site. This organic matter comprises an important source of energy for stream food webs. Changes in organic matter inputs as a result of canopy removal have been shown to reduce macroinvertebrate biomass and diversity in the harvested catchments (Entrekin *et al.*, 2007).

There existed no significant relationship between major macroinvertebrate taxonomic groups (oligochaetes, bivalves, Ephemeroptera and chironomids), macroinvertebrate density, biomass and canopy cover. Even though canopy cover provides organic matter to the stream either in form of aerial drift or bank run off, its retention in the wetted stream channel is influenced by factors such as stream retentiveness (Morara *et al.*, 2003). It is therefore not surprising to note that the moderately shaded site (Mugo) had higher macroinvertebrate density and benthic organic matter content as compared to the heavily shaded site (Njoro upstream). However, there was significant positive correlation between macroinvertebrate diversity and canopy cover. This can be attributed to the fact that diversity tended to increase with canopy cover. Riparian vegetation

5.6 Effects of coarse particulate organic matter on benthic macroinvertebrate density, diversity and biomass

Benthic organic matter (BOM) content and macroinvertebrate biomass and diversity differed significantly among the four sites in the Njoro River. Observations made by M'Erimba (2004) while working in the same river revealed significant differences in the benthic organic matter content and macroinvertebrate diversity and densities. The highest benthic organic matter content and macroinvertebrate biomass and densities were recorded at Mugo while the lowest were recorded at Mill House. The most feasible explanation for the higher macroinvertebrate diversity and biomass at Mugo could be due to the high BOM content recorded at this site as compared to Mill House. Invertebrates improve their fitness by seeking out BOM patches in detritus limited systems (Rowe & Richardson, 2001). Experimental addition of detritus to three Michigan streams by Sally (2008) led to significant increase in the diversity, density and biomass of various macroinvertebrate groups. It is therefore not surprising to note that macroinvertebrate density, diversity and biomass were higher at the highly retentive site (Mugo) in comparison to Mill House which had lower BOM content. The work of Johnson *et al.* (2003) substantiates this information. They reported that macroinvertebrate communities not associated with detritus were less diverse than invertebrate communities associated with detritus. Further, Pretty & Dobson (2004) and Damon (2006) reported that removal of benthic organic matter led to lower macroinvertebrate biomass and diversity due to reduction in allochthonous organic matter inputs which serve as a source of energy for stream food webs, especially in small, forested streams.

Macroinvertebrates were more similar in medium shaded, heavily shaded, and least shaded than they were to the least shaded and moderately shaded sites. Approximately 29 % of the total organisms were similar between Mugo and Mill House. Human and livestock disturbances which are common at Mill House unlike at Mugo could have attributed to this observation. Another possible explanation could be the presence of competitive exclusion where strong competitors outcompeted the weak ones, though further research is needed to establish this assertion as pointed out by Mathooko (2001). Taxon richness and diversity was higher in Mugo and Tree tops as compared to the other sites. This can be attributed to the fact that these sites had higher

BOM contents hence more food resources for macroinvertebrates. Detritus originating from the riparian vegetation canopy provides a surface on which algae and other micro-organisms can accumulate, creating a biofilm that augments invertebrate food sources (Raikow *et al.*, 2005). At Mugo, macroinvertebrates were dominated by one taxon mainly the oligochaetes. The sediments at this site are muddy whereas at Mill House they are a mixture of mud and sand. Oligochaetes prefer muddy sediments as their habitat (Dumnika, 1994).

There were significant positive linear correlations between benthic organic matter and major macroinvertebrate taxonomic groups (bivalves, Ephemeroptera, oligochaetes and chironomids), macroinvertebrate density, biomass and diversity. Organic matter is a crucial source of energy in shaded streams and detritus processing macroinvertebrates heavily rely on this organic matter as a source of energy. It is therefore not surprising to note that sites with high BOM content had higher macroinvertebrate density, biomass and diversity than sites with low BOM content. Previous studies have demonstrated significant positive correlations between benthic organic matter (BOM) and invertebrate community metrics such as abundance, diversity and biomass (e.g. Damon, 2006; Christina *et al.*, 2008). Sally (2008) found a significant increase in the biomass and abundance of caddis fly shredder, *Lepidostoma* sp., following wood addition in three Michigan streams.

There were significant positive correlations between various CPOM categories such as leaves, twigs and macroinvertebrate biomass and diversity. However, there were insignificant positive correlations between fruits, twigs and macroinvertebrate biomass and diversity. The most plausible explanation for this finding could be due to the fact that twigs and fruits are tougher than leaves hence can not be easily utilized by macroinvertebrates as food. Cordora *et al.*, 2009 asserts that different organic matter categories from different tree species decompose at different rates and supports different microbial and macroinvertebrate assemblages.

5.7 Effects of Benthic Organic Matter (BOM) and canopy cover on macroinvertebrate functional feeding groups

In the present study, there were significant positive linear correlations between benthic organic matter and gathering-collector, filtering-collector and predator abundances. However, there was insignificant positive correlation between scraper density and benthic organic matter. The possible reason for the positive correlations between BOM, gathering collectors and filtering

collectors could be due to the fact that they heavily rely on BOM as a source of food. Gathering-collectors and filtering-collectors feed on deposited and suspended organic matter in water respectively (Dana & Clifford, 2006). The possible reason for the insignificant positive correlation between BOM and scraper density could be due to stream flow that dislodges periphyton that serve as their food. Biggs (1995) states that periphyton development in rivers is greatly influenced by stream flow. The positive correlation between predators and BOM could be due to the fact that BOM is an important source of microorganisms and invertebrates which in turn serve as an important source of food for predators. BOM is an important source of energy for invertebrates and micro-fauna that serve as a source of food for predating macroinvertebrates. The positive correlation between benthic organic matter and predator density is similar to that of Murphy *et al.*, (1981) who found that insect predators increased correlatively with the increased prey base in highly retentive areas. Sally (2008) asserts that changes in organic matter standing stock can have ecosystem-wide effects in streams. For example, when organic matter standing stocks increase (e.g. via increased retention and storage), microbial and macroinvertebrate production may increase in response, thus increasing predator production and leading to an overall increase in energy transfer among trophic levels.

There were insignificant positive linear correlations between predator, scraper, filtering-collector, and gathering–collector densities and canopy cover in the Njoro River. The most probable reason for this finding could be due to differences in litter retention in the stream. The heavily shaded site (Njoro upstream) had fewer retentive structures whilst the moderately shaded site (Mugo) had more retentive structures. It is therefore not suprising that the heavily shaded site (Njoro upstream) had lower densities for the macro invertebrate feeding groups and organic matter content as compared to the (Mugo) moderately shaded site. Various macroinvertebrates such as filter feeders and collector gatherers utilize allochthonous organic matter as a source of energy (Dana & Clifford, 2006).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions were drawn from the study:

1) Mill House site (least shaded site) had lower organic matter quantities held on the stream banks than Njoro Upstream (heavily shaded site). This provides evidence that removal of canopy cover along rivers may lead to low organic matter held on river banks.

2) Tree-tops site (site with widest riparian vegetation buffer strip) held higher organic matter content on the stream banks than sites with narrow riparian vegetation buffer strips (Mill House). This indicates that riparian vegetation buffer strip destruction may lead to low organic matter content held in the dry zone zones.

3) Sites with low canopy cover intensities (Mill House) had fewer retentive structures (e.g. plant roots) and lower benthic organic matter content than heavily shaded sites. This indicates that canopy destruction may lead to reduced presence of retentive structures such as plant roots and hence low benthic organic matter content.

4) Sites with low canopy cover intensities (Mill House) had lower macroinvertebrate diversity and biomass than heavily shaded sites (Njoro Upstream). It can be concluded that high macroinvertebrate diversity and biomass appeared to occur in heavily shaded sites than in sites with low canopy cover intensities.

5) Sites with low canopy cover intensities and benthic organic matter content (Mill House) had lower densities for the macroinvertebrate functional feeding groups than heavily shaded sites. Destruction of canopy cover along streams by riparian communities leads to low canopy cover and benthic organic matter and hence low densities for the macroinvertebrate feeding groups.

6) Sites with low canopy cover intensities and benthic organic matter content had lower macroinvertebrate diversity and biomass than heavily shaded sites. These relationships may indicate that invertebrate community productivity may be limited by organic matter availability, possibly through food limitation.

7) In general, there was a strong relationship between macroinvertebrate density, diversity, biomass and benthic organic matter though canopy cover affects macroinvertebrates indirectly due to in stream processes such as differences in stream retentiveness and hydrology which affect organic matter retention in the stream.

6.2 Recommendations

1) A long term study should be undertaken to understand the spatial-temporal variation of macroinvertebrate density, diversity and biomass in the Njoro River. This should also include assessments of the nutritional value of organic matter to macroinvertebrates.

2) The quality of the Njoro River as well as other streams experiencing similar riparian vegetation destruction could be improved by leaving twenty five feet of riparian vegetation on either side of the river. The riparian zone should be demarcated and regularly monitored.

3) A management plan should be developed to enable the description of the riparian vegetation buffer strip in terms of its ecological and socio-economic function.

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APPENDICES

Appendix 1: Physical and chemical parameters measured in the Njoro River study sites between January 2009 and April 2009. Bolded values are means ± Standard Error, n = 3.

Stream variables	Njoro upstream				Treetops				Mugo				Mill House			
	Jan	Feb	March	April	Jan	Feb	March	April	Jan	Feb	March	April	Jan	Feb	March	April
Temperature (°C)	**15.84**	**19.08**	**19.81**	**21.09**	**15.67**	**20.67**	**20.26**	**21.4**	**15.47**	**19.13**	**21.37**	**23.66**	**17.42**	**21.77**	**22.90**	**23.89**
± SE	0.05	0.33	0.38	0.27	0.19	0.53	0.43	0.53	0.01	0.53	0.31	0.20	0.74	0.37	0.21	0.63
Conductivity (µs/cm)	**142.19**	**143.71**	**282.83**	**291.43**	**144.07**	**147.27**	**284.84**	**283.09**	**142.52**	**148.02**	**259.39**	**258.67**	**165.80**	**182.53**	**289.20**	**284.32**
± SE	0.77	1.09	2.04	0.52	1.50	1.55	1.41	1.63	0.22	2.16	3.39	2.65	0.57	3.52	1.49	1.08
Dissolved oxygen (mg/l)	**10.51**	**9.52**	**10.03**	**9.47**	**10.95**	**11.53**	**11.32**	**11.90**	**10.91**	**11.50**	**11.12**	**11.11**	**11.58**	**11.30**	**11.71**	**11.34**
± SE	0.08	0.27	0.15	0.02	0.05	0.02	0.30	0.01	0.19	0.50	0.20	0.19	0.09	0.35	0.05	0.09
% Oxygen saturation	**103.80**	**100.82**	**141.72**	**143.00**	**126.40**	**129.30**	**149.28**	**152.49**	**126.92**	**140.47**	**146.75**	**148.21**	**151.33**	**151.68**	**156.97**	**151.72**
± SE	0.65	1.28	0.56	0.46	0.22	0.64	1.67	0.55	1.00	1.65	0.26	0.53	0.80	0.09	0.09	1.25
pH	**6.87**	**6.90**	**7.38**	**8.05**	**7.00**	**6.98**	**8.20**	**8.20**	**6.96**	**6.96**	**7.14**	**7.99**	**6.94**	**6.95**	**7.90**	**8.37**
± SE	0.03	0.05	0.19	0.03	0.02	0.04	0.07	0.04	0.04	0.03	0.09	0.02	0.05	0.04	0.18	0.07
Velocity ($m\ s^{-1}$)	**0.11**	**0.08**	**0.07**	**0.08**	**0.12**	**0.15**	**0.11**	**0.08**	**0.13**	**0.16**	**0.12**	**0.08**	**0.17**	**0.22**	**0.09**	**0.07**
± SE	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.02	0.01	0.02
Discharge ($m^3\ s^{-1}$)	**0.51**	**0.44**	**0.31**	**0.11**	**1.88**	**1.04**	**0.91**	**0.39**	**2.16**	**1.95**	**1.43**	**1.10**	**1.54**	**0.89**	**0.51**	**0.09**
± SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2 : Quantities of ash free dry mass (AFDM) in grams per m^2 obtained from various categories of coarse particulate organic matter (CPOM) collected in the wet zone of the Njoro River between January 2009 and April 2009. Bolded values are means ± Standard Error, n = 40

	January				February				March				April			
CPOM	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**
Leaves	**1.45**	**0.84**	**0.48**	**0.03**	**1.24**	**0.74**	**0.86**	**0.40**	**1.02**	**0.78**	**0.67**	**0.36**	**1.47**	**0.86**	**1.27**	**0.54**
± SE	0.27	0.10	0.12	0.01	0.19	0.60	0.17	0.16	0.26	0.11	0.18	0.11	0.41	0.12	0.29	0.22
Twigs	**1.79**	**0.90**	**0.59**	**0.08**	**1.00**	**0.60**	**0.58**	**0.25**	**1.91**	**0.88**	**1.37**	**0.16**	**1.72**	**1.16**	**2.36**	**0.24**
± SE	0.49	0.60	0.15	0.03	0.18	0.14	0.15	0.11	0.45	0.25	0.23	0.09	0.51	0.31	0.73	0.11
Fruits	**0.87**	**0.59**	**0.57**	**0.02**	**0.58**	**0.11**	**0.55**	**0.19**	**0.82**	**0.39**	**0.18**	**0.03**	**0.90**	**0.40**	**0.54**	**0.00**
± SE	0.14	0.12	0.26	0.01	0.18	0.09	0.22	0.13	0.17	0.10	0.09	0.01	0.20	0.11	0.28	0.00
Others	**1.04**	**0.66**	**0.58**	**0.06**	**0.89**	**0.54**	**0.70**	**0.02**	**0.87**	**0.76**	**0.90**	**0.28**	**1.39**	**0.69**	**0.74**	**0.34**
± SE	0.20	0.14	0.23	0.02	0.19	0.11	0.32	0.01	0.21	0.34	0.17	0.13	0.65	0.28	0.31	0.13

Appendix 3: Quantities of ash free dry mass (AFDM) in grams per m^2 obtained from various categories of coarse particulate organic matter (CPOM) collected in the right bank of the Njoro River between January 2009 and April 2009 . Bolded values are means ± Standard Error, n = 40

	January				February				March				April			
CPOM	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**
Leaves	**113.59**	**24.00**	**18.63**	**11.28**	**62.51**	**23.62**	**25.05**	**10.18**	**96.60**	**39.92**	**73.61**	**24.76**	**57.66**	**102.76**	**34.38**	**57.66**
± SE	26.59	4.16	4.21	0.41	16.29	11.47	5.31	2.09	14.70	6.64	16.69	4.21	17.25	24.38	4.37	17.25
Twigs	**75.91**	**14.48**	**24.95**	**7.17**	**38.90**	**26.17**	**36.06**	**8.82**	**49.36**	**24.25**	**42.80**	**19.67**	**38.47**	**42.11**	**22.69**	**38.47**
± SE	17.03	4.27	9.78	1.96	13.27	10.00	7.99	1.26	6.45	11.91	8.60	9.99	7.74	7.25	11.42	7.74
Fruits	**95.60**	**23.57**	**28.11**	**0.00**	**40.60**	**19.55**	**18.47**	**2.59**	**37.83**	**12.62**	**14.13**	**1.68**	**14.20**	**34.98**	**8.21**	**14.20**
± SE	12.99	5.69	5.79	0. 00	16.55	8.99	4.18	1.85	12.73	3.54	7.45	1.06	6.82	10.05	2.92	6.82
Others	**128.59**	**22.89**	**9.40**	**15.35**	**11.35**	**6.84**	**30.63**	**7.28**	**16.94**	**14.45**	**24.03**	**4.35**	**18.74**	**14.57**	**13.44**	**18.74**
± SE	5.87	12.05	3.01	2.78	1.65	5.13	8.10	1.67	10.03	9.07	7.16	2.16	5.25	9.59	8.43	5.25

Appendix 4: Quantities of ash free dry mass (AFDM) in grams per m^2 obtained from various categories of coarse particulate organic matter (CPOM) collected in the left bank of the Njoro River between January 2009 and April 2009 . Bolded values are means ± Standard Error, n = 40

	January				February				March				April			
CPOM	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**
Leaves	**105.84**	**32.26**	**19.44**	**8.48**	**89.83**	**89.83**	**46.57**	**3.72**	**96.60**	**75.80**	**117.85**	**7.83**	**125.07**	**137.94**	**66.44**	**9.73**
± SE	29.71	8.57	8.69	1.72	24.15	24.15	8.02	1.03	14.70	17.95	25.64	2.80	27.77	25.14	13.25	2.95
Twigs	**114.35**	**26.57**	**18.56**	**2.94**	**38.61**	**39.61**	**44.02**	**6.85**	**49.36**	**37.58**	**142.77**	**20.53**	**140.71**	**87.43**	**32.90**	**10.32**
± SE	37.81	8.98	8.30	0.80	6.15	7.25	4.93	1.93	6.45	23.69	14.92	12.06	17.13	6.15	18.60	5.39
Fruits	**106.79**	**27.87**	**15.88**	**1.80**	**20.27**	**30.98**	**12.51**	**4.29**	**37.83**	**17.04**	**21.57**	**0.00**	**25.52**	**40.63**	**3.54**	**0.00**
± SE	28.90	4.67	7.10	1.01	6.06	7.98	4.92	2.04	12.73	8.39	10.23	0.00	13.82	32.97	2.12	0.00
Others	**44.00**	**28.31**	**24.23**	**7.35**	**8.59**	**15.21**	**32.24**	**6.38**	**16.94**	**11.64**	**23.14**	**5.88**	**21.61**	**10.97**	**14.60**	**1.74**
± SE	23.55	10.25	10.83	4.17	5.27	6.97	3.60	1.45	10.03	4.11	9.67	2.73	9.31	2.21	4.14	0.98

Appendix 5: Major macroinvertebrate groups (ind. m^{-2}) collected in benthic samples between January 2009 and April 2009 in the Njoro River sites. Bolded values are means ± Standard Error, n = 40

	January				February				March				April			
Groups	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**
Ephemero-ptera	**170.70**	**105.20**	**203.40**	**82.80**	**291.40**	**356.90**	**474.10**	**151.7**	**843.10**	**425.90**	**510.30**	**112.10**	**1855.20**	**1137.30**	**536.20**	**206.90**
± SE	83.30	41.03	96.43	35.09	112.60	82.76	129.11	70.27	248.60	174.37	84.57	56.70	617.00	274.36	188.26	70.49
Chirono-midae	**388.50**	**29.90**	**282.80**	**44.80**	**503.40**	**310.30**	**747.10**	**117.20**	**1204.60**	**690.80**	**540.20**	**155.20**	**2892.00**	**1427.60**	**581.60**	**406.90**
± SE	148.70	14.53	99.83	26.89	249.00	154.16	283.07	52.69	595.40	303.97	254.74	49.33	103.30	647.03	263.95	191.87
Bivalvia	**769.00**	**237.90**	**517.20**	**3.40**	**927.60**	**648.30**	**1158.60**	**72.40**	**1713.80**	**1262.10**	**841.40**	**306.90**	**6706.90**	**1620.70**	**806.90**	**341.40**
± SE	184.80	85.31	160.51	3.45	262.80	231.93	200.29	40.95	310.40	328.31	287.87	143.05	748.90	395.81	296.42	142.68
Oligochaeta	**1289.70**	**179.30**	**1441.40**	**155.20**	**2644.80**	**417.20**	**2717.20**	**572.40**	**4723.90**	**2669.00**	**1437.90**	**700.00**	**3727.60**	**3010.30**	**1437.90**	**724.10**
± SE	284.20	44.75	207.27	73.10	671.50	142.77	317.91	172.58	1122.10	610.72	274.09	189.08	613.60	778.19	274.09	192.88

Appendix 6: Biomass distribution of the major macroinvertebrate groups in benthos (g. m^{-2}) in the Njoro River study sites over the sampling months. Bracketed values are ± Standard Error, n = 40

	January				February				March				April			
Groups	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**
Ephemero Ptera	**0.17**	**0.09**	**0.71**	**0.17**	**0.39**	**0.33**	**0.30**	**0.06**	**0.12**	**0.14**	**0.15**	**0.02**	**0.14**	**0.04**	**0.03**	**0.04**
± SE	0.07	0.03	0.47	0.12	0.14	0.09	0.12	0.02	0.04	0.10	0.03	0.06	0.02	0.02	0.01	0.59
Chirono Midae	**0.54**	**0.04**	**0.65**	**0.16**	**0.57**	**0.35**	**0.82**	**0.12**	**0.14**	**0.69**	**1.26**	**0.08**	**0.48**	**0.05**	**0.07**	**0.02**
± SE	0.73	0.02	0.28	0.13	0.28	0.17	0.28	0.10	0.06	0.09	1.01	0.03	0.26	0.01	0.02	0.01
Bivalvia	**0.97**	**3.68**	**1.44**	**0.01**	**2.01**	**0.63**	**2.33**	**0.19**	**0.25**	**0.20**	**0.18**	**0.06**	**0.03**	**0.05**	**0.05**	**0.01**
± SE	0.22	3.07	0.93	0.00	0.92	0.13	1.01	0.15	0.06	0.02	0.03	0.02	0.01	0.03	0.02	0.00
Oligochaeta	**1.04**	**0.32**	**0.60**	**0.40**	**1.64**	**0.94**	**0.76**	**0.33**	**0.47**	**0.29**	**0.28**	**0.29**	**0.05**	**0.06**	**0.07**	**0.03**
± SE	0.38	0.06	1.67	0.27	0.75	0.25	2.90	0.15	0.07	0.01	0.04	0.12	0.01	0.02	0.01	0.01

Appendix 7: Functional feeding guilds for the macroinvertebrate groups in benthos (ind. m^{-2}) in the Njoro River sites over the sampling months. Bracketed values are ± Standard Error, n = 40

	January				February				March				April			
Groups	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro(US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**	**Mugo**	**Tree-tops**	**Njoro (US)**	**Mill House**
Scrapers	**196.60**	**17.20**	**34.50**	**0.00**	**29.79**	**217.24**	**13.80**	**3.45**	**600.00**	**768.97**	**131.03**	**258.62**	**1348.28**	**3358.62**	**220.69**	**217.24**
± SE	86.32	13.08	20.56	0.00	17.08	63.39	3.79	1.42	46.89	314.83	58.56	113.23	541.24	640.39	45.12	114.49
Gathering Collectors	**2548.30**	**437.90**	**2527.60**	**393.10**	**3144.73**	**1331.03**	**4344.80**	**1075.86**	**7368.97**	**4113.79**	**2658.62**	**1124.14**	**12903.45**	**6210.35**	**2882.76**	**1531.03**
± SE	488.59	82.73	315.20	71.08	730.12	222.30	350.57	191.70	1447.12	776.49	243.31	204.53	1308.86	889.31	330.12	371.86
Filtering Collectors	**931.00**	**362.10**	**655.20**	**6.89**	**913.02**	**1162.07**	**1255.20**	**106.90**	**2082.76**	**1434.48**	**1268.91**	**351.72**	**4072.41**	**1920.69**	**1234.48**	**410.34**
± SE	181.16	94.39	165.45	4.59	300.67	445.47	193.65	47.79	367.36	345.56	474.19	49.23	587.32	359.09	482.84	47.24
Predators	**500.00**	**69.00**	**255.20**	**68.96**	**1399.33**	**896.55**	**1665.50**	**224.14**	**3241.38**	**1617.24**	**1510.35**	**386.21**	**6603.45**	**3627.59**	**1462.07**	**927.59**
± SE	151.21	21.80	86.66	38.12	326.64	210.13	324.74	52.74	813.69	332.48	270.09	25.08	1221.52	820.54	293.78	203.90

Appendix 8: Matrix of regression correlation coefficients (r) and their associated levels of significance for comparisons between physical chemical variables and macroinvertebrate diversity, biomass, and functional feeding guilds abundances.

Variable	Diversity (H')	Biomass ($g.m^{-2}$)	Scrapers ($ind.m^{-2}$)	Gatherers ($ind.m^{-2}$)	Predators ($ind.m^{-2}$)	Filterers ($ind.m^{-2}$)
Grain size (mm)	0.47^{ns}	0.25^{ns}	0.43^{ns}	0.08^{ns}	0.02^{ns}	0.05^{ns}
Temperature (°C)	0.06^{ns}	0.24^{ns}	0.16^{ns}	0.26^{ns}	0.32^{ns}	0.22^{ns}
Conductivity (µs/cm)	0.30^{ns}	0.49^{ns}	0.31^{ns}	0.19^{ns}	0.12^{ns}	0.28^{ns}
Dissolved oxygen (mg/l)	0.07^{ns}	0.11^{ns}	0.36^{ns}	0.02^{ns}	0.04^{ns}	0.07^{ns}
% oxygen saturation	0.16^{ns}	0.15^{ns}	0.34^{ns}	0.11^{ns}	0.24^{ns}	0.09^{ns}
pH	0.17^{ns}	0.37^{ns}	0.55*	0.33^{ns}	0.43^{ns}	0.35^{ns}
Velocity ($m\ s^{-1}$)	0.17^{ns}	0.21^{ns}	0.22^{ns}	0.28^{ns}	0.25^{ns}	0.30^{ns}
Discharge (m^3s^{-1})	0.08^{ns}	0.69*	0.20^{ns}	0.02^{ns}	0.09^{ns}	0.04^{ns}

* $p < 0.05$; ^{ns} not significant

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