INFLUENCE OF LARGE WOODY DEBRIS ACCUMULATIONS ON MACROINVERTEBRATE DISTRIBUTION IN A LOW ORDER FORESTED TROPICAL STREAM, SAGANA RIVER, KENYA

***C. Odhiambo*[1] *and B. M. Mwangi*[2]**
[1, 2] *Department of Zoological Science, Kenyatta University, Nairobi, Kenya*
Email: chaodhiambo@yahoo.com

Abstract
Woody debris accumulations are important ecological components in low order forested streams. They provide forage and refuge for a macroinvertebrates, which are key trophic components for riverine fish. The occurrence of woody debris in tropical streams is however threatened by large scale destruction of catchment forests thereby threatening the riverine biodiversity. Despite their importance, the current status of woody debris accumulations in tropical forested streams is unknown. In this study we determined the densities of debris dams in a forested stream section, their effectiveness in coarse particulate organic matter (CPOM) retention and the associated macroinvertebrates along a 100m stream stretch within the mid-reaches of Sagana River. Volume of woody debris was estimated from length, width and height. All components retained were collected, sorted and dried to a constant weight at 85^{o}C. Prior to drying of the organic matter, macroinvertebrates in the CPOM were picked, sorted into different taxa and enumerated. The average density over the whole study period was 2 woody debris dam accumulations per 100m stream stretch. 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. Woody debris play an important role as long-term retention structures for organic matter and food resources. They forms an important component of riverine ecosystems with regard to CPOM retention, macroinvertebrates distribution and abundance which are indicators of habitat condition. There is therefore need for re-introductions of such structures for effective channel restoration. We recommend maintenance of buffer strips of riparian vegetation along river banks to protect riverine communities from adverse effects of land-use changes within Mt. Kenya catchment region.

Key words: Debris dams, macroinvertebrates, organic matter, streams

Introduction

Large woody debris (LWD) is an important part of the riverine ecosystem. They are common feature of second order forested streams (e.g. Gurnell and Gregory, 1995; Faustini and Jones, 2003). Andreoli *et al.,* (2007) noted that the presence of such accumulations increase flow resistance upto one order of magnitude and hence leads to increased water retention. Bilby (1984) and Gurnell *et al.,* (2002) observed that removal of woody debris may affect stream channel stability. They enhance aquatic habitat diversity in streams by creating hydraulic complexity, storing sediments and fine organic matter and creating off-channel habitats (Neumann and Wildman, 2002). The detritus accumulations greatly modify the abiotic factors of the streams such as water velocity patterns, sedimentation processes, and retention of particulate organic matter (Dobson et al*.,* 1992; Borchardt, 1993; Webster et al., 1990). Observations by Jones and Smock (1991), found woody debris acting as the primary retainers of particulate organic matter (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; Friberg and Larsen, 1998). In addition to this, they increase the retention of organic matter up to 75% of the standing stock in the stream (Bilby and Likens, 1980) and therefore very important in stream restoration (Manners, et al*.,* 2007).

The flow of the river also affects how much LWD falls into the river, because it can direct the flow of water to undercut a bank, which may result in more trees from the bank falling into the water (Bragg, 2000). Not only that the water effect tearing away sediments, but it also transfers minerals and organic sediments (Gurnell, et al*.,* 2002). This include woody debris, leaf litter (Roni, et al*.,* 2002), gravel and sediment (Mossop, 2004). By affecting the way the water flows, it enhances the complexity of hydrological flow, which, inturn, helps to move sediments around so that they can eventually get trapped behind LWD. Thus the sediments are retained in the environment, rather than getting washed downstream.

Although the role of large woody debris accumulation for the export of energy and material has been well studied (Winkler, 1991; Weigelhoefer and Waringer, 1999), little attention has been paid to their roles in tropical streams particularly in regard to structuring of stream macroinvertebrate distribution. In this study, we investigated the macroinvertebrate species distribution and abundance in relation to the large woody debris components along a 100m stream stretch of the mid-reaches of Sagana River, Kenya in order to assess their implications to the management of tropical streams.

Materials and methods

Sagana River is located in the Central Region of Kenya, originating from the south-eastern slopes of Mt. Kenya (Fig. 1) at altitude of about 4000 m above sea level (asl). It is low order stream (Strahler, 1957), draining a watershed area of approximately

2256 km^2. Along the banks of the river from an altitude of about 1790 m asl is fringed by a narrow band of mixed natural forest, behind which occurs plantation forests of *Pinus patula* Schiede and Deppe ex Schiede and *Eucalyptus saligna* Sm. 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 in the area varies annually, with a mean of 889.7 $\pm$ 49.5 mm (Mwangi, 2000).

The study was conducted along a 100 metres stretch of the river near the Government trout rearing farm at Kiganjo. Sampling was carried out between February 2003 and October 2003. Debris dams were surveyed and counted. Volume was calculated from length, width and height. The value was multiplied by 0.5 to allow for hollow spaces (Robinson and Beschta, 1990). Benthic Organic Matter (BOM) was estimated within the debris dams by collecting all the litter materials occurring within the Hess Sampler with an area of 0.0299m^2. In the laboratory, the materials were sorted into leaves, bark, and twig. Leaves were identified to species at the University of Nairobi herbarium. Each component of the materials was dried at 85^{0}C in an oven (Haraeus model T5050) to constant weight and measured to the nearest 0.01g. Data was recorded and expressed as dry weight (gDW m^{-2}) for the organic detritus of each component. For the macroinvertebrates, five samples of benthic fauna were taken within the debris dam. An area of 0.0299m^2 was enclosed with a sampler. Organisms dislodged in the sampling process were passed through the conical net into a detachable collecting tube closed at the rear with a fine (100 µm) mesh. The fauna 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, the 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 into family and genera where possible. The strength of faunal association with BOM distribution was assessed using the Pearson Correlation Coefficients. To determine the distribution pattern of the various BOM and the functional feeding group categories, Green's Coefficient of dispersion (Green, 1966) was 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

Results

The total number of debris dams found in the study area during the sampling period was 2
(Table 1).

Table 1. *Morphmetric and physical features of debris dams on each sampling occasion along the study reach of the mid-reaches of Sagana Stream, Kenya.*

	Date	Debris dam (number)	Width (m)	Length (m)	Height (m)	Area (m^2)	Volume (m^3)
	17/02/03	2	1.42	1.80	1.20	2.56	3.07
			0.93	1.24	0.47	1.15	0.54
	3/3/03	2	1.35	1.81	1.00	2.44	2.44
			0.81	1.31	0.51	1.06	0.54
	17/03/03	2	1.05	1.51	0.80	1.59	1.27
			0.83	0.98	0.50	0.81	0.41
	14/04/03	2	0.95	1.60	0.60	1.52	0.91
			0.79	1.64	0.43	1.30	0.56
	25/04/03	1	0.52	1.23	0.71	0.64	0.45
	6/05/03	0	0.00	0.00	0.00	0.00	0.00
	15/09/03	2	1.40	1.93	0.90	2.70	2.43
			0.95	1.11	0.49	1.05	0.52
	22/09/3	2	1.39	1.76	0.80	2.45	1.96
			0.76	1.03	0.52	0.78	0.41
	6/10/03	2	1.28	2.13	0.9	2.73	2.45
			0.81	0.84	0.63	0.68	0.43
	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**
n		**10**	**18**	**18**	**18**	**18**	**18**
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**

Measurements of the greatest breadth and length of the debris dams ranged from 0.52 m to 1.68 m and from 0.79m to 2.24m, respectively, while their heights ranged from 0.43m to 1.2 m. The horizontal projection area ranged from 0.64 m^2 to 3.76 m^2, with a mean of 1.55 $\pm$ 0.46 m^2. The total dam volume ranged from 0.38 m^3 to 3.76 m^3 with a mean of 1.25 $\pm$ 0.52 m^3. The average density of accumulation was 1.8

dams per 100 m. The main structural component of the dams was twig material, which made up 39.1 % out of the total retained organic matter (Table 2).

Table 2. *Total CPOM amounts g m^{-2}(DW) or gm^{-3}(DW) during the sampling sessions along the mid-reaches of Sagana stream, Kenya.*

	gm^{-2} (DW)	**gm^{-3} (DW)**	**% DW**
Twig	338.02	15.00	39.11
Bark	303.47	13.47	35.12
Leaves	185.75	8.24	21.49
Others	36.95	1.64	4.28
Total BOM	864.19	38.35	100.00

Total dry weight (DW) of retained organic matter averaged 864.19gm^2(Table 2). Twig litter was the largest fraction accounting for 39.1% of the total detrital standing stock. Barks, leaves and other materials amounted to 35.1%, 21.4%, and 4.2% respectively. BOM distribution was aggregated as evidenced by the positive values of the dispersion index (Table 3) except for twigs.

Table 3. *The dispersion index values for benthic detrital standing stock at different sites along the study reach between February 2003 and October 2003, Sagana Stream, Kenya.*

	Sites	
POM category	**Debris dam**	**Large woody debris**
Bark	+0.33	+0.12
Twig	-0.04	+0.08
Leaves	+0.05	-0.01
Others	+0.09	+0.11

+ Values indicate clumped pattern

- Values indicate uniform pattern

The macroinvertebrates occurring at the debris dams were dominated by Coleoptera (47.3%), followed by Diptera (22.7%) and Ephemeroptera (19.2%) (Table 4). The Coleoptera were dominated by Gyrinidae, Elmidae and Scirtidae. The main functional feeding groups were the collector-gatherers, dominated by Chironomidae (Diptera; 18.3%), (Ephemeroptera; 11.4%), (Oligochaeta; 5.0%), Elmidae (Coleoptera; 4.5%), Naididae (Oligochaeta; 1.3%), Tipulidae (Oligochaeta; 0.9%) and Lumbriculidae (Oligochaeta; 0.9%). Collector filterer (Simulidae) occurred in low abundance while Tipulidae known to switch between shredding and collector gathering food habits, were very rare, constituting 1% of the total faunal abundance (Table 4).

The amount of dry weight of twigs had a positive and significant correlation on Odonata, Hydracarina, Ephemeroptera and Decapoda (Table 5). In addition, a positive and significant correlation (r = 0.715; $P<0.05$) was discerned between dry weight of bark and the Odonata. However, the amount of dry weight of leaves had no significant correlation with any of the taxa.

Table 4. *Total counts and relative abundance of insect and non-insect taxa at the debris dam along the mid reaches of Sagana Stream, Kenya. (Data were sampled in 5 replicates twice a month over a period of nine months)*

Taxa	**Debris dam**	
	Indiv. count	**Relative abundance**
Insecta		
Ephemeroptera	103	19.18
Diptera	122	22.72
Coleoptera	254	47.30
Trichoptera	5	0.93
Odonata	2	0.37
Hemiptera	1	0.19
Sub-total	**487**	**90.69**
Crustacea		
Decapoda	4	0.74
Sub-total	**4**	**0.75**
Others		
Oligochaeta	25	4.66
Hydracarina	1	0.19
Others	20	3.72
Sub-total	**46**	**8.57**
Overall Total	**537**	**100**
Area sampled(m^2)	**1.55**	
Mean indiv./m^2	**346**	

Table 5. *Correlation analysis of dry weight of twigs, bark and leaves with different invertebrate taxa in Sagana Stream, Kenya.*

	Twigs		**Bark**		**Leaves**	
Taxa	**r - value**	**p- value**	**r - value**	**p - value**	**r - value**	**p - value**
Odonata	0.899	0.001	0.715	0.020	0.170	0.638
Hydracarina	0.899	0.001	0.715	0.020	0.170	0.638
Ephemeroptera	0.853	0.002	0.611	0.060	0.131	0.717
Decapoda	0.664	0.036	0.522	0.122	0.040	0.912

Discussion and conclusion

The stable and low average density accumulation of the debris dam reported in this study was due to the effect of logging, livestock grazing and agriculture along the riparian zone (Mwangi, 2000). It is apparent that virtually all forests along the catchment areas in Mt. 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 large woody debris. 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. Piegay and Gurnell (1997) while studying low order streams bordered by managed riparian forests in southern England noted that there is a close similarity in the functioning of tropical forested streams to temperate streams and the effect of disturbance can be predicted from studies in such streams. LWD therefore represent stable structures in Sagana river.

The observed total retained organic matter of 864.19g m^{-2}(DW) observed along Sagana river is relatively low compared to temperate streams. The low values of BOM may be due to reduced litter fall from the riparian vegetation and increased discharge during the study period. Litter fall occured in low amounts and much of it was flushed downstream during the rainy seasons. Maridet *et al.* (1995) observed that 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. Acuna *et al.* (2007) also made similar observations while carrying out a study at Fuirosos stream in Peninsula.

The increased amount of twigs at the debris dams may have contributed to the higher abundance of macroinvertebrates, averaging 346 indiv. /m^2. The twigs were certainly essential in providing stable attachment sites and trapping the floating leaves which are valuable food sources for the macroinvertebrates. This therefore created the heterogeneous architecture and a multitude of microhabitats which was colonized by the Odonata, Hydracarina, Ephemeroptera and Decapoda. Similar observations were made by Bilby and Likens (1980), Bilby (1981), Collier and Halliday

(2000) and Lemly and Hilderbrand (2000), all of whom underscored the importance of submerged twigs in relatively high-gradient mountainous streams as stable substrate for attachment, and providing food resources for wood-feeding individuals. CPOM in dams provides important habitats for organisms of low order streams (Friberg and Larsen, 1998). Other authors such as Friberg and Larsen (1998), O'Connor (1991), Phillips and Kilambi (1994) and Smock *et al*. (1989), Dobson *et al.* (1992), Hax and Golladay (1993) and Philips and Kilambi (1994) have also observed that organic matter stored by debris dams and fine particle accumulations are colonized by algae and biofilm, which provide valuable food resources for many functional feeding groups of stream biota and in turn attract secondary consumers and thus important for stream restoration (Manners et al. 2007).
In conclusion, the study highlights LWD as an important component of riverine ecosystems with regard to CPOM retention and macroinvertebrates abundance which are indicators of habitat condition. By damaging the riparian vegetation that provides it, human impact has severely damaged the ecosystem of Sagana river. There is therefore need to institute appropriate mechanisms to prevent loss of large woody debris in tropical streams, and where the streams have been heavily impacted, there is need for re-introductions of such structures into the channels. We recommend maintenance of buffer strips of riparian vegetation along river banks to protect riverine communities from adverse effects of land-use changes within Mt. Kenya catchment region.

Acknowledgement
We wish to thank Kenyatta University for availing equipment and laboratory space for the research work and technicians of the Department of Zoological Sciences for their generous support. We also thank the staff at Kiganjo Trout Farm for their field work support. Mr. Simeon Mathenge of the East African Herbarium, Nairobi University helped in identification of plant materials collected in the field.

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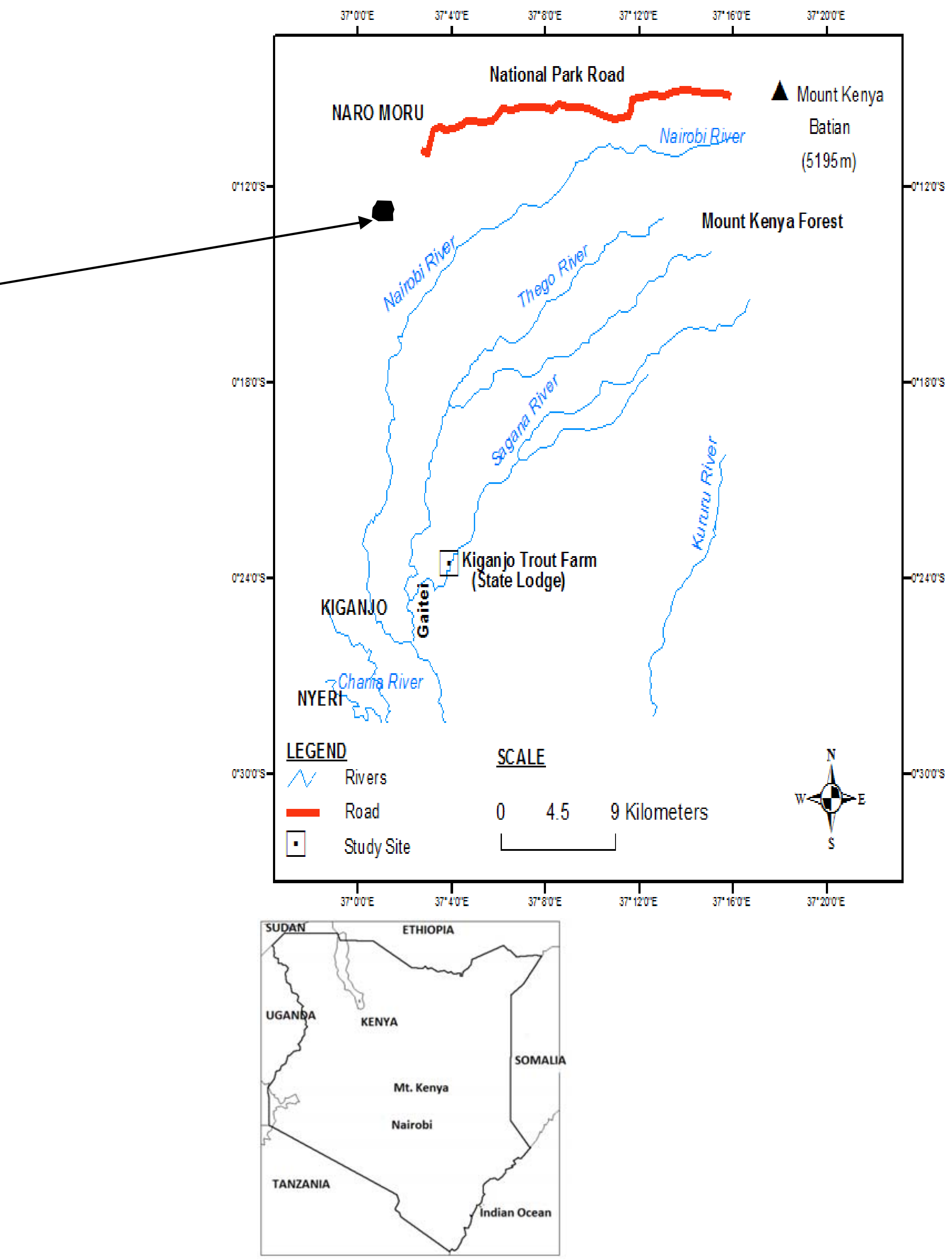

Figure 1. Location of Sagana River, Kenya showing the study site.