Coarse Particulate Organic Matter Drift in the Njoro River, Kenya, as a Function of Drift Net Mesh size, Exposure time and Position of Drift sampler

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Abstract

Streams transport organic materials to downstream areas and provide food resources and habitat to downstream consumers. Organic matter drift has been reported in streams and is affected by factors such as human-induced disturbances (e.g., damming), stream geomorphology and discharge. However, there is still a paucity of information on the influence of the mesh size of drift nets, drift sampler position and sampling duration (i.e., exposure time) on the drift dynamics of allochthonous particulate organic matter (POM) in Kenyan streams. In the current study, the downstream movement of POM was assessed in different habitats (i.e., pools and riffles) of the Njoro River, between 3rd January and 28th March, 2017. Drift samplers with varied net mesh-sizes (100 µm, 250 µm and 500 µm) were used and POM sampling time varied between 5-120 minutes. The average amount of POM that drifted (pooled data) differed significantly between the riffle and pool habitats ($p < 0.001$). The average amount of POM that drifted through the three drift nets did not vary significantly at the riffle ($p > 0.05$) and pool ($p > 0.05$) habitats. Based on the mesh size of drift samplers, the 100 µm drift sampler had the highest mean amount POM compared to the other (i.e. 250 and 500 µm) drift samplers at the pool habitat. The pool habitat had relatively low average POM content in drift samples. Organic matter drift was significantly affected by the duration of sampling at the riffle ($p < 0.001$) and pool habitats ($p < 0.001$). In general, POM drift increased with increase in the duration of sampling. Drift sampler position on the stream bed significantly influenced the mean amount of POM that drifted in both stream habitats ($p < 0.001$). This research indicates that the mesh size of drift samplers' nets, duration of sampling and drift sampler position on the stream bed should be considered when characterizing POM drift in running water ecosystems. In future, research on drift should assess the effects of other factors, such as stream size and seasonality on POM drift.

Key words: Leaf litter, sampling duration, Stream ecology, Tropical

INTRODUCTION

Running water ecosystems, such as streams, are those with unidirectional water flow responsible for sustaining ecological processes such as organic matter transport and sediment deposition (Vannote *et al.*, 1980; Angradi, 1991; Andersson & Nilsson, 2002; Bunte *et al.*, 2016). Invertebrate drift has been the subject of investigation by different stream ecologists (see literature in Waters, 1972; Brittain & Eikeland, 1988; Muehlbauer *et al.*, 2017). Apart from invertebrate drift, coarse particulate organic matter drift has also been reported in streams (e.g., Wagner, 2000; Gomi *et al.*, 2002) and it is influenced by factors such as human-induced disturbances (e.g. damming), stream gradient, water depth, season, and discharge (Naiman & Sedell, 1979; Angradi, 1991; Waringer, 1992; Shannon *et al.*, 1996).

Coarse particulate organic matter (CPOM) refers to organic materials that are larger than 1 mm in size (Tank *et al.*, 2010; Bunte *et al.*, 2016; Lamberti *et al.*, 2017). The main constituents of drifting CPOM include pieces of leaves, flowers, feacal pellets, excuvies, petals, fruits and twigs and are important energy sources for downstream food webs (Wantzen, *et al.*, 2008; Bunte *et al.*, 2016; Lamberti *et al.*, 2017). In terms of biomass, leaves from vegetation growing along river banks contribute the largest amount of CPOM into streams. In addition, the amount of leaf litter that gets into streams is variable and depends on factors such as the most common vegetation in the area, season, flow conditions and stream order (Wantzen *et al.*, 2008; Masese & McClain, 2012).

Drift of CPOM is an important ecosystem process in running waters but has rarely been investigated in many tropical stream ecosystems. However, drift of CPOM is a vital source of energy in running waters (Cuffney *et al.*, 1990; Otake *et al.*, 1993) and in estuarine ecosystems (Martineau *et al.*, 2004; Dias *et al.*, 2016). Drift of CPOM is also crucial in export of carbon from catchments, dispersal of plant propagules along rivers and in maintenance of the diversity of riparian vegetation (Hope *et al.*, 1994; Andersson & Nilsson, 2002; Bunte *et al.*, 2016).

Organic matter is found in high quantities in tropical streams (Wantzen *et al.*, 2008; Mesa *et al.*, 2013). In the riparian zones, the amount of organic matter is largely determined by the density of vegetation (Moser, 1991) and its duration of residence on the riparian area is affected by factors such as bank gradients (Magana & Bretschko, 2003). The riparian zones of a stream are vital pre-processing and storage areas for CPOM before it gets into the aquatic environment (Mathooko *et al.*, 2000). The quantities of organic matter on the riparian zones of most tropical riverline ecosystems are influenced by factors such as climate conditions and human-induced disturbances (e.g. grazing) which affect the vegetation (Mathooko & Kariuki, 2000).

Alot of CPOM gets into lotic ecosystems from the surrounding areas and forest canopy through runoff and aerial drift, respectively (Weigelhofer & Waringer, 1994; Wantzen *et al.*, 2008; Mbaka, *et al.*, 2014). The CPOM is transported over comparatively short distances before it becomes trapped by retentive structures (Cordova *et al.*, 2008; Bunte *et al.*, 2016; Lamberti *et al.*, 2017). The retained CPOM undergoes leaching, colonization by microorganisms, shredding by macroinvertebrates and abrasion by physical forces (Cordova *et al.*, 2008; Foucreau *et al.*, 2013; Lamberti *et al.*, 2017).

Information on CPOM drift as a function of drift-net mesh-size, exposure time and the position of drift sampler on the stream bed is scanty for Kenyan streams and most of the research conducted on the Njoro River has focused on the distribution of CPOM on the stream bed and along the banks (e.g., Mathooko *et al.*, 2001; Magana & Bretschko, 2003; Morara *et al.*, 2003; M'Erimba *et al.*, 2006; Mbaka *et al.*, 2015). The objective of the current study is to evaluate whether drift net mesh-size, exposure time and drift sampler position on stream bed has any significant effect on CPOM drift dynamics in two habitats (i.e., pools and riffles) of the Njoro River, Kenya.

MATERIALS AND METHODS

Study River and Site

Two contrasting habitats (i.e. pool and riffle) were selected at the midstream section of the Njoro River between 2263 and 2234 m.a.s.l. (Figure 1). The Njoro River, located in Nakuru County, Kenya, is a second order stream that originates from Entiyani Location at an elevation of about 2800 m above sea level (S 00° 34.588″, E 035° 54.684″) (Mureithi *et al.*, 2018). The river drains into Lake Nakuru at an elevation of approximately 1700 m.a.s.l (Mathooko, 2001). The length of the river is estimated to be 50 km (Mathooko, 2001) with a watershed of approximately 250 km^2 (Osano, 2015).

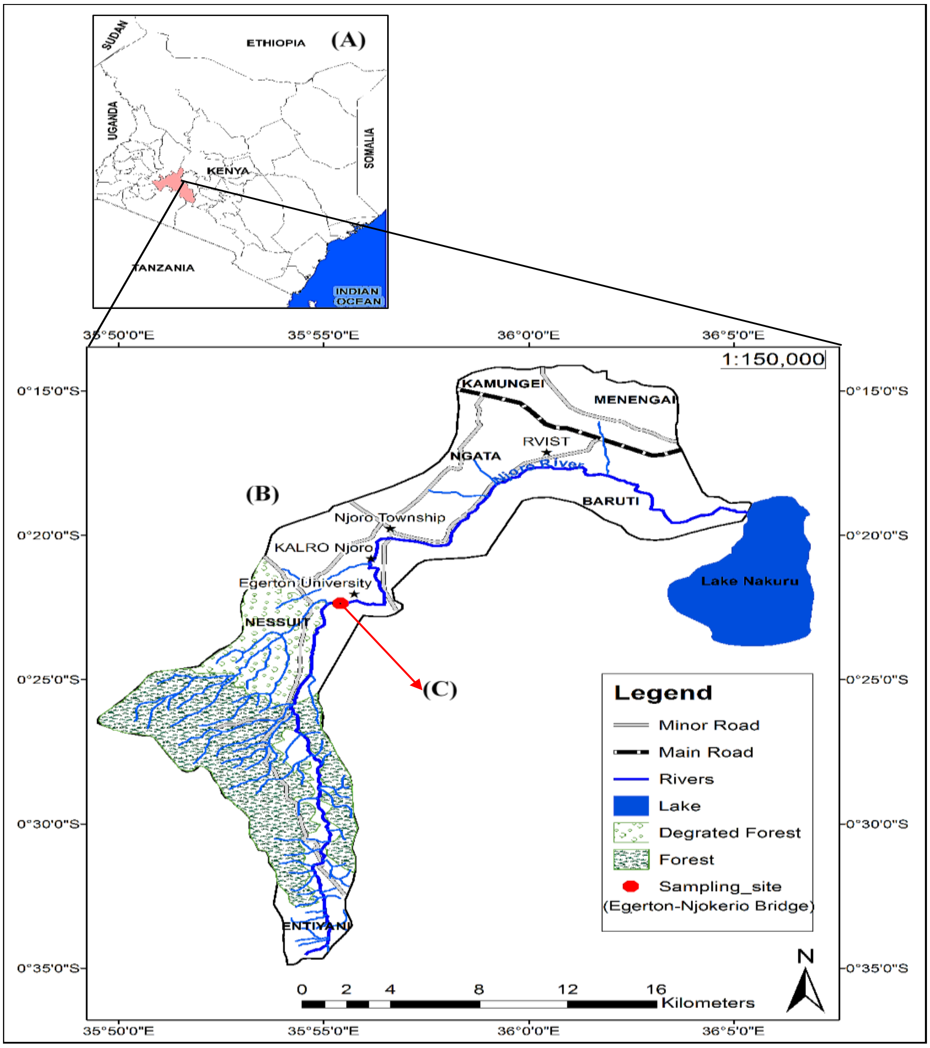

Figure 1: A figure showing theNjoro River in Kenya (A), the Njoro River from the source to the mouth (B) and the study reach (C)

The dry period usually occurs from December to March, while the wet period typically occurs from April to November (Mbaka *et al.*, 2014; M'Erimba *et al.*, 2014). The study site was situated on a reach of the Njoro River (Figure 1).

The pool and riffle habitats were located on a reach bordering Egerton University. The riffle habitat (length: 28 m; width: 5.5. m) was located between latitude 00°22′ 30.7″ S and longitude 035°56′ 02.7″ E at an elevation of 2263 meters above sea level (m.a.s.l). The vegetation cover intensity at the riffle was 70% and the stream substrates were mainly composed of bedrock (90%). The pool habitat (length: 22 m; width: 5.5 m) was located between latitude 00°22′ 31.2″S and longitude 035°56′ 02.7″ E at an elevation of 2234 m.a.s.l. The riparian vegetation cover intensity was 40% and the substrates were mainly composed of sand (40%) and boulders (30%). The distance between the pool and riffle habitats was 50 m. Details of water depth, velocity and discharge at the drift sampling points (i.e., right, mid and left banks) at the riffle and pools are provided in Table 1.

Table 1: Water depth, velocity and discharge at the riffle and pool habitats. Values are ± SE

	Riffle			**Pool**		
	Right bank	**Mid-stream**	**Left bank**	**Right bank**	**Mid-stream**	**Left bank**
Depth (m)	0.08 (0.008)	0.05 (0.004)	0.11 (0.01)	0.35 (0.02)	0.26 (0.01)	0.31 (0.01)
Velocity (m/s)	0.16 (0.01)	0.20 (0.01)	0.19 (0.01)	0.07 (0.002)	0.07 (0.002)	0.06 (0.003)
Discharge (m^3/s)	2.71 (0.37)	2.36 (0.32)	4.10 (0.48)	4.78 (0.55)	3.80 (0.43)	4.81 (0.43)

Generally, human-related activities were low at the study site, apart from limited farming activities at the right river bank of both the pool and riffle habitats. The right bank was characterized by small scale farming of maize (*Zea mays*), kales (*Brassica sp*.), potatoes (*Solanum sp.),* beans (*Phaseolus sp*.), among other plants. Additionally, washing of clothes and fetching of water was observed at the right bank of the river. The left bank borders Egerton University and is least impacted by human-related activities.

Organic Matter Sampling and Processing

Organic matter was evaluated using six drift samplers during the day, between 10:00 and 16:00 h. The samplers were named as follows: dr1, fitted with a 100µm net, dr2, fitted with a 250µm net, dr3, fitted with a 500µm net, dr4, fitted with a 100µm net, dr5, fitted with a 250 µm net and dr6, fitted with a 500µm net. The first group of samplers (dr1 - dr3) were used to sample the riffle while the second group of samplers (dr4 – dr6) were used to sample the pool habitat. The distance between the two categories of samplers was set at 50 m. The samplers were positioned at the left, mid and at the right banks of the river at each of the habitats. There were five sampling occasions and each sampling occasion was done over a period of three days. During every sampling occasion, the location (left bank, midstream, right bank) of the samplers in the stream bed was interchanged to ensure that each sampler had an equal opportunity of being situated at any of the three locations (plate 1 & 2). Samples were collected over varied time intervals (5, 10, 15, 20, 25 and 120 minutes) and samples were collected simultaneously in riffles and pools. The samples were emptied into well labeled polythene bags. Subsequently, sediment and other extraneous materials were removed from the samples by washing them into a 500 µm sieve. The samples were dried at 60^0C for 24 hours. The samples were weighed to obtain mass in grams. In total, 540 samples were obtained by the end of the study.

Plate 1: The riffle biotope in the Njoro River showing the researcher positioning a drift sampler at the right bank facing upstream
Source: Author

Plate: The pool biotope in the Njoro River showing the drift samplers at different positions
Source: Author

Data Analysis

The data was analyzed using the Statistical Package for Social Sciences (SPSS) Software, version 22. The data was evaluated for homogeneity of variance before use of parametric tests. Data that failed the test was $\log_{10}(x+1)$ transformed before use of parametric tests. t-test was applied in comparison of the average values of CPOM that drifted in both the pool and riffle habitats. One-way analysis of variance (ANOVA) was utilized to compare averages of CPOM among the drift nets in each habitat in relation to drift net mesh size, duration of sampling and drift sampler position on stream bed. Tukey contrasts were applied in post-hoc evaluations (Hothorn *et al.*, 2008).

RESULTS

Organic Matter Drift in the Riffle and Pool Habitats

The mean amount of CPOM that drifted into the three drift nets (Figure 1) did not vary significantly at the riffle (One-way ANOVA, $F_{(2,267)} = 2.39$, $p > 0.05$) and pool habitats (One-way ANOVA, $F_{(2,267)} = 0.06$, $p > 0.05$). The difference in the mean amount of CPOM that drifted into the 100 µm and 500 µm drift nets was statistically significant in the riffle (t = 4.48, d.f = 178, $p < 0.001$) and pool (t = 2.98, d.f = 178, $p < 0.05$) habitats respectively. However, there was no significant difference in the average amount of CPOM that drifted into the 250 µm nets between the two habitats (t = 1.57, d.f = 178, $p > 0.05$). Generally, the amount of CPOM drift (pooled data) differed significantly between the riffle and pool habitats (t = 5.17, d.f = 538, $p < 0.001$).

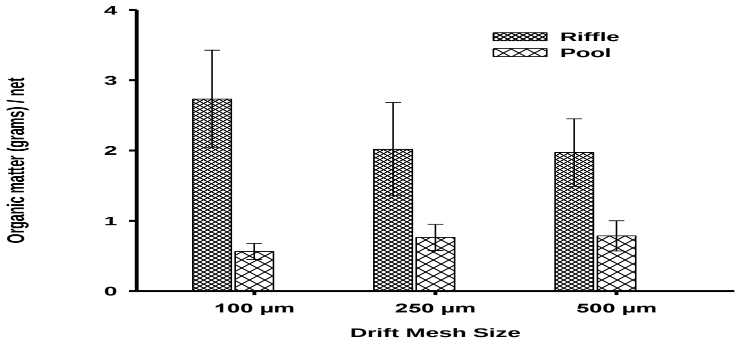

Figure 2: Average amount of CPOM that drifted into 100µm, 250 µm and 500µm drift nets in the Njoro River. Vertical bars are ± SE, n = 540

Organic Matter Drift in Relation to Duration of Sampling in the Riffle and Pool Habitats

The average amount of CPOM that drifted during different sampling times in the riffle and pool habitats in the Njoro River are presented in Figure 2. CPOM drift was significantly affected by exposure time at the riffle (One-way ANOVA, $F_{(5, 264)} = 47.58$, $p < 0.001$) and pool habitats (One-way ANOVA, $F_{(5, 264)} = 29.48$, $p < 0.001$).

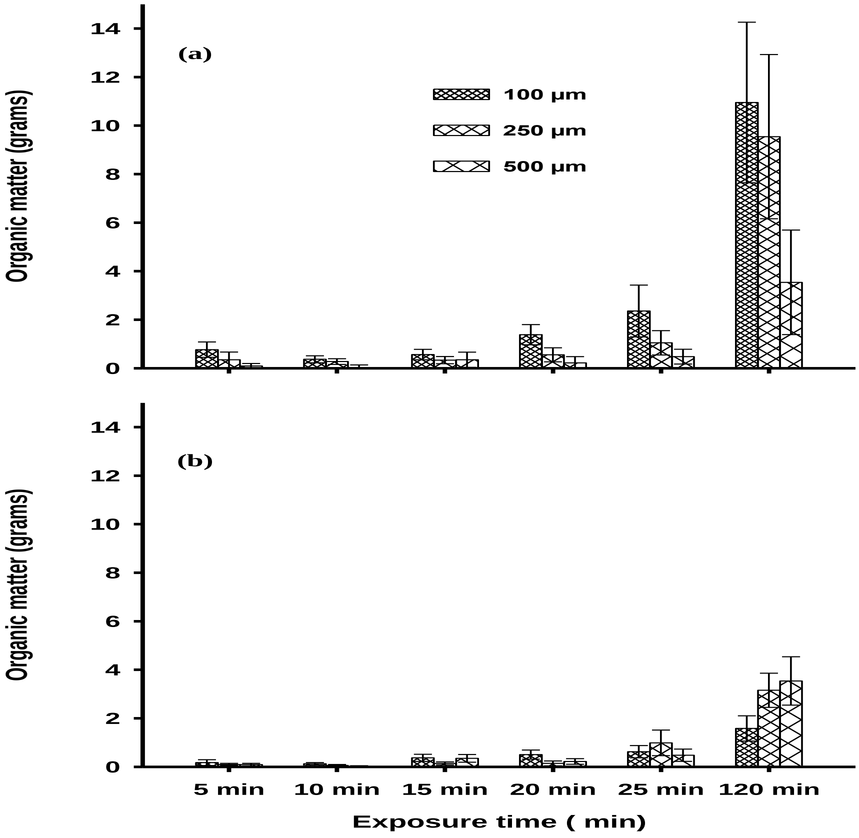

Figure 3: Average amount of CPOM that drifted into drift nets during different sampling times (5 – 120 min) in (a) riffle and (b) pool habitats in the Njoro River. Vertical bars are ± SE, n = 540.

Generally, CPOM drift increased with increase duration of sampling. In the riffles, duration of sampling had a significant effect on the mean amount of CPOM that drifted into the 100 µm (One-way ANOVA, $F_{(5,\ 84)} = 16.96$, $p < 0.001$), 250 µm (One-way ANOVA, $F_{(5,\ 84)} = 11.03$, $p < 0.001$) and 500 µm (One-way ANOVA, $F_{(5,\ 84\ )} = 22.35$, $p < 0.001$) mesh sized nets. Similarly, exposure time had a significant effect on the amount of CPOM that drifted into 100 µm (One-way ANOVA, $F_{(5,\ 84)} = 3.59$, $p < 0.05$), 250 µm (One-way ANOVA, $F_{(5,\ 84)} = 16.63$, $p < 0.001$) and 500 µm (One-way ANOVA, $F_{(5,\ 84\ )} = 17.87$, $p < 0.001$) mesh sized nets at the pool habitat.

Drift of Organic Matter in Relation to Drift Samplers Position in the Riffle and Pool Habitats

The amount of CPOM that drifted in the riffle habitat was apparently high in the left bank compared to the mid-stream and right bank positions. However, the amount of CPOM that drifted in the pool habitat was higher in the right bank compared to the mid-stream and left bank positions (Figure 3). There was a significant variation in the amount of CPOM that drifted at the three drift sampler positions using the 100 µm (One-way ANOVA, $F_{(2,87)} = 10.65$, $p < 0.001$) and 500 µm (One-way ANOVA, $F_{(2,87)} = 4.026$, $p < 0.05$) drift nets. In contrast, the amount of CPOM that drifted into the 250 µm drift net did not portray any significant difference (One-way ANOVA, $F_{(2,87)} = 0.77$, $p > 0.05$) at the three drift sampler positions. In the pool habitat, the three drift sampler positions had a significant variation in the mean amount of CPOM captured by the 100 µm (One-way ANOVA, $F_{(2,87)} = 26.19$, $p < 0.001$) drift net. In contrast, there was no significant variation in the amount of CPOM that drifted in the three drift net positions for the 250 µm (One-way ANOVA, $F_{(2,87)} = 2.01$, $p > 0.05$) and 500 µm (One-way ANOVA, $F_{(2,87)} = 2.31$, $p > 0.05$) drift nets.

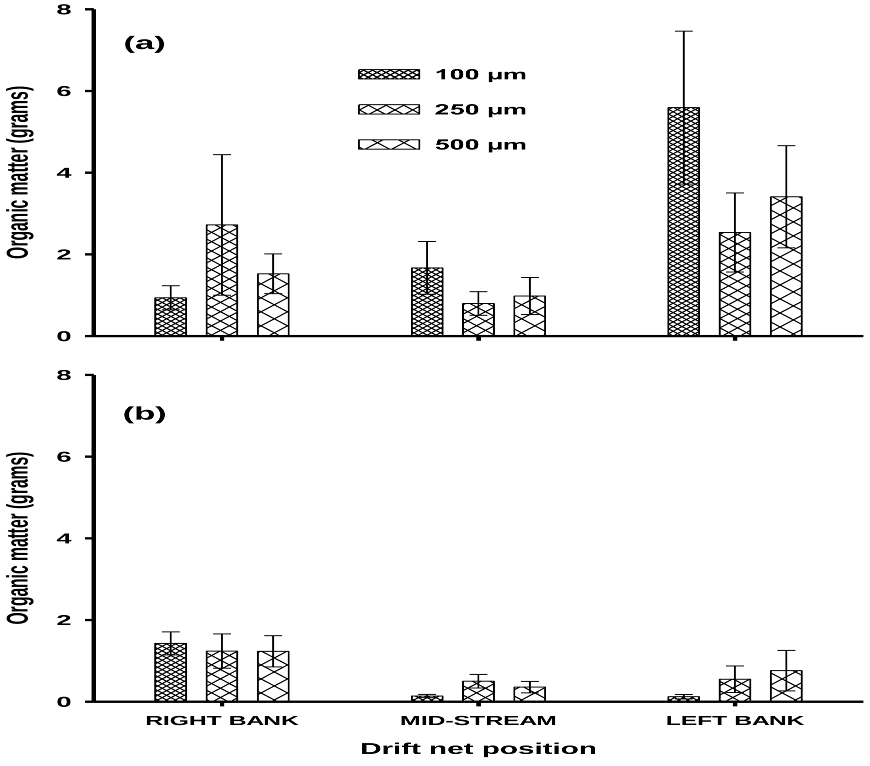

Figure 4: Average amounts of CPOM that drifted in (a) riffle and (b) pool habitats in the Njoro River. Vertical bars are ± SE, n = 540.

DISCUSSION

The average amount of CPOM that drifted in the Njoro River was higher in the riffle habitat than in the pool habitat (Figure 1). The possible reason for this observation is due to differences in habitat characteristics between the pool and riffle study sites. For example, pools tend to have greater depths and slower water currents than riffles and are largely depositional habitats (Waringer, 1992; Magana & Brestschko, 2003; Herbst *et al.*, 2018). Therefore, CPOM and fine substrates in drift are more likely to accumulate in pools. On the other hand, riffles are shallower than pools and there is a higher likelihood of CPOM being transported to downstream areas by the relatively strong water currents.

Beside differences in water current velocities between pools and riffles, abundance of CPOM in drift can also be influenced by variability in factors such as organic matter trapping structures (e.g. woody debris), stream bed roughness (e.g. increased substrate size) or riparian vegetation density (Naiman & Sedell, 1979; Angradi, 1991). For example, in the current study the pool habitat had a higher percentage of retention structures such as boulders and cobbles (40%), compared to riffle habitat (5%), and this could have contributed to the high coarse particulate organic matter drift in the riffle due to reduced retention of organic matter. Additionally, the riffle habitat had a higher (70%) canopy cover intensity than the pool habitat (40%) and the differences in canopy cover could have contributed to differences in the amount of CPOM getting into the river through aerial drift.

The results of this study demonstrates that CPOM drift is not uniform throughout the study site. This finding agrees with the findings of Shannon *et al.* (1996) that demonstrated that drift of CPOM is reach specific due to discharge and suspended sediment dynamics. The findings of the current study are also in agreement with the findings of other authors (e.g. Naiman & Sedell, 1979; Waringer, 1992; Mathooko, 1995; Bunte *et al.*, 2016) who found that drift density of coarse particulate organic matter is positively correlated to river flow rate. However, the interaction between water flow rate and retention structures is crucial in determining the quantity and size classes of particulate organic matter drifting downstream (Bunte *et al.*, 2016). For example, Angradi (1991) demonstrated that the mean amount of fine and coarse particulate organic matter that drifted downstream was not related to discharge, probably because aquatic plants increased the capacity of the river to retain particulate organic matter.

The river water depth is also an important factor that affects drift because when water reaches the banks some additional CPOM from the riparian areas is washed into the stream, increasing the amount of CPOM in drift. Finally, drift of CPOM in pool and riffle habitats may also be affected by other factors such as slope of the river and size and density of CPOM (Cordova *et al.*, 2008).

The drift samplers fitted with a 100 µm mesh-sized drift nets had the highest amount of CPOM, followed by the 250 µm and 500 µm samplers at the riffle habitat. On the other hand, the drift samplers fitted with 500 µm drift nets had the highest amount of CPOM, followed by the 250 µm and 100 µm samplers at the pool habitat. Increase in the content of CPOM in drift with decrease in drift net mesh size at the riffle habitat could be due to loss of small sized particulate organic materials that pass through coarse meshed drift nets. Other authors (e.g. Angradi, 1991; Faulkner & Copp, 2001) also demonstrated that the amount of CPOM sampled is influenced by the mesh size of drift nets.

Decrease in the amount of CPOM in drift with decrease in drift net mesh size at the pool habitat could be as a result of drift net clogging. Clogging is associated with drift nets with small mesh sizes and leads to backwash of organic materials from the drift nets (Kennedy *et al*., 2014). Clogging of drift nets causes reduction in filtration efficiency and can cause challenges in drift density evaluation in streams where the samplers are likely to trap suspended fine particulate organic and inorganic materials (Faulkner & Copp, 2001; Muehlbauer *et al.*, 2017).

Generally, drift of CPOM in the current study increased with increase in exposure time. Longer exposure time translates to high volumes of water filtered through the drift nets and this increases the content of CPOM retained in the nets (Faulkner & Copp, 2001; Perić & Robinson, 2015). Drift net design and position in the stream also have an effect on the evaluation of CPOM drift in streams (Faulkner & Copp, 2001; Janáč & Reicharda, 2016).

The average amounts of CPOM that drifted in the sampled habitats were highest in the left and right river banks, respectively. The observed differences in the amount of CPOM drift with respect to the drift samplers' position on the stream bed can be due to variability in water discharge at the different stream positions. For example, discharge at the riffle habitat was high at the left bank while the pool habitat was characterized by high discharge at the right bank. This could have increased the amount of organic matter that drifted at the left and right river banks at the riffle and pool habitats, respectively.

Another explanation for our findings is that the riparian vegetation at the left bank at the riffle and at the right bank at the pool was less disturbed and could have contributed more organic matter into the river. The vegetation growing on stream banks affects the content of CPOM that gets into rivers and lack of vegetation on river banks can lead to low quantities of CPOM in the river (Johnson *et al*., 1997; M'Erimba *et al.*, 2006; M'Erimba *et al.*, 2007). Human influence on the riparian vegetation in many African areas affects the quantities of CPOM that gets into rivers and this has an effect on the energy budget of the affected lotic ecosystems (Mathooko & Kariuki, 2000).

In the current study, the river banks had significantly higher mean quantities of CPOM in drift than the mid-section. This observation is in agreement with other authors who found that the quantity of CPOM retained at the banks was higher than at the mid channel (e.g. Gurtz *et al.* 1987; Angradi, 1991). According to the authors, the organic materials that get into the river are moved to the stream banks by the strong water currents. The meanders, and associated back water zones, provide ideal sites for accumulation of CPOM at the stream banks. Subsequently, this could increase the quantity of CPOM that is entrained into drift from the benthic zone.

CONCLUSION

Riffle and pool habitats are of ecological importance to lotic ecosystems in terms of carbon transport, retention and processing (i.e., organic carbon spiraling). This research indicates that the mesh size of drift sampler net, duration of sampling and drift sampler position should be considered when characterizing CPOM drift in streams. This research also offers a chance to appreciate the role of different stream habitats in drift of CPOM in streams. Future studies should evaluate the drift of other types of organic energy resources (e.g. dissolved organic carbon). Additionally, future studies should consider the influence of land degradation, river size and seasonality on CPOM drift in streams.

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