CHARACTERIZATION OF COARSE PARTICULATE ORGANIC MATTER (CPOM) STANDING CROP AND ITS RETENTIVE STRUCTURES ALONG A LOW ORDER TROPICAL STREAM: SAGANA RIVER, KENYA.

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I56/7219/2001

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A Thesis submitted in partial fulfillment of the requirements
for the Degree of Masters of Science in the School of
Pure & Applied Sciences of Kenyatta University

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DEDICATION

This work is dedicated to my parents

ELIAKIM OWUOR AND PAMELA AWINO

ACKNOWLEDGEMENT

In the course of preparation and completion of this study, many people offered assistance, encouragement and co-operation for which I am greatly indebted to.

Foremost, I wish to extend grateful thanks to my University supervisors, Dr. B.M. Mwangi and Dr. P. A. Obudho who made me have a fascination for Aquatic Ecology, especially after their tactful and lucid approach to the course, their splendid selfness professional academic guidance, wise counsel, and inspiration throughout the research work.

I owe a great deal of thanks to members of staff at Kiganjo Trout Farm and the officer in-charge of the Sagana State Lodge Meteorological station for offering their time and rainfall data without which this study would not have been completed. Their guidance during this research project is greatly acknowledged. No work would have been possible without identification of the plants; for this, I acknowledge the assistance of the plant taxonomist, Mr. Simeon Mathenge from the University of Nairobi.

The technical assistance from Mr. J. Mwangi and Mr. John Ofula both of Biological Sciences Department, Kenyatta University are highly appreciated. I am also grateful to Mr. Maina of Chemistry department, Kenyatta University for his assistance in setting up the muffle furnace for my analysis.

To crown it all, I acknowledge with much thanks the role-played by my beloved parents Eliakim Owuor and Pamella Awino during the whole of my study period. Their devotion to prayers, care, encouragement and moral support during that time is all appreciated.

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ABSTRACT

Retention capacity of coarse particulate organic matter (CPOM) was studied in a low order forested tropical stream, Sagana River, Kenya from February to October 2003. Sampling was carried out bi-weekly along a 100 metres stream stretch. Retentive features were examined for their abundance, types, sizes, and distribution along the stream reach. The characteristics (length, breadth, height, area and volume) of the retentive features were measured and related to the amount of CPOM retained. A Hess sampler (area = $0.0299m^2$) was used for collecting benthic organic matter (BOM), which was then sorted into leaves, barks, twigs, fruits, roots, wood debris and others. Prior to sorting, all associated macroinvertebrates were picked, identified, enumerated and classified to functional feeding group categories. The distribution and abundance was determined and related to the amount of CPOM retained by the retentive features. Materials from retentive features were ashed and weighed. The horizontal projection area (HPA) ranged from $0.64m^2$ to $3.76m^2$ and the volume of debris dam from $0.38m^3$ to $3.76m^3$. At the exposed riffle gravel bar (ERGB), the HPA varied greatly from 0 to $32.62m^2$. Large woody debris (LWD) retained the highest amount of BOM totaling 68.89g $AFDWm^{-2}$ followed by ERGB with 65.34 g $AFDWm^{-2}$ and debris dam with a total of 58.83g $AFDWm^{-2}$. Leaf litter dominated the BOM inputs accounting for over 47% at the debris dam. *Ficus thorningii* leaves dominated the leaf inputs accounting for upto 44% of the total BOM. Correlation analysis showed that the most important factor influencing the accumulation of leaf litter was the volume of the debris dam ($r = 0.83$; $P<0.01$). The highest macroinvertebrate abundance was recorded at the exposed riffle gravel bar totaling to 675 individuals followed by LWD with 671 individuals and debris dam with a total of 537 individuals. However, diversity and evenness was highest at the debris dam ($H^1 = 1.96$; $E = 0.67$). Among the retention structures the main functional feeding groups were the collector-gatherers. The abundance increased greatly due to increased abundance of midges (Chironomids) and collector gathering mayflies (*Baetis sp., Caenis sp., Afronurus sp.* and *Choroterpes sp.*) Contrary to the predictions of the River Continuum Concept (RCC), macroinvertebrates belonging to the shredding functional group that were dominated by Scirtidae (Coleoptera) and Tipulidae (Oligochaeta) constituted a small proportion of the total faunal abundance among the retentive structures. Organic debris dams and LWD, therefore, are extremely important components of the stream ecosystem. The present study showed that debris dam supported high diversity of rare macroinvertebrate taxa which is due to the highly heterogeneous architecture of dam, that offers a multitude of microhabitats for many functional feeding groups. They retain and regulate the size and amount of organic matter input within the system, thereby allowing it to be processed into finer size fractions rather than transported downstream in a coarse particulate form, which in turn affect the community structure of the stream ecosystem. It is therefore concluded that most of the relationships between macroinvertebrate assemblages and the BOM accumulation among the retentive features were due to the existence of good substrate grounds for refuge or attachment and as habitats for prey insects which various taxa feed upon and not BOM as food source.

CHAPTER ONE: INTRODUCTION

1.1 Background

The clearance of forest to provide agriculture, settlement and grazing land has had some of the most widespread human impacts on the natural ecosystems. In Kenya, the destruction of tropical forests has received a lot of attention because of the unique role they play in evolutionary and ecological terms, the diversity of the functions they serve and the accelerating threats to their existence. Mount Kenya acts as one of the main water towers for the country. The indiscriminate harvesting of the vegetation along low order stream banks in this region as a result of poor land use practices and lack of management skills is of a particular concern due to their importance in structuring and functioning of the stream ecosystems.

Early studies done by Thienemann in 1912 (quoted in Hynes, 1975) noted that streams are basically heterotrophic deriving most or all of their energy from uphill or the surrounding forest. Since then the importance and influence of the riparian vegetation on the structure and function of the stream ecosystems has been studied extensively over the last two and half decades (Webster and Meyer 1997; Decamps 1984 and Hynes 1975). Odum (1957), Teal (1957), Nelson and Scott (1962), Hynes (1963) and Tilly (1968) through their studies on the allochthonous organic matter that enters a stream, gave foundation for better understanding of organic matter dynamics in stream ecosystems.

1.2 Problem statement and justification

In Mt. Kenya region, an increase in the destruction of riparian vegetation and replacement with agricultural farmlands along low order streams is at the peak. Large tracks of indigenous forests are being cleared to give way for human settlement and exotic tree plantations. The removal of riparian vegetation along the tropical streams in the region is causing a lot of concern to ecologists and environmentalists due to its effects on the stream ecosystem. Similarly, in spite of the key role played by coarse particulate organic matter in the ecological functioning of low order streams, little attention has focused on this subject in tropical streams. Though some work has been carried out in Kenyan streams, no research studies have paid attention to organic matter-retentive feature interaction and its influence on the macroinvervtebrates functional feeding group distribution and species composition. In order to build a case for the conservation and management of such streams, studies on energetic and faunal constituents are urgently required. The present study therefore seeks to fill this gap.

1.3 Research questions

In order to comprehend and bridge the intriguing complexities which exists in the understanding of the ecological aspects in tropical running waters in relation to organic matter as energy resource and its influence on the functional feeding group categories, the following questions were addressed.

1. Is there any relationship between the types of organic matter retentive features and the amount and type of CPOM retained?
2. What is the relationship between the type and amount of CPOM retained by the organic matter retentive features and the colonization of invertebrate functional feeding groups?

The specific questions addressed were:

1. What are the types, sizes and location of organic matter retentive features?
2. What are the amounts and types of CPOM retained?

3. Which are the functional feeding group categories associated with CPOM retained?

1.4 Hypotheses

1. The stream bottom is characterized by homogenous retentive structures.
2. Benthic organic matter standing stock is uniformly distributed along the stream bottom, with a homogenous species composition.
3. There is a close linkage between the abundance of shredding macroinvertebrates and the distribution of BOM.

1.5 Objectives of the study

General objective

To assess the retention capacity of coarse particulate organic matter in a low order forested tropical stream.

Specific objectives

The specific objectives of the study are:

1. To characterize the retentive features along the river.
2. To determine the content, distribution and composition of organic matter standing stock.
3. To examine the dominant functional feeding group categories associated with the benthic organic matter standing stock.

1.6 Significance of the study

Benthic coarse particulate organic matter (BOM) entering low order stream through aerial and lateral inputs constitutes the primary source of energy for the stream invertebrates. Removal or alteration of the riparian vegetation may therefore impact negatively on the ecology of low order streams. Knowledge about the composition, distribution and content of benthic organic matter standing crop in low order tropical streams is therefore important to stream ecologists and fisheries managers in management and conservation of aquatic habitats. The information obtained from this study will form the foundation for further research by bridging some of the gaps, which exists in the knowledge on stream bioenergetics and its relationship with the macroinvertebrates functional feeding group categories.

CHAPTER TWO: LITERATURE REVIEW

The first comprehensive account of a complete budget of organic matter inputs, standing stocks and output of streams was studied by Fisher and Likens (1973) in Bear Brook, New Hampshire. This therefore made it possible to compare the relative importance of various sources and losses of organic matter and calculations of stream ecosystem budgets. Generally, organic matter in aquatic systems has been partitioned in the past on the basis of particle size. There has been proliferation of terms used to describe categories of material within the particulate phase. This prompted Boling *et al.* (1975) to propose a system consisting of six fractions for particles in the range 0.4um to 16mm. (Table 1.1). Thereafter, comparison both within and between streams was possible.

Table 1.1 Organic matter particle size ranges (Boling *et al.*, 1975)

Particle size range	Descriptor and dominant constituents	Acronym
> 16mm	Aggregate whole organic matter (2 or more leaves, pieces of bark, branches and masses of twigs)	AWOM
<16mm	Small whole organic matter (individual leaves)	SWOM
1mm - 16mm	Large particulate organic matter (leaf, twig and bark fragments)	LPOM
250um – 1mm	Medium particulate organic matter	MPOM
75um - 250um	Small particulate organic matter (small detrital and faecal fragments)	SPOM
0.45um - 75um	Fine particulate organic matter (fine detrital and faecal fragments	FPOM

Since Fisher and Likens (1973) estimated that allochthonous coarse particulate organic material (CPOM) was the source of 99.8% of the energy in Bear Brook, it is now recognized that headwater streams draining forested watersheds are dependent upon allochthonous coarse particulate organic material as a source of energy for stream biota (Cummins, *et al*., 1983; Webster 1983; Webster, *et al*., 1994). This was also reported by Leichtfried (1986), who states that the demand of the very abundant and diverse brook invertebrates is covered by energy bound to allochthonous organic matter which include twigs, leaves, logs and also the exudates. According to Petersen & Cummins (1974) and Vannote *et al.* (1980), sediment dynamics of such headwater streams are large and primary productivity is light limited due to shading by the riparian vegetation and hence have to rely on the input of terrestrial litter. Many studies have also shown that most of the particulate organic matter (POM) and dissolved organic matter (DOM) are derived from areas immediately adjacent to the stream channel (Sedell *et al*., 1974; Mc Dowel & Fisher, 1976; Winterbourn, 1976; Sidle, 1986; King *et al*.,1987; Chauvet & Jean-Louis, 1988; Cushing, 1988; Gurtz *et al*., 1988; Benson and Pearson, 1993; Sweeney, 1993). Similarly, Webster and Meyer (1997) and Pozo *et al.* (1997) noted that the main source of BOM along low order forested stream reaches is allochthonous organic matter, which enters the stream directly from the surrounding riparian vegetation or through the lateral bank surface run-off.

The retention of organic matter in the bed sediment is of primary importance in the understanding of the stream bioenergetics since the retention capacity dictates what amount of allochthonous organic matter is available in that particular stream reach in time and space (Mathooko, 1995). Speaker *et al.* (1984) noted that the main retentive features in high gradient streams include debris dams, cobbles, blocks, and bedrock while at low gradient streams mid-channel bars covered by small cobbles and gravel forms the main retentive features. The amount of CPOM retained by these features depends upon a complex interaction between stream power, particle size and the effectiveness of the retentive feature to retain CPOM. Further, the retention capacity of the stream is influenced by stream hydrological and riparian characteristics (Speaker, *et al.*, 1984). High roughness of the channel (e.g. large substrate particle size and abundant woody debris), combined with certain hydraulic conditions (e.g. presence of backwaters and interstitial flow), tends to increase the CPOM trapping efficiency of stream reaches. However, the content of BOM standing stock is strongly influenced by stream retentive characteristics. Campbell *et al.* (1992) reported that leaf species composition and the amount of woody debris material may also influence the content of detrital standing stock due to differences in their relative dry weights and processing rates.

Retention of organic matter in a given area of stream channel is a parameter determining density and composition of the stream invertebrates (Bretschko, 1990). Speaker *et al.* (1984) and Webster *et al.* (1994) found that when allochthonous litter enters a stream reach, it becomes saturated with water and settle on the bottom or it may be transported downstream and becomes stranded in dead zones associated with rocks, debris dam and other obstacles. However, imported CPOM is fractioned into fine particulate organic matter (FPOM), which is either retained, transported downstream or seeping into the bedsediments (Naiman and Sedell, 1979). Magana (2000) concluded that retention involves entrapment of organic detritus in transport and subsequent storage in the stream as benthic organic matter (BOM).

A broad spectrum of processes has been shown to influence and govern the distribution and composition of benthic organic matter (BOM) standing stock (Naiman and Sedell, 1979, Minshall *et al.*, 1983, Conners and Naiman, 1984). Minshall (1978) reported that the extent of canopy and stream physiography which vary markedly in time and space govern such variations in distributions. These variations are dependent on complex interaction between hydrological regimes, stream geomorphology, organic detritus input and microbial processing of organic detritus (Naiman & Sedell, 1979; Dudgeon, 1982; Bretschko 1990; Maridet *et al.*, 1995). Naiman *et al.* *(*1987) showed that BOM tends to decrease downstream as channels become larger and riparian vegetation influence decline. Channel characteristics like gradient and interaction between main channel and flood-plains also influence the distribution of BOM (Benke and Wallace, 1990; Smock, 1990). Nevertheless, the importance of longitudinal linkages decreases in rivers with extensive floodplains where storm could serve as an element subsidy by mobilizing previously unavailable nutrient sources thereby increasing the amounts of detrital standing stocks in these ecosystems (Meyer & Tate, 1983). Additionally, individual reaches are also influenced by local factors such as riparian vegetation characteristics (Minshall *et al.*, 1983; Conners and Naiman, 1984; Jones, 1997).

Bilby & Likens (1980) and Bilby (1981) noted that heterogeneity of channel structure and frequency of obstacles such as debris dams, roots and rock outcrops enhance retention of CPOM thereby increasing the rate of accumulation of BOM in streams. The magnitude of discharge variations directly affects the retention capacity of streams (Snaddon *et al.*, 1992; Maridet *et al.*, 1995; Ractliffe *et al.*, 1995). Mwangi (2000) reported that reduced rainfall, low discharge and increased temperature during the dry season promote significant increase in CPOM inputs due to increased leaf defoliation. The rate of breakdown of organic detritus litter (Petersen & Cummins, 1974; Casas and Gessner, 1999) as well as quality, quantity and timing of allochthonous inputs in streams also play an important role in determining the standing stock of benthic organic matter (Bretschko, 1990; Bretschko & Moser 1993).

Once the organic matter falls within the stream channel, it can either be entrained by the water current or retained in the "dry-store zone" and the "wet-store zone" or the overflown zone of the stream. Dry zones are channel areas that are characterized by periodic flooding and whose retention capacities depend on flood frequency and development of terrestrial vegetation (Bretschko and Moser, 1993). During flooding, deposited materials in the dry zone are washed into the main stream channel and transported downstream or retained within the channel retentive features where processing is continued (Mwangi, 2000). Bird and Kaushik (1981) noted that leaves if not already leached undergo a rapid weight loss because of soluble compounds within about 24 hours. The soluble compounds which are important sources of dissolved organic matter (DOM) are rapidly removed from water by both biotic (microbial) and abiotic factors such as flocculation (Wetzel and Manny, 1972). In general, fragmentation of the material increases with its time of retention at or near its site of origin. Speaker *et al.* (1984) noted that the initial capture and subsequent retention of the transported organic material is dependent on both physical characteristics of the stream and the character of its riparian vegetation. When the stream bed is uneven, buoyant particles such as leaves are likely to be trapped while woody material falling into the stream from trees may lodge between boulders and provide a framework upon which other transported material may accumulate. This is the genesis of in-stream structures like leaf packs and debris dams which might influence the distribution of invertebrates in the bedsediment (King *et al.*, 1987).

Large accumulations of woody debris and organic matter (debris dams) are common within natural low order tropical streams. They greatly modify the abiotic framework of the streams such as water velocity patterns, sedimentation processes and retention of particulate dissolved organic matter (Dobson *et al.*, 1992; Borchardt, 1993; Webster *et al.*, 1990). Observations by Jones and Smock (1991), found debris dam acting as the primary retainers of POM during times of high discharge. Debris dams alter channel morphology and thus enhance stream heterogeneity by providing structurally complex habitats for macroinvertebrates colonization (O' Connor, 1991; 1992; Friberg and Larsen, 1998). In addition to this, they increase the retention of organic matter upto 75% of the standing stock in the stream (Bilby and Likens, 1980). Although the role of debris dam accumulation for the export of energy and material have been thoroughly studied (Winker, 1991; Weigelhoefer and Waringer, 1999), little attention has been paid to the patterns of macroinvertebrates distribution in relation to the CPOM quantity in the tropics.

One of the most important contributions of forests to streams is the addition of large wood (Vannote *et al.*, 1988; Likens and Bilby, 1982; Hedin *et al.*, 1988). In fact, almost the entire large woody debris originates from the riparian zone (Webster, 1977; Sedell & Frogart, 1984; Harmon *et al.*, 1986; Moser, 1994; Keller & MacDonald, 1995). It has been shown that most of the structural and functional properties of small streams in forested areas is controlled by large woody debris (LWD) (Bilby and Likens 1980; Harmon *et al.*, 1986; Bisson *et al.*, *1987;* Bilby and Ward, 1989). Related studies in streams draining old-growth, clear-cut and second-growth forests in Southern Washington indicate that changes in LWD amounts, characteristics and function occur very rapidly following removal of streamside vegetation (Bilby and Ward, 1991). In addition to this, streams with LWD retain POM more efficiently than streams without wood (Bilby and Likens, 1980; Bilby, 1981; Speaker *et al.*, 1984; Speaker, 1985; Golladay *et al.*, 1987; Webster *et al.*, 1988). Similar observations were made by Naiman and Sedell (1979) and Bilby & Likens (1980). They noted that a large proportion of the standing stock of POM in streams is often associated with LWD. Trotter (1990) also reported that reaches of stream with stored LWD retained twice the organic matter than reaches without wood.

On the other hand, studies in Pacific Northwest streams have shown that various management activities in and adjacent to the channel influence the amounts and characteristics of LWD. For example, removal of wood from rivers for navigation or to provide upstream access for anadromous fishes has greatly reduced LWD amounts in some systems. Sedell and Luchessa (1982) and Bilby (1984) further noted that even though the practice no longer occurs, there are many streams where amount of LWD and the composition and structure of the riparian vegetation are influenced as a result of other human activities. Similar sentiments were given by Hedin *et al.* (1988) who proposed a direct relationship between the number of logs in a stream and the successional state of the forest through which the stream runs and suggested that disturbances in forests can impact streams for more than 100 years.

Apart from interaction with drainage basin geomorphology, large wood changes stream morphology and creates depositional areas for storage and processing and can itself serve as habitat (Nilson and Larimore, 1973; Keller and Swanson, 1979; Keller and Tally, 1979; Benke *et al.*, 1985; Sedell *et al.*, 1988). Molles (1982) showed that streams with no wood have low standing stocks of organic matter and support few shredding insects. In some cases, large woody debris can be essential for the establishment or survival of plant and animal riparian communities. For example, Miller and Burger (1990) have shown the importance of coarse debris and interaction with groundwater level on the establishment of the salici-mycicarietum community. In addition, Hering and Reich (1997) reiterated on the importance of LWD as a major ecological consequences not only for the stream itself but also for oceanic ecosystems.

High retention by cobbles and boulders has been shown to slow downstream transport of organic matter resulting into short spiraling distance (Minshall *et al.*, 1983; Naiman *et al.*, 1987). While carrying out a study on bedsediment, organic matter and macroinvertebrate response to changes in catchment land use along the upper reaches of Sagana River, Mwangi (2000) found large amounts of bark and wood debris at forested wetted zones due to abundant cobbles and boulders. Additionally, Jones and Smock (1991) reported increased leaf retention with low flow in high gradient, cobble-dominated stream.

The stream invertebrates have been classified into functional feeding groups based on their modes of feeding (Table 2.1) (Merritt, Cummins and Burtons, 1984 and Allan, 1995) as opposed to the taxonomic units or food eaten. (Cummins and Klug, 1979). However, this classification pose some practical problems since the diet of macroinvertebrate species can be varied depending on age (Fuller and Stewart, 1977) as well as on site (William and Williams, 1982). Predaceous stoneflies have been found ingesting more periphyton and detritus when small and more animal prey when large (Allan, 1982). Short *et al.* (1980) found collectors much more numerous than other functional groups in leaf packs. However, it is the shredders that generally account for most of the leaf weight loss, about 21% (Petersen and Cummins, 1974). Cummins (1988) predicted that peak shredder activity should occur when the suitability of a leaf pack as a shredder habitat would decline when only 50% remained because food and hiding places would become increasingly difficult to obtain. But Short *et al.* (1980) suggested that the remaining skeletonized leaf fragments would continue to act as a filter and the accumulated materials such as fine particulate organic matter (FPOM), would attract collector organisms. As noted by Webster (1983) it is therefore quite difficult to assign functional feeding groups to various taxa because invertebrates are known to switch from one food type to another as food base changes.

According to the RCC concept, the occurrence of large amount of coarse particulate organic matter in low order streams should be associated with a dominance of shredding macroinvertebrates (Vannote *et al.*, 1980; Cummins, 1974). In New Zealand streams, for example, Winterbourn *et al.* (1981), found a close association between abundance of benthic organic matter standing stock with abundance of shredding macroinvertebrates. Leaves accumulate in areas of reduced current and tend to form packs or dams on the streamside of rocks, sticks or other obstructions. These accumulations then, provide the sites for shredder activity. The feeding activities of large shredders such as *Tipula spp.* are important in loosening up the material that aids in penetration by other species. Lepidostomatid caddisflies, nemourid stoneflies and snails are more abundant on small accumulation or on individual leaves than within closely appressed leaf packs (Anderson and Sedell, 1979).

Zoobenthic organic matter in the bedsediment is also a very important energy resource for stream invertebrate and fish (Mathooko, 1995). The relative abundance of functional feeding groups of invertebrates in a particular stream segment indicate the relative availability of various organic substrates. An abundance of shredders indicates that leaves are a major energy source whereas high populations of grazers suggest that photosynthesis in the stream is important. Filter feeding aquatic invertebrate occupy an important niche in the functioning of stream ecosystems (Wallace *et al.*, 1977) since they

Table 2.1. Functional Feeding Group (FFGs) categories of invertebrate consumers (based on Meritt, Cummins and Burtons 1984 and Allan 1995).

Feeding role	Food source	Feeding mechanism	General particle size in microns	Examples
Shredders	Living vascular hydrophyte plant tissue	Herbivores-chewing and mining	$>10^3$	Several families of Trichoptera, Plecoptera, Crustacea, some Diptera, snails
	Decomposing vascular plant tissue and wood-course CPOM	Detritus-chewers, wood borers, and gougers		Some members of the caddisfly families Limnephilidae and Lepidostomatidae, the tipulid subfamilies Limnoniinae and Tipulidae, and a few species of Chironomidae and Coleoptera
Filter Feeders	FPOM and microbiota, especially bacteria filtered in water column	Collect particles using setae, specialized filtering apparatus or nets and secretions	$<10^3$	Caddisfly larvae of the family Hydropsychidae, Philopotamidae and Polycentropodidae, black fly larvae (Simulidae)
Deposit-feeders/ collector-gatherer	FPOM and microbiota, especially bacteria and organic microlayer	Collect surface deposits, browse on amorphous material, burrow in soft sediments	$<10^3$	Many Ephemcroptera, Chironomidae (particularly subfamily Orthocladiinae) and Ceratopogonidae
Scrappers	Periphyton, especially attached algae and associated material	Scrapping, rasping and browsing adaptations	$<10^3$	Several families of Ephemeroptera and Trichoptera, some Diptera, Lepidoptera and Coleoptera
	Macrophytes	Pierce tissues or cells and sunk fluids		Some species of Trichoptera, Ephemeroptera and Chironomidae (mainly Orythocladius sp.)
Predators	Animal prey	Biting and piercing	$>10^3$	Odonata, Megaloptera and Plecoptera, Trichoptera, Diptera and Coleoptera.

capture and alter the component of FPOM in transport, thereby influencing the food available to collectors and also provide important energy subsidies to predators.

Anderson and Kikkairu (1986) suggested that the environs are made up of mosaics ("harlequin" environment) with mosaic patches of organic matter resources fluctuating in time and space. This was also emphasized by Solbreck (1978) who discussed the environment as containing an archipelago of habitat patches. The distribution of various forms of organic matter (living plants and animals, dead organic particles and biofilm) may vary in the long and cross profiles of streams and rivers and create organic matter gradients. Apart from these gradients, there is habitat heterogeneity. According to Washburn and Cornell (1981), habitat heterogeneity is a pervasive characteristic of natural environments and within this context plants and animal populations persist in a mosaic of occupied and unoccupied sites. However, Elton (1966) recognized environmental patchiness as fundamental to the distribution of organisms. He noted that the animals' response to patch will be a consequence of the scale and richness of the patch in particular as well as their own mobility. According to him, mobility enables organisms to enter new habitats thereby avoiding environmental stresses in the old habitat and extending the range of population. In a nutshell, the movement may result in a more complete utilization of resources within the habitat. Different patches are ranked according to the density and/or quality of the organic matter resources contained within them (Orians and Pearson, 1978). The structure and function of zoobenthic community may be influenced by the variation in quantity and quality of the organic matter resources in the individual patches.

The dynamics of CPOM in lotic ecoystems have been well studied in temperate Australia (Blackburn & Petr 1979; Bunn, 1988; Campbell *et al.*, 1992), Europe (Dudgeon &

Bretschko, 1996), America (Webster & Meyer, 1997) and in South Africa (King *et al.*, 1989; Davies, 1987). However, in the tropics, very few studies have been done (Stout, 1980; Dudgeon, 1982; Jackson and Sweeney, 1995). Some published data on the biological studies on the benthic organic matter in tropical Africa (Papua New Guinea) exists (Dudgeon, 1994; Dudgeon and Bretschko, 1996). Although there has been much interest in the role of riparian vegetation on stream bioenergetics, there is still little information about organic matter-riparian vegetation interaction. In Kenya, studies have been carried out on the organic matter and the invertebrate drift of Naro Moru River (Mathooko, 1994; Mathooko and Mavuti, 1992), the inputs and retention of coarse particulate organic matter in Njoro River (Mathooko, 1995; Magana, 2000). Mwangi (2000) also carried out a study on the inputs of coarse particulate organic matter and the distribution and composition of macrobenthos among sites differing in their land use characteristics along the upper reaches of Sagana River. These studies paid no attention to organic matter-retentive feature interaction and its influence on the macroinvervtebrates functional feeding group distribution and species composition. The present study therefore seeks to fill this gap.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Introduction

Sampling of coarse particulate organic matter (CPOM) standing stock and its retention features was carried out along a 100 metres stretch along Sagana River, Kenya. Sampling was carried out every fortnight between February 2003 and October 2003. In May 2003, heavy rainfall occurred around the study area curtailing sampling till August 2003 when sampling resumed.

3.2 The study area

3.2.1 Sagana River catchment and location

Sagana River occurs in Nyeri district, Central Province, Kenya (Fig. 3.1). It is a second order stream (Strahler, 1957), originating from the South-eastern slopes of Mt. Kenya at about 4000 m asl (Fig. 3.2). Its catchment stretches from latitude 0^0 13'S to 0^0 22'S and from longitude 37^0 16'E to 37^0 03'E draining a watershed area of approximately 2256 Km^2 (Mwangi, 2000). The length of the river from the source to the confluence point with Nairobi River is approximately 43 km.

The Sagana river is joined by two small moorland derived tributaries (1st order) at an elevation of about 2800 m asl and 2470 m asl on its right bank, respectively. To the right bank of the river at an altitude approximately 2285 m, is a Government Trout Hatchery called Kabaru. Two tributaries and streams derived from the forest- Gathaikaini and Little Sagana joins at about 2205 m and 2100 m, respectively. Additionally, small tributaries (Gunia and Satumi) (1st order) derived from Ragati forest join on its left bank at approximately 1940 m and 1805 m asl, respectively. The sampling site (Kiganjo Trout Farm - State Lodge) is located on its left bank at an elevation of 1790 m asl. Thego river which is a second order river (Strahler, 1957) derived from the mountain, join Sagana river on its right bank and then flows as a third order stream joining Nairobi river at an altitude of approximately 1660 m asl. The river is ephemeral throughout its course due to several water abstraction projects which are operational and some under construction upstream (Table 3.1). The watercourses in the area generally display radial pattern of drainage (Fig. 3.3).

Mount Kenya rises to an altitude of 5195 m along the equator and has a steep ecological gradient. It is one of the largest most ecologically significant and economically important natural forest areas in Kenya and is considered among the highest priority forest for natural conservation (Wass, 1995; Winiger *et al.*, 1990).

Table 3.1 Water abstraction projects status above Sagana Fisheries Intake

	NAME OF PROJECT	PERMIT NO.	AMOUNT ALLOCATED	REMARKS
1.	Ndathi Mbiriri	26442	$197m^3$ - domestic $800m^3$ - irrigation	Operational
2.	Kazara W/project	D.W.B. Level	$4.86m^3.d^{-1}$ -domestic $40m^3.d^{-1}$ - irrigation	Under construction
3.	Gikanga W/P	P26459	$101m^3.d^{-1}$ - domestic $522m^3.d^{-1}$ - irrigation	Operational
4.	Muthaiga W/P	P28467	$18m^3.d^{-1}$ - domestic $272m^3.d^{-1}$ - irrigation	Operational
5.	Maragima W/P	W.A.B. Level	$94m^3.d^{-1}$ -domestic $1350m^3.d^{-1}$ -irrigation	Under construction
6.	Kiahia/Karurumo W/P	T.C.B. Level	$31.050m^3.d^{-1}$ -domestic	Under construction
7.	Iruri W/P	W.A.B. Level	$473m^3.d^{-1}$ -domestic $2250m^3.d^{-1}$ -irrigation	Under construction
8.	Sagana Scheme W/P	P20951	$88100m^3.d^{-1}$ -irrigation	Operational

Source: Fisheries Department: Kiganjo (2003)

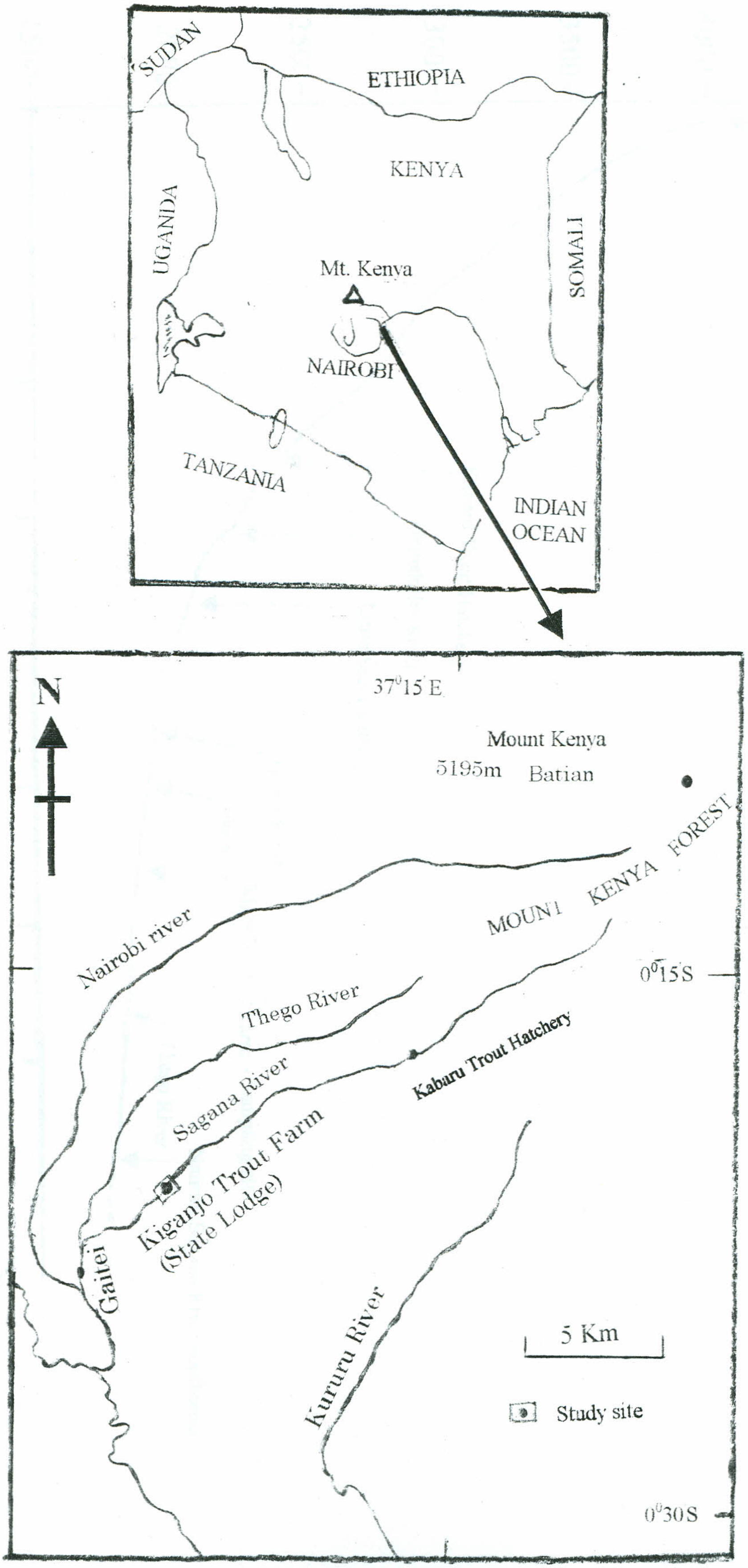

Fig. 3.1 Location of Sagana River, Kenya showing the study site. (State Lodge)

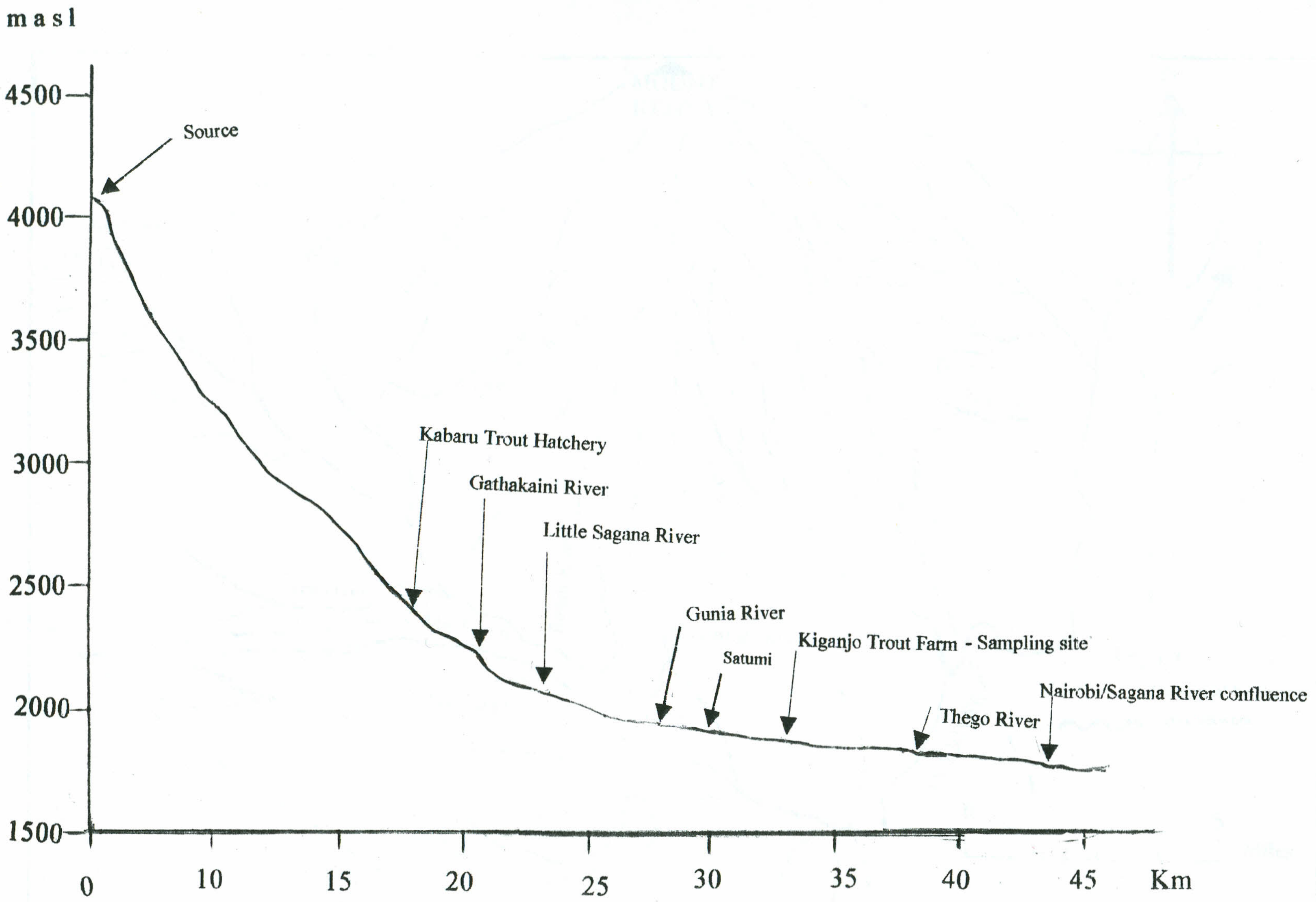

Fig. 3.2 Longitudinal profile of the Sagana River drawn from the Geological map of the Mount Kenya area, Sheet No. 121.

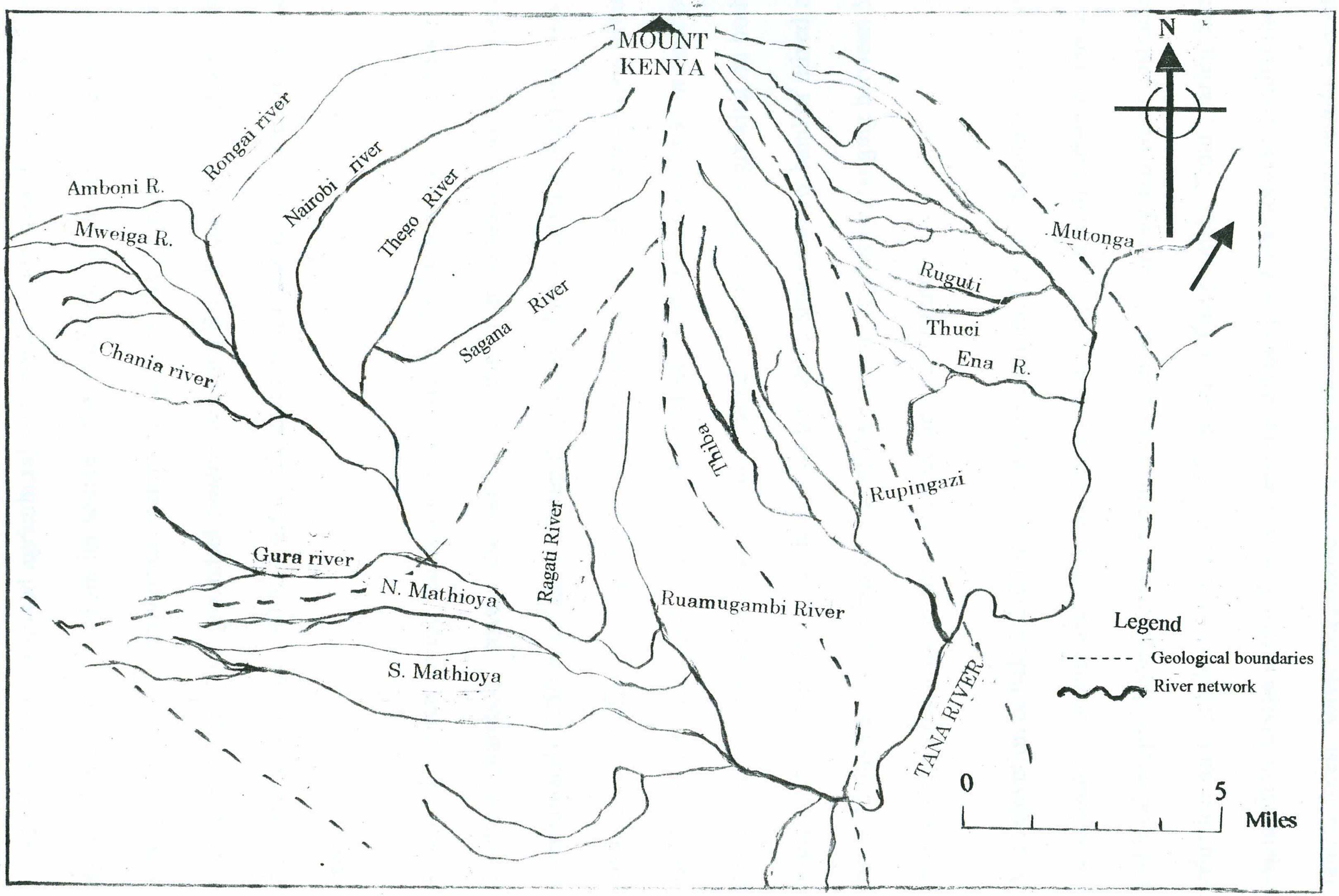

Fig. 3.3 Drainage pattern of Mt. Kenya.

3.2.2 Vegetation, climate and geology

Sagana River drains a mixed agricultural and forested watershed (Fig. 3.4). In the upper region of Sagana river (from its source), the catchment is an open moorland which is heavily grazed by herbivorous mammals such as the antelopes. The vegetation is dominated by the giant groundsel *Senecio brassica* R.E. Fr and Th. Jr. (Baker, 1967). In this area (alpine belt- 4000 - 6000 m), there is no vegetation cover along the river channel.

A dense luxuriant forest vegetation dominated by *Podocarpus sp.*, *Arudinaria alpina* K.Schum (bamboo) covers the section of the river extending to an elevation of approximately 2280 m asl along a steep deep valley. The vegetation is grazed upon by the elephants and buffaloes. This has led to development of small-scale tourism offered by the Mountain Lodge Hotel found within the Mount Kenya National Park. In most parts of this region, the riparian vegetation is dominated by natural forest growing on both sides of the river channel. The river then flows through a small narrow band of mixed natural forest. In this section, the buffer strip of the riparian vegetation, ranging between 5 to 20 metres, covers the bank on either sides of the river channel.

At an elevation of below 2100 m asl, the mixed natural forest is dominated by *Croton sp.*, *Clerodendron capense* and *Ficus sp.* The riparian zone is often disturbed by the livestock and local people through tree poaching, illegal charcoal burning and water abstraction for irrigation and laundry. At around 1790 m asl, a Government Trout rearing farm and Sagana State Lodge exists. This is where the sampling site was located. Behind the mixed natural forest, forest plantations consisting of *Cyperus sp.*, *Pinus patula* Schiede and Deppe ex Schiede and *Eucalyptus saligna* Sm. occur for a greater length of Sagana River.

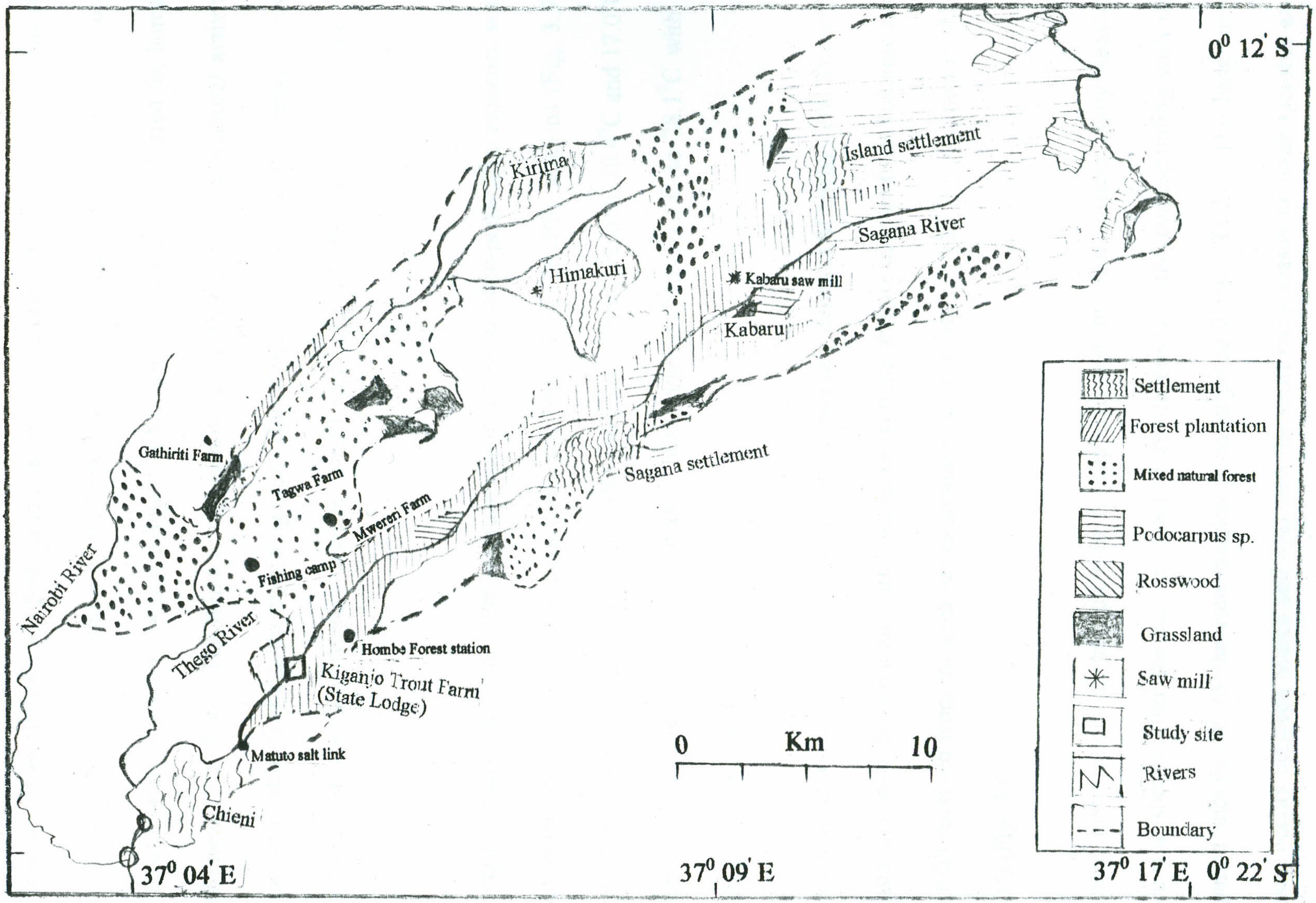

Fig. 3.4 Vegetation and land use patterns along the Sagana River, Kenya.

Management of forest plantation has been based on the shamba system - a principle of the early British settlers. However, the government reached a decision to evict thousands of squatters from the gazetted forestland in Kenya in the year 2003 and eventually banned the shamba system due to abuse by the beneficiaries. As noted by Mwangi (2000), large areas of forests within the lower catchment of Sagana River have been cleared for human settlement (Fig. 3.4). The trend is still continuing with the main agricultural activity being vegetable farming through irrigation. Ranching, sheep and goat keeping is also practiced. At the downstream section, small-scale agriculture and rock mining is practiced.

Along the study reach, the river is structured in a typical riffle-pool-riffle sequence with predominantly soft substrata in pool areas and bedrock in the riffle sections (Fig. 3.5). Annual mean water temperature at the riffle and pool is approximately 18.4^0C and 17.0^0C respectively. Air temperature is generally high ranging from 20.3^0C to 28.1^0C with a mean of 25.1 ± 1.62 CI.

The whole area overlies volcanic larva and fragmentary deposits of tertiary era. The soils consist mostly of brown loam with high humic content and are derived from volcanic ash. Rainfall received from the area varies annually, with a mean of 889.7 ± 49.5 mm (1981 - 2003) (Fig. 3.6).

Annual distribution of precipitation is characterized by two distinct rainy seasons occurring shortly after the sun has reached zenith position and corresponding with the apparent movement of the Inter-tropical Convergence Zone (ITCZ). The long rainy season occurs between March and May and the short rainy season between October and December (Fig. 3.7).

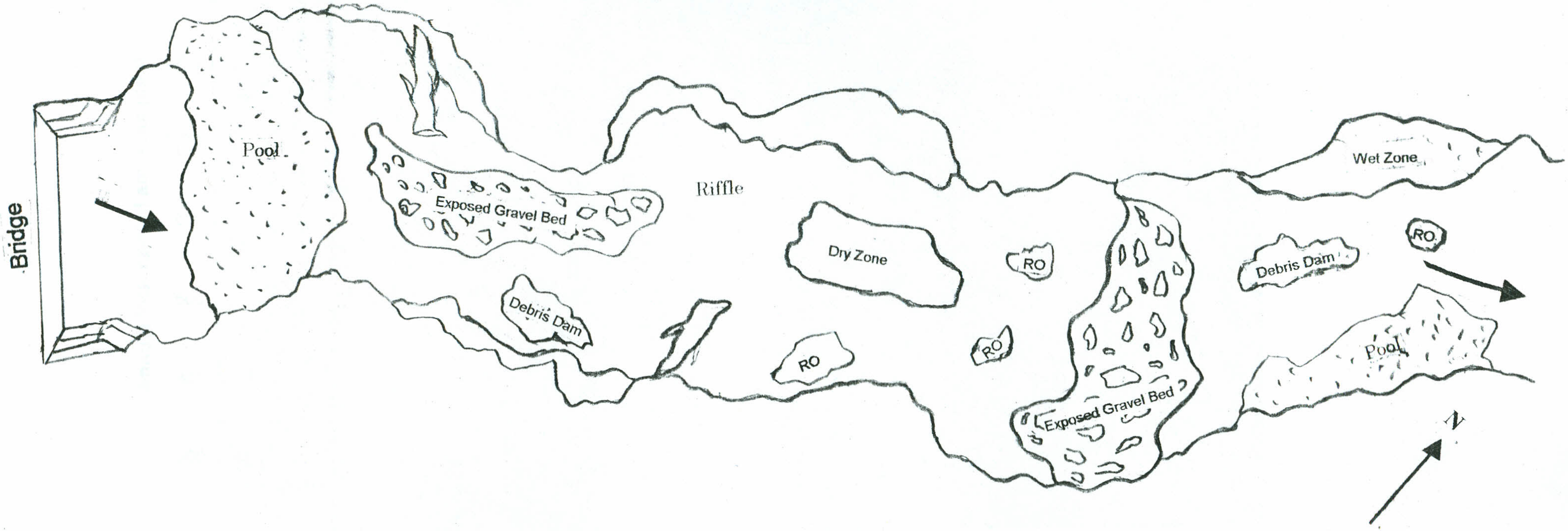

Fig. 3.5 The topological structures at the study site/reach of the Sagana River, Kenya during the dry season on 17th February, 2003.

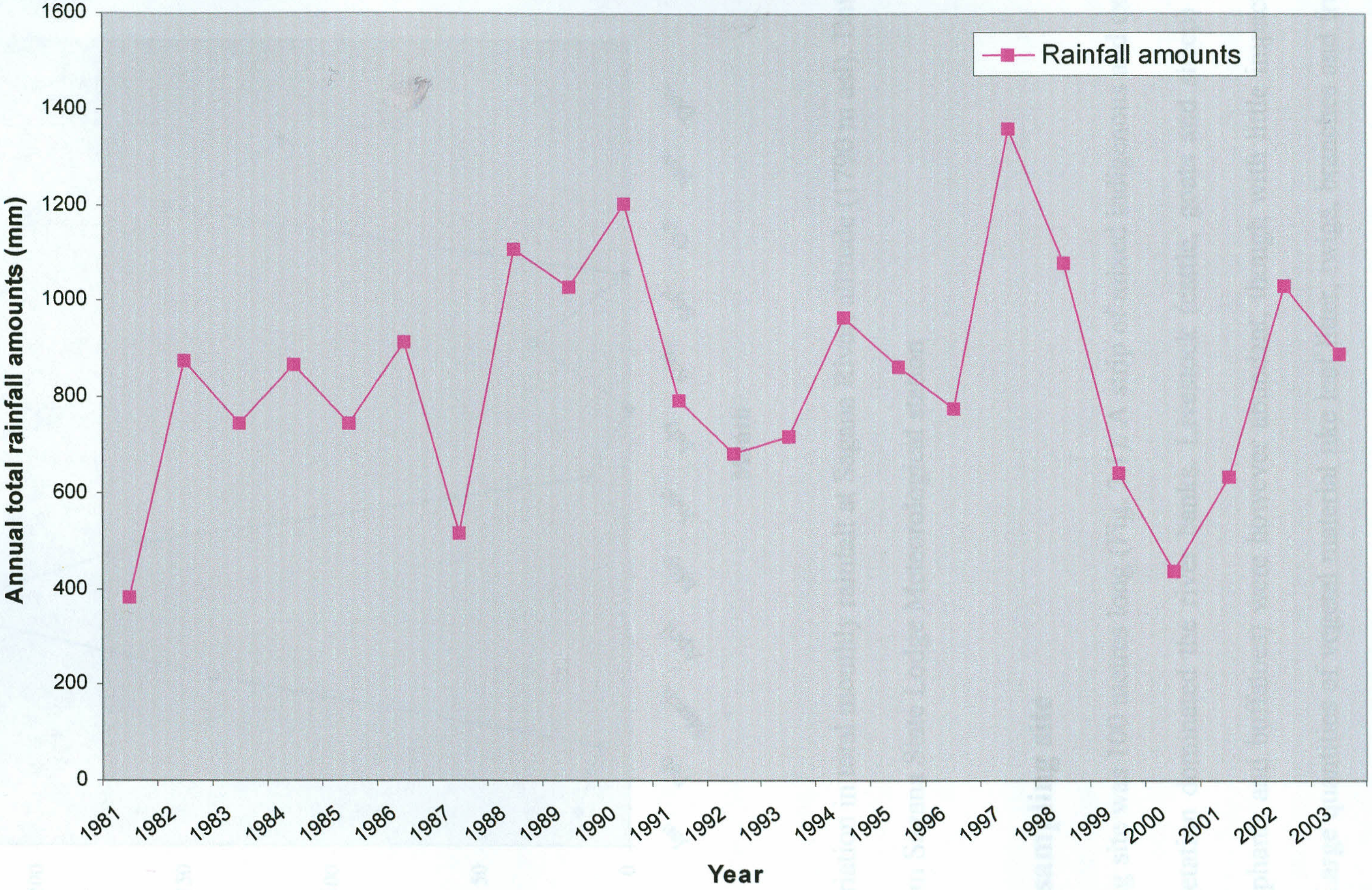

Fig. 3.6. Variation in total annual rainfall at Sagana River, altitude (1790 m asl). Data from Sagana State Lodge Meteorological station

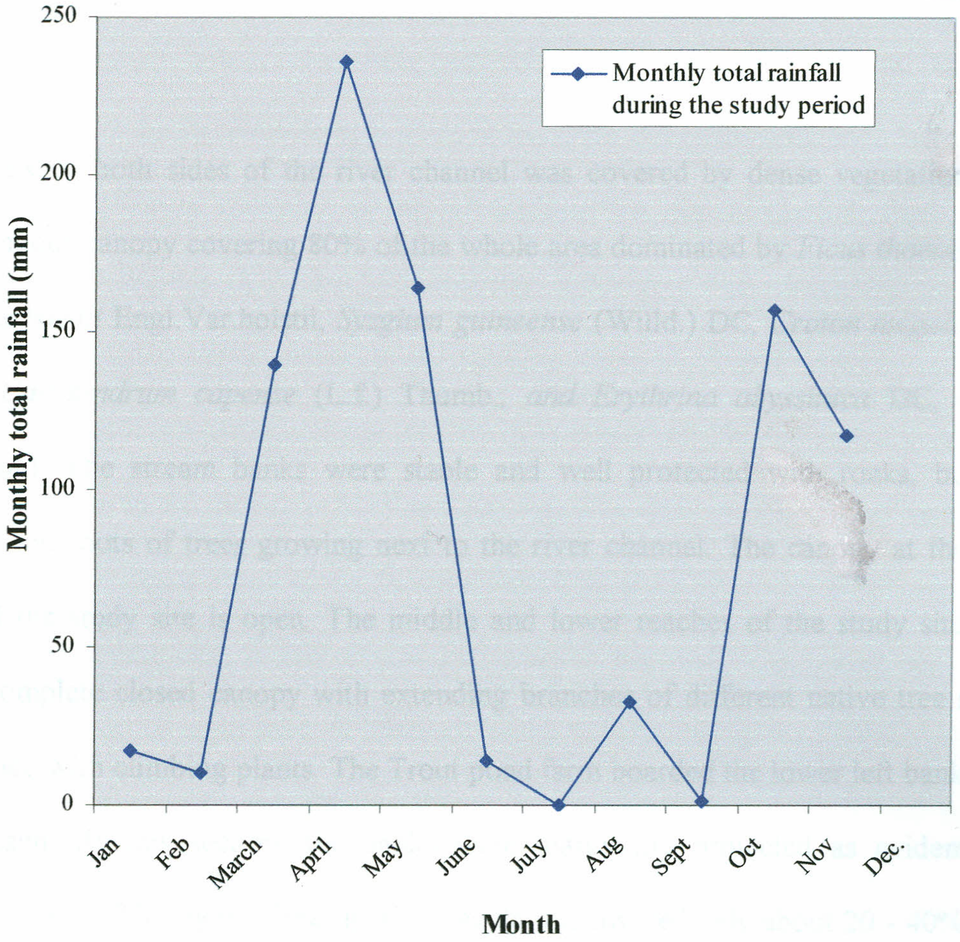

Fig. 3.7. Variation in total monthly rainfall at Sagana River, altitude (1790 m asl). Data from Sagana State Lodge Meteorological station

3.2.3 The sampling site

The sampling site was 100 metres long (Fig. 3.1). A strip of mixed indigenous and exotic riparian vegetation dominated the river banks. Livestock (cattle, goats and sheep) and wildlife (elephants and buffaloes) were however abundant, though with little impact on the stream. Large quantities of vegetal material like leaf litter, twigs, branches and fruits, which are at different stages of decomposition, strewed the riverbank at the study site. The colour of the water was very clear except during the rainy seasons when it attained dark brown coloration due to the sediment load as a result of soil erosion in the catchment area.

The banks on both sides of the river channel was covered by dense vegetation and a discontinuous canopy covering 80% of the whole area dominated by *Ficus thorningii,*BL *Cussonis holstii* Engl.Var.holstii, *Syzgium guineense* (Willd.) DC, *Croton megalocarpus* Hutch, *Calodendrum capense* (L.f.) Thumb., *and Erythrina abyssinica* DC, (Visual estimation). The stream banks were stable and well protected with rocks, boulders, bedrock and roots of trees growing next to the river channel. The canopy at the upper reach of the study site is open. The middle and lower reaches of the study site had a nearly complete closed canopy with extending branches of different native tree species intertwined with climbing plants. The Trout pond farm boarded the lower left bank of the study reach. At this section, the banks were marginally protected as evident from erosional marks. The roots of the riparian vegetation covered only about 20 - 40% of the bank. Generally, the habitat was complex with a variety of types including different sizes of boulders, macrophyte growth on the dry zone, undercut banks and a rough bottom profile providing a diverse habitat for the fauna. The exposed gravel bar covered by large cobbles, boulders and bedrock covered more than 65% of the bottom. Both pool and riffle biotope characterized the river channel. The bottom substrate at the riffle mainly consisted of bedrock, boulders and several rock outcrops inundated only during high floods. At bankfull flows, pools and riffles were inundated to such an extent that the channel appeared to have a uniform gradient but local pool-riffle-bar features emerged as flow receded. The channel shape of pool-riffle reaches was often sinuous and contained a predictable sequence of pools, riffles and bars in the channel depicting a braided stream reach.

There were a variety of relief structures such as exposed gravel bar at the riffle mid channel, plunge pool, lateral scour, eddy pool and runs. Bedrock, boulders and many rock outcrops predominantly covered the bottom of the riffle. An obstruction by a large woody debris (LWD) near the shoreline on the left bank of the middle reach formed a lateral scour pool with a depth of 52 cm. Additionally, a concrete line constructed across the stream channel at the upper section of the study reach to block and re-direct water flow during periods of low water discharge into the trout ponds resulted into vertical fall of the water giving rise to the plunge pool. The presence of an eddy pool was also noted at the right bank of the upper reach along the shoreline behind large woody debris measuring about 20 cm in diameter. A run created between the exposed riffle gravel bar and the shoreline at the upper right bank of the study reach directed the water flow into the trout ponds. It was steep with fast flowing water and generally deep (20-70 cm) near the shoreline.

The presumed bankfull width as indicated by scour lines, vegetation limits and the presence of flood deposits ranged from 0.3 m to 2.8 m averaging 1.3 m. The stream width taken at low flow ranged from 7.6 m to 15.1 m with a mean of 10.36 ± 1.11 m while the one taken at bankful discharge ranged from 15.6 m to 25.1 m averaging 21.11 ± 1.67 m at 95% CL. The water depth varied considerably with seasons and sections. Profiles taken on 3rd March 2003 and 15th September 2003 at low flow shows that the water depth ranged from 0 cm to 153 cm with a mean of 49.7 ± 20.1 cm (Fig. 3.8 & 3.9).

3.3 Physical parameters

On every sampling occasion, the physical variables were measured at the study reach. Water and air temperatures were measured using a portable thermometer to the nearest

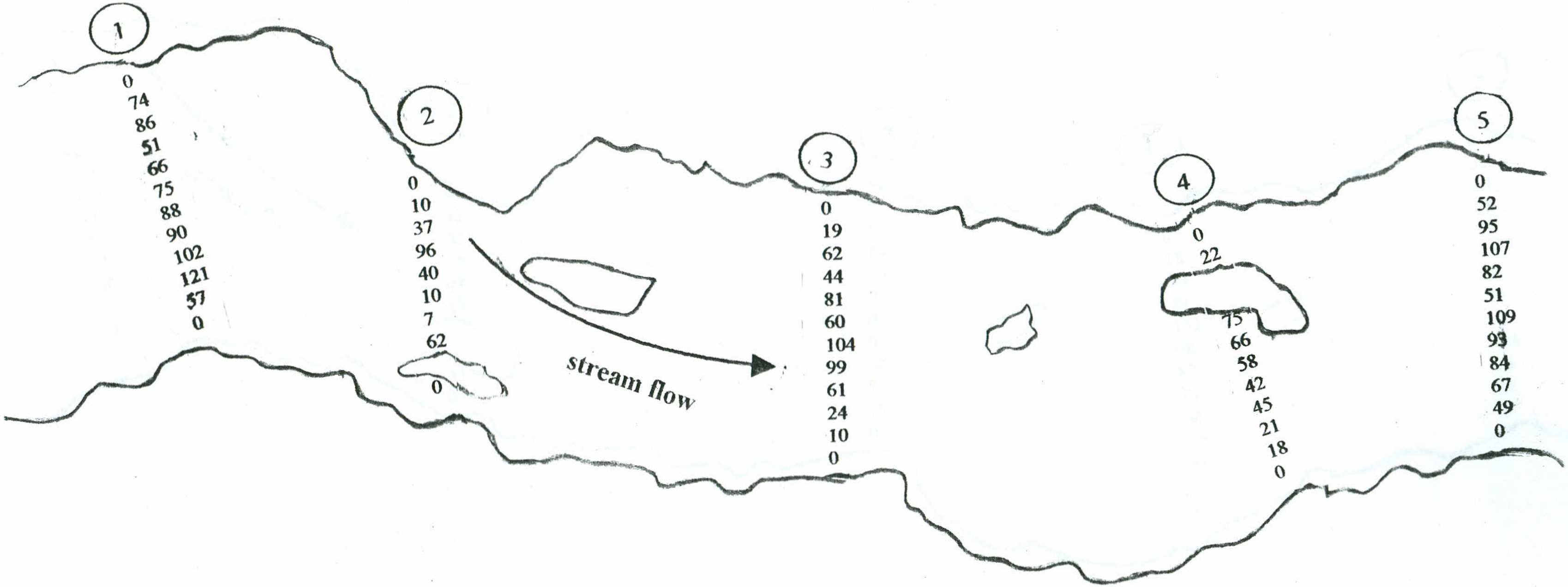

Fig. 3.8 Map showing the water depth in cm at low discharge during the dry season on 15th September, 2003.

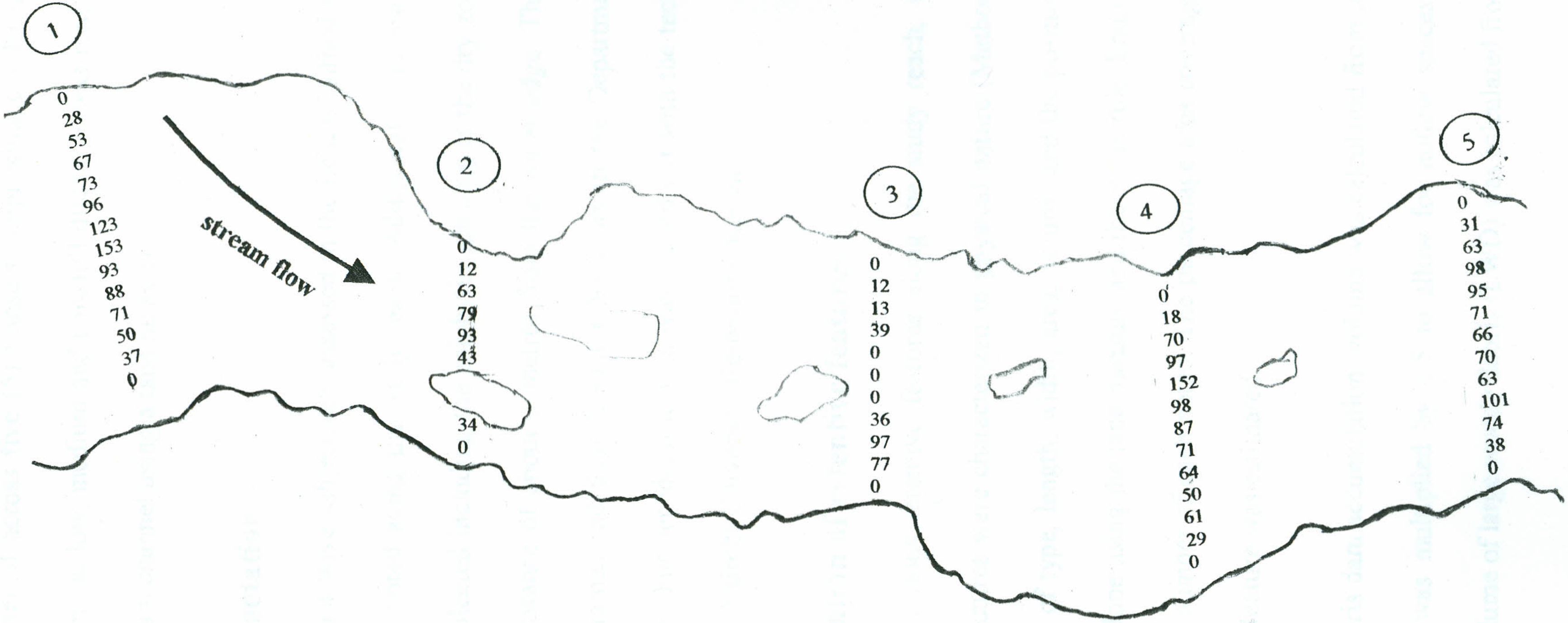

Fig. 3.9 Map showing the water depth in cm at low discharge during the dry season on 3rd March, 2003.

0.1 unit. Data on rainfall was obtained from Sagana State Lodge Meteorological Station located 200 metres from the sampling site. Stream depth was measured using a meter rule at every 50 cm interval across five (5) transects approximately 10 metres apart. The average stream width at low, medium and bankfull discharge was measured at 10 cross-sections of the stream channel using a tape measure.

3.4 Riparian vegetation

The dominant species were subjectively assessed in the field (Canfield and Hoyer, 1988) and their presence noted along the study reach. Additionally, quantitative samples of vegetation were collected including the epiphytes growing at the dry zone and along the shoreline upto a distance of about 3 metres from the water edge. They were pressed between wooden frames and then dried for 36 hours in the Department of Botany at Kenyatta University. Further identification was carried out with the technical assistance of Mr. Mathenge of Nairobi University Herbarium, Kenya.

3.5 Characterization of retentive features

To determine the various retentive features along the study reach, various instream organic matter structures were characterized in physical nature (Mathooko, 1995). This was made in terms of type, length, width, area, volume and the position of occurrence. Measurement was done using the tape measure and the metre rule. Enumeration was also carried out and the number of each noted. The percentage area coverage by each of the dominant retentive feature was estimated.

For each of the debris dam accumulation, volume was calculated from length, width and height. The value was multiplied by 0.5 to allow for hollow spaces (Robinson and Beschta, 1990). Volume of large woody debris (LWD) was calculated from the formulae:

$$\text{Volume} = \left(D_1^{\,2} + D_2^{\,2}\right) \times L \times \frac{\pi}{8}$$

Where: D is the diameter of either end and;

L is the length of LWD (Murphy and Hall, 1981).

Only the main trunk of whole trees was measured neglecting branches and twigs (Hering *et al.*, 2000). LWD was defined as any piece of wood larger than 10 cm in diameter and more than 2 metres long. Any organic material that did not qualify as LWD by this definition was not considered during the study.

The method used by Behmer and Hawkins (1986) in determining the inter-cobble sampling units was employed to calculate the area of the streambed under the exposed riffle gravel bar. Composition and distribution of the bottom substrate within the structures was estimated visually across the bed. Different sediment types were classified according to Gordon *et al.* (1992).

3.6 Benthic organic matter standing stock

Benthic Organic Matter Standing Stock (BOM) was estimated among different types of retentive features by collecting all the litter materials occurring within the Hess Sampler with an area of 0.0299m^2 (Fig. 3.10). The small area sampler used was inadequate for measuring inputs of large woody debris. Only twigs, small branches, leaves, fruits, roots, grass and barks were trapped. At least five samples of BOM from each type of retentive feature (most dominant types) was collected. At least 10 samples from the wet zone and 10 samples from the dry zone was also collected during each sampling occasion. For this, the sampling points were located randomly. To mark the first sampling point, a conspicuous well-marked object was thrown into the stream while the collector faced away from the bank. The collector turned and noted the exact point. Random degree numbers ranging from 0 - 360 were generated for locating the Hess Sampler. Using a compass and the degree numbers from a random table, a distance of 2 metres was taken from the previous sampling point. The Hess Sampler was placed and all the coarse particulate organic matter (CPOM) enclosed therein were collected, placed in an enamel tray, put into the polythene bags (12x18 inch in size) and then transported to the laboratory for analysis.

In the laboratory, the materials were sorted into leaves, bark, twig, wood debris, fruit, grass and roots. The fragmentary materials that could not be identified was designated "others" or "miscellanous" and then put into separate khaki bags. Leaves were then identified to species at the University of Nairobi herbarium. Each component of the materials was then dried at 85^0C in an oven (Haraeus model T5050) to a constant weight, measured to the nearest 0.01g. Materials were further ashed at 550^0 C for 4 hours and the ash free dry weight (AFDW) taken to the nearest 0.01g. Data was recorded and expressed as g AFDW m^{-2} for the organic detritus of each component.

3.7 Macroinvertebrate sampling

Using a Hess sampler with an area of $0.0299m^2$ and a mesh size of 100 µm, five samples of benthic fauna from among the retentive structures was taken during each sampling occasion. The sampler was carefully introduced into the water walking upstream in the riverbed to avoid collection of induced drift organisms. The enclosed area was vigorously stirred up for three minutes. The small cobbles and other organic matter trapped inside were washed off by hand. Organisms dislodged in the sampling process were passed through the conical net (100 µm mesh) into a detachable collecting tube closed at the rear

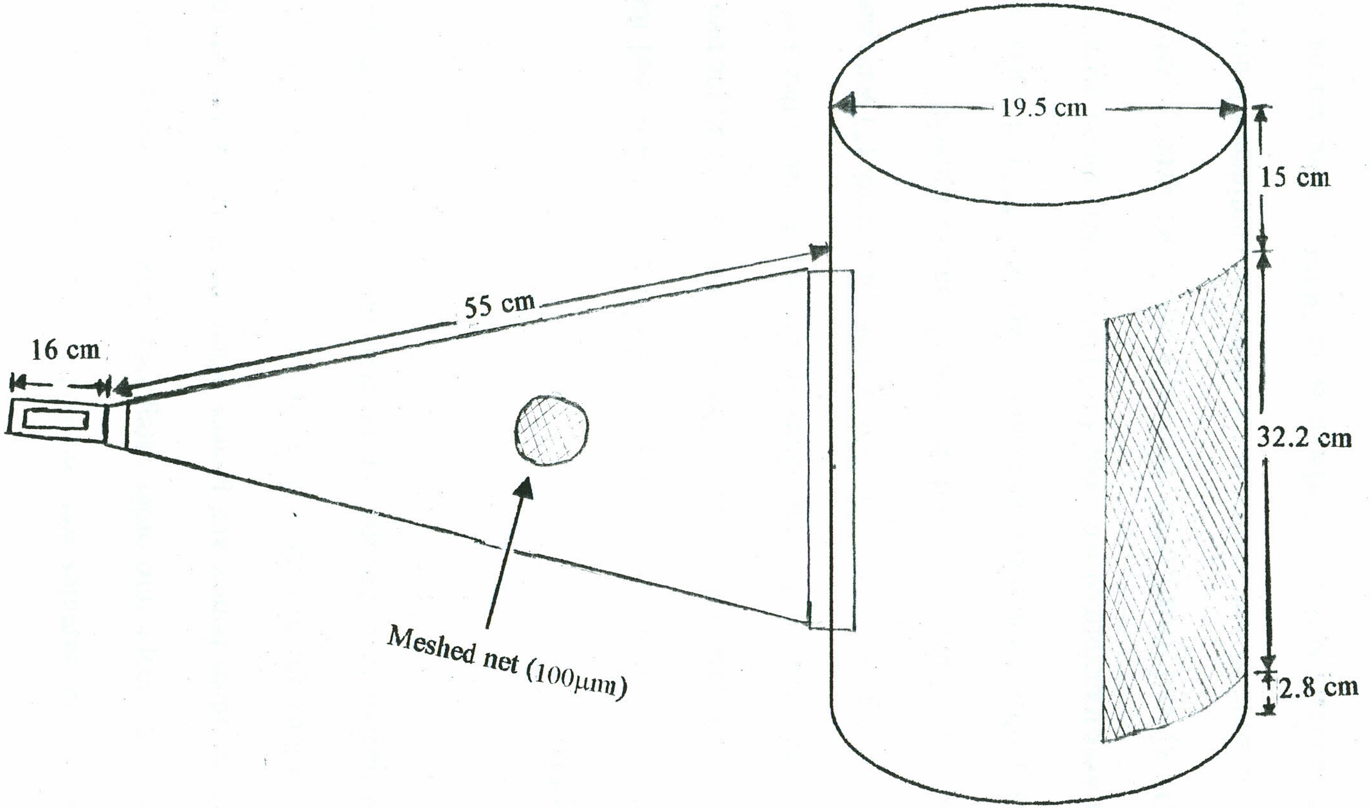

Fig. 3.10 A view of the Hess Sampler used for collecting benthic organic matter and the invertebrate fauna in the Sagana River, Kenya.

with a fine (100 µm) mesh. The animals were washed out of the tube (backwashed) using a wash bottle into sample bottles and immediately preserved in 4-5% formalin for further sorting.

In the laboratory, benthic samples were washed through sieves of 100 µm and sorted using a binocular microscope into order categories. Each order was preserved in 70% alcohol and later sorted to family and genera where possible. Identification was done using available literature and assistance from the supervisor Dr. B.M. Mwangi. It was not possible for identification to go beyond genera level due to lack of the necessary detailed keys.

3.8 Data analysis

The Statistical Package for Social Sciences (SPSS version 9.0) was used for statistical analysis of the data. The probability values of $P< 0.05$ was used for all the two tailed tests to show statistical significance of mean values for all the parameters that were analyzed. All means were reported with ± 95% CL. The number of asterisk (*) was used to denote different levels of significance. A single asterisk (*) shows significant ($P< 0.05$), two asterisks (**) is highly significant and three asterisks (***) denotes very highly significant. Data were transformed with $\log_{10}(x+1)$ before carrying out parametric test (t-test and ANOVA) and satisfied for normality and homogeneity tests of variance (Elliot, 1977). This allowed consistency in calculation of confidence limits of the mean values for the parameters analyzed. Differences in BOM content among wet and dry zones were examined by performing a Mann-Whitney U test while the strength of faunal association with BOM distribution was assessed using the Pearson Correlation Coefficients. Diversity and evenness of macroinvertebrates among BOM standing stock in the retention structures were analyzed using the Shannon-Wiener Diversity Index

(Shannon, 1964), Simpson Diversity Index (Simpson, 1949) and Batters evenness (Batter, 1976) computed respectively as follows-

$H = -\sum pi \log_e Pi$, $D = \sum (pi)^2$ and $E = \frac{H^1}{Ins}$ where,

H = An index of diversity

$\sum pi$ = Sum of the percentage value of species

E = Species evenness

H^1 = Species diversity of site i

Ins = Natural logarithm of species number

The higher the value of H and E, the greater the diversity and the less the community is dominated by one or a few kinds. To determine the distribution pattern of the various BOM and the functional feeding group categories among the retention structures, Green's Coefficient of dispersion (Green, 1966) was used, computed as follows:

Dispersion index $= \frac{S^2/\bar{X} - 1}{\sum x - 1}$ where,

S^2 = Sample variance

$\bar{X}$ = Sample mean

$\sum x$ = Total number in the sample

Negative values of this index indicated uniform pattern and positive values indicated clumped pattern.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Hydrological parameters

4.1.1. Stream width

The main hydrological and morphometric features measured at the study site are summarized in Table 4.1. Stream width measured during the dry season ranged from 7.64 m to 15.05 m, with a mean of 10.36 ± 0.78 m (Table 4.2a). Stream width during the rainy season varied between 8.2 m to 13.7 m, with a mean of 10.4 ± 0.59 m (Table 4.2b). Stream width at bankful ranged from 15.6 to 24.9m with a mean of 21.1 ± 1.4 m (Table 4.2c)

4.1.2. Water depth

Water depth varied widely from 0 to 153 cm in the study site with a mean of 51.5 ± 7.07 cm (Table 4.3).

Table 4.1. The main morphometric, hydrological and physical variables noted at the study reach along Sagana River, Kenya.

Parameter	Units	Methods	MSS_1
Stream width	Metres	Tape measure	13.97
Bankfull width	Metres	Tape measure	1.29
Stream depth	Centimeters	Metre rule	51.48
Elevation (metres above sea level)	-	Map	1790
Strahler stream order	-	Map	2
Bank stability	-	Visual	Moderately stable
Closure of canopy (%)	-	Visual	70 %
Water temperature	Degrees centigrade	Portable mercury thermometer	18.38

Table 4.2. Stream width measurements (metres) at low flow, medium and bankfull taken at different dates. For each date, 10 width transects were taken across the river at 5 m apart. TS1 to TS10 are transects across the stream. Means are attached to 95% Confidence limits.

a) Low flow

	Width (m) across the stream												
Date	**TS 1**	**TS 2**	**TS 3**	**TS 4**	**TS 5**	**TS 6**	**TS 7**	**TS 8**	**TS 9**	**TS 10**	*n*	$\bar{x}$	*CL*
17/02/03	9.85	10.25	14.34	11.03	14.98	15.05	9.96	11.34	12.65	10.65	10	**12.01**	**1.29**
15/9/03	8.24	7.64	9.67	9.23	12.07	13.41	9.05	8.04	9.08	13.65	10	**10.01**	**1.37**
22/09/03	10.12	8.06	10.12	9.15	8.76	8.49	8.01	8.06	8.78	11.12	10	**9.07**	**0.66**
										MEAN		**10.36**	**0.78**

b) Medium flow

	Width (m) across the stream												
Date	**TS 1**	**TS 2**	**TS 3**	**TS 4**	**TS 5**	**TS 6**	**TS 7**	**TS 8**	**TS 9**	**TS 10**	*n*	$\bar{x}$	*CL*
14/04/03	10.65	10.34	11.65	12.01	9.65	8.24	9.69	9.78	8.98	10.32	**10**	**10.13**	**0.70**
6/10/03	10.31	10.69	10.34	11.01	9.63	8.95	13.01	13.65	9.07	10.56	**10**	**10.72**	**0.95**
									MEAN			**10.43**	**0.59**

c) Bankfull width

	Width (m) across the stream												
Date	**TS 1**	**TS 2**	**TS 3**	**TS 4**	**TS 5**	**TS 6**	**TS 7**	**TS 8**	**TS 9**	**TS 10**	*n*	$\bar{x}$	*CL*
25/04/03	15.63	17.09	22.03	20.15	24.93	21.67	19.95	16.12	18.9	17.12	**10**	**19.36**	**1.83**
6/5/03	20.12	21.36	20.19	25.05	24.98	24.99	24.98	23.62	24.34	18.97	**10**	**22.86**	**1.50**
										MEAN		**21.11**	**1.40**

Table 4.3. Cross-sectional water depth measurements taken on different dates during the dry season at 5 transects for each date at 5 metres apart along the mid reaches of the study site - Sagana River, Kenya. TS1 to TS 5 are transects across the stream.

Date	**Transects**	**Water depth (cm) across the stream**												**n**	$\bar{\chi}$	**95% CL**
3/3/03	TS 1	28	53	67	73	96	123	153	93	88	71	50	37	**12**	**77.67**	**20.24**
	TS 2	12	63	79	93	43	34							**6**	**54.00**	**24.04**
	TS 3	12	13	39	0	0	0	36	97	77				**9**	**30.44**	**23.24**
	TS 4	18	70	97	152	98	87	71	64	50	61	29		**11**	**72.45**	**21.60**
	TS 5	31	63	98	95	71	66	70	63	101	74	38		**11**	**70.00**	**13.27**
											Mean				**60.91**	**16.82**
15/9/2003	TS 1	74	86	51	66	75	88	90	102	121	57			**10**	**81.00**	**13.04**
	TS 2	10	37	96	40	10	7	62						**7**	**37.43**	**24.33**
	TS 3	19	62	44	81	60	104	99	61	24	10			**10**	**56.40**	**20.14**
	TS 4	22	75	66	58	42	45	21	18					**8**	**43.38**	**15.12**
	TS 5	52	95	107	82	51	109	93	84	67	49			**10**	**78.90**	**14.20**
											Mean				**59.42**	**17.50**

4.1.3. Water temperature

Water temperature at the pool ranged from 14 to 20.3^{0}C with a mean of 17.03 ± 1.31^0 C, with a positive but not significant correlation with air temperature (t-value = 0.57; P> 0.05). At the riffle, the water temperatures were higher and more variable ranging between 14.2^{0}C and 22.2^{0}C with a mean of 18.38 ± 1.57^0 C. It was relatively high for the months of February and March coinciding with high ambient air temperature (Fig. 4.1). The difference in mean water temperature at the pool and riffle gravel bar sites along the study reach was highly significant (t- value = 5.81; P<0.001).

4.2. Riparian Vegetation

Indigenous plants and a few exotic species dominated the riparian vegetation (Table 4.4). A total of 31 plant species were identified along the study reach. The most common trees and shrubs were *Ficus thorningii* Blume, *Croton megalocarpus* Hutch., *Syzgium guineense* (Willd.) Dc., *Cussonia holstii* Engl. Var. holstii, *Calodendrum capense,* (L.f.) Thunb. *Jacaranda mimosifolia* D.Don, *Ekebergia capensis* Aparrm, *Erythrina abyssinica* DC, *Croton macrotachyus* DC, *Cordia africana* Lam., *Acacia abyssinica* (Hochst. Ex. Benth.), *Agelaea pentagyna* (Lam.) Baill., *Newtonia buchananii* (Bark) Gild and Bont. *Typha domingensis* Pers., *Grewia similes* (K.Schum), *Ochna insculpta* Sleumer, *Thevetia peruviana* (Pers.) and *Solanum mauriticinum* Scop.

4.3. Retentive features

4.3.1. Types of retentive features

The main instream organic and in-organic retentive structures identified along the study reach were debris dams, large woody debris and exposed riffle gravel bars with large woody debris being the most common feature (Table. 4.5).

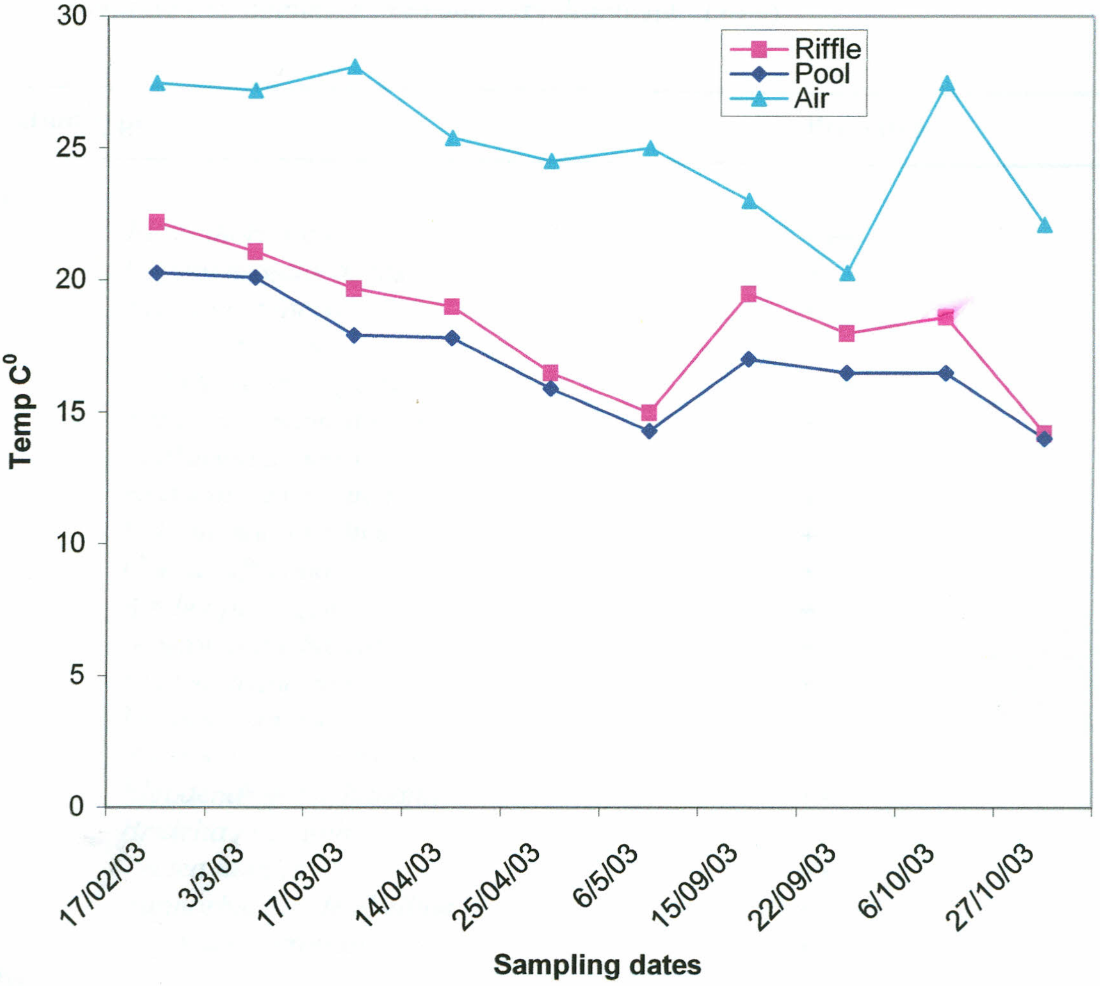

Fig. 4.1. Variations in water (pool & riffle) and air temperatures during each sampling occasion at the study reach along the mid-reaches of Sagana River, Kenya, between February 2003 and November 2003.

4.3.2. Debris dam

During the study period, the number of debris dams ranged from 0 to 2. Measurements of the greatest breadth ranged from 0.52 m to 1.68 m with a length of 0.79 m to 2.24 m and a height ranging between 0.43 m to 1.2 m. The mean for the greatest breadth, length and height were 0.99 ± 0.18 m, 1.39 ± 0.26 m to 0.66 ± 0.13 m, respectively. The horizontal

Table 4.4. List of dominant plant species in the riparian vegetation at the study site along the mid-reaches of Sagana River, Kenya. The relative dominance is denoted by: rare (+), dominant (++) and very dominant (+++).

Vegetation type	Presence
Trees	
Ficus thorningii	+++
Croton megalocarpus	++
Syzgium guineense	++
Cussonia holstii	+
Calodendrum capense	+++
Jacaranda mimosifolia	+
Ekebergia capensis	+
Erythrina abysisnica	+
Croton macrotachyus	+
Cordia africana	+
Agelea pentagyna	+
Newtonia buchananii	+
Euclea divinorum	+
Ficus sycomorus	+
Rapanea melanophlaeos	+
Eleodendron buchananii	++
Bridelia micrantha	+
Teclea nobilis	++
Euphorbia candelebellum	+
Drypetes gerrandii	+
Shrubs	
Typha domingensis	+
Grewia similes	+
Dracaena laxissima	+
Thevetia peruviana	+
Solanum mauriticinum	+
Herbs	
Fuerstia africana	++
Tagetes minuta	+
Verbena bonariensis	+
Polygraum pulcherum	+
Spiranthes mauritianum	+
Ocimum gratissinum	+

projection area ranged from 0.64 m^2 to 3.76 m^2, with a mean of 1.55 ± 0.46 m^2 (Table 4.6). The percentage area coverage of the debris dam in the reach was 0.34 %. The total dam volume ranged from 0.38 m^3 to 3.76 m^3 with a mean of 1.25 ± 0.52 m^3. The average density of accumulation was 1.7 dams per 100 m (Table 4.6). The main structural component of the dams was leaf material, which made up 47.8 % of the total detrital standing stock. Small pieces of wood were sealed on the upstream surface with fine gravel, sand and silt sediments.

Table 4.5. Total counts of the retentive features on each sampling occasion along the mid reaches of Sagana River, Kenya.

Sample No.	Date	Debris Dam	LWD	Exposed riffle gravel bar
1st	17/02/03	2	2	2
2nd	03/03/03	2	2	2
3rd	17/03/03	2	2	2
4th	14/04/03	2	1	1
5th	25/04/03	1	1	0
6th	06/05/03	0	1	0
7th	15/09/03	2	3	2
8th	22/09/03	2	3	2
9th	06/10/03	2	2	1
10th	27/10/03	2	1	0
Totals		**17**	**18**	**12**

4.3.3. Large woody debris

During the study period, a total of 18 large woody debris (LWD) were observed within the study site. In relation to stream length of the study site, the mean number of LWD was 1.8-log/100 metre. Occurrence ranged from 1 to 3 with a mean of 1.8 ± 0.42. The highest number recorded (6) was during the dry month of September and the lowest (3) occurred during the wet season from April to May (Table 4.5). The diameter of LWD throughout the study period ranged from 0.17 m to 0.49 m, while the length varied

Table 4.6. Morphmetric and physical features of debris dam on each sampling occasion along the study reach of the mid-reaches of Sagana River, Kenya.

Sam No.	Date	Count	Breadth	Length	Height	H P Area	Volume
1st	17/02/03	2	1.42	1.80	1.20	2.56	3.07
			0.93	1.24	0.47	1.15	0.54
2nd	3/3/03	2	1.35	1.81	1.00	2.44	2.44
			0.81	1.31	0.51	1.06	0.54
3rd	17/03/03	2	1.05	1.51	0.80	1.59	1.27
			0.83	0.98	0.50	0.81	0.41
4th	14/04/03	2	0.95	1.60	0.60	1.52	0.91
			0.79	1.64	0.43	1.30	0.56
5th	25/04/03	1	0.52	1.23	0.71	0.64	0.45
6th	6/5/03	0	0.00	0.00	0.00	0.00	0.00
7th	15/09/03	2	1.40	1.93	0.90	2.70	2.43
			0.95	1.11	0.49	1.05	0.52
8th	22/09/3	2	1.39	1.76	0.80	2.45	1.96
			0.76	1.03	0.52	0.78	0.41
9th	6/10/03	2	1.28	2.13	0.9	2.73	2.45
			0.81	0.84	0.63	0.68	0.43
10th	27/10/03	2	1.68	2.24	1.00	3.76	3.76
			0.96	0.79	0.50	0.76	0.38
Sum		**17**	**17.88**	**24.95**	**11.96**	**27.98**	**22.53**
Mean		**1.7**	**0.99**	**1.39**	**0.66**	**1.55**	**1.25**
95% CL		**0.42**	**0.18**	**0.26**	**0.13**	**0.46**	**0.52**

between 7.2 m to 13.1 m. The volume of the LWD average per stream length of the study area (1397 m^2) varied from 0.12 m^3/100 to 1.19 m^3/100 metres. The geometric mean of LWD volume related to study reach length was 0.00364 m^3/100 metres.

The proportion of the species of trees that produced the piece of LWD was higher for the unidentified ones (56%) and only 44% for the identified (Table 4.8) during the sampling periods. Out of 44 % of the identified species, 33 % was produced by *Podocarpus sp.* and the remaining 11% by *Eucalyptus sp.* (Table 4. 9; Fig. 4.2). The main structural component was fine sediments of sand and silt on the upstream surface. However, the main components were leaves and twigs comprising 28.1% and 22.9%, respectively.

Table 4.7. Morphmetric and physical features of large woody debris along the study site within the mid-reaches of Sagana River, Kenya.

S. No	Date	Count	C1 (cm)	C2 (cm)	D1 (m)	D2 (m)	L (m)	Vol. (M^3)	% Vol. (M^3)
1st	17/02/03	2	152.5	18.6	0.49	0.06	13.1	1.23	0.012
			85.5	13	0.27	0.04	10.5	0.31	0.003
2nd	3/3/03	2	152.5	18.6	0.49	0.06	13	1.22	0.012
			85.5	13	0.27	0.04	10.3	0.31	0.003
3rd	17/03/03	2	150.6	17.3	0.48	0.06	12.7	1.16	0.011
			83.4	12.5	0.27	0.04	11.8	0.33	0.003
4th	14/04/03	1	151.5	17.9	0.48	0.06	12.8	1.19	0.011
5th	25/04/03	1	151.4	17.5	0.48	0.06	12.1	1.12	0.011
6th	6/5/03	1	150.8	17	0.48	0.05	12	1.10	0.011
7th	15/09/03	3	55.7	34	0.18	0.11	12.5	0.21	0.002
			71.3	31.9	0.23	0.10	8.5	0.21	0.002
			62.8	40.5	0.20	0.13	9.4	0.21	0.002
8th	22/09/03	3	54	33.5	0.17	0.11	12.3	0.19	0.001
			70.5	30	0.22	0.10	8.1	0.19	0.001
			58.5	36.9	0.19	0.12	8.6	0.16	0.001
9th	6/10/03	2	68.4	32.6	0.22	0.10	7.5	0.17	0.001
			52	35.4	0.17	0.11	7.7	0.12	0.001
10th	27/10/03	1	68.1	7.3	0.22	0.02	7.2	0.14	0.001
Mean			**95.83**	**23.75**	**0.31**	**0.08**	**10.56**	**0.53**	
CL at 95%			**19.25**	**4.77**	**0.06**	**0.02**	**0.99**	**0.22**	
GM VOL. (M^3)									**0.00364**

Table 4.8. The total count of species of tree that produced LWD material at the study reach on each sampling occasion along the mid reaches of Sagana River, Kenya. The cross (X) represents unidentified species.

Sample No.	Date	Counts	Tree species
1st	17/02/03	2	*Podocarpus sp.*
			x
2nd	3/3/03	2	*Podocarpus sp.*
			x
3rd	17/03/03	2	*Podocarpus sp.*
			x
4th	14/04/03	1	x
5th	25/04/03	1	x
6th	6/5/03	1	x
7th	15/09/03	3	*Podocarpus sp.*
			Podocarpus sp.
			Eucalyptus sp.
8th	22/09/03	3	*Eucalyptus sp.*
			x
			x
9th	6/10/03	2	*Podocarpus sp.*
			x
10th	27/10/03	1	X

Table 4.9. The total count of both identified and unidentified species of tree that produced LWD material at the study reach along the mid reaches of Sagana River, Kenya.

Species	Podocarpus sp.	Eucalyptus sp.	Unidentified sp.
No. of species	6	2	10
%	33	11	56

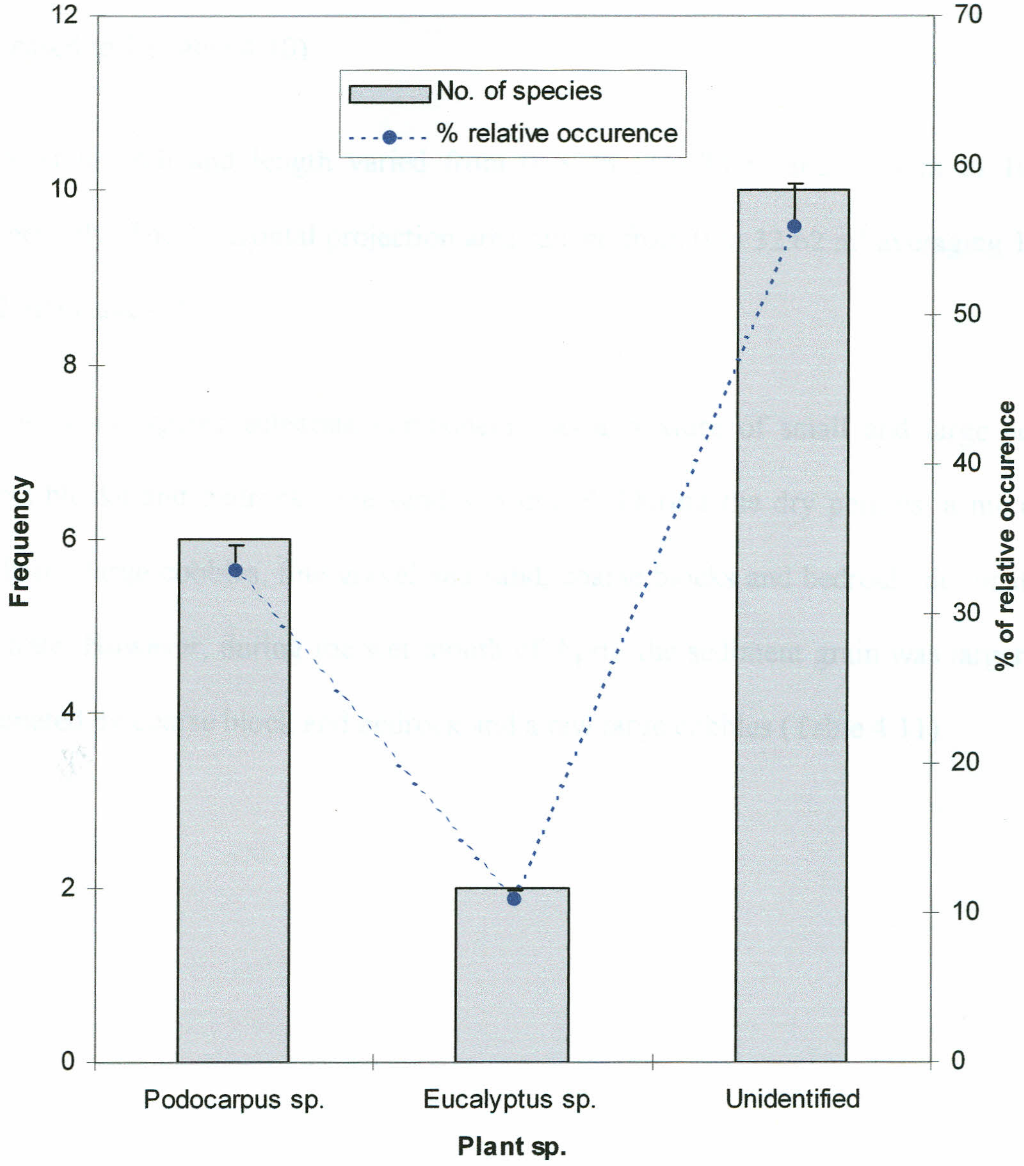

Fig. 4.2. The proportion of species of trees that produced the LWD piece along the study reach, Sagana River, Kenya.

4.3.4. Exposed riffle gravel bar

In the course of the study period, twelve (12) exposed riffle gravel bars were observed along the study reach. The occurrence was relatively stable with a range of 0 to 2. The average density of accumulation was 1.2 gravel bars per 100 metres of the study site (Table 4.10). The highest number was recorded during the dry months of February to early-March and September. However, as from mid-March, April and May, the number decreased to 1 (Table 4.10).

Greatest breadth and length varied from 0.79 m to 3.78 m and 1.64 m to 10.38 m respectively. The horizontal projection area ranged from 0 to 32.62 m^2 averaging 16.02 ± 6.32 m^2 (Table 4.10).

The main in-organic substrate component was a mixture of small and large cobbles, coarse blocks and bedrock, fine sand and gravel. During the dry periods, a mixture of small and large cobbles, fine gravel and sand, coarse blocks and bedrock, dominated the substrate. However, during the wet month of April, the sediment grain was larger being dominated by coarse block and bedrock and a few large cobbles (Table 4.11).

Table 4.10. Morphmetric and physical features of the exposed riffle gravel bar along the study reach of the mid-reaches of Sagana River, Kenya.

Sample No.	Date	Count	Breadth (m)	Length (m)	Area (m^2)
1st	17/02/03	2	3.56	7.53	26.81
			2.15	10.34	22.23
2nd	3/3/03	2	3.59	7.65	27.46
			2.59	10.38	26.88
3rd	17/03/03	2	2.15	5.54	11.91
			1.67	8.12	13.56
4th	14/04/03	1	1.53	1.92	2.94
			0.79	1.64	1.30
5th	25/04/03	0	0	0	0.00
6th	6/5/03	0	0	0	0.00
7th	15/09/03	2	3.72	8.51	31.66
			2.67	9.14	24.40
8th	22/09/3	2	3.78	8.63	32.62
			2.94	10.14	29.81
9th	6/10/03	1	1.46	3.24	4.73
10th	27/10/03	0	0	0	0.00
Total		**12**	**32.6**	**92.78**	**256.31**
Mean		**1.20**	**2.04**	**5.80**	**16.02**
95% CL		**0.57**	**0.66**	**1.95**	**6.32**

Table 4.11. The substrate components at the exposed riffle gravel bar site along the mid reaches of Sagana River, Kenya.

Sample No.	Date	Count	Substrate component
1st	17/02/03	2	A mixture of small & large cobbles, fine gravel sand and silt, coarse blocks and bedrock,
2nd	03/03/03	2	A mixture of small & large cobbles, fine gravel sand and silt coarse blocks and bedrock,
3rd	17/03/03	2	A mixture of large cobbles and gravel, coarse blocks and bedrock
4th	14/04/03	1	Few large cobble, coarse blocks and bedrock
5th	25/04/03	0	-
6th	6/5/03	0	-
7th	15/09/03	2	A mixture of small & large cobbles, fine gravel sand and silt coarse blocks and bedrock,
8th	22/09/3	2	A mixture of small & large cobbles, fine gravel sand and silt coarse blocks and bedrock,
9th	6/10/03	1	Large cobbles, gravel, coarse block, and bedrock
10th	27/10/03	0	-

4.4. Effectiveness of organic matter retention

4.4.1. Debris dam

4.4.1.1. Quantitative constituents of retained organic matter

Total ash free dry weight (AFDW) of retained organic matter averaged 58.83g. Leaf litter was the largest fraction accounting for 47.8% of the total detrital standing stock at the site. Barks, twigs, roots and wood debris amounted to 18.7%, 16.7%, 6.4% and 1.6%

AFDW, respectively (Table 4.12). Unidentifiable fraction of the stored organic matter accounted for 8.6% and fruits accounted for 0.3%.

4.4.1.2. Qualitative constituents of retained organic matter

A total of 26 species of plant vegetation were identified in the detrital standing stock. Unidentifiable leaf fragments accounted for about 30% of the total leaf mass. Out of 31 species of plant identified along the riparian zone (Table 4.4), only 16 species contributed appreciably to the benthic organic matter. The leaf litter, mainly composed of *Ficus thorningii,* constituted 44.1%. *Croton macrotachyus, Cussonia holstii, Calodendrum capense* and *Grewia similis* (Fig 4.4) represented 1.31%, 0.88%, 0.61%, 0.61% and 0.54% of the detrital leaf litter respectively. The other species occurred rarely and in small amounts (Table 4.12).

4.4.1.3. Variation in retention capacity

The accumulation of BOM mainly composed of leaves, barks, twigs and roots was highly variable. The quantity and dynamics varied among the sampling periods (Fig. 4.4). Woody debris, twigs and roots occurred only occasionally and in very small amounts. The distribution was aggregated as evidenced by the positive values of the dispersion index (Table 4.13) except for twigs. The spatial distribution pattern was distinct for leaves and barks. In February and September a marked peak was discerned (Fig. 4.3).

Table 4.12. Total POM amounts (gAFDWm^{-2}) at the debris dam site along the mid-reaches of Sagana River, Kenya.

	AFDW gm^{-2}	**% AFDW**	**% of leaves**
Bark	10.99	18.68	
Twig	9.80	16.66	
Fruit	0.18	0.31	
Root	3.77	6.41	
Wood debris	0.94	1.60	
Miscellaneous	5.04	8.57	
Leaves	28.11	47.78	
Ficus thorningii	12.40		44.11
Croton macrotachyus	1.31		4.66
Cussonia holstii	0.61		2.17
Calodendrum capense	0.61		2.17
Grewia similis	0.54		1.92
Syzgium guineese	0.38		1.35
Bridelia micrantha	0.38		1.35
Solanum mauritianum	0.38		1.35
Croton mengalocarpus	0.32		1.14
Typha domegensis	0.29		1.03
Agelaea pentagyna	0.28		1.00
Podocarpus latifolia	0.19		0.68
Dalbergia lactea	0.14		0.50
Zizisphus abyssinica	0.13		0.46
Ochna inoculpata	0.13		0.46
Newtonia buchanani	0.11		0.39
Clerodendrum johnstonii	0.10		0.36
Drypetes gerrandii	0.10		0.36
Euclea divinorum	0.09		0.36
Stychnos hemifsii	0.09		0.32
Dracaena laxissima	0.05		0.18
Mimilops kumel	0.05		0.18
Jacaranda mimosifolia	0.05		0.18
Podocarpus falcatus	0.02		0.07
Others	8.41		29.92
Total BOM	**58.83**		**100.00**

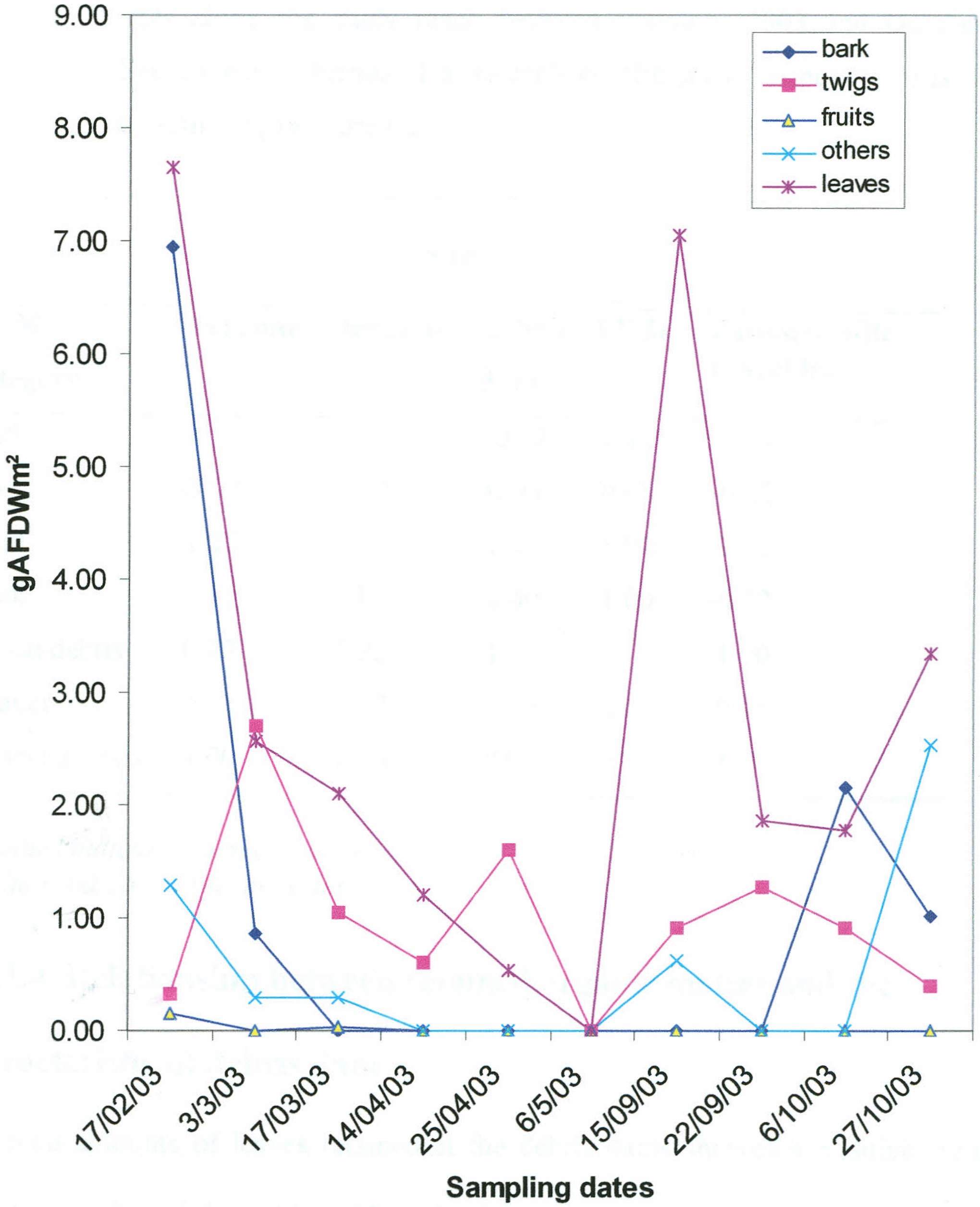

Fig. 4.3. The variation pattern for barks, twigs, fruits, leaves and miscellaneous materials collected at the debris dam along the study reach, Sagana River, Kenya.

Table 4.13. The dispersion index values for benthic detrital standing stock at different sites along the study reach between February 2003 and October 2003, Sagana River, Kenya. The Green's coefficient of dispersion was used for determining the distribution.

	Sites				
BOM category	**Wet zone**	**Dry zone**	**Debris dam**	**LWD**	**Exposed riffle gravel bar**
Bark	-	-	0.33	0.12	0.40
Twig	-0.02	0.31	-0.04	0.08	-0.20
Fruit	1.22	0.94	1.07	1.00	1.02
Root	-	1.00	1.00	1.00	-0.12
Wood debris	0.27	0.22	1.00	-	1.00
Leaves	0.04	0.17	0.05	-0.01	0.16
Miscellaneous	1.00	-0.43	0.09	0.11	1.00

+ Values indicate clumped pattern
- Values indicate uniform pattern

4.4.1.4. Relationship between retained organic matter and the characteristic of debris dam

The total amounts of leaves retained at the debris dams showed a positive significant correlation with height and breadth of the debris dam ($r = 0.74$; $P< 0.05$ and $r = 0.75$; $P< 0.05$), respectively. The amount of leaves retained correlated strongly with the volume of debris dam ($r = 0.833$; $P < 0.001$) and the horizontal projection area ($r = 0.75$; $P < 0.05$) (Table 4.14; Fig. 4.5).

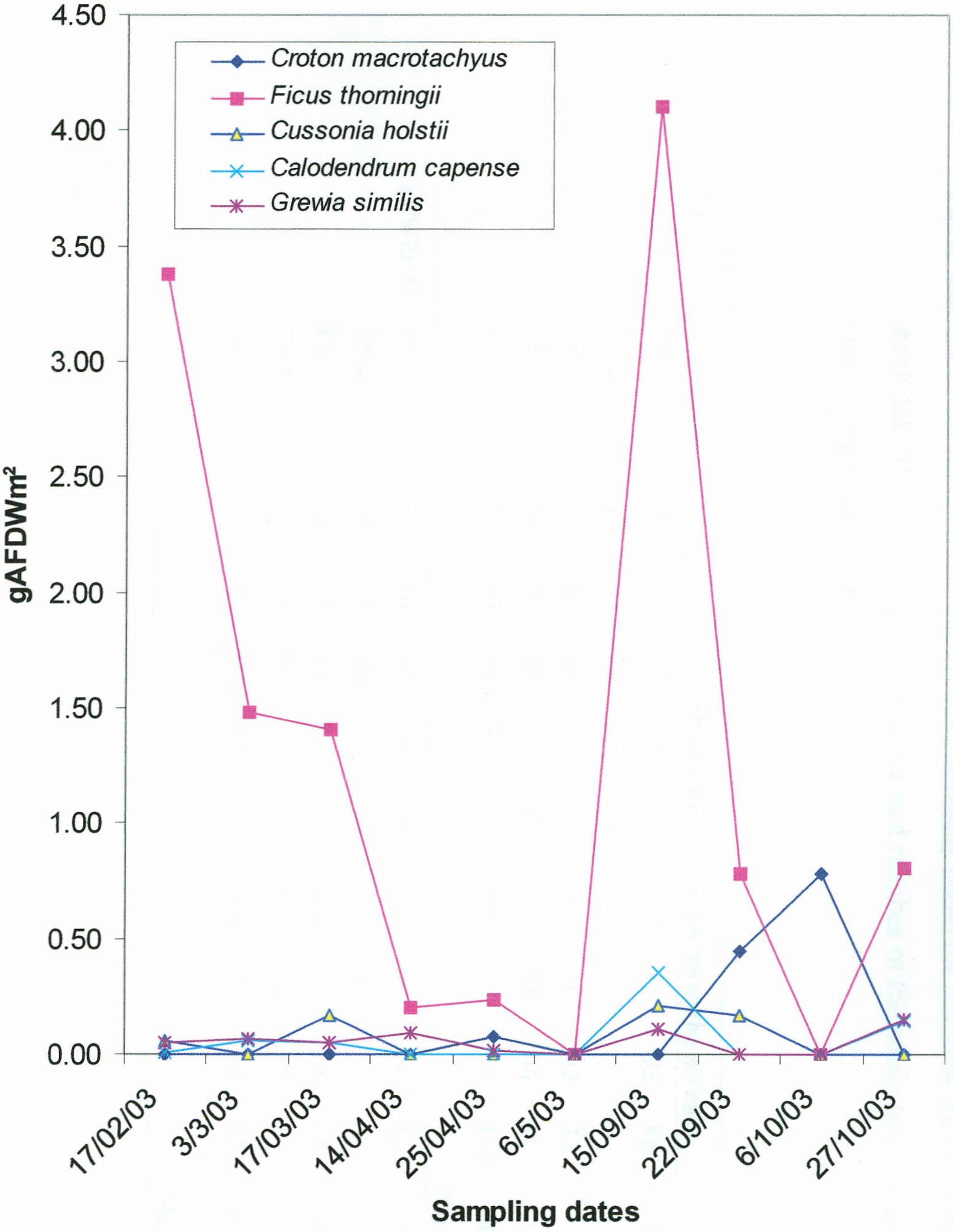

Fig. 4.4. The variation in the main detrital standing stock leaves species constituents at the debris dam along the study reach, Sagana River, Kenya.

Table 4.3. Cross-sectional water depth measurements taken on different dates during the dry season at 5 transects for each date at 5 metres apart along the mid reaches of the study site - Sagana River, Kenya. TS1 to TS 5 are transects across the stream.

Date	**Transects**	**Water depth (cm) across the stream**												**n**	**$\overline{\chi}$**	**95% CL**
3/3/03	TS 1	28	53	67	73	96	123	153	93	88	71	50	37	**12**	**77.67**	**20.24**
	TS 2	12	63	79	93	43	34							**6**	**54.00**	**24.04**
	TS 3	12	13	39	0	0	0	36	97	77				**9**	**30.44**	**23.24**
	TS 4	18	70	97	152	98	87	71	64	50	61	29		**11**	**72.45**	**21.60**
	TS 5	31	63	98	95	71	66	70	63	101	74	38		**11**	**70.00**	**13.27**
											Mean				**60.91**	**16.82**
15/9/2003	TS 1	74	86	51	66	75	88	90	102	121	57			**10**	**81.00**	**13.04**
	TS 2	10	37	96	40	10	7	62						**7**	**37.43**	**24.33**
	TS 3	19	62	44	81	60	104	99	61	24	10			**10**	**56.40**	**20.14**
	TS 4	22	75	66	58	42	45	21	18					**8**	**43.38**	**15.12**
	TS 5	52	95	107	82	51	109	93	84	67	49			**10**	**78.90**	**14.20**
											Mean				**59.42**	**17.50**

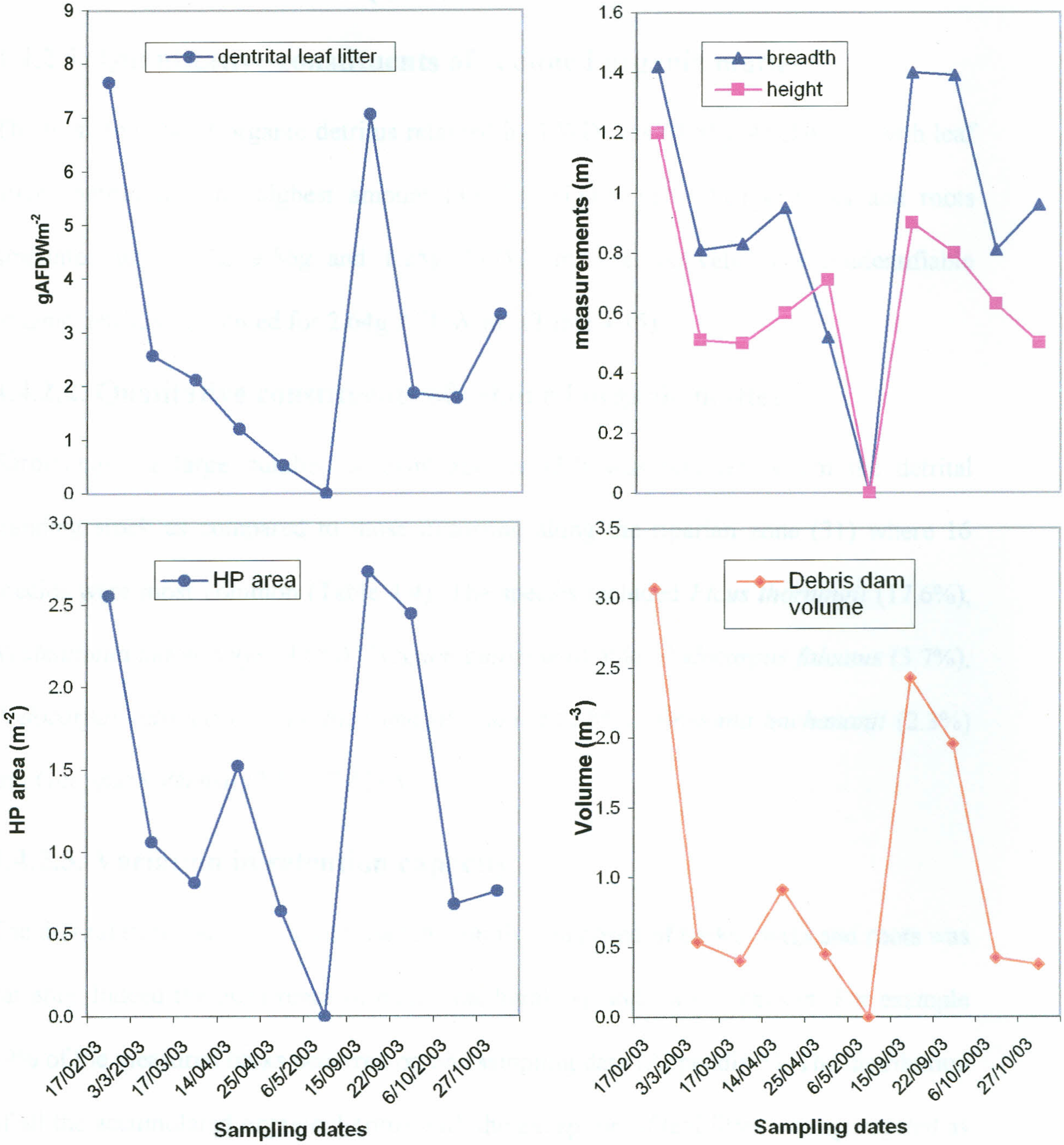

Fig. 4.5. Relationships of the detrital leaf litter accumulation with various morphometric characteristics of the debris dam at the study reach along the mid reaches of Sagana River, Kenya. A very high significant correlation was obtained between the detrital leaf litter and the volume of debris dam.

4.4.2. Large Woody Debris (LWD)

4.4.2.1. Quantitative constituents of retained organic matter

The total amount of organic detritus retained by LWD was 68.89g AFDW m^{-2} with leaf litter contributing the highest amount (39.57g AFDW m^{-2}). Twigs, barks and roots amounted to 15.77g, 9.56g and 1.25g AFDW m^{-2}, respectively. The unidentifiable organic detritus accounted for 2.64g AFDW m^{-2} (Table 4.15).

4.4.2.2. Qualitative constituents of retained organic matter

Surprisingly, a large number of plant species (37) was retained within the detrital standing stock as compared to those occurring along the riparian zone (31) where 16 species were most common (Table 4.4). The species included *Ficus thorningii* (17.6%), *Neobautonia macrocalyx* (4.6%), *Syzgium guineese* (4.5%), *Podocarpus falcatus* (3.7%), *Podocarpus latifolia* (3.6%), *Barsama abyssinica* (2.8%), *Newtonia buchananii* (2.3%) and *Garcinia volkensii* (2 %) (Table 4.15).

4.4.2.3. Variation in retention capacity

The detrital standing stock accumulation, mainly composed of barks, twigs and roots was variable. Indeed the occurrence of barks was highly episodic and localized. For example 39% of the measured barks occurred on one sampling date (Appendix 5). The distribution of all the accumulated organic detritus with the exception of leaf litter was aggregated as evidenced by the positive values of the dispersion index. The total leaf litter showed a negative value of the index depicting a uniform distribution pattern (Table 4.13). Barks, twigs and leaves showed marked peaks in February/March and September. The other BOM such as roots and woody debris showed no distinct peak during the study period (Fig. 4.6). *Ficus thorningii* showed a small peak in September. The other species showed no discernable trends (Fig. 4.7).

Table 4.15. Total BOM amounts (gAFDWm^{-2}) at the LWD along the mid-reaches of Sagana River, Kenya.

	AFDW	**% AFDW**	**% of leaves**
Bark	9.56	13.88	
Twig	15.77	22.89	
Fruit	0.10	0.15	
Root	1.25	1.81	
Wood debris	0.00	0.00	
Miscellaneous	2.64	3.83	
Leaves	39.57	57.44	
Ficus thorningii	6.96		17.59
Neobautonia macrocalyx	1.83		4.63
Syzgium guineese	1.79		4.52
Podocarpus falcatus	1.46		3.69
Podocarpus latifolia	1.44		3.64
Bersama abyssinica	1.12		2.83
Newtonia buchanani	0.90		2.28
Garcinia volkensii	0.80		2.02
Lasianthus kilimandscharicus	0.67		1.69
Ficus sycomorus	0.57		1.44
Apodites dimidiata	0.41		1.06
Eleodendron buchananii	0.37		0.94
Calodendrum capense	0.36		0.91
Typha domegensis	0.35		0.89
Ziziphus abyssinica	0.34		0.86
Grewia similes	0.34		0.86
Cussonia holstii	0.31		0.78
Bridelia micrantha	0.30		0.76
Croton mengalocarpus	0.28		0.70
Euclea divinorum	0.27		0.68
Agelaea pentagyna	0.24		0.61
Vernonia macrocalyx	0.23		0.58
Afromomum zanguebaricum	0.22		0.56
Ochna inoculpata	0.21		0.53
Rapanea melanophlaeos	0.18		0.46
Harungana madagascariensis	0.17		0.43
Croton macrotachyus	0.15		0.38
Dalbergia lactea	0.15		0.38
Diospyros abyssinica	0.14		0.35
Senna didymobotrya	0.13		0.33
Cyperus sp.	0.12		0.30
Dracaena laxissima	0.10		0.25
Clerodendrum johnstonii	0.07		0.18
Pterrolobium stellatum	0.06		0.15
Rhammus prinoides	0.05		0.13
Mimulops kumel	0.04		0.10
Psychotria orophila	0.04		0.10
Others	16.4		41.45
Total BOM	**68.89**		**100.00**

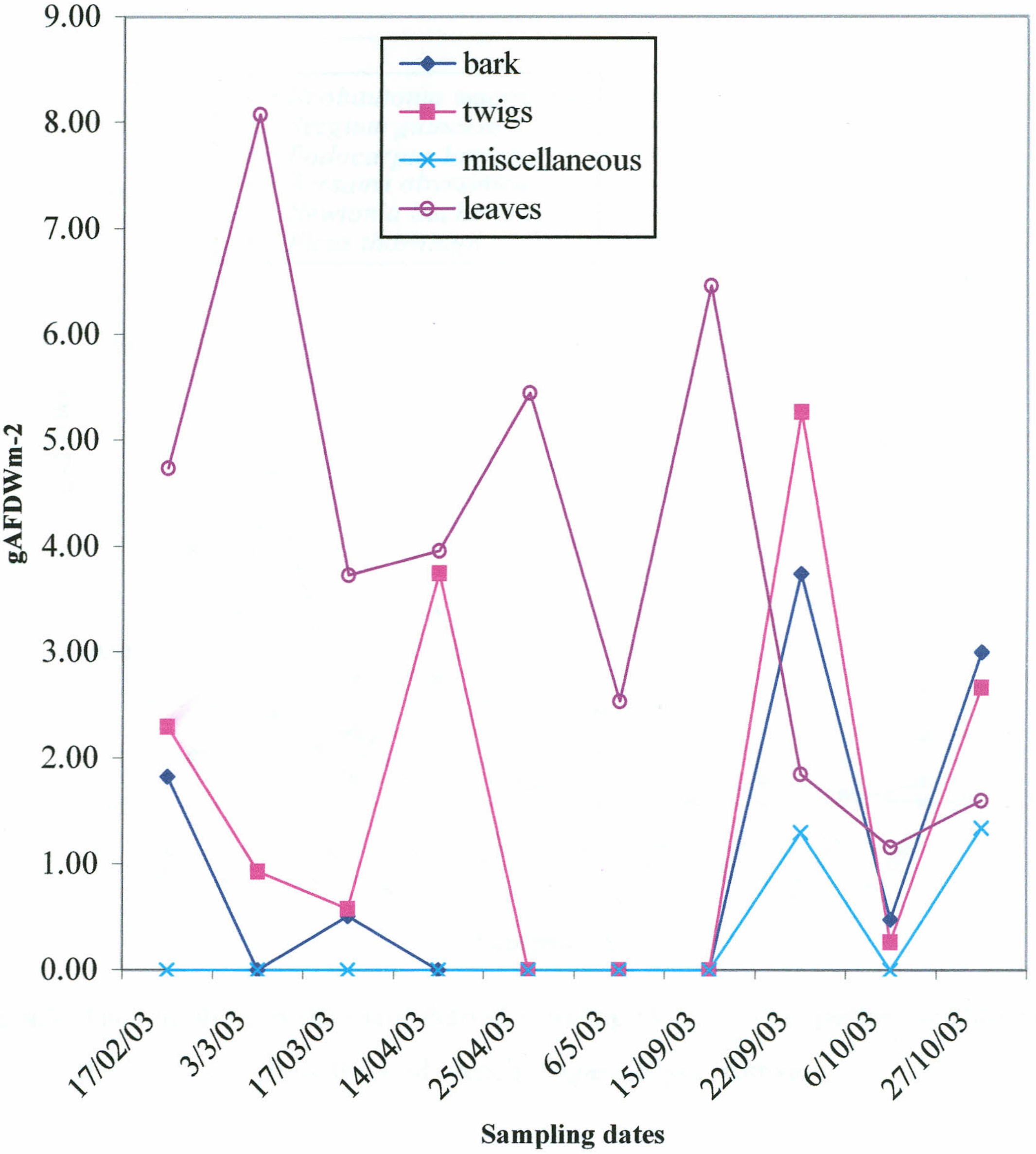

Fig. 4.6 The variation pattern for bark, twig, leaves and miscellaneous materials at the LWD along the study reach, Sagana River, Kenya.

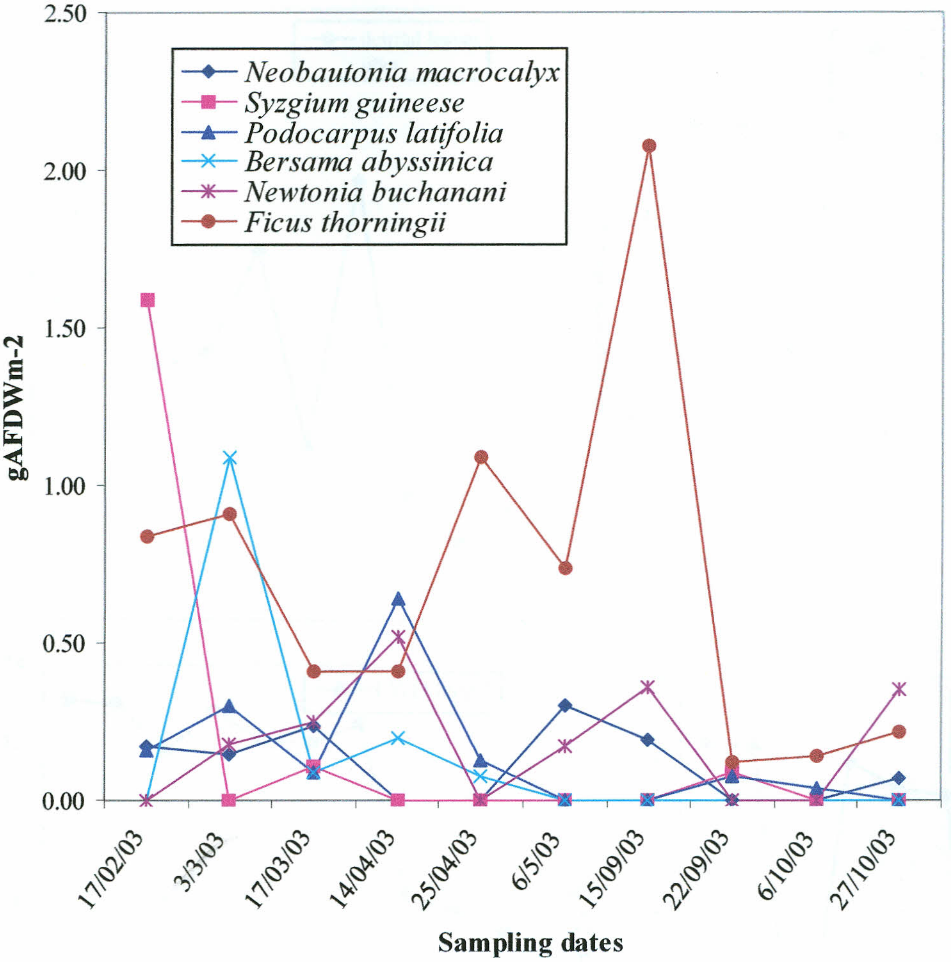

Fig. 4.7. The variation in the main detrital standing stock leaves species constituents at the LWD site along the study reach, Sagana River, Kenya.

4.4.2.4. Relationship between retained organic matter and characteristics of large woody debris (LWD).

The diameter of large woody debris showed no significant relationship with the retained organic matter standing stocks. However, the length was positively and highly correlated with the leaf litter AFDW ($r = 0.767$; $P < 0.001$). Volume showed no relationship ($P>0.05$) with the AFDW of detrital organic matter (Fig. 4.8).

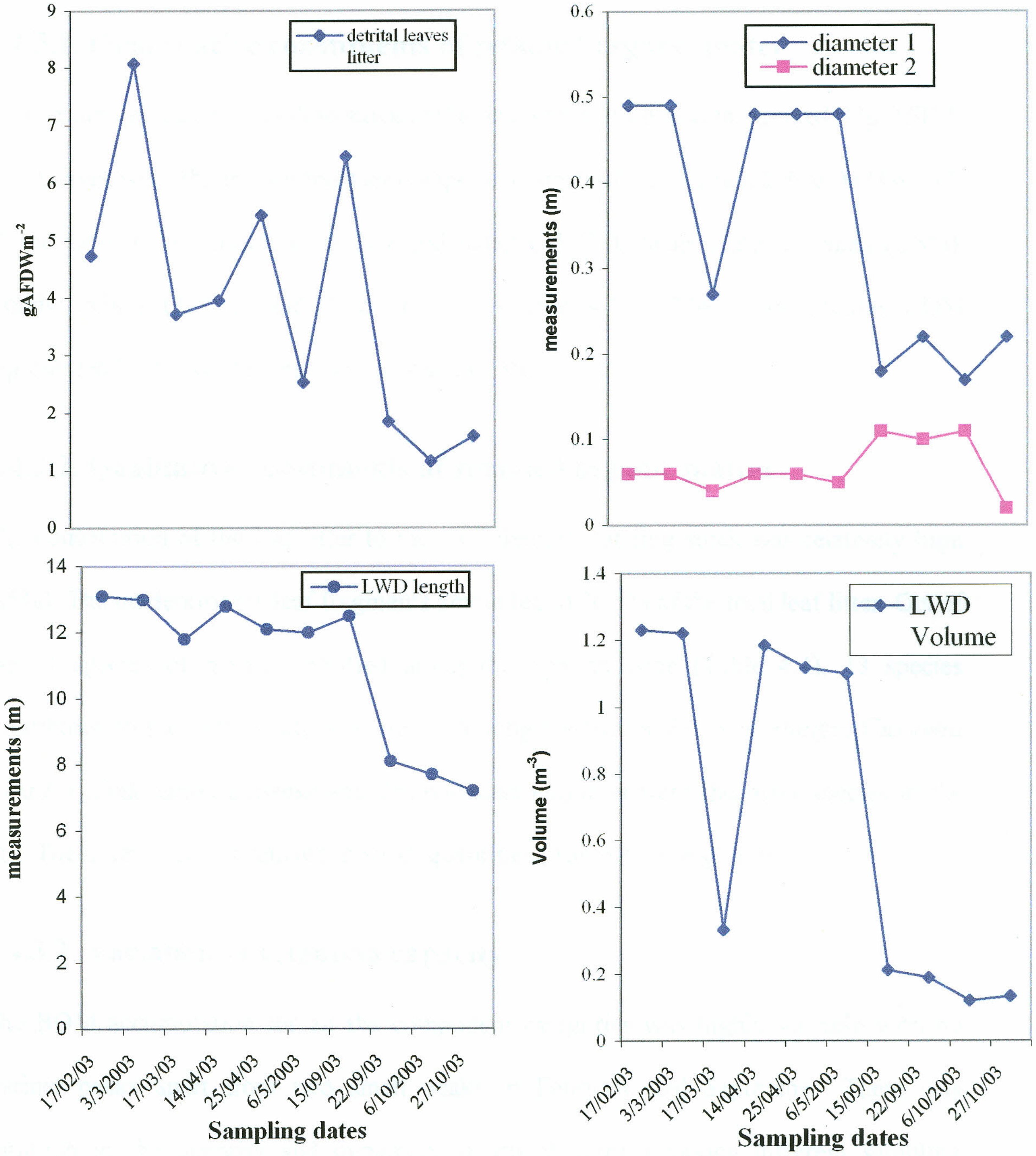

Fig. 4.8. Relationship of the detrital leaf litter accumulation with various LWD morphometric characteristics at the study reach along the mid-reaches of Sagana River, Kenya. A very high significant correlation was obtained between the LWD length and the detrital leaf litter. No significant statistical correlation was obtained with the diameter and volume.

4.4.3. Exposed riffle gravel bar (ERGB)

4.4.3.1. Quantitative constituents of retained organic mater

Total estimated detrital standing stock at the retentive feature amounted to 64.34g AFDW m^{-2}. Leaves were the most important component constituting 35.3% (22.87g AFDW m^{-2}) of the total. Other components included barks (31.7%), twigs (12.3%), roots (2.8%), woody debris (1.4%), and fruits (0.1%) (Table 4.16). The unidentifiable BOM represented 20.5% of the total detrital standing stock.

4.4.3.2. Qualitative constituents of retained organic matter

The contribution of the leaf litter to the total detrital standing stock was relatively high (35%). The unidentifiable leaf fragments amounted to 20.3% of the total leaf litter. Out of the 31 species of plants identified along the riparian zone (Table 4.4), 13 species contributed to the detrital standing stock. Among the leaves, *Ficus thorningii, Cussonia holstii, Calodendrum capense* and *Trichocladus elliptium* were the main species at the site. The other species occurred in small quantities (Table 4.16; Fig. 4.9).

4.4.3.3. Variation in retention capacity

The BOM accumulation for all the component categories was highly variable with no distinct peaks apart from two small peaks in February and September. There was variation in the quantity and dynamics of stored detritus among different sampling occasions. The highest amount of leaf litter and bark was recorded during the dry months of September and February, respectively. *Ficus thorningii, Cussonis holstii* and *Calodendrum capense* showed a small peak in September.

Table 4.16. Total BOM amounts (gAFDWm^{-2}) at the exposed gravel bar along the mid-reaches of Sagana River, Kenya.

	AFDW gm^{-2}	**% AFDW**	**% of leaves**
Bark	20.68	31.65	
Twig	8.06	12.34	
Fruit	0.08	0.12	
Root	1.85	2.83	
Wood debris	0.94	1.44	
Miscellaneous	10.69	16.36	
Leaves	23.04	35.26	
Ficus thorningii	11.16		48.44
Cussonia holstii	1.83		7.94
Calodendrum capense	1.02		4.43
Trichocladus elliptium	0.88		3.82
Newtonia buchananii	0.49		2.13
Croton macrotachyus	0.45		1.95
Bersama abyssinica	0.43		1.87
Grewis similis	0.37		1.61
Croton mengalocarpus	0.35		1.52
Syzguim guineese	0.32		1.39
Euclea divinorum	0.22		0.95
Strychnos hemifsii	0.18		0.78
Phoenix reclinata	0.11		0.48
Eleodendron buchananii	0.09		0.39
Psydrax schimperiana	0.09		0.39
Dalbergia lactea	0.08		0.35
Rapanea melanophlaeos	0.07		0.30
Podocarpus latifolia	0.06		0.26
Drypetes gerrandii	0.06		0.26
Ochna inoculpata	0.05		0.22
Viscum fischeri	0.01		0.04
Others	4.72		20.49
Total BOM	**65.34**		**100.00**

The other species showed no discernable trends (Fig. 4.9). The dispersion index (Table 4.13) showed leaves, barks, wood debris, fruits and grass to be aggregated while twigs and roots were uniformly distributed.

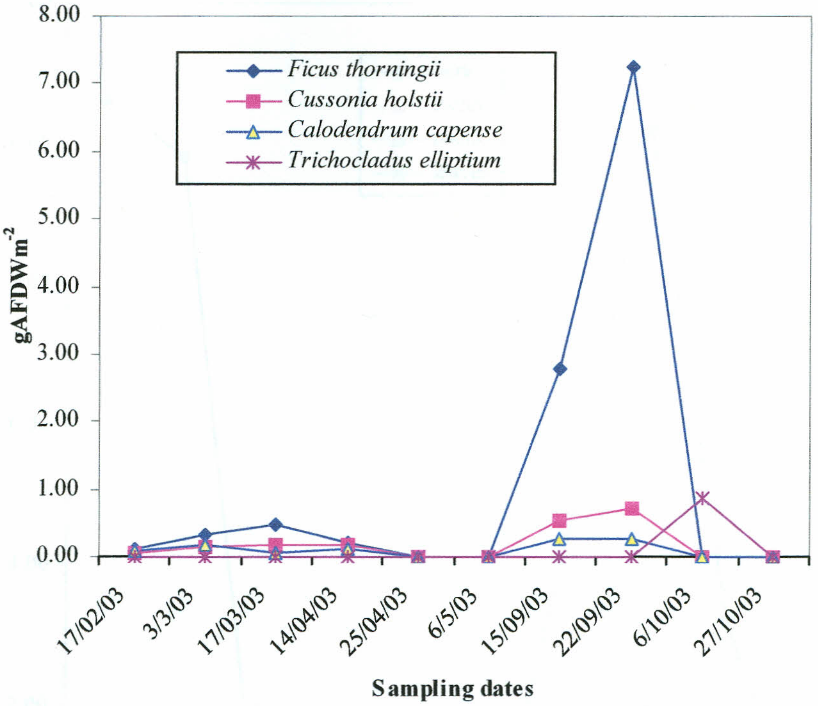

Fig. 4.9. The variation in the main detrital standing stock leaves species constituents at the exposed riffle gravel bar along the study reach, Sagana River, Kenya.

4.4.3.4. Relationship between retained organic matter and characteristics of the exposed riffle gravel bar (ERGB)

AFDW of twigs at the exposed riffle gravel bar showed a positive and significant correlation with breadth ($r = 0.650$; $P < 0.05$) and length of exposed riffle gravel bar ($r = 0.650$; $P < 0.05$). Similarly, breadth was positively correlated with the quantity of leaves ($r = 0.704$; $P < 0.05$). The amount of leaves was significantly correlated with the area of exposed riffle gravel bar ($r = 0.696$; $P < 0.05$). In addition, a positive and significant correlation was discerned ($r = 0.747$; $P < 0.05$) between the area and amount of twigs (Table 4.14; Fig. 4.11).

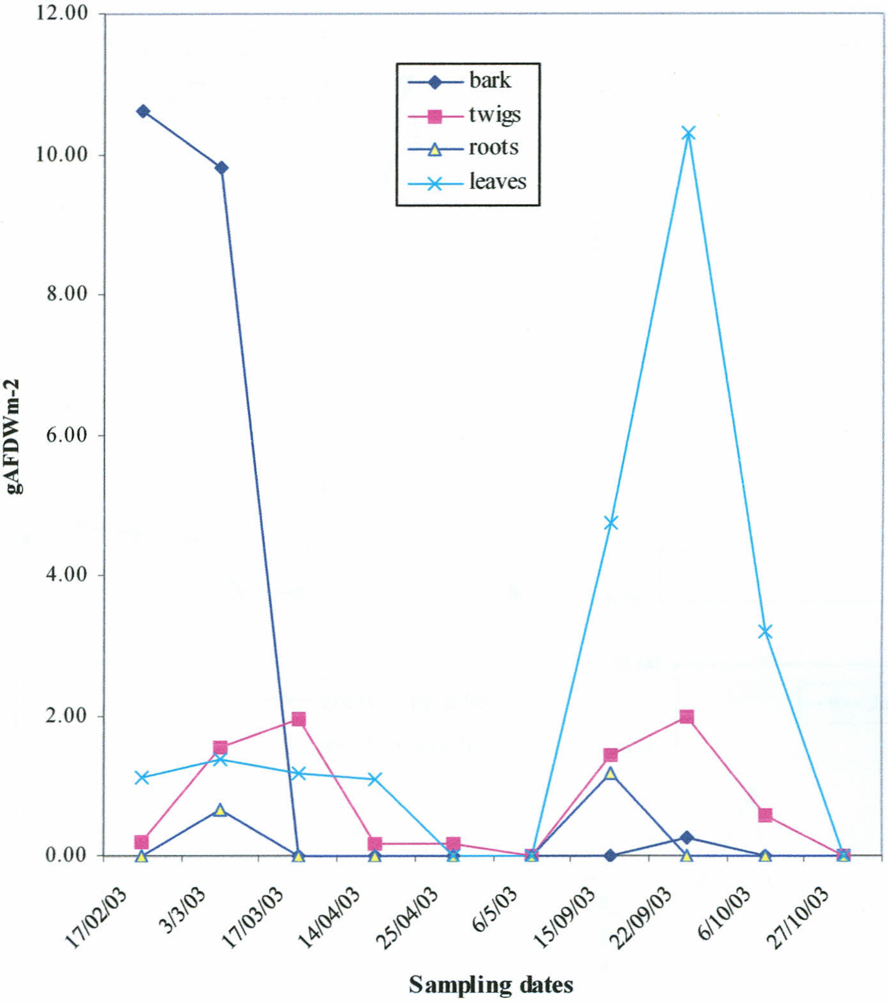

Fig. 4.10 The variation pattern for barks, twigs, roots and leaves at the exposed riffle gravel bar along the study reach, Sagana River, Kenya.

4.5. Benthic organic matter standing stock

4.5.1. Composition of BOM

The main BOM standing stock components identified at the wet and dry zone sites are summarized in Table 4.17 and Table 4.18, respectively. Barks, twigs and woody debris constituted over 72% of the detrital benthic organic matter standing stock at the wet zone site. Surprisingly, the leaf litter comprised over 60% of the total BOM standing stock

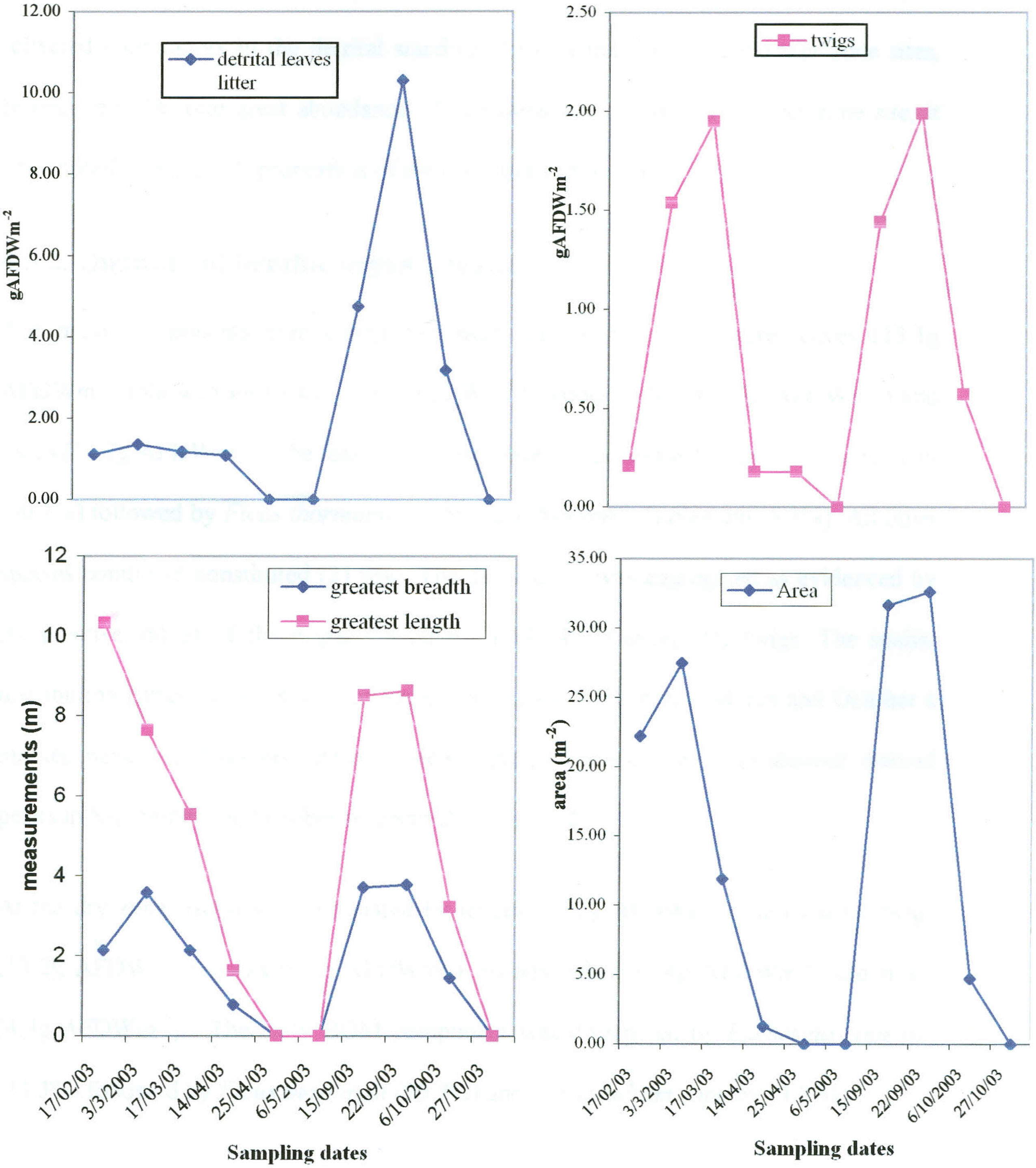

Fig. 4.11. Relationship of the main detrital BOM standing stock with various morphometric characteristics of the exposed riffle gravel bar at the study reach along the mid-reaches of Sagana River, Kenya. Significant correlations were obtained between breadth and length and twigs; breadth and leaf litter; and area and the leaf litter and twigs.

accumulation. Out of the 31 identified plant species along the study site, only 13 and 10 reflected their inputs in the detrital standing stock at the dry zone and wet zone sites, respectively. Despite great abundance of *Calodendrum capense* at the wet zone site, it constituted only a small proportion of the leaf litter (Table 4.17).

4.5.2. Quantity of benthic organic matter

The main components constituting the BOM at the wet zone were leaves (13.1g AFDWm^{-2}) followed by barks (12.9g AFDWm^{-2}), woody debris (11.9g AFDWm^{-2}) and twigs (11.7g AFDWm^{-2}). The leafy BOM component was dominated by *Cussonia holstii* (30.1%) followed by *Ficus thorningii* (18.5%) and *Newtonia buchanani* (5.1%). All other species combined constituted (21.9%). The distribution was aggregated as evidenced by the positive values of the dispersion index (Table 4.13) except for twigs. The spatial distribution pattern was distinct for leaves and barks. In February, March and October a marked peak was discerned. At the species level, *Cussonia* and *Ficus* showed marked peaks in September and October respectively (Fig. 4.12).

At the dry zone, BOM was dominated by leaves (52.2g AFDWm^{-2}) followed by twigs (13.2g AFDWm^{-2}), barks (6.4g AFDWm^{-2}), woody debris (4.4g AFDWm^{-2}) and fruits (4.4g AFDWm^{-2}). The leafy BOM component was dominated by *Ekebergia capensis* (33.3%) followed by *Ficus thorningii* (20.7%) and *Calodendrum capense* (3.2 %).

The dispersion index (Table 4.13) showed all the identified BOM categories to be aggregated while unidentifiable components was uniformly distributed. The spatial distribution pattern was distinct for leaves. In September and October a marked peak was discerned (Fig. 4.13). At the species level, *Ficus* and *Ekebergia* showed a marked peak in September and October (Fig. 4.14).

Overall, more BOM occurred at the dry zone (83.5g AFDWm^{-2}) as compared to the wet zone (50.6 g AFDWm^{-2}) although the two were not statistically significantly different (Mann-Whitney U test; $P > 0.05$).

Table 4.17. Total BOM components and amounts (gAFDWm^{-2}) at the wet zone site along the mid-reaches of Sagana River, Kenya.

BOM composition	**AFDW gm^{-2}**	**% AFDW**	**% of leaves**
Bark	12.95	25.59	
Twig	11.72	23.16	
Fruit	0.29	0.57	
Root	0.00	0.00	
Wood debris	11.97	23.65	
Miscellaneous	0.58	1.15	
Leaves	13.10	25.88	
Cussonia holstii	3.95		30.15
Ficus thorningii	2.43		18.55
Newtonia buchanani	0.67		5.11
Neobautonia macrocalyx	0.37		2.82
Eleodendron buchananii	0.35		2.67
Podocarpus latifolia	0.33		2.52
Calodendrum capense	0.32		2.44
Podocarpus falcatus	0.23		1.76
Syzgium guineese	0.22		1.68
Thelypteris quintziana	0.20		1.53
Grewia similis	0.19		1.45
Bersama abyssinica	0.18		1.37
Croton macrotachyus	0.17		1.30
Croton mengalocarpus	0.08		0.61
Stychnos hemifsii	0.08		0.61
Ziziphus abyssinica	0.06		0.46
Trichocladus elliptium	0.05		0.38
Rapanea melanophlaeos	0.05		0.38
Ochna inoculpata	0.04		0.31
Viscum fischeri	0.03		0.23
Others	3.10		23.66
Total BOM	**50.61**		**100.00**

Table 4.18. Total BOM composition and amounts (gAFDWm^{-2}) at the dry zone site along the mid-reaches of Sagana River, Kenya.

BOM composition	**AFDW gm^{-2}**	**% AFDW**	**% of leaves**
Bark	6.49	7.77	
Twig	13.28	15.90	
Fruit	4.44	5.32	
Root	0.55	0.66	
Wood debris	4.45	5.33	
Miscellaneous	2.07	2.48	
Leaves	52.23	62.54	
Ekebergia capensis	17.40		33.31
Ficus thorningii	10.85		20.77
Calodendrum capense	1.72		3.29
Erythrina abyssinica	1.38		2.64
Stychnos hemifsii	0.75		1.44
Podocarpus latifolia	0.73		1.40
Bersama abyssinica	0.44		0.84
Croton mengalocarpus	0.43		0.82
Agelea pentagyna	0.41		0.78
Neobautonia macrocayx	0.38		0.73
Euclea divinorum	0.28		0.54
Dalbergia lactea	0.25		0.48
Newtonia buchananii	0.20		0.38
Ziziphus abyssinica	0.15		0.29
Podocarpus falcatus	0.14		0.27
Grewia similis	0.11		0.21
Dissotis sp.	0.10		0.19
Trichocladus elliptium	0.10		0.19
Syzgium guineese	0.10		0.19
Croton macrotachyus	0.10		0.19
Rapanea melanophlaeos	0.09		0.17
Ochna inoculpata	0.07		0.13
Cyperus sp.	0.06		0.11
Garcinia volkensii	0.05		0.10
Cussonia holstii	0.05		0.10
Others	15.89		30.42
Total BOM	**83.51**		**100.00**

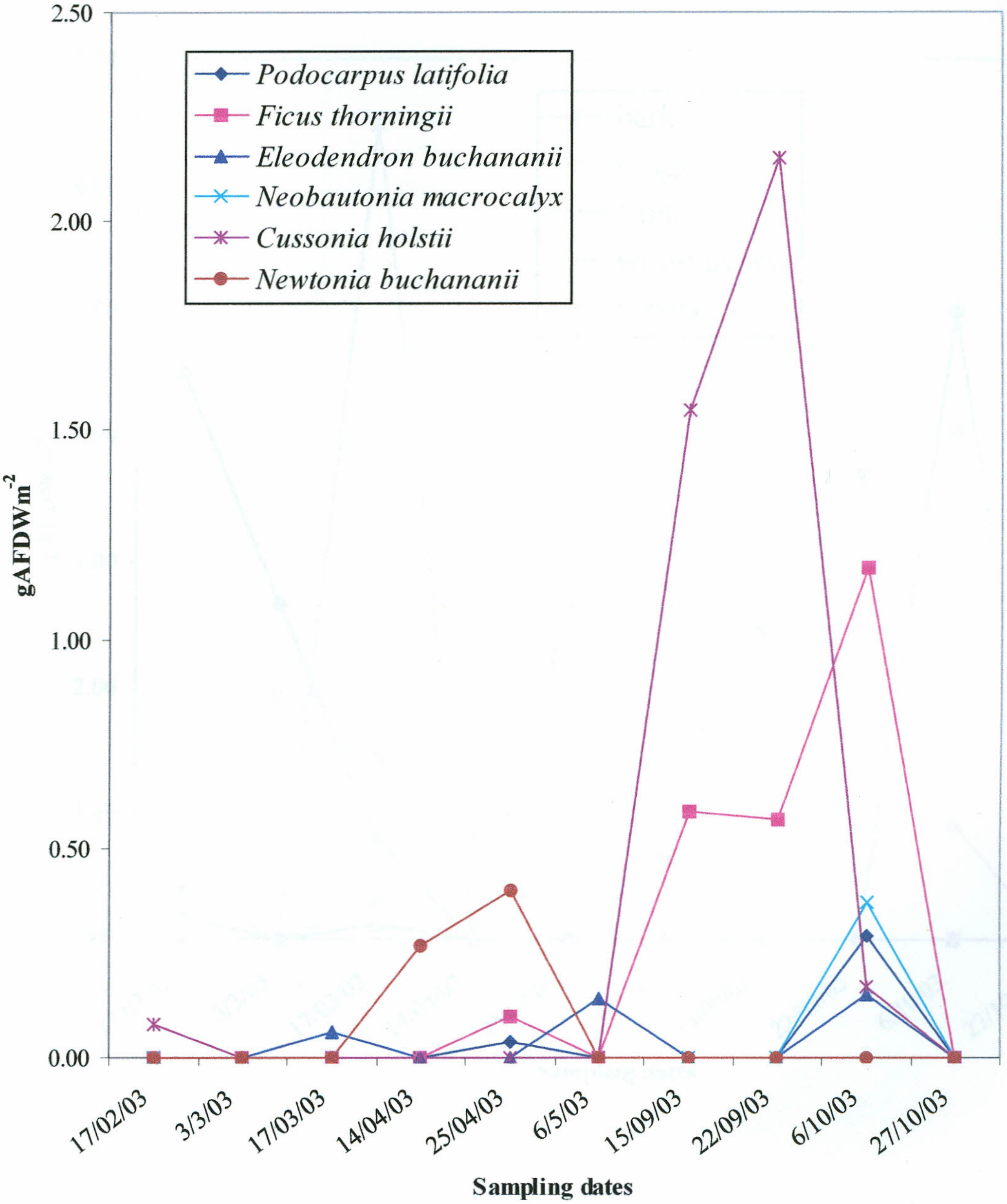

Fig. 4.12. The variation of the main detrital standing stock leaves species constituents at the wet zone site along the study reach, Sagana River, Kenya.

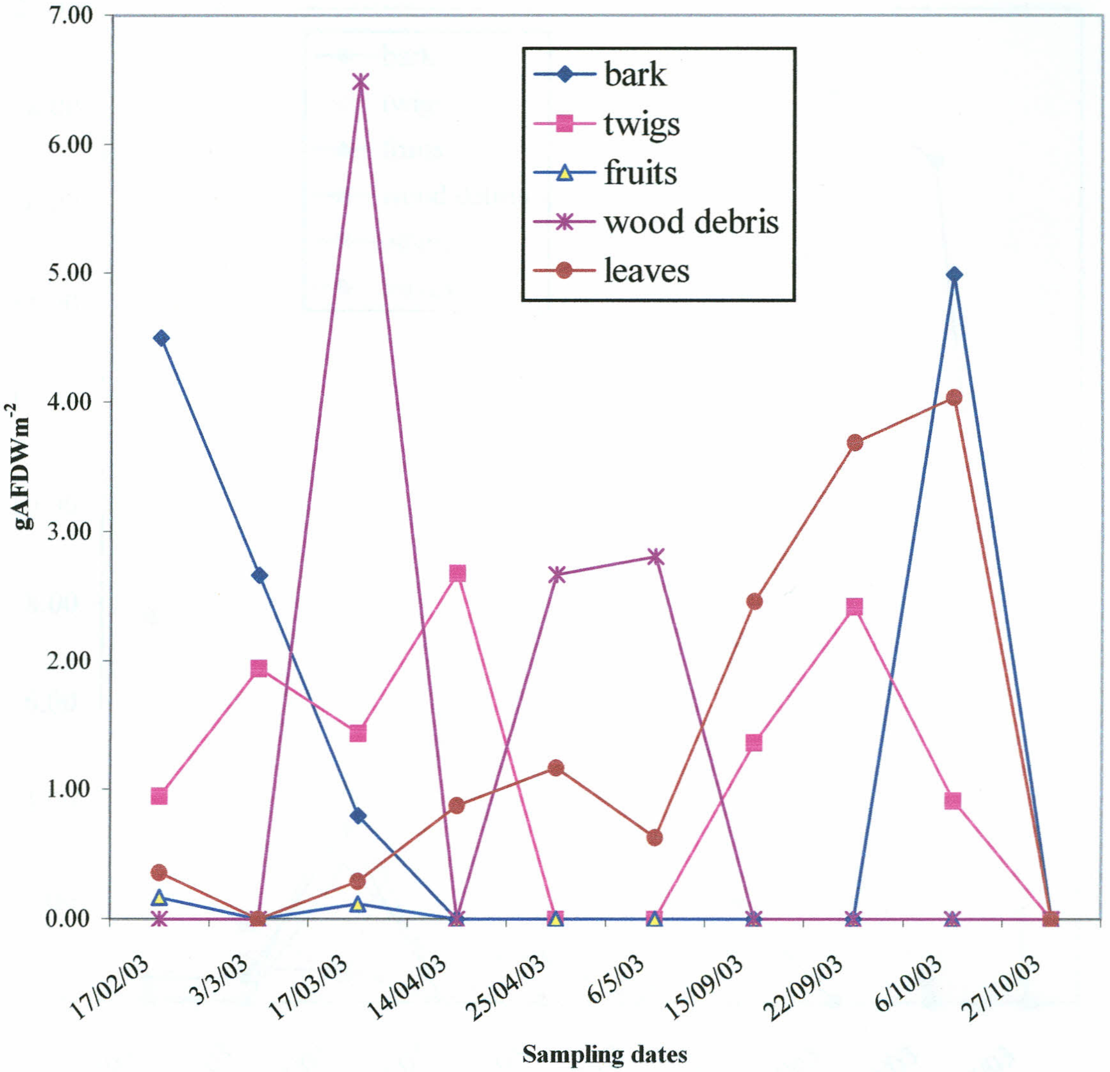

Fig. 4.13. The variation pattern for leaves, bark, twigs, fruits, and woody debris at the wet zone site along the study reach, Sagana River, Kenya.

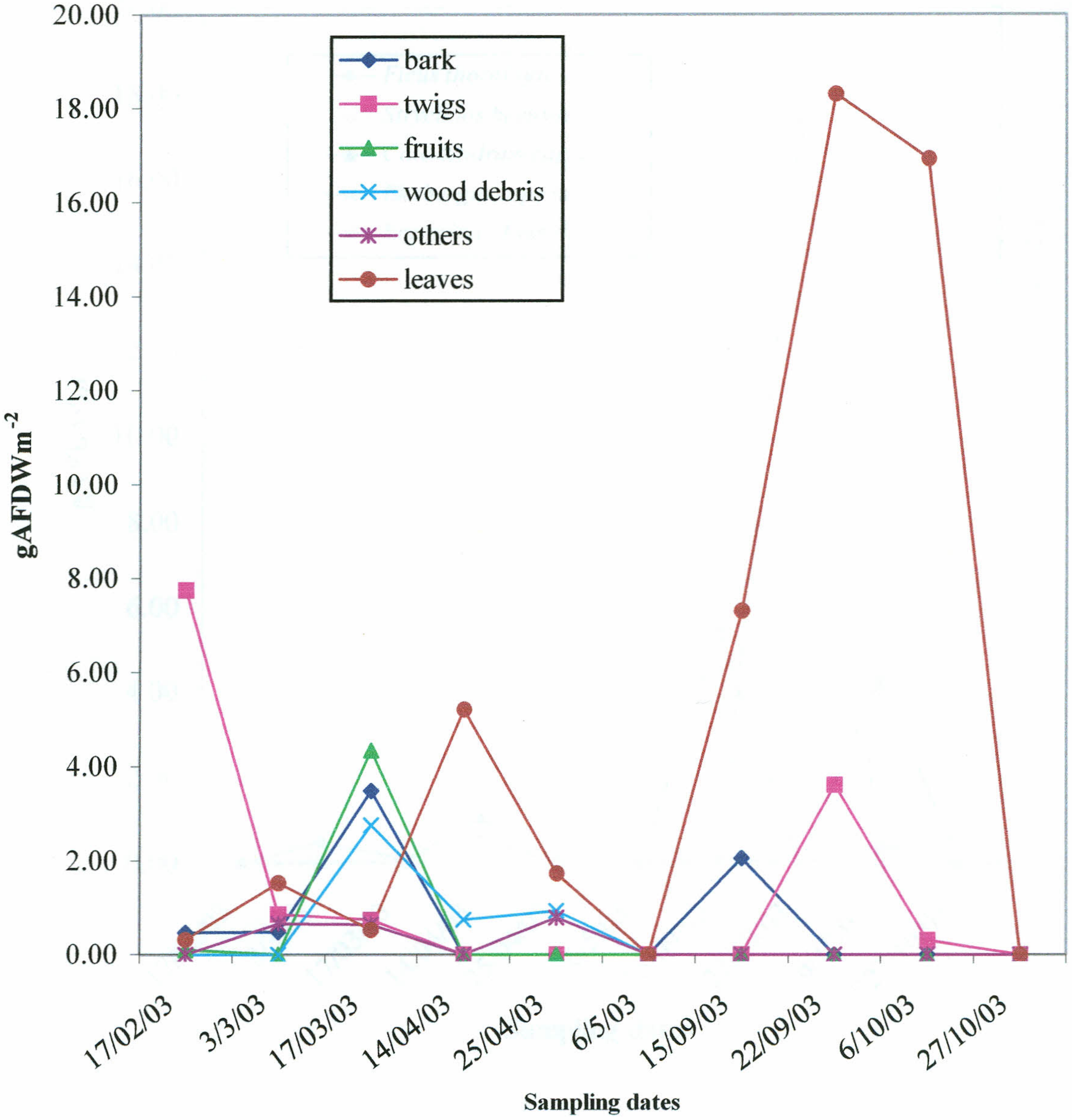

Fig. 4.14. The variation pattern for leaves, bark, twigs, wood debris and miscellaneous materials at the dry zone site along the study reach, Sagana River, Kenya.

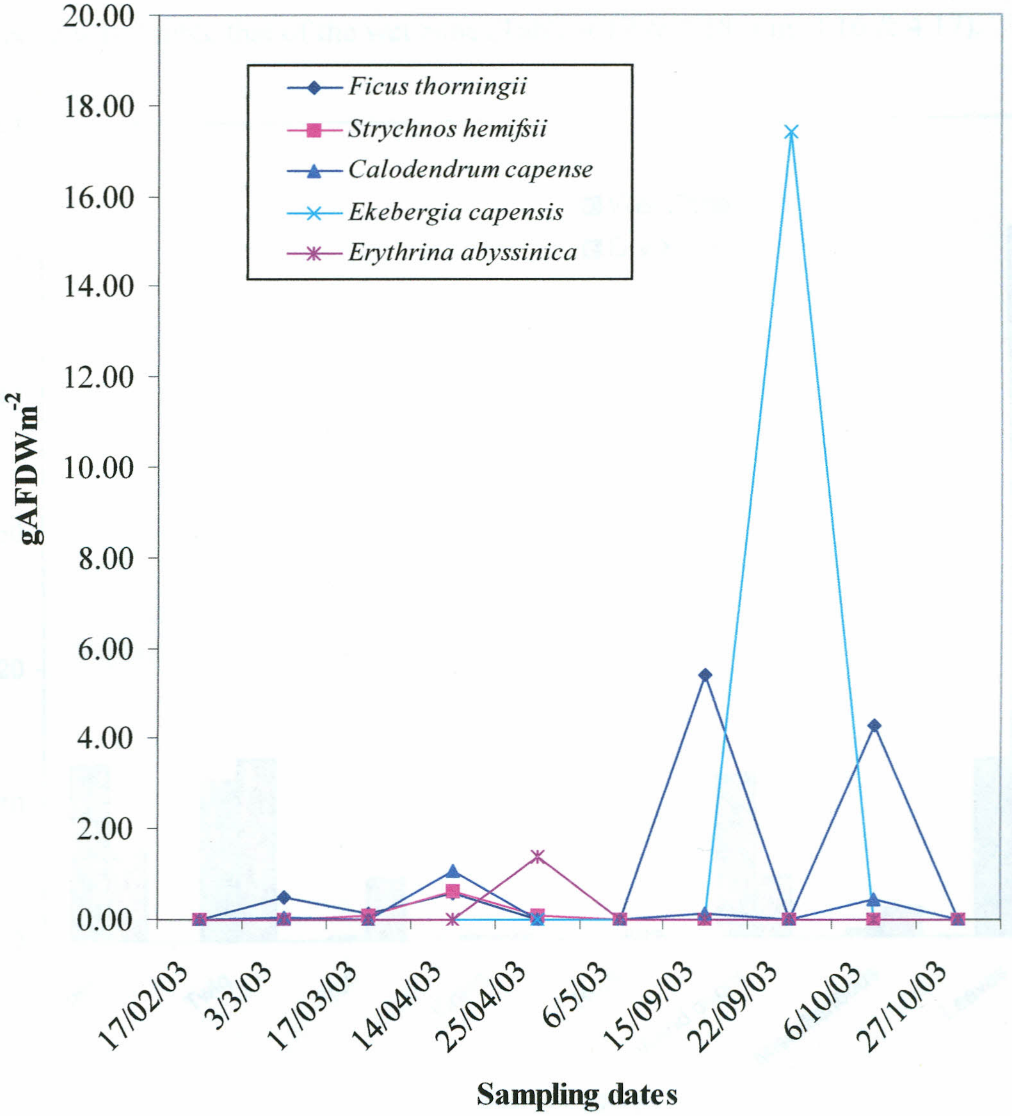

Fig. 4.15. The variation of the main detrital standing stock leaves species constituents at the dry zone site along the study reach, Sagana River, Kenya.

4.5.3. Comparison between zones

The total detrital standing stock was higher at the dry zone than at the wetted zone with a total of 83.51g AFDW m^{-2} and 50.61g AFDW m^{-2} respectively. The total amount of leaves was higher (4 times) at the dry zone than at wet zone though not significant

(Mann-Whitney U test; P > 0.05). The detrital standing stock (bark and woody debris) at the dry zone was double that of the wet zone (Table 4.17 & 4.18; Fig. 4.16 & 4.17).

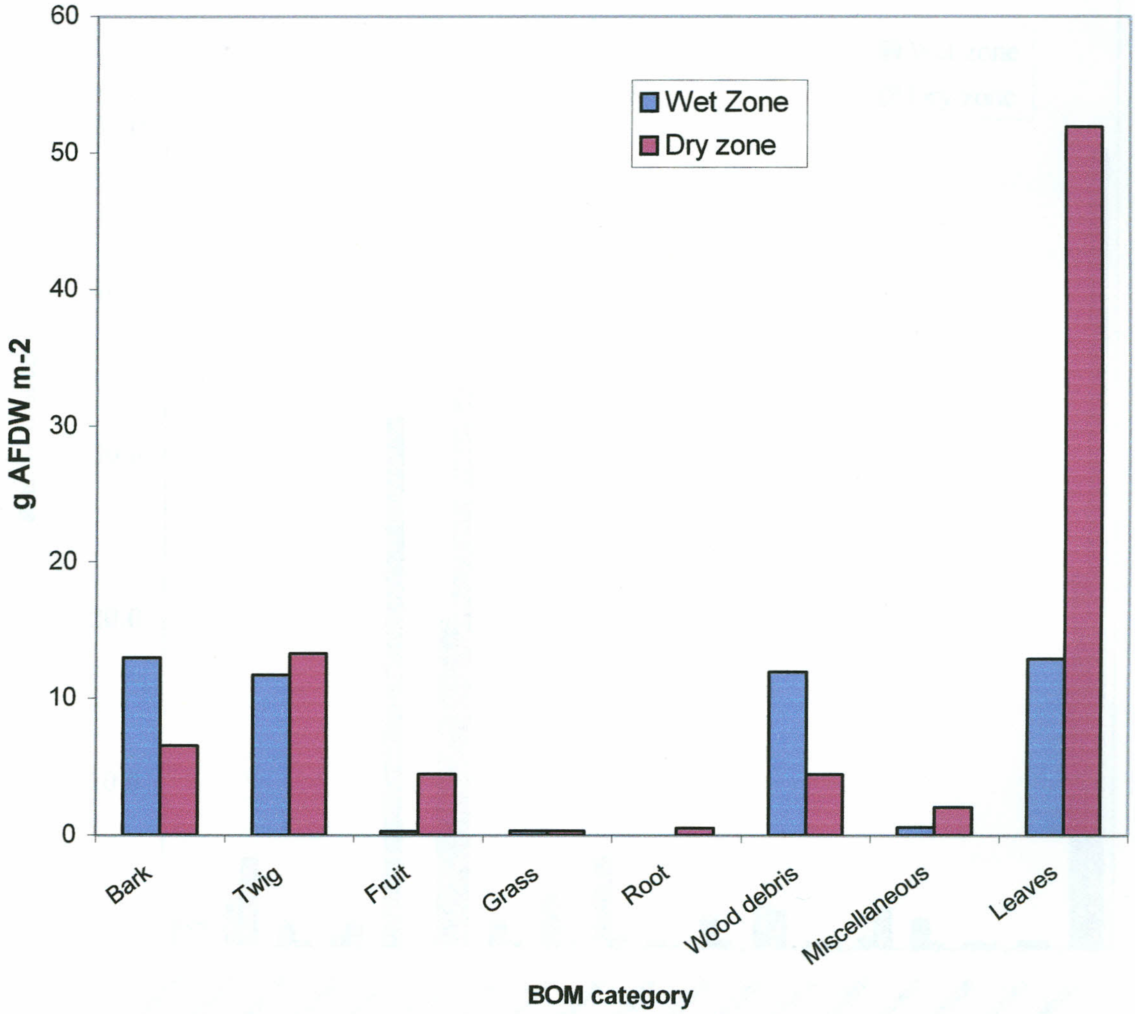

Fig. 4.16. The amounts of the main components of BOM collected at the wet and dry zone sites along the study reach, Sagana River, Kenya between February 2003 and October 2003.

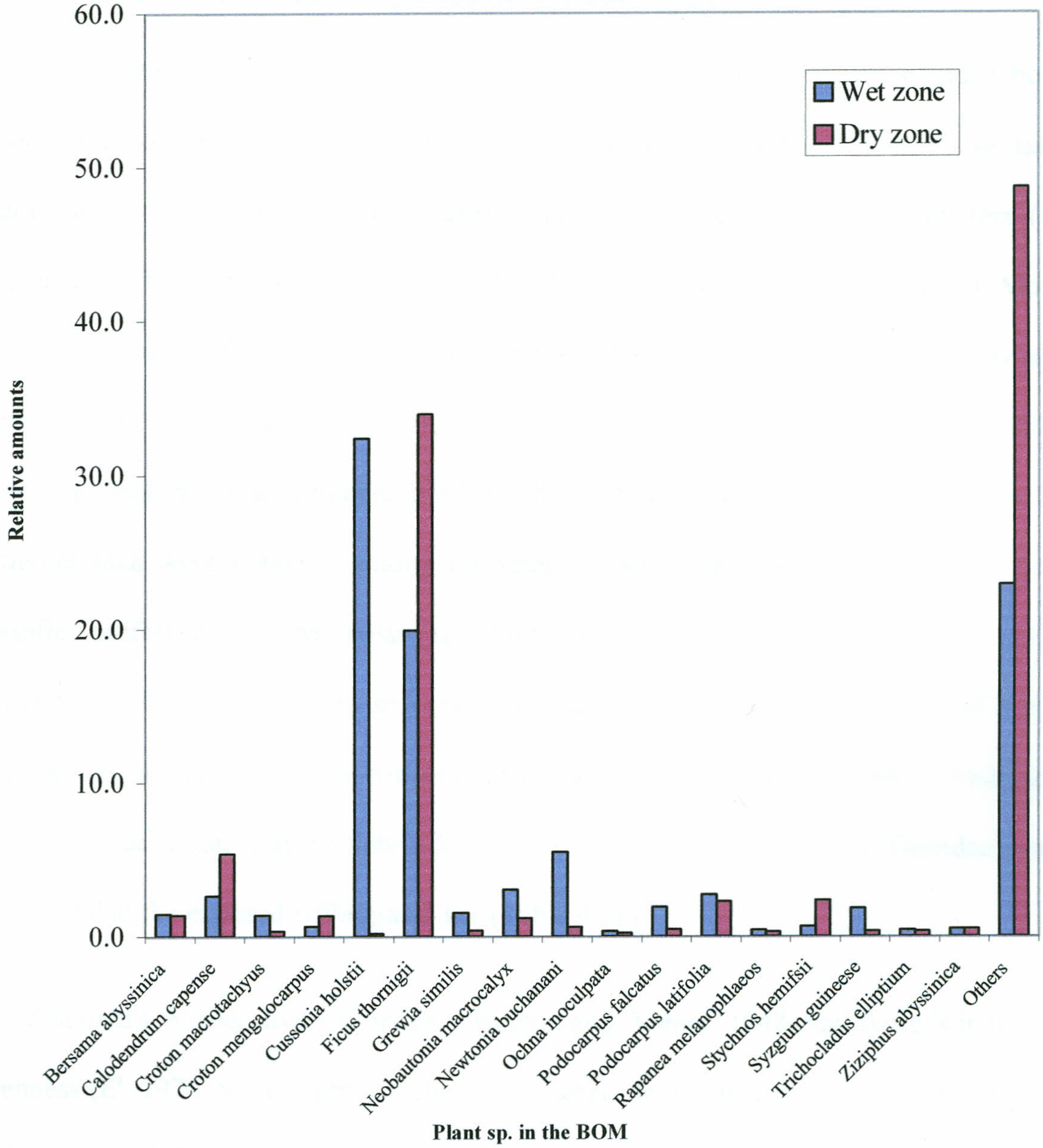

Fig. 4.17. Qualitative composition of BOM standing stock collected between February 2003 and October 2003 at the wet and dry zone sites along the study reach, Sagana River, Kenya.

4.6. Macroinvertebrates

4.6.1. Macroinvertebrates species abundance and diversity

Benthic macroinvertebrates found among the various retentive features included both insect and non-insect taxa, comprising 22 different taxa (Table 4.19). These taxa belonged to the Ephemeroptera (6 taxa), Diptera (3) Coleoptera (3), Trichoptera (1) Odonata (1), Hydracarina (1), Decapoda (1), Hemiptera (2) and Oligochaeta (4). More taxa were obtained from the debris dam (18 taxa) than the large woody debris (15) and exposed riffle gravel bar (16) (Table 4.20). The order Ephemeroptera and specifically *Baetis* sp. was the most dominant at all the three retentive features. Half (11) of the 22 different taxa were common among the retention structures. However, some showed specific preference to particular retention feature. For example, Ephemeroptera (Trichorythidae and *Acanthiops sp.*) and Oligochaeta (Hirudinae) were only found at the large woody debris. In addition, some Oligochaeta (Lambriculidae), Hemiptera (Vellidae) were specifically found at the debris dam. Moreover, the taxa Hemiptera (Gerridae) was only found at the exposed riffle gravel bar (Table 4.21).

The Shannon's Wiener diversity index (Shannon and Wiener, 1948) and Batter's index of evenness (E'; 1976) were slightly higher at the debris dam than at the large woody debris and exposed riffle gravel bar. This suggested that rare species were present in large numbers. The taxa diversity of the exposed gravel bar was higher than that at the large woody debris and debris dam on a Simpson Index of diversity (D'; 1949). This implied that there was a greater number of common species at the exposed gravel bar than at the LWD and debris dam, which was largely dominated by *Baetis sp.* and Simulidae representing 53% of the total taxa (Table 4.20).

Table. 4.19. The list of taxa of benthic macroinvertebrates in samples collected along the mid- reaches of Sagana River, Kenya, February 2003 to October 2003.

Ephemeroptera
Baetis sp.
Caenis sp.
Afronurus sp.
Choroterpes sp.
Tricorythus sp.
Acanthiops sp.

Coleoptera
Elmidae
Scirtidae

Diptera
Chironomidae
Simulidae
Tipulidae

Oligochaeta
Tubifindae
Naididae
Lumbricidae

Hiridinea

Hemiptera
Gerridae
Vellidae

Hygrobatidae

Decapoda
Glossiphonidae
Potamonautes sp

Trichoptera
Hydropsychidae
(Hydropsych sp.)

4.6.2. Macroinvertabrates associated with debris dam

The macroinvertebrates occurring at the debris dams were dominated by Coleoptera (47.3%), followed by Diptera (22.7%) and Ephemeroptera (19.2%). The Coleoptera were dominated by Gyrinidae, Elmidae and Scirtidae (Table 4.21 and 4.22).

Among the debris dam, the main functional feeding groups were the collector-gatherers, dominated by Chironomidae (Diptera; 18.3%), *Baetis sp.* (Ephemeroptera; 11.4%), *Caenis sp.* (Oligochaeta; 5.0%), Elmidae (Coleoptera; 4.5%), Tubificidae (Ephemeroptera; 1.3%), Naididae (Oligochaeta; 1.3%), Tipulidae (Oligochaeta; 0.9%) and Lumbrilidae (Oligochaeta; 0.9%). Collector filterer (Simulidae) occurred in low abundance while Tipulidae known to switch between shredding and collector gathering food habits (Table 4.23), were very rare, constituting 1% of the total faunal abundance.

Table 4.20. Taxa richness, diversity and evenness at the debris dam, LWD and exposed riffle gravel bar sites along the mid reaches of Sagana River, Kenya.

Taxa		**Total taxa**	**Exposed riffle gravel bar**	**Debris dam**	**LWD**
Ephemeroptera		6	4	4	6
Diptera		3	3	3	2
Coleoptera		3	3	3	2
Trichoptera		1	1	1	1
Odonata		1	0	1	1
Hydracarina		1	1	1	1
Decapoda		1	1	1	1
Hemiptera		2	1	1	0
Oligochaeta		4	2	3	1
Total		**22**	**16**	**18**	**15**
Diversity	**(H')**		**1.91**	**1.96**	**1.80**
	(D')		**0.81**	**0.77**	**0.77**
Evenness	**(E')**		**0.67**	**0.67**	**0.65**

Shredders represented by Scirtidae constituted less than 2% of the total faunal abundance (Table 4.23; Fig. 4.18).

4.6.3. Macroinvertebrates associated with LWD

The Macroinvertebrates occurring at the large woody debris were dominated by Ephemeroptera (66.6%) followed by Coleoptera (16.8%) and Diptera (11.8%). The Ephemeroptera were dominated by *Baetis sp; Caenis sp.*, *Afronurus* and *Choroterpes sp.* (Table 4.23). Among the LWD, the main functional feeding groups were the collector-gatherers, dominated by *Baetis sp.* (38.8%), Caenis sp. (18.6%), Chironomidae (10.6%), and *Afronurus* (3.4%). Predators (Gyrinidae and Agriidae), collector filterers (Simulidae and Hydropsychidae) and Scrappers (Tricorythidae) were very rare (Table 4.23; Fig 4.18).

Table 4. 21. Total individual counts and relative abundance of major taxa at the debris dam, LWD and exposed riffle gravel bar along the mid reaches of Sagana River, Kenya.

Taxa	**Debris dam**		**LWD**		**Exposed riffle gravel Bar**	
	Indiv. count	**Relative abundance**	**Indiv. count**	**Relative abundance**	**Indiv. count**	**Relative abundance**
Baetis	61	11.36	260	38.75	188	27.85
Caenis	27	5.03	125	18.63	77	11.41
Afronurus	8	1.49	36	5.37	59	8.74
Choroterpes	7	1.30	25	3.73	22	3.26
Trichorythidae	0	0.00	1	0.15	0	0.00
Acanthiops	0	0.00	1	0.15	0	0.00
Elmidae	24	4.47	0	0.00	3	0.44
Scirtidae	3	0.56	7	1.04	5	0.74
Gyrinidae	227	42.27	106	15.80	8	1.19
Hydropsychidae	5	0.93	1	0.15	15	2.22
Chironomidae	98	18.25	71	10.58	113	16.74
Simulidae	19	3.54	8	1.19	168	24.89
Tipulidae	5	0.93	0	0.00	2	0.30
Agriidae	2	0.37	2	0.30	0	0.00
Hygrobatidae	1	0.19	1	0.15	1	0.15
Decapoda	4	0.74	2	0.30	2	0.30
Gerridae	0	0.00	0	0.00	1	0.15
Vellidae	1	0.19	0	0.00	0	0.00
Tubificidae	13	2.42	0	0.00	3	0.44
Naididae	7	1.30	0	0.00	5	0.74
Lumriculidae	5	0.93	0	0.00	0	0.00
Hirudinae	0	0.00	2	0.30	0	0.00
Others	20	3.72	23	3.43	3	0.44
Total	**537**	**100**	**671**	**100**	**675**	**100**

Table 4.22. Total counts and relative abundance of insect and non-insect taxa at the debris dam, LWD and exposed riffle gravel bar along the mid reaches of Sagana River, Kenya.

Taxa	Debris dam		LWD		Exposed riffle gravel Bar	
	Indiv. Count	Relative abundance	Indiv. Count	Relative abundance	Indiv. Count	Relative abundance
Insecta						
Ephemeroptera	103	19.18	448	66.77	346	51.26
Diptera	122	22.72	79	11.77	283	41.93
Coleoptera	254	47.30	113	16.84	16	2.37
Trichoptera	5	0.93	1	0.15	15	2.22
Odonata	2	0.37	2	0.30	0	0.00
Hemiptera	1	0.19	0	0.00	1	0.15
Total	**487**	**90.69**	**643**	**95.83**	**661**	**97.93**
Crustacea						
Decapoda	4	0.74	2	0.30	2	0.30
Total	**4**	**0.75**	**2**	**0.29**	**2**	**0.29**
Others						
Oligochaeta	25	4.66	0	0.00	8	1.19
Hirudinae	0	0.00	2	0.30	0	0.00
Hydracarina	1	0.19	1	0.15	1	0.15
Miscellaneous	20	3.72	23	3.43	3	0.44
Total	**46**	**8.57**	**26**	**3.88**	**12**	**1.78**
Overall Total	**537**	**100**	**671**	**100**	**675**	**100**

4.6.4. Macroinvertebrates associated with the exposed riffle gravel bar

The macroinvertebrates occurring at the exposed riffle gravel bar were dominated by Ephemereoptera (51.3%), and Diptera (41.9%). The Ephemeroptera were dominated by *Baetis sp.*, *Caenis sp.* and *Afronurus sp.* while the Diptera by Simulidae and Chironomidae (Table 4.21; Fig. 4.18).

Among the exposed riffle gravel bar, the main functional feeding groups were the collector-gatherers, dominated by *Baetis sp.* (27.9%), *Afronurus sp.* (8.7%) and *Choroterpes sp.* (3.3%). Shredders/collector-gatherer (Tipulidae), Predators (Gyrinidae and Gerridae) abundance represented less than 2% of the total faunal abundance (Table 4.23; Fig. 4.18).

Table 4.23. Composition, occurrence and functional feeding groups of major taxa at the debris dam, LWD and at the exposed riffle gravel bar sites along the mid-reaches of Sagana River, Kenya. Functional feeding groups are indicated for each taxon as Shredder (SH), filter feeder (FF), collector-gatherer (CG), scrapers (SC) and predators (PR) (Armitage *et al.*, 1995; Merritt and Cummins, 1979; 1996 and Canton and Chandwick, 1983).

Major taxa Debris dam site	**Occurrence**	**RA**	**FFG**	**Major taxa LWD site**	**Occurrence**	**RA**	**FFG**	**Major taxa ERGB site**	**Occurrence**	**RA**	**FFG**
Gyrinidae	227	42.3	PR	*Baetis sp.*	260	38.8	CG	*Baetis sp.*	188	27.9	CG
Chironomidae	98	18.3	CG/SC	*Caenis sp.*	125	18.6	SC/CG	Simulidae	168	24.9	CF
Baetis sp.	61	11.4	CG	Gyriniididae	106	15.8	PR	Chironomidae	113	16.7	CG/SC
Caenis sp.	27	5.0	SC/CG	Chironomidae	71	10.6	CG/SC	*Caenis sp.*	77	11.4	SC/CG
Elmidae	24	4.5	SC/CG	*Afronurus sp.*	36	3.4	CG	*Afronurus sp.*	59	8.7	CG
Simulidae	19	3.6	CF	*Choroterpes sp.*	25	3.7	SC/CG	*Choroterpes sp.*	22	3.3	SC/CG
Tubificidae	13	2.4	CG	Simulidae	8	1.2	CF	Hydropsychidae	15	2.2	CF
Afronurus sp.	8	1.5	CG	Scirtidae	7	1.0	SH/SC	Gyriniididae	8	1.2	PR
Choroterpes sp.	7	1.3	SC/CG	Agriidae	2	0.3	PR	Scirtidae	5	0.7	SH
Naididae	7	1.3	CG	Decapoda	2	0.3		Naididae	5	0.7	CG
Hydropsychidae	5	0.9	CF	Hirudinae	2	0.3	CG	Elmidae	3	0.4	SC/CG
Tipulidae	5	0.9	SH/CG	Tricorythidae	1	0.2	SC	Tubificidae	3	0.4	CG
Lumbriculidae	5	0.9	CG	*Acanthiops sp.*	1	0.2		Tipulidae	2	0.3	SH/CG
Decapoda	4	0.7		Hydropsychidae	1	0.2	CF	Decapoda	2	0.3	
Scirtidae	3	0.6	SH	Hygrobatidae	1	0.2		Hygrobatidae	1	0.2	
Agriidae	2	0.4	PR	Others	23	3.4		Gerridae	1	0.2	PR
Hygrobatidae	1	0.2						Others	3	0.4	
Vellidae	1	0.2	PR								
Others	20	3.7									

LWD - Large Woody Debris	RA - Relative Abundance
ERGB - Exposed Riffle Gravel Bar	FFG - Functional Feeding Group

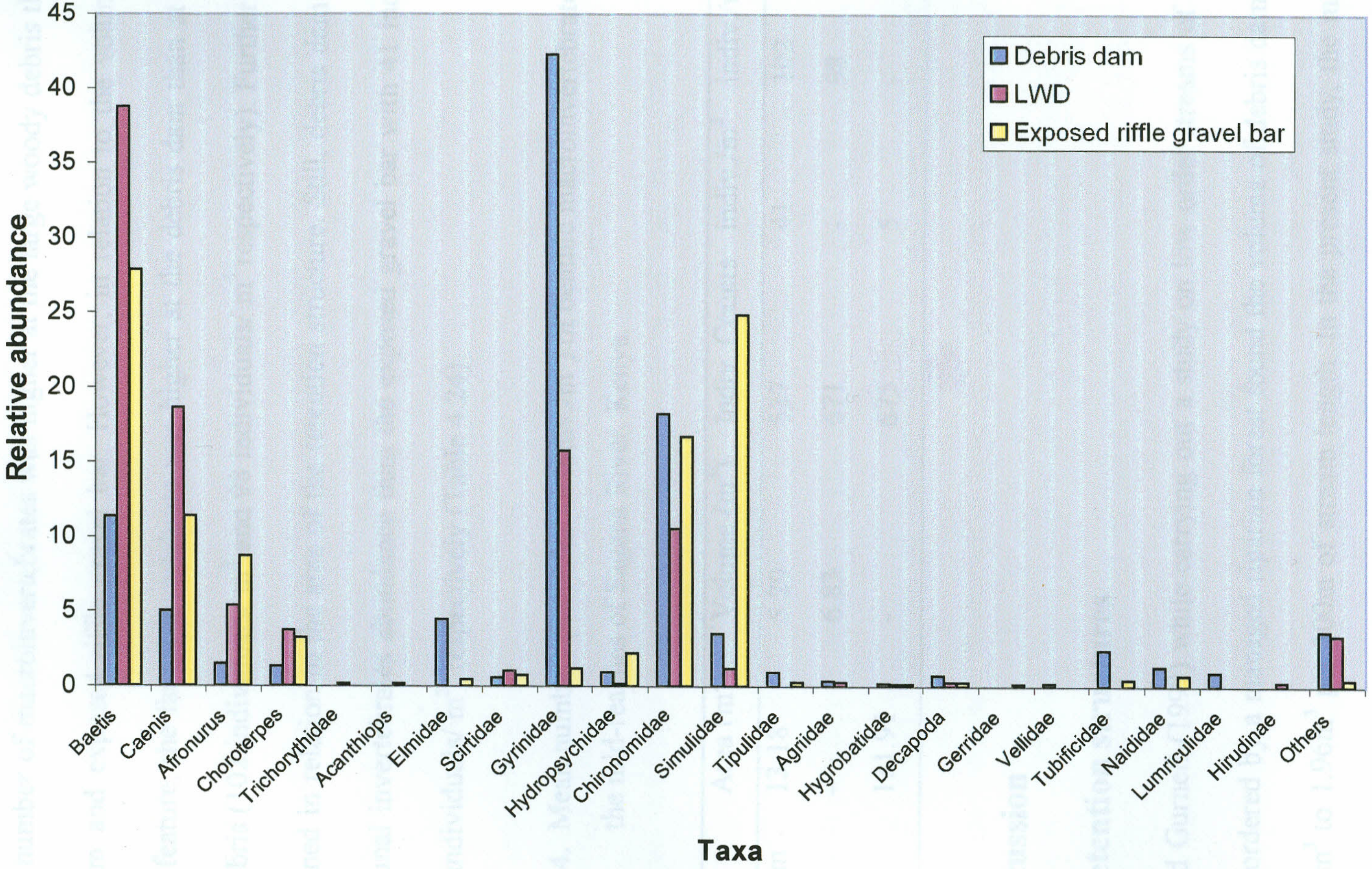

Fig. 4.18. Relative abundance of major taxa at the debris dam, large woody debris and exposed riffle gravel bar sites along the mid-reaches of Sagana River, Kenya.

4.6.5. Comparison between retention structures

The total number of macroinvertebrates was higher at the large woody debris than at the debris dam and exposed riffle gravel bar. However, in relation to the volume of the retention feature, the faunal invertebrate was higher at the debris dam than at the large woody debris (102 individuals/ m^3 and 98 individuals/ m^3 respectively). Further variation was obtained in relation to the area of the retention structure. Still, debris dam recorded higher faunal invertebrates abundance than the exposed gravel bar with 41 individuals/ m^2 and 5 individuals/ m^2, respectively (Table 4.24).

Table 4.24. Mean numbers (indiv./m^2 or indiv./m^3) of benthic macroinvertebrates along the mid-reaches of Sagana River, Kenya.

Site	Area (m^2)	Volume (m^3)	Indiv. Counts	indiv./m^2	indiv./m^3	Taxa
Debris dam	13.18	5.29	537	41	102	18
LWD	-	6.83	671	-	98	15
ERGB	131.91	-	675	5	-	16

4.7. Discussion

4.7.1. Retention structures

Piegay and Gurnell (1997) while carrying out a study on low order streams of southern England bordered by a managed riparian forest found the volume of debris dam ranging from 1.02m^3 to 1.96m^3 per 100m of stream length. In the present study, the mean dam volume for the entire study period was 1.25 ± 0.52 m^3 per 100m of the reach. This is well within the range limit given by Piegay and Gurnell. The results further demonstrate that debris dam represent relatively stable retention structures along the mid reaches of Sagana River. Though several floods occurred during the study period, the occurrence of debris dams remained relatively stable (Table 4.5). Similar observations were made by Weigelhofer and Waringer (1999) while carrying out a study on woody debris accumulations at Weidlingbach stream in lower Austria. In addition, they noted that dams tend to be consistent in size, shape and structure throughout the year. In some other related studies, Smock *et al.* (1989) observed that only extreme hydrological events tended to disrupt the woody matrix or completely destroy dams while Raikow *et al.* (1995) observed a high seasonal variability with debris dams in a wide high gradient 3rd order streams.

The main structural components of debris dam for the entire study period were the leaves, bark and twigs. The result agrees with the findings of Weigelhofer and Waringer (1999) who reported leaf packs and twigs as important prerequisites for dam formation.

Forest productivity and management largely determines the amount of large woody debris (LWD) supplied to the streams. However, the amounts and frequencies of LWD, which should heavily influence the morphology of streams under potentially natural conditions, are unknown. Nevertheless, there should be difference in the amount and distribution of LWD when dealing with streams of different types. According to Harmon *et al.* (1986), the volume of LWD present in 83 stream sections of unmanaged forests throughout North America ranged from 2.5 to 4500m^3/ha. In Canadian boreal forest streams, LWD (>10cm in diameter) standing stock ranged from 0.2 to 794m^3/m^2 (Naiman *et. al.*, 1986). In France along the alluvial floodplains, Piegay and Gurnell (1997) found LWD volume ranging from 0.28 to 743.4m^3/ha. Similarly, Hering *et al.* (2000) while carrying out a study on the quantity and distribution of LWD in central European streams reported that LWD volume related to stream length was 1.44m^3/100 meter reach.

However, in the present study, the volume of LWD (≥10 cm in diameter) related to the study reach length was 1.25m^3/100 meter reach. Considering results from other rivers in some parts of the world, the present LWD volume is slightly lower predominantly because logs of size class category (≥10 cm in diameter) is lacking due to continuous cutting down of trees along the riparian zone. It is apparent that virtually all forests along the catchment areas in Kenya have been managed and used in the past. This has led to lack or low numbers of old, dying trees, which potentially could provide most of the LWD.

The proportion of species of trees that produced the piece of LWD was higher for the unidentified species due to decomposition of the material in the channel. Similar observation was made by Bilby and Ward (1991) while carrying out a study at some streams in southern Washington. They noted that advanced decomposition of wood in the stream made it impossible for the identification of specific species of tree that produced the LWD.

4.7.2 Benthic organic matter standing stock

In the present study, the dry zone site (periodically flooded during wet season) accumulated higher BOM detrital standing stock (83.51g AFDWm^{-2}) than the wet zone (58.83g AFDWm^{-2}) possibly due to the presence of abundant retention structures such as large cobbles and boulders at the site. Similarly the leaves was stored more at the dry zone (51.89g AFDWm^{-2}) than at the wet zone (28.11g AFDWm^{-2}). The results are consistent with observations made by Bretschko (1990) and Mathooko (1995) that the dry zone store more leaves than the wetted zone. Infact Bretschko noted that at any time of the year, amounts of deposited leaf material are four (4) times greater in dry channel areas than in wet areas. In this study leaf litter at the dry zone was four times higher than that at the wetted zone (Table 4.17 & 4.18). This is partly explained by the fact that leaf materials falling on the water surface at the wet zone are quickly transported downstream. The idea is supported by Mwangi (2000) who found higher total detrital standing stock at the cultivated dry zone than at the wetted zone along the upper reaches of Sagana River. However, contrary to the present results, he noted that the leaf litter at the dry zone was only higher by almost twice than that of the wetted zone.

The riparian plant vegetation composition reflected the qualitative characteristics of the benthic organic matter standing stock. The detrital standing stock at the wetted zone site comprised 10 different species while that of the dry zone; 13 different riparian zone plant species. The difference in leaf litter accumulation at the dry and wet zones is attributed to species composition and density of the riparian vegetation. A very dense canopy closure of *Ekebergia capensis*, *Ficus thorningii* and *Calodendrum capense* covered the stream channel at the dry zone site. This introduced large quantities of leaves into the stream through direct inputs. The dominance of these species in the detrital standing stock at the site was consistent with the trends that the surrounding riparian vegetation constitutes the main source of allochthonous CPOM inputs (Vannote *et al.*, 1980). These results support the observations made by Moser (1994) that the aerial inputs at the Oberer Seebach (Austria) were significantly correlated with the canopy closure. The findings further agree with the observations made by Webster *et al.* (1990) and Bilby and Bisson (1992) that clear cutting of riparian vegetation drastically reduce litter inputs to streams. Similarly, Wallace *et al.* (1999) noted that the exclusion of canopy inputs to a first order stream at Coweeta study area (USA) reduced the direct litter inputs.

The dominance in canopy cover by a particular plant species did not necessarily result in a corresponding magnitude of input. For example, at the wet zone site *Cussonia holstii* and *Ficus thorningii* surprisingly dominated the BOM detrital standing stock with over 50% of the total leaf litter despite the dominance by *Syzgium guinesse*, which grew to large heights with canopy spreading over the stream. This is probably due to its low turnover in leafing and defoliation. *Cussonia holstii* and *Ficus thorningii* are of great significance as sources of energy to the stream macro-invertebrates and if removed from the riparian zone, litter inputs could be drastically reduced. These findings agree with those of Magana (2000) who observed the dominance of *Pittosporum viridiflorum* Sims ssp. over *Rhus natalensis* Krauss at the open canopy site but contributed less of leaf litter than *R. natalensis* at Njoro River (Kenya). Similarly, Mwangi (2000) found *Afrocrania volkensii* (Harms) Hutch and *Dombeya torrida* (J.F. Gmel) Bamps dominating the detritus standing stock despite the dominance by *Ilex mitis* (L.) Radlk at the riparian zone along the upper reaches of Sagana River, Kenya.

4.7.3. Effectiveness in retention of BOM

The total detrital standing stock of benthic organic matter within debris dam at Sagana River are not comparable to that of temperate rivers draining watersheds. For example, Winkler (1991) recorded 13 Kg DWm^{-2} of standing stock of BOM in a dam structure situated in a secondary branch of the Oberer Seebach in Lunz (Austria). Smock *et al.* (1989) collected standing stock of benthic organic matter ranging between 922 and 3356g AFDW m^{-2} in Oberer Seebach, Austria. While highest standing stock of benthic organic matter are recorded by Weigelhofer and Waringer (1999) in Weidlingbach, lower Austria, with 22 kg DWm^{-2}. These values are higher than the ones of the present study (i.e. 566.36g DWm^{-2} or 49.99g AFDWm^{-2}).

The low values are possibly due to lack of thick un-impacted riparian vegetation undergrowth particularly along the upper left bank of the study reach. It can also be apparently related to discharge. An increase in discharge as a result of high rainfall during the study period flushed organic material from the debris dam. This is in agreement with observation made by Maridet *et al.* (1995) that the seasonality of benthic organic matter standing stock is related to discharge in streams adjacent to catchments in the French granitic central mountains. They further noted that the low amount of BOM stored in certain months of the year was due to the flushing flows during peak leaf fall.

However, the leaf litter detrital standing stock of BOM of 155.91g DWm^{-2} recorded in the present study is comparable to that observed by Weigelhofer and Waringer (1999) in Weidlingbach lower Austria. They recorded detrital standing stock of leaf litter material ranging from 60g DWM^{-2} to 340g DWm^{-2}. Additionally, for low order streams, CPOM storage capacity of debris dams is estimated to range from 20 to 85% of the total benthic CPOM (Bilby and Liken, 1980; Smock *et al.*, 1989; Naiman and Likens, 1997; Newbold *et al.* 1997). The data of the present study demonstrate that Sagana River is within this range (30.5%), illustrating that debris dams play an important role as long-term retention structures for organic matter and food resources. The results are in agreement with the findings of Weigelhofer and Waringer (1999) who noted that the Weidlingbach, a low order forest stream in Austria, is near the upper end of the range. However, Jones (1997) cautioned that the total benthic organic matter and the accumulation of the debris dam in streams is influenced by a multitude of variables, which includes latitudes, climatic conditions, vegetation and the channel morphology. Therefore, the amount of CPOM and its storage capacity varies greatly among stream system or among sites within a given stream.

Higher percentage (13.5%) of the materials that could not be identified was as a result of decomposition. This suggests that the materials were presumably brought in from the catchments through erosional processes. Similar sentiments have also been given by Mwangi (2000) while currying out a study at the upper reach of Sagana River.

The accumulation of BOM detrital standing stock mainly composed of leaves was as a result of various strips of native riparian vegetation of about 15 metres on either side of the lower and middle bank of the river channel. A canopy of *Ficus thorningii* mixed with *Croton macrotachyus* covered the river channel and this apparently resulted into direct inputs. This finding corroborates the observations made by Johnson *et al.* (1997) that various strips of riparian forests (buffer strips) may contribute substantial amounts of allochthonous debris to streams. Similar sentiments were given by Dudgeon & Bretschko (1996). They recommended maintenance of buffer strips of riparian vegetation along stream banks to protect riverine communities from adverse effects of land-use changes with the drainage basin. Additionally, Newbold *et al.* (1980) found significantly higher diversity of macroinvertebrates in streams with wide buffer strips than in streams with no buffer strips after logging of the watersheds. The idea is supported by Mwangi (2000) who recognized the presence of a narrow strip of native and exotic tree species along the stream banks as having a significant effect on the amount of organic matter stored at the site.

The observed peak in the detrital standing stock of the leaf litter during the dry months of February and September at the debris dam site is presumably due to shortage of rainfall that limited biological processes and hence facilitating defoliation. The results agree with the statements by Dudgeon and Bretschko (1996) that in some parts of tropical Asia with distinct wet-dry seasonality, particulate organic matter loads increases slightly during the dry season when some trees shed their leaves. Similar observations were made by Magana (2000) where direct inputs showed a peak during the dry season constituting 44% of the leaf input and 27% of the total input at Njoro River Kenya.

The most important variable influencing the accumulated leaf litter at the debris dam site in Sagana River is volume. This is best illustrated by a strong and positive correlation between the total ash free dry weights of leaf litter and the volume of the debris dam. This suggests that increased amount of leaf litter at the debris dam site may be related to high dam volume.

The results of this study suggest that large woody debris is an important determinant of the detrital accumulation among patches in Sagana River. Research in temperate and tropical streams has shown that LWD plays a key role in shaping channel morphology and retaining sediment particularly in smaller higher gradient streams (Murphy and Hall, 1981). Apparently, streams with large woody debris accumulations retain BOM more efficiently than streams without (Bilby and Likens, 1980; Bilby, 1981; Speaker *et al.*, 1984; Speaker 1985; Golladay *et al.*, 1987). However Triska *et al.* (1982) showed that logs have different effects on retention and storage of organic matter depending on changes in seasonal discharge rates. Therefore, the results of the present investigation are in general agreement with those of such studies in that the highest accumulation of detrital benthic organic matter standing stock was recorded at the LWD (Table 4.15).

Moreover, Naiman and Sedell (1979) and Bilby and Likens (1980) explain that a large proportion of standing stock of particulate organic matter in streams is often associated with LWD. A similar sentiment was also given by Molles (1982) who showed that streams with no LWD has lower standing stocks of organic matter and support few shredding insects. The idea is supported by Young *et al.* (1978) who state that LWD increase retention rates of the detritus directly by catching particles and indirectly by altering particle travel patterns. He further noted that different sizes and shapes of particles travel at different rates. For example, leaves are ventrally buoyant in water column and are caught by obstructions within the water column.

The total detrital benthic organic matter standing stock measured in the present study at the LWD is far much higher than that of the debris dam and the exposed riffle gravel bar site which were within the same study reach. Since sampling among the retention sites was done during the same period, the difference could be due to trapping of smaller debris by the extensive branches and sticks of the LWD. This is in agreement with the notion that the accumulation of LWD such as branches and sticks greatly increase retention efficiency of streams by trapping smaller debris (Webster *et al.*, 1994; Jones, 1997).

Similarly, high accumulation of detrital standing stock during high flow period is attributed to high discharge variations. It is presumed that spates which occurred from April to June and October to November 2003 inundated the river beyond bankful line and flushed large amounts of plant litter into the stream channel. Subsequently, the flashy hydrograph which characterized the stream flow, caused rapid decrease in stream power with receding water depositing large amounts of particulate organic matter in the channel and hence trapped by LWD.

The composition of the leaf material collected at the LWD site along the study reach reflected the composition of the plants along the riparian zone with *Ficus thorningii* still dominating. The findings agree with results of a study conducted in a 2nd order stream (Njoro river) previously where adjacent trees growing not beyond 20 metres from the river contributed most of the material reaching the reference stream (Magana, 2000).

However, much of the detrital leaf litter species retained by the LWD but could not be identified along the riparian zone vegetation were presumably from drifting organic matter or instream macrophyte production. This is in agreement with the findings of Maridet *et al.* (1995) through a study on benthic organic matter dynamics on streams near Ussel at French granitic Massif central mountains. He noted that in the unshaded stream (Triouzoune), the main source of litter was from drifting organic matter and production of macrophyte in the stream.

A wide range of species composition of the detrital leaf litter observed at the site is advantageous in energy provision to the stream biota because some species decompose faster than others (Campbell *et al.*, 1992).

The most important feature of the LWD influencing the accumulation of leaf litter in Sagana River is length. This is best illustrated by the correlation analysis, which showed very high significant relationship between the ash free dry weights of detrital leaf litter standing stock and the length of the LWD.

The large and more stable cobbles and boulders at the exposed riffle gravel bars usually act as sediment retainers. According to Speaker *et al.* (1984), retention by obstacles in these sites is more efficient than in dead zones at low current velocity. However, Snaddon *et al.* (1992) shows that the retentive efficiency of riffle decreases with increasing discharge. Discharge regime is regarded as a driving variable for CPOM retention (Bretschko, 1990). Similarly, Pozo *et al.* (1994) posits that when litter inputs coincide with low flow, CPOM tends to accumulate on the streambed but if otherwise, downstream transport is favoured. The detrital material entering the river is thus rapidly exported as the flow increases. The idea is supported by Magana (2000) who states that the exposure of cobbles, boulders and pebbles increase the relative retentiveness of riffle biotopes during the low discharge period. Similar sentiments were also given by Mwangi (2000) while carrying out a study at the upper reaches of Sagana River. He showed that the storage of allochthonous organic matter inputs into the stream was achieved through retention by the abundant small cobbles and gravel occurring within a large exposed gravel bar. These tenets and the results of the present investigation are in general agreement with such observations. It is therefore possible that the high accumulation of the detrital material at the exposed riffle gravel bar site may have been related to the presence of cobbles and boulders and discharge regime.

As reported by Fisher and Likens (1973), the dominance of leaves in litter/detritus appears to be a general trend in forests. The phenomenon has been reported for regions as far apart as NewZealand where leaves in a beech forest contributed 62% to the litter (Winterbourn, 1976), Guatemala, where leaves contributed 67-77% of the litter of an undisturbed rainforest (Kunkel-Westphal and Kunkel, 1979), and in the USA where leaves in a hardwood forest accounted for 66% of the total allochthonous inputs into a stream. Additionally, Jones and Smock (1991) reported increased leaf retention with flow in high-gradient, cobble-dominated streams. Similarly, in Kenya, Magana (2000) while carrying out a study on inputs and retention of POM at the Njoro River found leaf litter dominating the aerial input accounting for 62% of the total inputs. It is therefore not surprising that large amount of the leaf litter was obtained in the detrital benthic organic matter standing stock. This might have been possible due to the abundant retention features such as cobles and boulders. It is also apparent that the flexible leaves were trapped between the cobles and boulders as had been already observed by Young *et al.* (1978) and Prochazka *et al.* (1991). Thus the detritus entering the river is rapidly exported when flow increase at the exposed riffle gravel bars. It is therefore possible that the high accumulation of leaf litter at the exposed riffle gravel bar beds may have been related to the flexibility of leaves, presence of cobbles and boulders and the discharge regime. However, Chergut *et al.* (1993) observed lower relative trapping efficiencies of gravel, boulders and cobbles in comparison with the branches of LWD.

Nevertheless, harder elements of the accumulated detritus accounted for a significant fraction of the detrital benthic organic matter standing crop. For example, bark and wood debris amounted to over 30% (Table 4.16) of the total accumulated BOM at the site. A more closely similar results were reported by Blakburn and Petr (1979) in a forest of mountain ash and myrthe beech in Australia where wood contributed 43% and bark 23% of the litter. Additionally, Triska and Cromack (1980) found that in a coniferous forest input in Oregon USA, wood accounted for 70% of the input. This concurs with the findings of Meyer *et al.* (1997) who also found woody debris forming the largest fraction of stored organic matter in the Ogeechee River, USA. In Kenya, the results are similar to those of Mwangi (2000) who obtained large amounts of bark and wood debris at forested wetted zones due to the occurrence of abundant cobbles and boulder at the site along the upper reaches of Sagana River. However, even though bark, wood and twigs accounted for a greater portion of the BOM, only a few species of aquatic organisms use them directly. They are known to be poor resource for fresh water organisms.

The composition of the leaf material collected at the site reflected the distribution of plants vegetation along the riparian zone, agreeing with the findings of Johnson *et al* (1997) that narrow strips of riparian forests (buffer strip) may contribute substantial amounts of allochthonous debris to streams. Similar sentiments were also given by Sedell *et al.* (1978) and King *et al.* (1987). They asserted that most of the organic matter entering the stream through aerial or lateral input is derived from the immediate adjacent vegetation along the stream channel and the content is largely dependent upon the riparian vegetation density. *Ficus thorningii* and *Cussonia holstii* dominated the benthic leaf litter suggesting that the local riparian vegetation has a strong influence on the control of energetic resources in Sagana River.

4.7.4 Macroinvertebrate abundance associated with BOM

The present study showed that debris dam supported high densities of macroinvertebrate than the other retentive features (Table 4.24). Weigelhoefer and Waringer (1994) made similar observations while carrying out a study in a low order stream-Weidlingbach, Lower Austria. They noted that the heterogeneous architecture, the multitude of microhabitats differing in water velocity and porosity adds to colonization capacity of dams and hence makes it function as hot spots of macroinvertebrates. The findings are also supported through studies done by Friberg and Larsen (1998), O'Connor (1991), Phillips and Kilambi (1994) and Smock *et al.* (1989) who stressed the importance of debris dam in sustaining high invertebrate densities. In addition, Friberg and Larsen (1998) noted that CPOM in dams provides important habitats for organisms of a low order stream-Weidlingbach. The idea is supported by Smock *et al.* (1989), Winkler (1991), Dobson *et al.* (1992), Hax and Golladay (1993) and Philips and Kilambi (1994) who reported that organic matter stored by debris dams as well as fine particle accumulations are colonized by algae and biofilm, which provide valuable food item for many functional feeding groups of stream biota and in turn attract secondary consumers (Baumgartner, Waringer and Waringer, 1999).

4.7.5. Functional feeding group categories associated with retentive features.

Most species of Chironomids are collector-gatherers, which construct tubes on the substrate surface and burrow in catchnets thereby creating current by body undulations (Allan, 1995). However, Lamberti and Moore (1984) noted that some species are collector-filterers; constructing tubes on the plant stems or in the bottom sediments and spin coarse, irregular nets. Among the debris dam, the availability of large interstitial spaces created by the trapped detritus might have provided suitable habitat for tube and net construction. During periods of exposure, detritus provide conducive environment for burrowing as decomposition continued.

The high relative abundance of predators (Gyrinidae, Agriidae and Vellidae; 42.9%) among the debris dam may relate to the availability of prey insects and not CPOM as food source. The results of the present study is in agreement with White (1979) who noted that Predators feed upon live and dead insects trapped or floating on the water surface. In addition, Borrow *et al.* (1992) reported that water striders live on the surface of the water running or skating over the surface and feeding on insects that fall onto the water. Moreover, Weigelhoefer and Waringer (1999) while carrying out a study at a low order forest stream, Weidlingbach in Austria observed that debris dam trap drifting stream biota and attract rheophilic organism due to high water velocities acting on the upstream side near the water surface. They further noted that since food item is always omnipresent in debris dam, CPOM as food source is therefore not limiting.

Most adults, riffle beetles and larvae are collector-gatherers/scrappers feeding upon encrusted algae on solid substrates (Haeffner and Wallace, 1981). However, Henry and Seagle (1982) showed that allochthonous detritus material is the important chief food source for the riffle beetles. They noted that the taxa feed primarily on detritus (≥ 68.3%)

while green algae and diatoms constituted the remaining proportion. It is therefore possible that their high relative abundance at the debris dam may be related to greater availability of detritus. Similarly, periphytic algae growing on these detritus as a result of higher primary production caused by increased light penetration with greater site openness could be another factor. The idea is in agreement with the findings of Hawkins *et al.* (1982) who emphasized on the importance of food quality in influencing invertebrate abundance.

Collector gatherers (*Baetis sp.*) dominated the Ephemenoptera taxa at the large woody debris. Heede (1972) observed that LWD influence sediment routing through the formation of depositional sites where current velocity is low. Allan (1995) noted that *Baetis* streamlined body shape provides an adaptation to avoid and resist the pressure of flow. In addition, the clinging behaviour allows them great resistance to passing fluids (William & Feltmate, 1992). The low water velocity coupled with the 'fusiform' body shape and the clinging behaviour may explain their high abundance. Even though increased discharge as a result of spates during some wet months in the course of the study period altered the population dynamics, the short generation time (Wirth and Stove, 1956; Hynes, 1970; Kerst and Anderson, 1975) and rapid colonization rates (Sprules, 1947; Hynes, 1970) enabled them to cope with the fluctuating environments and build up large populations opportunistically.

The dominance of collector-gatherers (Ephemeroptera; *Baetis sp., Caenis sp.*) at the exposed riffle gravel beds was due to favourable habitat/substrate ground for attachment and refuge by the individual species. As noted by William and Feltmate (1992) the clinging behaviour and the streamlined body shape of *Baetis sp.* allows great resistance to passing fluids. Food availability was not a limiting factor to the distribution and abundance of the species as it was present in excess and rarely limiting.

The result of the present study is in agreement with the findings of a research in HongKong (Dudgeon and Chan, 1992), which suggested that detritus might not restrict the abundance of invertebrates in stream. Similarly, the results concurs with findings of Mwangi (2000) that food availability is not a limiting factor to the distribution and abundance of *Baetis sp.* at the cultivated site along the upper reaches of Sagana River.

In Speed River, *Caenis sp.* was observed to be common member of hyporheos (Williams, 1984). He noted that its' possession of a pair of large operculate gills on the second abdominal segment provides it with protection that enables the species to live in the interstial environment. It is therefore possible that the adaptation allowed them to take refuge in large interstitial spaces provided for by the twigs that were trapped between the cobbles and gravel at the exposed riffle gravel beds, hence the reason for the existence of such dominance.

Similarly good substrate grounds for attachment contributed to the occurrence of collector-filterer (Simulidae and Hydropsychidae) exposed riffle gravel beds. The black fly larvae (Simulidae) which are highly specialized suspension feeders (Allan, 1995), attach to the substrate (rocks/cobbles) in rapids often shallow water (runs) by hooks at the end of the abdomen held in silken pad spun onto rock fan-like antennae (paired cephalic fans) each consisting of primary secondary and medial fans (Chance, 1970; Currie and Cruig, 1987). It is therefore not surprising that the black fly larvae occurred in a relatively high abundance (27.1%) due to the availability of large substrate dominated by rocks and cobbles for attachment. Additionally, the existence of runs across the site which are often fast water units of shallow gradient typically with substrate ranging in size from sand to cobbles (Hawkins *et al.*, 1993) provided suitable sites for the operation of suspension feeding organs as they depend on current for food. Similar sentiments were also made by Mwangi (2000) while carrying out a study at the upper reaches of Sagana River. He observed filter-feeding Simuliids occurring in great abundance at the forested riffle habitat dominated by gravel and cobbles.

The dominance of Hydropsychidae at the exposed riffle gravel bed could be associated with the presence of appreciably high water velocity. Merritt and Cummins (1996) report that the filter-feeding Hydropsychidae are net spinning clingers that build fixed retreats of organic and mineral fragments on any solid object that is located in a suitable water current regime. Similarly, Mwangi (2000) observed that Hydropsychidae prefer substrates offering large surface area for construction of nets. Such habitats were readily available at the exposed riffle gravel beds where small cobbles and gravel dominated. The result is further supported by the findings of Edington (1968) who found Hydropsychidae nets reconstructed only at high velocity currents and most larvae desert the low velocity locales created by the baffle.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

From the foregoing discussion, the following conclusions can be made:

1. The main retentive features along the mid-reaches of Sagana River are debris dam, large woody debris and exposed riffle gravel bar whose retention efficiency greatly depend on water level and discharge.
2. Dam volume and the length of LWD are important parameters that influence the quantity and composition of BOM accumulation at the debris dam and large woody debris sites, respectively. The greatest breadth, length and area of the exposed riffle gravel bar have a significant effect on the BOM accumulation.
3. The abundance and distribution of various functional invertebrate feeding group categories among various retention structures is influenced by BOM retained as an important habitat for prey and substrate-shelter/refuge. The quantity and composition of BOM available is rarely used as a food source item.
4. Narrow strip of riparian vegetation is an effective source of allochthnous organic matter input into the stream.
5. The findings of the present study provide pertinent information on the retention capacity and the role of retentive features in the retention of CPOM inputs to the Sagana River. In addition, the role of riparian vegetation as an effective source of allochthonous organic matter input and the building blocks materials for retention structures (debris dams & LWD) is discerned.

5.2. Recommendations

1. Since studies of aquatic ecosystems in tropical Africa are scanty, any attempts in the conservation and management of rivers should focus on the river organic matter, which is the main energy source for forested stream communities.
2. The results shows that retentive structures play an important role in the river system and therefore artificial structures be introduced into the stream to retain organic matter in such areas where the features are lacking.
3. The government of Kenya should institute proper guidelines and regulations requiring retention of standing trees along stream channels to provide a future source of large woody debris (LWD).
4. Institutes of higher learning should stress aspects of river organic matter retention in the teaching of limnology.

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APPENDICES

Appendix 1. Rainfall data of Sagana area recorded at the Sagana state lodge meteorological station from January 1981 to November 2003.

Year	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Total**	**Mean**
1981						36	20.7	21.7	34.8	123.5	71.8	73	**381.5**	**54.5**
1982	23.2	24.4	28	134.7	226.3	7.4	18.5	12	30.3	164.6	155.5	50.7	**875.6**	**72.9**
1983	12.2	110	8.7	115.8	212.9	25.6	5.9	12.9	2.6	45.2	69.4	124.3	**745.5**	**62.1**
1984	19.6	11.1	11.9	141.7	9.5	8.2	6	0	40.6	133	377	110	**868.6**	**72.4**
1985	17	23.4	140.5	131.2	110.3	5.6	13.6	6.5	9.2	53	85.3	149.1	**744.7**	**62.1**
1986	26.7	11.9	52.2	322.7	185.4	54.7	4.6	0.5	1.4	49.1	126.4	77.3	**912.9**	**76.1**
1987	29.4	21.3	40.8	62.1	94.8	27.6	16.1	20.3	0	6.7	152.5	45.1	**516.7**	**43.1**
1988	43.4	7.7	136.7	369	20	36.1	10.2	25.8	59.1	24.2	141.4	233.3	**1106.9**	**92.2**
1989	27.7	75.9	63.6	158.6	78	4.5	23.1	8.7	48.4	120.3	160.1	259.3	**1028.2**	**85.7**
1990	175.4	81.3	333.5	167.6	74.3	6.6	9.9	23.7	15	46.2	134	132.9	**1200.4**	**100.0**
1991	31.4	11.8	84	108.2	277.1	16.7	17.9	22.8	0.2	24.1	149.3	47.3	**790.8**	**65.9**
1992	13.2	39.2	28.9	120.2	77.2	2.2	11.4	7	11.6	113	119.7	139.2	**682.8**	**56.9**
1993	132.1	69.8	41.8	53.2	125.5	7.2	3.6	9	1	31.6	154.1	88	**716.9**	**59.7**
1994	22.1	28.2	62.1	131.5	216.8	5	43.8	14.5	14.6	142.9	235.8	47.7	**965**	**80.4**
1995	51.2	57	101.6	102.3	214.1	0	3.1	31.9	30.6	135.5	28.6	107.1	**863**	**71.9**
1996	68.9	21	97.8	62.6	83.1	48.4	12.4	19.2	9	23.4	309.2	20.9	**775.9**	**64.7**
1997	49.5	6.8	38.8	287.7	69.4	24.4	16.8	9.6	1.2	330.8	289.3	234.2	**1358.5**	**113.2**
1998	243.8	66.7	191.6	101.5	132.5	6.8	7.9	27.5	26.1	13.2	115.2	148.7	**1081.5**	**90.1**
1999	21	6.4	60.6	109.3	132.5	0	22.8	4.2	3.2	13.8	126.5	141.3	**641.6**	**53.5**
2000	32	16.4	18.7	41.3	87.5	9.7	14.3	16.8	8.6	52.5	50	89	**436.8**	**36.4**
2001	97.2	26.7	41.9	145	84.7	7	2	5.2	6.6	14.4	170.6	34	**635.3**	**52.9**
2002	0	22	59.4	233.4	91.7	20.8	0	14.4	24	174.5	110.7	281.8	**1032.7**	**86.1**
2003	17.1	10.2	139.6	236	164	14	0	32.9	1.6	157	117.3		**889.7**	**80.9**
Count	**22**	**22**	**22**	**22**	**22**	**23**	**23**	**23**	**23**	**23**	**23**	**22**	**23**	**22.5**
SD	**59.9**	**29.3**	**74.0**	**87.0**	**70.5**	**15.4**	**9.9**	**9.6**	**17.1**	**77.9**	**83.1**	**75.1**	**238.3**	**50.7**
Mean	**52.5**	**34.1**	**81.0**	**151.6**	**125.8**	**16.3**	**12.4**	**15.1**	**16.5**	**86.6**	**149.9**	**119.7**	**837.0**	**71.8**
95% CL	**25.0**	**12.2**	**30.9**	**36.4**	**29.5**	**6.3**	**4.0**	**3.9**	**6.9**	**31.8**	**33.9**	**31.4**	**97.4**	**21.0**

Appendix 2. Detrital BOM amounts (gAFDWm^{-2}) at the wet zone site along the mid reaches of Sagana River, Kenya between February 2003 and November 2003.

Samp. No.	Date	POM-B	POM-T	POM-F	POM-G	POM-R	POM-WD	POM-O	POM-L2	POM-L3	POM-L4	POM-L6	POM-L7	POM-L8	POM-L9	POM-L10
1st	17/02/03	5	0.95	0.17	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.12	0.00	0.00
2nd	3/3/03	3	1.94	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
3rd	17/03/03	1	1.44	0.12	0.00	0.00	6.49	0.58	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00
4th	14/04/03	0	2.68	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.54	0.00	0.00
5th	25/04/03	0	0.00	0.00	0.00	0.00	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.00	0.04
6th	6/5/03	0	0.00	0.00	0.00	0.00	2.81	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00
7th	15/09/03	0	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.11	0.00
8th	22/09/3	0	2.42	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.38	0.00	0.00
9th	6/10/03	5	0.92	0.00	0.31	0.00	0.00	0.00	0.00	0.07	0.00	0.05	0.17	0.69	0.00	0.29
10th	27/10/03	0	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
Total		**12.95**	**11.72**	**0.29**	**0.31**	**0.00**	**11.97**	**0.58**	**0.05**	**0.18**	**0.22**	**0.05**	**0.17**	**2.79**	**0.11**	**0.33**
Mean		**1.30**	**1.17**	**0.03**	**0.03**	**0.00**	**1.20**	**0.06**	**0.01**	**0.02**	**0.02**	**0.01**	**0.02**	**0.28**	**0.01**	**0.03**
Dispersion index value			**-0.02**	**1.22**	**1.00**	**-!**	**0.27**	**1.00**	**1.00**	**1.16**	**1.12**	**1.00**	**1.00**	**-0.41**	**1.00**	**1.12**

KEY

POM-B - Bark
POM-T - Twig
POM-F - Fruit
POM-G - Grass
POM-R - Root
POM-WD- Wood debris
POM-O - Unidentifiable materials
POM-L2 - *Euclea divinorum*
POM-L3 - *Bersama abyssinica*
POM-L4 - *Syzgium guineense*
POM-L6 - *Rapanea melanophloes*
POM-L7 - *Croton macrotachyus*
POM-L8 - *Unidentifiable*
POM-L9 - *Dalbergia lacteal*
POM-L10 - *Podocarpus latifolia*
POM-L12 - *Ziziphus abyssinica*
POM-L15 - *Ficus thornigii*
POM-L16 - *Eleodendron buchananii*
POM-L17 - *Croton mengalocarpus*
POM-L18 - *Strychnos hemmifsii*
POM-L20 - *Podocarpus falcatus*
POM-L21 - *Neobautonia macrocalyx*
POM-L22 - *Cussonia holstii*
POM-L23 - *Newtonia buchananii*
POM-L25 - *Calodenrum capense*
POM-L27 - *Viscum fischeri*
POM-L40 - *Ochna inoculpata*
POM-L41 - *Grewia similis*
POM-L50 - *Thelypteris quintziana*
POM-LT - Leaf total
POM-T - Total

Appendix 2. ***contd.***

POM-L12	POM-L15	POM-L16	POM-L17	POM-L18	POM-L20	POM-L21	POM-L22	POM-L23	POM-L25	POM-L27	POM-L40	POM-L41	POM-L50	POM-LT
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.06	0.00	0.36
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	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.29
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.88
0.00	0.10	0.00	0.00	0.08	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	1.17
0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.63
0.00	0.59	0.00	0.00	0.00	0.00	0.00	1.55	0.00	0.05	0.00	0.00	0.00	0.00	2.46
0.00	0.57	0.00	0.08	0.00	0.00	0.00	2.15	0.00	0.11	0.00	0.04	0.11	0.20	3.69
0.06	1.17	0.15	0.00	0.00	0.23	0.37	0.17	0.00	0.00	0.00	0.00	0.00	0.00	3.42
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
0.06	**2.43**	**0.35**	**0.08**	**0.08**	**0.23**	**0.37**	**3.95**	**0.67**	**0.32**	**0.03**	**0.04**	**0.19**	**0.20**	**12.90**
0.01	**0.24**	**0.04**	**0.01**	**0.01**	**0.02**	**0.04**	**0.40**	**0.07**	**0.03**	**0.00**	**0.00**	**0.02**	**0.02**	**1.29**
1.00	**-0.23**	**1.38**	**1.00**	**1.00**	**1.00**	**1.00**	**0.19**	**2.09**	**1.32**	**1.00**	**1.00**	**1.14**	**1.00**	**0.04**

Appendix 3. Detrital BOM amounts (gAFDWm^{-2}) at the dry zone site along the mid reaches of Sagana River, Kenya between February 2003 and November 2003.

Sample No.	Date	POM-B	POM-T	POM-F	POM-G	POM-R	POM-WD	POM-O	POM-L1	POM-L2	POM-L3	POM-L4
1st	17/02/03	0	7.76	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2nd	3/3/03	0	0.86	0.00	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.00
3rd	17/03/03	3	0.75	4.34	0.00	0.00	2.76	0.64	0.00	0.00	0.00	0.00
4th	14/04/03	0	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00
5th	25/04/03	0	0.00	0.00	0.00	0.00	0.94	0.78	0.00	0.00	0.00	0.10
6th	6/5/03	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7th	15/09/03	2	0.00	0.00	0.00	0.55	0.00	0.00	0.10	0.10	0.09	0.00
8th	22/09/3	0	3.61	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00
9th	6/10/03	0	0.30	0.00	0.34	0.00	0.00	0.00	0.00	0.05	0.35	0.00
10th	27/10/03	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		**6.49**	**13.28**	**4.44**	**0.34**	**0.55**	**4.45**	**2.07**	**0.10**	**0.28**	**0.44**	**0.10**
Mean		**0.65**	**1.33**	**0.44**	**0.03**	**0.06**	**0.45**	**0.21**	**0.01**	**0.03**	**0.04**	**0.01**
Dispersion Index value			**0.31**	**0.94**	**1.00**	**1.00**	**0.22**	**-0.43**	**1.00**	**1.27**	**1.28**	**1.00**

KEY

POM-B - Bark
POM-T - Twig
POM-F - Fruit
POM-G - Grass
POM-R - Root
POM-WD- Wood debris
POM-O - Unidentifiable materials
POM-L1 - *Trichocladus elliptium*
POM-L2 - *Euclea divinorum*
POM-L3 - *Bersama abyssinica*
POM-L4 - *Syzgium guineense*
POM-L6 - *Rapanea melanophloes*
POM-L7 - *Croton macrotachyus*
POM-L8 - Unidentifiable
POM-L9 - *Dalbergia lacteal*
POM-L10 - *Podocarpus latifolia*
POM-L11 - *Agelea pentagyna*
POM-L12 - *Ziziphus abyssinica*
POM-L13 - *Cyperus sp.*
POM-L14 - *Garcinia volkensii*
POM-L15 - *Ficus thornigii*
POM-L17 - *Croton mengalocarpus*
POM-L18 - *Strychnos hemmifsii*
POM-L20 - *Podocarpus faicatus*
POM-L21 - *Neobautonia macrocalyx*
POM-L22 - *Cussonia holstii*
POM-L23 - *Newtonia buchananii*
POM-L25 - *Calodenrum capense*
POM-L40 - *Ochna insculpata*
POM-L41 - *Grewia similis*
POM-L48 - *Ekebergia capensis*
POM-L53 - *Dissotis sp.*
POM-L54 - *Erthrina abyssica*
POM-T - Total
POM-LT - Leaf total

Appendix 3. *contd.*

POM-L6	POM-L7	POM-L8	POM-L9	POM-L10	POM-L11	POM-L12	POM-L13	POM-L14	POM-L15	POM-L17	POM-L18	POM-L20
0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.65	0.00	0.00	0.00	0.00	0.06	0.00	0.48	0.12	0.00	0.00
0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.07	0.09
0.00	0.00	2.86	0.00	0.04	0.00	0.00	0.00	0.00	0.57	0.00	0.61	0.00
0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	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	0.94	0.08	0.00	0.08	0.00	0.00	0.00	5.40	0.21	0.00	0.00
0.00	0.00	0.48	0.10	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	0.10	10.06	0.07	0.69	0.13	0.15	0.00	0.05	4.28	0.10	0.00	0.05
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
0.09	**0.10**	**15.55**	**0.25**	**0.73**	**0.41**	**0.15**	**0.06**	**0.05**	**10.85**	**0.43**	**0.75**	**0.14**
0.01	**0.01**	**1.56**	**0.03**	**0.07**	**0.04**	**0.02**	**0.01**	**0.01**	**1.09**	**0.04**	**0.08**	**0.01**
1.00	**1.00**	**0.36**	**1.24**	**1.31**	**1.48**	**1.00**	**1.00**	**1.00**	**0.28**	**1.53**	**2.07**	**1.08**

Appendix 3. *contd.*

POM-L21	POM-L22	POM-L23	POM-L25	POM-L40	POM-L41	POM-L48	POM-L53	POM-L54	POM-LT	POM-T
0.00	0.05	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.00
0.00	0.00	0.08	0.04	0.00	0.00	0.00	0.10	0.00	2.00	4.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	13.00
0.00	0.00	0.00	1.08	0.00	0.06	0.00	0.00	0.00	5.00	6.00
0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	1.00	2.00	3.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	0.00	0.00	0.14	0.07	0.00	0.00	0.00	0.00	7.00	10.00
0.00	0.00	0.00	0.00	0.00	0.00	17.04	0.00	0.00	18.00	22.00
0.27	0.00	0.04	0.46	0.00	0.00	0.00	0.00	0.00	17.00	18.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.38	**0.05**	**0.20**	**1.72**	**0.07**	**0.11**	**17.04**	**0.10**	**1.00**	**52.00**	**84.00**
0.04	**0.01**	**0.02**	**0.17**	**0.01**	**0.01**	**1.74**	**0.01**	**0.14**	**5.19**	**8.40**
1.28	**1.00**	**1.18**	**-0.40**	**1.00**	**1.07**	**1.00**	**1.00**	**1.00**	**0.17**	**0.07**

Appendix 4. Detrital BOM amounts (gAFDWm^{-2}) and macroinvertebrates abundance at the debris dam site along the mid reaches of Sagana River, Kenya between February 2003 and November 2003.

Sample No.	Date	POM-B	POM-T	POM-F	POM-G	POM-R	POM-WD	POM-O	POM-L2	POM-L4	POM-L5	POM-L7	POM-L8	POM-L9	POM-L10
1st	17/02/03	6.94	0.33	0.15	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00	3.96	0.03	0.03
2nd	3/3/03	0.87	2.71	0.00	0.00	0.00	0.00	0.29	0.00	0.07	0.00	0.00	0.41	0.00	0.00
3rd	17/03/03	0.00	1.05	0.03	0.00	0.00	0.00	0.30	0.00	0.14	0.00	0.00	0.18	0.00	0.00
4th	14/04/03	0.00	0.60	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.00	0.00	0.73	0.00	0.00
5th	25/04/03	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.12	0.00	0.00
6th	6/05/03	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
7th	15/09/03	0.00	0.91	0.00	0.00	3.77	0.00	0.62	0.00	0.00	0.00	0.00	1.92	0.06	0.00
8th	22/09/3	0.00	1.28	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.45	0.19	0.00	0.00
9th	6/10/03	2.16	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.78	0.39	0.05	0.16
10th	27/10/03	1.02	0.40	0.00	0.00	0.00	0.00	2.53	0.00	0.00	0.10	0.00	0.51	0.00	0.00
Sum		**10.99**	**9.80**	**0.18**	**0.00**	3.77	**0.94**	5.04	**0.10**	**0.38**	**0.10**	**1.31**	**8.41**	**0.14**	**0.19**
Mean		**1.10**	**0.98**	**0.02**	**0.00**	**0.38**	**0.09**	**0.50**	**0.01**	**0.04**	**0.01**	**0.13**	**0.84**	**0.01**	**0.02**
SD		**2.17**	**0.77**	**0.05**	**0.00**	**1.19**	**0.30**	**0.82**	**0.03**	**0.07**	**0.03**	**0.27**	**1.22**	**0.02**	**0.05**
Dispersion Index value		**0.33**	**-0.04**	**1.07**	-	**1.00**	**1.00**	**0.09**	**1.00**	**1.43**	**1.00**	**-1.46**	**0.11**	**1.12**	**1.07**

KEY

POM-B - Bark
POM-T - Twig
POM-F - Fruit
POM-G - Grass
POM-R - Root
POM-WD- Wood debris
POM-O - Unidentifiable materials
POM-L2 - *Euclea divinorum*
POM-L4 - *Syzgium guineense*
POM-L5 - *Drypetes gerrardii*
POM-L7 - *Croton macrotachyus*
POM-L8 - Unidentifiable
POM-L9 - *Dalbergia lactea*
POM-L10 - *Podocarpus latifolia*
POM-L11 - *Agelaea pentagyna*
POM-L12 - *Ziziphus abyssinica*
POM-L13 - *Cyperus sp.*
POM-L15 - *Ficus thornigii*
POM-L17 - *Croton mengalocarpus*
POM-L18 - *Strychnos hemminfsii*
POM-L20 - *Podocarpus faicatus*
POM-L21 - *Neobautonia macrocalyx*
POM-L22 - *Cussonia holstii*
POM-L23 - *Newtonia buchananii*
POM-L25 - *Calodenrum capense*
POM-L26 - *Typha domingensis*
POM-L37 - *Dracaena laxissima*
POM-L40 - *Ochna inoculpata*
POM-L41 - *Grewia similis*
POM-L42 - *Clerodendron johnstonii*
POM-L44 - *Jacaranda mimosifolia*
POM-L49 - *Bridelia micrantha*
POM-L51 - *Mimilops kumel*
POM-L52 - *Solanum mauriticinum*

Appendix 4. *contd.*

POM-L11	POM-L12	POM-L13	POM-L15	POM-L17	POM-L18	POM-L20	POM-L21	POM-L22	POM-L23	POM-L25	POM-L26	POM-L37	POM-L40	POM-L41
0.00	0.00	0.00	3.38	0.06	0.00	0.02	0.00	0.06	0.00	0.01	0.00	0.00	0.05	0.05
0.00	0.00	0.00	1.48	0.10	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.07
0.00	0.00	0.00	1.41	0.06	0.00	0.00	0.00	0.17	0.00	0.05	0.00	0.00	0.00	0.05
0.00	0.00	0.00	0.20	0.05	0.09	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.09
0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.02
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	0.00	0.00	4.10	0.00	0.00	0.00	0.05	0.21	0.00	0.35	0.00	0.00	0.00	0.11
0.06	0.00	0.00	0.78	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00
0.04	0.13	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.18	0.00	0.00	0.81	0.05	0.00	0.00	0.83	0.00	0.00	0.14	0.29	0.05	0.08	0.15
0.28	**0.13**	**0.06**	**12.40**	**0.32**	**0.09**	**0.02**	**0.88**	**0.61**	**0.11**	**0.61**	**0.29**	**0.05**	**0.13**	**0.54**
0.03	**0.01**	**0.01**	**1.24**	**0.03**	**0.01**	**0.00**	**0.09**	**0.06**	**0.01**	**0.06**	**0.03**	**0.01**	**0.01**	**0.05**
0.06	**0.04**	**0.02**	**1.43**	**0.04**	**0.03**	**0.01**	**0.26**	**0.09**	**0.02**	**0.11**	**0.09**	**0.02**	**0.03**	**0.05**
1.22	**1.00**	**1.00**	**0.06**	**1.41**	**1.00**	**1.00**	**1.87**	**2.25**	**1.06**	**2.05**	**1.00**	**1.00**	**1.08**	**2.07**

Appendix 4. *contd.*

POM-L42	POM-L44	POM-L49	POM-L51	POM-L52	POM-LT	MIE-B	MIE-C	MIE-Af	MIE-Ch	MICo-El	MICo-Sc	MICo-Gy	MID-Ch	MID-Si	MID-Ti	MIO-Tub	MIO-Nai
0.00	0.00	0.00	0.00	0.00	7.65	2	1	0	0	0	1	0	49	1	0	0	0
0.00	0.00	0.00	0.00	0.38	2.57	8	5	0	0	0	0	0	12	10	0	0	1
0.00	0.00	0.00	0.05	0.00	2.11	0	0	0	0	0	0	0	1	0	1	4	1
0.00	0.00	0.00	0.00	0.00	1.20	0	2	2	0	24	0	87	20	0	4	0	0
0.00	0.00	0.00	0.00	0.00	0.53	0	0	0	0	0	0	0	0	0	0	0	0
0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0
0.00	0.00	0.26	0.00	0.00	7.06	1	1	0	0	0	0	29	0	0	0	2	0
0.00	0.00	0.12	0.00	0.00	1.87	2	6	0	0	0	0	105	0	0	0	7	3
0.00	0.00	0.00	0.00	0.00	1.78	13	1	1	0	0	2	5	8	0	0	0	2
0.10	0.05	0.00	0.00	0.00	3.34	33	11	5	7	0	0	1	6	8	0	0	0
0.10	**0.05**	**0.38**	**0.05**	**0.38**	**28.11**	**61**	**27**	**8**	**7**	**24**	**3**	**227**	**98**	**19**	**5**	**13**	**7**
0.01	**0.01**	**0.04**	**0.01**	**0.04**	**2.81**	**6.10**	**2.70**	**0.80**	**0.70**	**2.40**	**0.30**	**22.70**	**9.80**	**1.90**	**0.50**	**1.30**	**0.70**
0.03	**0.02**	**0.09**	**0.02**	**0.12**	**2.58**	**10.34**	**3.59**	**1.62**	**2.21**	**7.59**	**0.67**	**39.87**	**15.24**	**3.78**	**1.27**	**2.41**	**1.06**
1.00	**1.00**	**1.29**	**1.00**	**1.00**	**0.05**	**0.28**	**0.15**	**0.33**	**1.00**	**1.00**	**0.26**	**0.31**	**0.23**	**0.36**	**0.56**	**0.29**	**0.10**

KEY

MIE- Macroinvertebrate (Ephemeroptera)
MICo- Macroinvertebrate (Coleoptera)
MID - Macroinvertebrate (Diptera)
MIO - Macroinvertebrate (Oligochaeta)
MICru - Macroinvertebrate (Crustacea)
MITr - Macroinvertebrate (Hydropsychidae)
MIAca- Macroinvertebrate (Acarina)
MIHem- Macroinvertebrate (Hemiptera)
MIOd. - Macroinvertebrate (Odonata)

MIE-B - *Baetis sp.*
MIE-C - *Caenis sp.*
MIE-Af - *Afronurus sp.*
MIE-Ch - *Choroterpes sp.*
MICo-El - Elmidae
MICo-Sc -Scirtidae
MICo-Gy -Gyriniidae
MID-Ch - Chironomidae
MID-Si - Simulidae
MID-Ti - Tipulidae
MIO-Tub-Tubificidae
MIO-Nai- Naididae

MIO-Lum- Lumbriculidae
MICru-Dec- Decapoda
MITr-Hyd- Hydropyschidae
MIAa-Hyg- Hygrobatidae
MIHem-Vel- Vellidae
MIOd-Agr - Agriidae
MI-Others

Appendix 4. ***contd.***

MIO-Lum	MICru-Dec	MITr-Hyd	MIAca-Hyg	MIHem-Vel	MIOd-Agr	MI-Others	Total
0	0	0	0	1	0	2	57
0	0	0	0	0	0	0	36
3	0	1	0	0	0	1	12
2	1	1	0	0	0	9	154
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	36
0	1	0	0	0	0	2	126
0	0	1	0	0	0	6	39
0	1	2	1	0	2	0	77
5	**4**	**5**	**1**	**1**	**2**	**20**	**537**
0.50	**0.40**	**0.50**	**0.10**	**0.10**	**0.20**	**2.00**	**53.70**
1.08	**0.52**	**0.71**	**0.32**	**0.32**	**0.63**	**3.09**	**51.84**
0.33	**-0.11**	**0.00**	**-**	**-**	**1.00**	**0.20**	**0.09**

Appendix 5. Detrital BOM amounts (gAFDWm^{-2}) and macroinvertebrates abundance at the large woody debris site along the mid reaches of Sagana River, Kenya between February 2003 and November 2003.

Sample No	Date	POM-B	POM-T	POM-F	POM-G	POM-R	POM-WD	POM-O	POM-L2	POM-L3	POM-L4	POM-L6	POM-L7	POM-L8	POM-L9	POM-L10
1st	17/02/03	1.83	2.30	0.00	1.82	0.00	0.00	0.00	0.00	0.17	1.59	0.00	0.00	0.06	0.00	0.16
2nd	3/3/03	0.00	0.93	0.00	2.71	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.15	1.52	0.00	0.30
3rd	17/03/03	0.51	0.58	0.00	0.26	1.25	0.00	0.00	0.00	0.24	0.11	0.00	0.00	0.94	0.12	0.09
4th	14/04/03	0.00	3.75	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.64
5th	25/04/03	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.18	0.00	0.13
6th	6/5/03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.30	0.00	0.07	0.00	0.70	0.03	0.00
7th	15/09/03	0.00	0.00	0.00	2.18	0.00	0.00	0.00	0.09	0.19	0.00	0.00	0.00	0.99	0.00	0.00
8th	22/09/03	3.74	5.27	0.00	0.00	0.00	0.00	1.30	0.00	0.00	0.09	0.00	0.00	0.48	0.00	0.08
9th	6/10/03	0.48	0.27	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.04
10th	27/10/03	3.00	2.67	0.00	0.00	0.00	0.00	1.34	0.06	0.07	0.00	0.11	0.00	0.47	0.00	0.00
Sum		**9.56**	**15.77**	**0.10**	**7.81**	**1.25**	**0.00**	**2.64**	**0.27**	**1.12**	**1.79**	**0.18**	**0.15**	**8.59**	**0.15**	**1.44**
Mean		**0.96**	**1.58**	**0.01**	**0.78**	**0.13**	**0.00**	**0.26**	**0.03**	**0.11**	**0.18**	**0.02**	**0.02**	**0.86**	**0.02**	**0.14**
SD		**1.40**	**1.85**	**0.03**	**1.05**	**0.40**	**0.00**	**0.56**	**0.05**	**0.11**	**0.50**	**0.04**	**0.05**	**0.63**	**0.04**	**0.20**
Dispersion Index value		**0.12**	**0.08**	**1.00**	**0.06**	**1.00**	**-**	**0.11**	**1.26**	**-7.39**	**0.48**	**1.12**	**1.00**	**-0.07**	**1.06**	**-1.66**

KEY

POM-B - Bark
POM-T - Twig
POM-F - Fruit
POM-G - Grass
POM-R - Root
POM-WD- Wood debris
POM-O - Unidentifiable materials
POM-L2 - *Euclea divinorum*
POM-L3 - *Bersama abyssinica*
POM-L4 - *Syzgium guineense*
POM-L6 - *Rapanea melanophloes*
POM-L7 - *Croton macrotachyus*
POM-L8 - *Unidentifiable*
POM-L9 - *Dalbergia lacteal*
POM-L10 - *Podocarpus latifolia*
POM-L11 - *Agelea pentagyna*
POM-L12 - *Ziziphus abyssinica*
POM-L13 - *Cyperus sp.*
POM-L14 - *Garcinia volkensii*
POM-L15 - *Ficus thornigii*
POM-L16 - *Eleodendron buchananii*
POM-L17 - *Croton mengalocarpus*
POM-L20 - *Podocarpus faicatus*
POM-L21 - *Neobautonia macrocalyx*
POM-L22 - *Cussonia holstii*
POM-L23 - *Newtonia buchananii*
POM-L24 - *Diospyros abyssinica*
POM-L25 - *Calodenrum capense*
POM-L26 - *Typha domegensis*
POM-L28 - *Ficus sycomorus*
POM-L29 - *Afromomum zanguebaricum*
POM-L30 - *Senna didymobotrya*
POM-L31 - *Pterolobium stellatum*
POM-L32 - *Apoidates dimidiata*
POM-L33 - *Lasianthus kilimanscharicus*
POM-L34 - *Vernonia macrocalyx*
POM-L35 - *Psychotria orophilia*
POM-L37 - *Dracaena laxissima*
POM-L40 - *Ochna inoculpata*
POM-L41 - *Grewia similis*
POM-L42 - *Clerodendron johnstonii*
POM-L45 - *Rhammus privoides*
POM-L46 - *Harungana madagascariensis*
POM-L49 - *Bridelia micrantha*
POM-L51 - *Mimilops kumel*

Appendix 5. *contd.*

POM-L11	POM-L12	POM-L13	POM-L14	POM-L15	POM-L16	POM-L17	POM-L20	POM-L21	POM-L22	POM-L23	POM-L24	POM-L25	POM-L26	POM-L28
0.00	0.00	0.00	0.10	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.12	0.18	0.91	0.00	0.00	1.09	0.18	0.18	0.14	0.00	0.00	0.00	0.10
0.10	0.00	0.00	0.37	0.41	0.00	0.10	0.09	0.25	0.00	0.00	0.00	0.10	0.00	0.47
0.00	0.20	0.00	0.00	0.41	0.00	0.00	0.20	0.52	0.00	0.00	0.00	0.00	0.06	0.00
0.11	0.14	0.00	0.00	1.09	0.14	0.14	0.08	0.00	0.00	0.38	0.00	0.11	0.00	0.00
0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00
0.03	0.00	0.00	0.06	2.08	0.00	0.00	0.00	0.36	0.00	0.00	0.14	0.08	0.00	0.00
0.00	0.00	0.00	0.00	0.12	0.00	0.04	0.00	0.00	0.13	0.38	0.00	0.07	0.00	0.00
0.00	0.00	0.00	0.00	0.14	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00
0.00	0.00	0.00	0.09	0.22	0.12	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00
0.24	**0.34**	**0.12**	**0.80**	**6.96**	**0.37**	**0.28**	**1.46**	**1.83**	**0.31**	**0.90**	**0.14**	**0.36**	**0.35**	**0.57**
0.02	**0.03**	**0.01**	**0.08**	**0.70**	**0.04**	**0.03**	**0.15**	**0.18**	**0.03**	**0.09**	**0.01**	**0.04**	**0.04**	**0.06**
0.04	**0.07**	**0.04**	**0.12**	**0.59**	**0.06**	**0.05**	**0.34**	**0.19**	**0.07**	**0.16**	**0.04**	**0.05**	**0.09**	**0.15**
1.21	**1.28**	**1.00**	**4.12**	**-0.08**	**1.43**	**1.26**	**-0.47**	**-0.98**	**1.24**	**7.19**	**1.00**	**1.46**	**1.17**	**1.43**

Appendix 5. ***contd.***

POM-L29	POM-L30	POM-L31	POM-L32	POM-L33	POM-L34	POM-L35	POM-L37	POM-L40	POM-L41	POM-L42	POM-L45	POM-L46
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
0.22	0.13	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	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.05	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.06	0.34	0.55	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	0.06	0.04	0.07	0.07	0.00	0.17
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.12	0.00	0.05	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.00	0.00	0.00
0.00	0.00	0.00	0.07	0.07	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	0.04	0.00	0.07	0.00	0.00	0.00	0.00
0.22	**0.13**	**0.06**	**0.41**	**0.67**	**0.23**	**0.04**	**0.10**	**0.21**	**0.34**	**0.07**	**0.05**	**0.17**
0.02	**0.01**	**0.01**	**0.04**	**0.07**	**0.02**	**0.00**	**0.01**	**0.02**	**0.03**	**0.01**	**0.01**	**0.02**
0.07	**0.04**	**0.02**	**0.11**	**0.17**	**0.07**	**0.01**	**0.02**	**0.03**	**0.05**	**0.02**	**0.02**	**0.05**
1.00	**1.00**	**1.00**	**1.22**	**1.70**	**1.00**	**1.00**	**1.06**	**1.22**	**1.42**	**1.00**	**1.00**	**1.00**

Appendix 5. *contd.*

POM-L49	POM-L51	POM-LT	POM-T	MIE-B	MIE-C	MIE-Af	MIE-Ch	MIE-Tric	MIE-Acan	MICo-Sc	MICo-Gy	MID-Ch
0.00	0.00	0.94	8.87	4	4	4	0	0	0	1	0	4
0.00	0.00	3.13	9.01	22	11	0	1	0	0	2	0	3
0.00	0.00	1.87	6.07	52	15	13	0	0	0	0	6	7
0.00	0.00	1.47	7.71	2	6	0	1	1	0	0	43	7
0.00	0.00	2.89	5.55	32	8	5	4	0	0	1	3	0
0.00	0.00	1.32	2.54	27	2	0	2	0	1	2	1	2
0.00	0.00	2.98	6.46	34	25	11	5	0	0	0	36	10
0.30	0.04	1.20	12.16	26	16	1	1	0	0	0	8	17
0.00	0.00	0.68	1.91	27	33	0	11	0	0	1	9	16
0.00	0.00	0.89	8.61	34	5	2	0	0	0	0	0	5
0.30	**0.04**	**17.37**	**68.89**	**260**	**125**	**36**	**25**	**1**	**1**	7	106	71
0.03	**0.00**	**1.74**	**6.89**	**26**	**13**	**4**	**3**	**0**	**0**	1	11	7
0.09	**0.01**	**0.93**	**3.09**	**15**	**10**	**5**	**3**	**0**	**0**	1	16	6
1.00	**1.00**	**-0.03**	**0.01**	**0**	**0**	**0**	**0**	-	-	0	0	0

KEY

MIE- Macroinvertebrate (Ephemeroptera)
MICo- Macroinvertebrate (Coleoptera)
MID - Macroinvertebrate (Diptera)
MIO - Macroinvertebrate (Oligochaeta)
MICru - Macroinvertebrate (Crustacea)
MITr - Macroinvertebrate (Hydropsychidae)
MIAca- Macroinvertebrate (Acarina)
MIOd. - Macroinvertebrate (Odonata)

MIE-B - *Baetis sp.*
MIE-C - *Caenis sp.*
MIE-Af - *Afronurus sp.*

MIE-Ch - *Choroterpes sp.*
MIE-Tri - Tricorythidae
MIE-Acan -*Acanthiops sp.*
MICo-Sc - Scirtidae
MICo-Gy - Gyriniidae
MID-Ch - Chironomidae
MID-Si - Simulidae
MID-Ti - Tipulidae
MIO-Hiru- Hirudinae
MICru-Dec- Decapoda
MITr-Hyd- Hydropyschidae
MIAa-Hyg- Hygrobatidae
MI - Others

Appendix 5. *contd.*

MID-Si	MIO-Hiru	MICru-Dec	MITr-Hyd	MIOd-Agr	MIAca-Hyg	MI-Others	Total-MI
1	0	0	0	0	0	8	26
1	0	0	0	0	0	1	41
1	0	1	0	0	0	0	95
0	0	0	0	1	0	3	64
0	1	0	0	0	0	3	57
2	1	0	0	1	0	2	43
0	0	0	1	0	1	5	128
0	0	0	0	0	0	1	70
1	0	0	0	0	0	0	98
2	0	1	0	0	0	0	49
8	**2**	**2**	**1**	**2**	**1**	**23**	**671**
1	**0**	**0**	**0**	**0**	**0**	**2**	**67**
1	**0**	**0**	**0**	**0**	**0**	**3**	**31**
0	**0**	**0**	**-**	**0**	**-**	**0**	**0**

Appendix 6. Detrital BOM amounts (gAFDWm^{-2}) and macroinvertebrates abundance at the exposed riffle gravel bar site along the mid reaches of Sagana River, Kenya between February 2003 and November 2003.

Samp. No.	Date	POM-B	POM-T	POM-F	POM-G	POM-R	POM-WD	POM-O	POM-L1	POM-L2	POM-L3	POM-L4	POM-L5
1st	17/02/03	10.63	0.21	0.07	0.00	0.00	0.00	10.69	0.00	0.00	0.00	0.00	0.00
2nd	03/03/03	9.80	1.54	0.01	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3rd	17/03/03	0.00	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00
4th	14/04/03	0.00	0.18	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.00	0.00	0.00
5th	25/04/03	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6th	06/05/03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7th	15/09/03	0.00	1.44	0.00	0.00	1.18	0.00	0.00	0.00	0.00	0.13	0.00	0.00
8th	22/09/03	0.25	1.99	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.10	0.00	0.00
9th	06/10/03	0.00	0.57	0.00	0.17	0.00	0.00	0.00	0.88	0.09	0.20	0.23	0.06
10th	27/10/03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		**20.68**	**8.06**	**0.08**	**0.17**	**1.85**	**0.94**	**10.69**	**0.88**	**0.22**	**0.43**	**0.32**	**0.06**
Mean		**2.07**	**0.81**	**0.01**	**0.02**	**0.19**	**0.09**	**1.07**	**0.09**	**0.02**	**0.04**	**0.03**	**0.01**
SD		**4.30**	**0.83**	**0.02**	**0.05**	**0.41**	**0.30**	**3.38**	**0.28**	**0.05**	**0.07**	**0.08**	**0.02**
Dispersion Index value		**0.40**	**-0.02**	**1.02**	**1.00**	**-0.12**	**1.00**	**1.00**	**1.00**	**1.15**	**1.53**	**1.21**	**1.00**

KEY

POM-B - Bark
POM-T - Twig
POM-F - Fruit
POM-G - Grass
POM-R - Root
POM-WD- Wood debris
POM-O - Unidentifiable materials
POM-L1 - *Trichocladus elliptium*
POM-L2 - *Euclea divinorum*
POM-L3 - *Bersama abyssinica*
POM-L4 - *Syzgium guineense*
POM-L5 - *Drypetes gerrardii*

POM-L6 - *Rapanea melanophloes*
POM-L7 - *Croton macrotachyus*
POM-L8 - Unidentifiable
POM-L9 - *Dalbergia lactea*
POM-L10 - *Podocarpus latifolia*
POM-L13 - *Cyperus sp.*
POM-L14 - *Garcinia volkensii*
POM-L15 - *Ficus thornigii*
POM-L16 - *Eleodendron buchananii*
POM-L17 - *Croton mengalocarpus*
POM-L18 - *Strychnos hemifsii*
POM-L22 - *Cussonia holstii*

POM-L23 - *Newtonia buchananii*
POM-L25 - *Calodendrum capense*
POM-L27 - *Viscum fischeri*
POM-L40 - *Ochna inoculpata*
POM-L41 - *Grewia similis*
POM-L47 - *Psydrax schimperiana*
POM-L55 - *Phoenix reclinata*
POM-LT - Leaf total
POM-T - Total

Appendix 6. *contd.*

POM-L6	POM-L7	POM-L8	POM-L9	POM-L10	POM-L15	POM-L16	POM-L17	POM-L18	POM-L22	POM-L23	POM-L25
0.00	0.00	0.59	0.00	0.00	0.11	0.09	0.10	0.08	0.05	0.00	0.09
0.00	0.00	0.20	0.00	0.00	0.33	0.00	0.11	0.00	0.14	0.29	0.19
0.00	0.07	0.25	0.00	0.00	0.47	0.00	0.02	0.00	0.18	0.00	0.06
0.00	0.00	0.33	0.00	0.00	0.22	0.00	0.05	0.10	0.18	0.00	0.12
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.76	0.08	0.00	2.78	0.00	0.00	0.00	0.55	0.00	0.28
0.00	0.21	1.16	0.00	0.00	7.25	0.00	0.07	0.00	0.73	0.20	0.28
0.07	0.17	1.26	0.00	0.06	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	0.00	0.00	0.00
0.07	**0.45**	**4.55**	**0.08**	**0.06**	11.16	0.09	0.35	**0.18**	**1.83**	**0.49**	**1.02**
0.01	**0.05**	**0.46**	**0.01**	**0.01**	1.12	0.01	0.04	**0.02**	**0.18**	**0.05**	**0.10**
0.02	**0.08**	**0.47**	**0.03**	**0.02**	2.31	0.03	0.04	**0.04**	**0.26**	**0.11**	**0.11**
1.00	**1.56**	**-0.14**	**1.00**	**1.00**	0.37	1.00	1.45	**1.12**	**-0.78**	**1.52**	**-43.74**

Appendix 6. *contd.*

POM-L27	POM-L40	POM-L41	POM-L47	POM-L55	POM-LT	POM-T	MIE-B	MIE-C	MIE-Af	MIE-Ch	MICo-El	MICo-Sc	MICo-Gy
0.01	0.00	0.00	0.00	0.00	1.12	22.72	5	6	0	1	2	0	0
0.00	0.00	0.00	0.00	0.11	1.37	13.39	4	4	0	1	0	0	0
0.00	0.00	0.05	0.00	0.00	1.19	3.14	0	8	0	0	1	0	0
0.00	0.00	0.10	0.00	0.00	1.10	2.22	7	0	0	0	0	0	0
0.00	0.00	0.00	0.00	0.00	0.00	0.18	0	0	0	0	0	0	0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0
0.00	0.00	0.09	0.09	0.00	4.76	7.38	96	30	1	9	0	5	7
0.00	0.05	0.13	0.00	0.00	10.31	12.55	25	29	50	11	0	0	0
0.00	0.00	0.00	0.00	0.00	3.02	3.76	51	0	8	0	0	0	1
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0
0.01	**0.05**	**0.37**	**0.09**	**0.11**	**22.87**	**65.34**	**188**	**77**	**59**	**22**	**3**	**5**	**8**
0.00	**0.01**	**0.04**	**0.01**	**0.01**	**2.29**	**6.53**	**18.80**	**7.70**	**5.90**	**2.20**	**0.30**	**0.50**	**0.80**
0.00	**0.02**	**0.05**	**0.03**	**0.03**	**3.19**	**7.52**	**31.62**	**11.85**	**15.69**	**4.16**	**0.67**	**1.58**	**2.20**
1.00	**1.00**	**1.47**	**1.00**	**1.00**	**0.16**	**0.12**	**0.28**	**0.23**	**0.70**	**0.33**	**0.26**	**1.00**	**0.72**

KEY

MIE- Macroinvertebrate (Ephemeroptera)
MICo- Macroinvertebrate (Coleoptera)
MID - Macroinvertebrate (Diptera)
MIO - Macroinvertebrate (Oligochaeta)
MICru - Macroinvertebrate (Crustacea)
MITr - Macroinvertebrate (Hydropsychidae)
MIAca- Macroinvertebrate (Acarina)
MIHem- Macroinvertebrate (Hemiptera)

MIE-B - *Baetis sp.*
MIE-C - *Caenis sp.*
MIE-Af - *Afronurus sp.*
MIE-Ch - *Choroterpes sp.*
MICo-El - Elmidae
MICo-Sc - Scirtidae
MICo-Gy -Gyriniidae
MID-Ch - Chironomidae
MID-Si - Simulidae
MID-Ti - Tipulidae
MIO-Tub- Tubificidae

MIO-Nai- Naididae
MICru-Dec- Decapoda
MITr-Hyd- Hydropyschidae
MIAa-Hyg- Hygrobatidae
MIHem-Gerr- Gerridae
MI-Others

Appendix 6. *contd.*

MID-Ch	MID-Si	MID-Ti	MIO-Tub	MIO-Nai	MICru-Dec	MITr-Hyd	MIAca-Hyg	MIHem-Gerr	MI-Others	MI total
50	0	0	1	2	2	1	0	1	0	66
10	3	0	0	0	0	5	0	0	1	24
7	0	1	0	0	0	3	0	0	0	20
1	0	1	1	0	0	0	0	0	1	4
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
26	4	0	1	3	0	1	0	0	1	88
17	7	0	0	0	0	3	0	0	0	117
2	154	0	0	0	0	2	1	0	0	168
0	0	0	0	0	0	0	0	0	0	0
113	**168**	**2**	**3**	**5**	**2**	**15**	**1**	**1**	**3**	**487**
11.30	**16.80**	**0.20**	**0.30**	**0.50**	**0.20**	**1.50**	**0.10**	**0.10**	**0.30**	**48.70**
16.13	**48.27**	**0.42**	**0.48**	**1.08**	**0.63**	**1.72**	**0.32**	**0.32**	**0.48**	**58.96**
0.20	**0.82**	**-0.11**	**-0.11**	**0.33**	**1.00**	**0.07**	**-**	**-**	**-0.11**	**0.14**