EFFECT OF NET MESH SIZE, EXPOSURE DURATION AND NET POSITIONING ON MACROINVERTEBRATE DRIFT DENSITIES IN THE NJORO RIVER, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted or presented for examination in any institution.

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Recommendation

This thesis has been presented for examination with our approval as official university supervisors.

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DEDICATION

To the loving memory of my Mum, the late Regina N. Mureithi who did all she could to establish the foundation of my education.

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ABSTRACT

Macroinvertebrate drift is a phenomenon that has fascinated and occupied ecologists for a longtime and has produced varied results. Drift samples were collected in a riffle and pool biotopes in the Njoro River between 3rd January and 28th March 2017 with a sole objective of determining whether drift net mesh size, positioning and variation in exposure time could have significant influence on drift densities. Purposive systematic random sampling was employed to collect samples using six nets of 100 µm, 250 µm and 500 µm mesh sizes for three consequent days always alternating the nets at the right, middle and left banks respectively, during seven sampling occasions. The nets were emptied at intervals of 5, 10, 15, 20, 25 and 120 minutes. Benthic samples were also collected during each sampling for quantification of the proportions of benthos that drifted. The mean drift densities (pooled data) between the pool (20.73 ± 0.10 ind.m^{-3}) and riffle (38.79 ± 5.15 ind.m^{-3}) was statistically significant (t-value = 2.821, d.f = 754, $P < 0.05$). The difference in drift densities among the 100 µm, 250 µm and 500 µm nets was very highly significant ($P < 0.001$). The 500 µm net collected the lowest drift densities, followed by the 250 µm net Tukey's Honestly Significance Difference (HDS) test, ($P < 0.001$). Drift densities decreased significantly with increase in exposure time in all the three nets in both biotopes ($P < 0.001$). Drift densities differed significantly with the net positions at the riffle (One – way ANOVA, $F_{(2,375)} = 11.43$, $P < 0.001$) with the left bank having significantly higher densities than the mid-stream and the right bank. One – way ANOVA indicated insignificant difference in mean drift densities among the three positions in the pool ($F_{(2,375)} = 0.839$, $P > 0.05$). There was no significant interaction observed among drift net mesh size, drift net position and exposure time in the riffle (Three way- ANOVA, $F_{(20,324)} = 0.375$, $P > 0.05$) and pool (Three way- ANOVA, $F_{(20,324)} = 0.374$, $P > 0.05$) biotopes. Mean proportion of benthos differed significantly between the riffle and pool biotopes ($t = -9.473$, d.f = 106, $P < 0.001$) with the pool having higher proportions than the riffle. This study demonstrates that drift net mesh size, position and exposure time should be taken into account when characterizing invertebrate drift in streams. Maximum drift densities can be obtained by sampling for 5 minutes irrespective of the mesh size used. Future drift studies should consider reduction of sampling time below five minutes as this was omitted in this study. Future studies should also consider drift sampling as a standard complementary tool to benthic sampling in bioassessment protocols of tropical streams.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
APHA	American Public Health Association
DO	Dissolved Oxygen
DR	Drift
EC	Electrical Conductivity
HSD	Honestly Significance Difference
PCA	Principal Component Analysis

CHAPTER ONE
INTRODUCTION

1.1 Background information

Stream scientists have for decades conducted ecological studies on landscape perspectives in streams (Forman, 2014) and more so on macroinvertebrate drift (Muehlbauer *et al.,* 2017). Fenoglio *et al.* (2002) defined drift as the downstream transport of aquatic organisms in a river. Invertebrate drift is also described as the downstream dispersal of benthic invertebrates in the water column that usually live on or amongst the substratum of the stream bed (Elliott, 2003), with macroinvertebrates being defined as organisms lacking a backbone and visible to the naked eye (Birmingham *et al.,* 2005). They include insects larvae such as Dipterans (Simuliidae and Chironomidae), aquatic bugs (Hemiptera) among others. In most streams and rivers, the larval stages dominate the macroinvertebrate community (Rosenberg and Resh, 1993). Brittain and Eikeland (1988) identified the causes of drift as pollution, changes in food supply, dislodgement by current and predation. Furthermore, invertebrates have been known to enter the drift to avoid an unfavorable environmental conditions (Hall *et al.,* 1980), with catastrophic drift occuring when physico-chemical changes take place as a result of pollution (Wallace *et al.,* 1986).

Brittain and Eikeland (1988) reviewed four types of drift, namely catastrophic, behavioral, distributional and constant drifts. Of the four types of drifts, catastrophic drift is associated with strong bedload transport due to high discharge, while the others are regarded as means of survival in a dynamic ecosystem. According to Williams and Hynes (1976), invertebrate drift is a mechanism of recolonization of denuded areas, especially after spates and has extensively been studied over the decades by stream ecologists both in temperate (Wagner, 2001; James *et al.,* 2009) and tropical streams (Mathooko and Mavuti, 1994a; Dudgeon, 2006).

Macroinvertebrate drift in lotic ecosystems can be assessed on different scales in space and time (Karen *et al.,* 2002). Drift as it relates to time has received the most attention ranging from daily (Lancaster, 1992) to seasonal variations (Dudgeon, 1990; Rincón and Lobón-Cerviá, 1997). It can be studied in streams by placing nets of known mesh sizes for a certain duration of time. According to Svendsen *et al.* (2004) drift net mesh size is usually a compromise between clogging, filtration efficiency and later samples sorting time. In most situations to avoid clogging, a drift mesh size of around 440 μm has been used (Bishop and Hynes, 1969; Kovalak,

1978). Furthermore, modifications are often made to meet sampling challenges under differing field conditions ranging from large rivers to steep headwater streams.

Drifting organisms are derived from benthos and spend very little time in drift (Elliott, 2003). Drifting invertebrates have also been known to exhibit diel periodicity with nocturnal densities being higher than diurnal drift densities (Flecker, 1992; Mathooko and Mavuti, 1994b; M'Erimba, 2004). Faulkner and Copp (2001), in a study to provide a model for accurate drift estimation, reported that total taxa and abundance increases with length of sampling period. However, M'Erimba *et al.* (unpublished) observed that drift densities varied with exposure time duration in two tropical streams, using a drift sampler fitted with a 100 μm mesh size net. Maximum densities were obtained between 5 and 10 minutes of exposure. This study, however, was limited to one drift net mesh size.

Drift plays a key role spatial distribution of stream macrobenthos (Grzybkowska, 2000) in riffles and pools. Brussock and Brown (1991) identified riffles and pools as distinct habitats based primarily on depth, slope and flow even though their specific physical characteristics like substrate composition may vary even in the same stream reach (Angradi, 1996). According to Lewis (2012) aquatic organisms are affected by stream physical characteristics like channel width, depth and the distance between banks. Indeed, Leung *et al.* (2009), using a drift net mesh size of 250 μm, in a Husdon Creek, Canada, found consistently higher drift densities in riffles than in pools, glides and runs habitats. Furthermore, Hansen and Closs (2007), using a drift net mesh size of 400 μm, reported increased drift densities with regard to riffle area and length.

Aquatic water bodies are affected by human and natural activities in their catchments, which contribute to changes in macroinvertebrate abundance, species richness, diversities and distribution. Macroinvertebrate communities have been applied widely in biomonitoring of streams (Raburu *et al.*, 2009; Masese *et al.*, 2009, 2013) to assess the effects of anthropogenic stress in healthy water bodies (Harris and Silveira, 1999) and highly contribute to aquatic food webs. Similarly, drift has been applied in the assessment of impacts of anthropogenic induced disturbances in streams such as agricultural runoff (Olsen and Watzin, 2009), river impoundments (Tonkin and Death, 2013), insecticide pollution (Lugthart *et al.*, 1990) and sediment coring (Bretschko, 1990). The operational definition of a disturbed stream in this study is a stream disturbed by humans and animals on its banks and streambed on a daily basis.

In the Njoro River, studies have mainly concentrated on the factors influencing the structure and composition of benthic macroinvertebrates (Shivoga, 2001; Mbaka *et al.,* 2015) and their use as indicators of water quality (Makoba *et al.,* 2008; Makoba *et al*., 2010). The Njoro River is constantly disturbed on the streambed by anthropogenic activities. These activities are highly dependent on time of the day and season (Mathooko, 2001), peaking around midday and during the dry season and are known to influence drift in this river. This study offers an opportunity of studying macroinvertebrate drift in a physically disturbed stream, and relating its densities with drift net mesh size, exposure duration and positioning in the Njoro River. This study will also provide insights and opportunities in understanding drift dynamics in similar systems and its applicabilities and potentialities in stream ecology and management.

1.2 Statement of the problem

Majority of drift studies have focused on the behaviour of invertebrates during a 24-hour cycle (diel periodicity) by exposing nets of 250 μm mesh sizes in relatively undisturbed streams for 120 minutes to quantify natural drift. The applicability of drift as an index of measuring disturbances in streams is hampered by the fact that samples collected are too many to process, lack of adequate knowledge on where to place the nets, what type of net mesh size to be used and lack of information on the maximum time of drift net exposure. Thus, this study addresses these limitations by linking net exposure duration, sampling net mesh size and drift net position to macroinvertebrate drift community.

1.3 Objectives

1.3.1 General objective

This study aimed at establishing sampling time threshold using three commonly used nets in drift studies. It also envisaged to outline the differences in drift densities between two ecologically different biotopes

1.3.2 Specific objectives

1. To determine drift density, composition and diversity in riffle and pool biotopes in the Njoro River.
2. To evaluate the effect of varying drift net mesh size, sampling time and net positioning on macroinvertebrate drift densities in the two biotopes.
3. To determine the proportions of benthos in drift in the two biotopes.

1.4 Hypotheses

H_{01}: The mean drift densities between the riffle and pool biotopes are not statistically significant.

H_{02}: Variations of net mesh size, sampling time and drift net position do not significantly affect drift densities in the two biotopes.

H_{03}: There is no significant difference between the proportions of benthos drifting from the riffle and pool biotopes.

1.5 Justification

The Njoro River, being polluted from diffuse sources such as pesticide, insecticides, domestic wastes and sewage effluents, offers an excellent opportunity to study drift. The Njoro River watershed is a critical water source for Lake Nakuru, a large shallow saline lake designated as a Ramsar wetland site of international importance. Since pristine streams exhibit natural macroinvertebrate drift, this phenomenon can be used to measure the success of stream rehabilitation efforts as a component of biomonitoring which is usually less costly and more reliable in stream and watershed restoration and aquatic bioremediation programmes. Macroinvertebrates communities have been used in streams as bioindicators to assess the effects of anthropogenic stress. Drift besides being a daily occurrence phenomenon in streams and as a response by macroinvertebrates to external stimuli, is an important ecological phenomenon. It facilitates mass transport and later macroinvertebrate developmental stages and further recolonization of denuded areas. Drift biomass also acts as a source of food for fish. The study helps to establish critical exposure time (sampling time) since there is no standard exposure time established in streams with similar characteristics using a particular drift net mesh size. The results of this study offer an opportunity to explore the impact of human and animal disturbances in the river by quantifying the amount of drift (drift density) and quality of drift (drift composition), thus facilitating the formulation of an index of pollution and disturbance levels in Kenyan streams. The outcome of this research is crucial for restoration managers to have an informed opinion on the success of rehabilitation efforts in tropical streams that are physically disturbed.

CHAPTER TWO
LITERATURE REVIEW

2.1 The drift concept

The downstream drift of benthic invertebrates is a feature of running waters and has greatly been studied since 1920s (Needham, 1928) to date (Weber *et al.,* 2017). Brittain and Eikland (1988) reviewed four main types of drift. The first one is catastrophic drift, which is usually associated with flood conditions, during which the substrate is physically disturbed by high discharge. Drought, heated waters and pesticides can also lead to catastrophic drift (Waters, 1972). The second type is the behavioral drift usually attributed to different behavioral aspects. For example, animals may be dislodged from the substratum and enter the drift while foraging. They may actively enter the water column, for instance to escape from a predator (active drift). The third category is the distributional drift, which is envisaged as a method of dispersal, especially in the larval stages soon after hatching. A final category, constant drift (background drift), is where organisms drift in low numbers due to accidental dislodgement from the substrate irrespective of any diurnal periodicity. According to Brittain and Eikeland (1988), invertebrate drift is usually taxa specific, though catastrophic drift can affect any taxon.

Three drift patterns are known to occur in streams. The bigeminus drift pattern has a major peak early in the night and a minor peak just before dawn. The Alternans pattern which is a reversal of the bigeminus pattern, is rare (Mathooko and Mavuti, 1994b) and has been given less attention by stream ecologists. The bigeminus drift pattern has been reported widely both in the tropics (Mathooko and Mavuti, 1994b) and in temperate regions (Elliott, 1967). Amalgamated pattern is where a clear and definable pattern is not discernible (Mathooko and Mavuti, 1994b) and is common in fishless streams (Flecker, 1992). Diel peridiocity has confirmed that drift densities are nocturnally biased because nocturnal drift of macroinvertebrates is viewed as an escape adaptation to the optically oriented predators such as fish (Mathooko, 1996).

Research on invertebrate drift has largely focused on temporal patterns, effect of physico-chemical variables such as light intensity, water temperature, sediment, predators presence, life stage, disturbance and competition for resources (Brittain and Eikeland, 1988; Naman *et al.*, 2016; Béjar *et al.,* 2017; Weber *et al.,* 2017). However, invertebrate drift is also influenced by other factors such as drift sampler exposure time, mesh size of nets used during sampling and

section of stream habitat sampled (Slack *et al.,* 1991; Culp *et al.,* 1994; Leung *et al.,* 2009). In a review on drift of stream insects Waters (1972) emphasized that there is no distinct drift fauna but rather it is the benthic community that participates in drift due to many complex biotic and abiotic factors. In addition, this review emphasized that drift is quite variable in space and time both within and among stream systems. From habitats, most frequently encountered insect taxa that dominate drift composition include Ephemeroptera, Simuliidae, Plecoptera and Trichoptera (Bishop and Hynes, 1969; Brittain and Eikeland, 1988). However, Megaloptera, Diptera, Crustacea and Coleoptera may also contribute significantly to the drift (Benke *et al*., 1991).

2.2 Drift sampler mesh sizes and exposure time used to study drift

Studies of macroinvertebrate drift on tropical and temperate streams have used different sampling mesh sizes, Allan (1987), for example used 300 μm in Cement Creek stream (Colorado) while Collier and Wakelin (1992) used a 500 μm in Manganuiateao River (New Zealand). Ramírez and Pringle (2001) used 363 μm in Neotropical streams while M'Erimba (2004) used 100 μm in the Njoro and Ellegirini Rivers (Kenya). Others such as Mathooko (1996) 105 μm in the Naro Moru River (Kenya), Thornton (2008) 250 μm in Murrumbidgee River (Australia), and Romaniszyn *et al.* (2007) 1000 μm in an Appalachian Mountain stream (North America).

Waters (1969) compared different versions of his samplers and suggested that backwash could be eliminated by varying mesh size, sampling interval and size of net mouth, length and shape of the drift sampler. He further suggested that the drift sampler mesh aperture should also be as large as possible to prevent clogging, and still retain small invertebrates. Mundie (1964) commented that a mesh size of 1000 μm leads to samples being selective since the smallest adult insects would escape through the screen above the water. Bishop and Hynes (1969) used fixed nets of 560 μm mesh size for a 3 hours sampling period without the net clogging. This was supported by Kovalak (1978), who worked in a Club Stream in Michigan, using a drift net of 471 μm mesh size and observed that the net allowed sampling for a longer time without the net backwashing and clogging. Kennedy *et al*. (2014) working in Colorado River in Lees Ferry used a finer mesh of 250 μm to capture small invertebrates and to prevent backpressure and clogging associated with the smaller mesh size. A drift sampler mesh size of close to 100 μm is associated with clogging and backwash but has an advantage of capturing small sized invertebrates and has

high drift densities since it captures all invertebrates of all sizes. Slack *et al*. (1991), working in a USA mountain stream observed that there was a general pattern of an increase in abundance and number of taxa with decreasing drift mesh size.

Invertebrate drift is studied by exposing nets of known mesh sizes for a certain period of time. Generally, drift sampler net mesh size and exposure time depend on the size and density of organisms under study and the amount of suspended coarse sediment and organic materials (Muehlbauer *et al.,* 2017). However, drift sampler exposure times vary greatly between studies, ranging from a few minutes to hours, and the used drift samplers had varied net mesh sizes (Flecker, 1992; Kerby *et al.,* 1995; Kennedy *et al.,* 2014). Benke *et al.* (1986) sampled for 10 to 15 minutes using a 400 μm and recorded drift density ranges of 2-5 individuals/m^3. Kennedy *et al.* (2014), using a mesh size of 1000 μm, sampled for 5 minutes and found out that Chironomidae had the largest average drift concentrations of any taxon with a mean of 3.2 individuals/m^3, followed by *Potamopyrgus* with a mean of 2.3 individuals/m^3, *Simulium* with a mean of 0.30 individuals/m^3 and *Gammarus* were the lowest with a mean of 0.11 individuals/ m^3. This was also observed by Bruno *et al.* (2010) who sampled for 5 to 10 minutes using a 100 μm drift mesh size and found six most abundant taxa (comprising 95% of the total, that is, Chironomidae, Oligochaeta, Plecoptera, Baetidae, Psychodidae and Trichoptera) with a decreasing order of total abundance. Furthermore, Watson (1971) sampled for 24 hours using a drift mesh size of 1000 μm and found that Trichoptera component was by far the largest, constituting about 50% of any one sample followed by *Potamopyrgus* which formed about 25%, while the remaining 25% was composed of Ephemeroptera and Plecoptera. Kovalak (1978) sampled for 2 hours intervals over 10 hours period, using a drift mesh size of 471 μm and obtained high drift densities dominated by *Ephemerella* and *Simulium* in Club Stream in Michigan. In a review on drift sampling by Elliott, (1970), high diversity was associated with longer sampling duration of drift collections than shorter periods of net exposure.

2.3 Factors influencing macroinvertebrate drift

Factors influencing drift of macroinvertebrates can either be divided into biotic or abiotic factors. Abiotic factors as noted by Brittain and Eikeland (1988) can result in either active drift, which is initiated by the organism or passive (or accidental) drift, which can be as a result of a change in

the physical conditions of the stream. The overall importance of abiotic verses biotic factors in initiating drift depends on the type of strength of these cues.

2.3.1 Abiotic factors

Current discharge has been found to be positively correlated with stream drift (Cuffney and Wallace, 1989; Robinson *et al.,* 2004). Further, physical disturbances of the stream substrate, sedimentation, anchor ice, or pollution lead to catastrophic drift (Waters, 1972; Wallace *et al*., 1986). Similarly, diel periodicity is known to initiate and influence drift densities, with higher densities during the night than during the day (M'Erimba, 2004).

Seasonal patterns that lead to spring and summer in temperate regions have also been found to induce drift variations, with peaks of total drift in spring and summer (Schreiber, 1995). Other studies from temperate regions have shown similar patterns (Dudgeon, 1990; Moser and Minshall, 1996). In a seasonal tropical stream in Hong Kong, community level trends in drift were lacking, although some species had their highest drift rates during summer when productivity was highest (Dudgeon, 1990). Water temperature, which has not been shown to have any primary influence on stream drift, has been indicated as a factor that increases insect activity with its increase, thus enhancing the risk of accidental drift (Winterbottom *et al.,* 1997).

2.3.2 Biotic factors

Predation is one of the biotic factors that plays a prominent role in drift. A literature review of 22 studies by Wooster and Sih (1995) revealed that the presence of predatory invertebrates caused an increase in drift. Spatial distribution of benthic invertebrate populations is primarily by downstream drift through emigration from, and immigration into, habitat patches downstream (Minshall *et al.,* 1985; Matthaei *et al.,* 1997). Waters (1972) postulated that intraspecific competition within cohorts could result in drift when they reach older life cycle stages. Coupled with intraspecific competition is interspecific competition which is evidenced by a predatory stonefly (Perlidae) which enters drift as a result of interference competition for refugia both within and between species (Rader and McArthur, 1995). Peak drift levels recorded during the wet season in northern Australia appeared to be more closely associated with life cycles of the drifting taxa than with the disturbance caused by increased current velocities (Benson and Pearson, 1987). In Neotropical streams various larval stages of shrimp make up a majority of the drift (Pringle and Ramírez, 1998), but no adults were reported. Monthly drift samples for a

period of one year in a Minnesota stream found that Megaloptera and Ephemeroptera drift may have been mostly associated with pupation (Krueger and Cook, 1984). Drift responses to streamflow fluctuations in a Colorado study showed that, for several mayfly species with poor swimming ability and unfavorable hydrodynamic profiles, drift rates of larger age classes increased with increasing flow due to passive displacement. This was not as pronounced in smaller individuals (Poff *et al.*, 1991). Predicting which life cycle stage that is most prone to drift is very species specific (Svendsen *et al.*, 2004). However, Hershey *et al.* (1993) demonstrated using benthic density and drift samples that the entire *Baetis* population moves downstream during the arctic summer, which indicates that all life stages participate in drift. Finally, ecological interactions have an influence on drift densities, the continuous downstream movement could potentially depopulate the upper reaches long term, which would require upstream movement for recolonization as initially proposed by Müller (1954). On the contrary, opponents argue that downstream drift only represent excess production, which has no long-term effect on the population viability (Waters, 1972).

2.4 Stream biotopes effects on macroinvertebrate drift

Variations in channel morphology, discharge, catchment geology and sediment transport determine streambed structure and create distinct hydro-morphological units, such as pools and riffles within streams (Church, 1996). Johnston and Slaney (1996) defined pools as 0% gradient, deep habitats and low current velocity and riffles as 1–3% gradient, high current velocity, water surface broken by protruding substrata, and shallow habitats.

Drift abundances can be affected by habitat preferences more than changes in magnitude of high flows (Mochizuki *et al*., 2006). Small streams show striking gradients in depth, substrate and velocity among discrete habitat types such as pools, riffles, runs, and glides (Montgomery and Buffington, 1997) and thus drift abundance might differ between these habitat types (Peterson and Rabeni, 2001). Invertebrates using pool and riffle biotopes are subjected to different biotic conditions and hydraulic forces (Walters *et al.*, 2003) that can be expected to influence the dynamics of drift entry, transport, and exit. At one extreme, drift entry and transport may be highest in riffles, erosional habitats with greater turbulence and shear stress and often greater benthic densities (Scullion *et al.*, 1982; Grossman, 2014). Alternatively, drift entry and transport

would be expected to be low, while exit through settlement and predation would be high, in pools, which are low-velocity depositional habitats.

Drifting invertebrates once entrained in the water column, may be less likely to settle out in faster water relative to slow water (Bond *et al.*, 2000), hence invertebrate drift will accumulate along a riffle. Waters (1962) suggested that pools are the major sites of drift consumption hence the decrease of drift rates in the pools which was attributed to losses to deposition with subsequent mortalities, decomposition and fish predation. Hansen *et al.* (2007) observed that the total invertebrate drift density varied with respect to the downstream end of riffles whereby large, long riffles produced higher macroinvertebrates drift densities than small, short riffles downstream ends. Waters (1965) and Martin and Knight (1989) observed that drift concentration reduced at the downstream end of pools while Elliott (1971) and Kovalak, (1978) neither found change nor increased drift concentration below pools.

2.5 Ecological importance of drift

Macroinvertebrate drift is one of the important responses by which aquatic invertebrates persist through disturbances such as sediment transport and high flow conditions (Kobayashi *et al.*, 2010). It therefore plays a key role in spatial distribution of organic biomass in form of stream macrobenthos. It acts as a principal means of recolonizing different habitats of the streambed (Palmer *et al*., 1996) after a drought, heavy pollution or physical disturbance and of the colonization of substrata suspended in the water column. Drift is also an important ecological phenomenon for macroinvertebrates to avoid predation pressure (Mathooko, 1996) and as food source for drift feeding fish (Hayes *et al.*, 2000).

Drift is a part of colonization cycle that involves two unidirectional movements' patterns, upstream and downstream (Müller,1954). It is an important continuous mechanism for dispersal of macroinvertebrates downstream. At the head waters competition for resources result in active drift downstream causing a depletion of the headwaters populations and subsequent colonization in downstream reaches. Drift also helps in population regulation (Mochizuki *et al*., 2006) by reducing intra and inter-specific competition for resources among macroinvertebrate communities in aquatic ecosystems. The variations in drift densities with seasonal or diel periodicity can be vital in biomonitoring as signatures of either natural or anthropogenic perturbations in aquatic ecosystems (Pringle and Ramírez 1998).

2.6 Application of macroinvertebrate drift as an indicator of pollution

Macroinvertebrates are good indicators of environmental variation because of the ease of sample collection and taxa identification. This is also due to their relatively long life cycle, limited migration ability and different sensitivity to the different environment (Barbour *et al*., 1999). Presence of macroinvertebrates in any water bodies manifest the status of water quality and pollution level (Maybeck *et al.,* 1996). According to Carlisle *et al.* (2007) macroinvertebrate populations in streams and rivers can assist in the assessment of the overall health of the stream.

Macroinvertebrate drift can be applied as a measure of pollution in rivers and streams, since organisms respond to disturbance by entering into drift. In an experimental study in an Arizona stream, application of high concentrations of Antimycin A (a fungal antibiotic piscicide) caused detrimental effects on macroinvertebrate species composition, increasing mortality rates and reducing drift densities (Dinger and Marks, 2007). Both laboratory experiments and field monitoring have shown increases in macroinvertebrate drift in response to changes in the concentration of suspended sediments and the bed load transport rate (Imbert and Perry, 2000; Gibbins *et al.,* 2007; Molinos and Donohie, 2009). For example, increases in the drifting abundances of Ephemeroptera and Plecoptera coincided with increases in bed load yield of sediments rather than peaks in discharge or suspended sediment concentrations (Gomi *et al.,* 2010). In addition, the percentage of benthos in the drift was significantly higher from sediment-treated channels than from untreated channels (Suren and Jowett, 2001). However, responses of stream biota such as the abundance of macroinvertebrate drift to changes in specific physical conditions can be sensitive to the timing of sediment movement (Shaw and Richardson, 2001).

2.7 Synthesis of drift studies in streams

In the past half-century, most studies on stream drift have concentrated in the temperate regions though there are a few studies in tropical streams. One of the most studied properties of drift is its diel periodicity. Investigations in both tropical and temperate regions have shown that drift displays distinct diel/circadian patterns. Although mesh size effects on drift densities have been well documented for temperate regions, little is known about these effects in the tropical regions. Most drift studies have been done using mesh sizes of different apertures and at different exposure time in different streams. There is no consensus in drift densities between pools and riffles whereby some studies found there were reduced drift concentration at the downstream end

of pools while others found no change or even increased drift concentration below pools. No single study has been done on the effects of varying mesh size, exposure time and drift position in a single stream.

Drift studies in Kenya include studies on drift as natural source of food for the rainbow trout (Mathooko, 1996), factors influencing drift transport (Mathooko and Mavuti, 1994a) and diel dynamics of organic drift (Mathooko and Mavuti, 1994b). Drift studies in the Njoro River have been conducted on diel periodicity and anthropogenic disturbances (M'Erimba, 2004). Investigations of the effects of sampling time on drift in the Njoro River, which is highly disturbed, and Kamweti River, a semi-pristine river, have also been carried out (M'Erimba *et al.*, unpublished). Thus, the proposed study will be filling the gap on the relationship between stream biotope, drift net position, exposure time and drift mesh size on macroinvertebrate drift.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study area and study site

3.1.1 Study Area

The study was carried for a period of three months from January to March 2017 in the mid reaches of the Njoro River (Fig. 1). The watershed is estimated to be approximately 250 km^2 (Osano, 2015) with a human population of more than 300,000 (Lelo *et al.,* 2005). The river's origin is traced at Olokurto Division, Entiyani Location in Entiyani Sub-location Narok North District at an altitude of 2887 metres above sea level (m.a.s.l.) (S 00° 34.588″, E 035° 54.684″). The river passes through large farms of wheat in the Maasai land before entering the Logman forest. Its main tributary is Little Shuru that joins the main channel at Beestons (border of Egerton University and Beestons) at an altitude of 2293 m.a.s.l. The length is estimated to be 50 km^2 (Mathooko, 2001) and the dominant vegetation types along the length being montane *Juniperus procera-Olea europaea* spp. *africana* and sub-montane *Acacia abyssinica* forest form the riparian vegetation of the Njoro River (Mathooko and Kariuki, 2000). The river discharges into Lake Nakuru at an altitude of 1750 m.a.s.l. Generally, rainfall patterns in the Njoro River catchment display a characteristic bimodal distribution, with much of the rain falling in April and August. Dry periods normally occur between December and March, while wet seasons occur between April and November (Shivoga, 2001; M'Erimba *et al.,* 2014).

3.1.2 Description of study site

This study was conducted in the middle reaches of the Njoro River bordering Egerton University and the Njokerio settlement. The study site selection was based on ease of accessibility and presence of biotopes (riffle and pool). The selected reach was 100 m long and with an average width of 3.5 m and depth of 0.56 m. The reach was characterized by an alternation of riffle (Plate 1) and pool (Plate 2) biotopes.

Physical anthropogenic activities were low at this reach with the exception of small scale farming on the right bank. The riffle was 28 m in length by 5.5 m in width straddling between latitude 00°22′ 30.7″ S and longitude 035°56′ 02.7″ E at an elevation of 2263 m above sea level (m.a.s.l). The pool measured 22 m in length and 5.5 m in width and straddled between latitude 00°22′ 31.2″S and longitude 035°56′ 02.7″ E at an elevation of 2234 m.a.s.l.

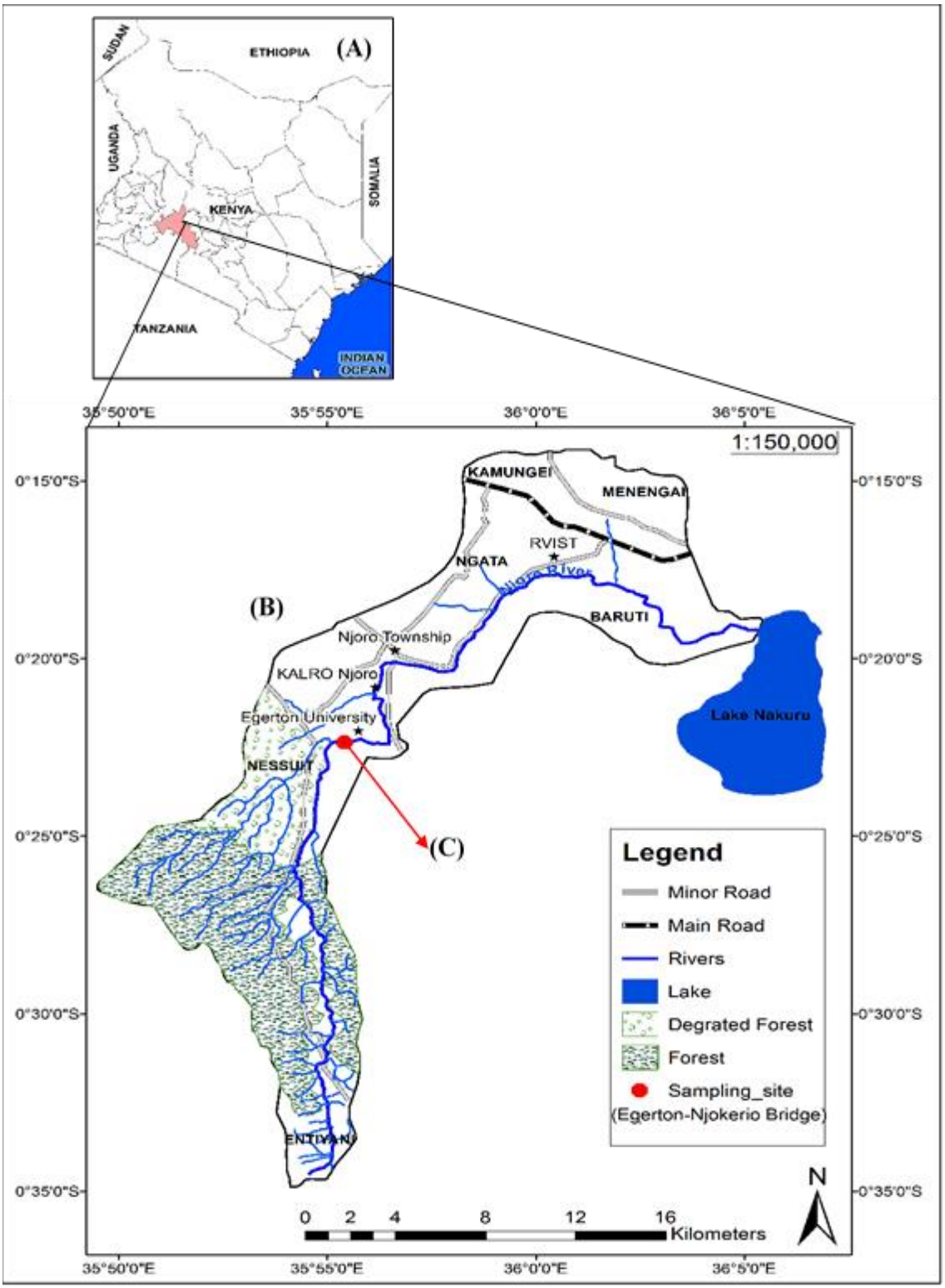

Figure 1: Location of the Njoro River in Kenya (A), the Njoro River from the source to the mouth (B) and the reach (C). (Source: Redrawn from the Survey of Kenya maps, sheet; No.118/4, 119/3 and 132/14).

The dominant riparian vegetations around the study reach was *Syzygium cordatum* spp., *Euclea* spp., *Juniperus procera-Olea europaea* spp. and *Maytenus senegalensis* spp. The riffle had 70% canopy cover and the stream bed was composed of 90% bedrock, 5% boulders and 5% sand and silt sediments. The pool had 40% canopy cover and the stream bed was composed of 30% boulders, 10% cobbles, 10% pebbles, 40% sand and 10% of gravel.

Plate 1: The riffle biotope in the Njoro River showing the drift nets facing upstream (Source: Photograph by the Author 23/01/2017).

Plate 2: The pool biotope in the Njoro River showing the drift nets facing upstream (Source: Photograph by the Author 22/02/2017).

3.2 Study design

The study design adopted was purposive systematic random sampling where the drift samplers were placed at the right bank, mid-stream and left bank in a riffle and pool biotopes during the first day of sampling and then randomly interchanged during subsequent sampling days and occasions.

3.2.1 Determination of selected physico-chemical variables in the biotopes

Site characterization was conducted during each sampling occasion within the sampling reach which involved assessment of both in-stream and riparian conditions as described by Barbour *et*

al. (1999). Selected physico-chemical parameters were determined *in-situ* (APHA, 2005) during each sampling occasion for a period of three months (January to March 2017). Each time, five readings of water temperature, pH, dissolved oxygen (DO), turbidity and electrical conductivity (EC) were taken. The EC, pH and temperature were measured using the HACH HQ 40d. Turbidity was measured using the HACH HQ 11d while the HACH HQ 30d was used to measure dissolved oxygen (DO) concentrations in the river water. Mean water velocity was measured at 60% of the total water depth with a Vale port flow meter model 0012/B (Richard and Gary, 2007).

3.2.2 Drift Sampling and sample processing

Drift samples were collected during the daytime between 1000 hrs and 1600 hrs in order to capture constant drift. Six drift samplers of various mesh sizes were used in this study. They consisted of a rectangular inflow section measuring 65 x 10 x 30 cm mounted in an upright position on a base plate, fixable to the river bottom and allowing numerous drift measurements in the same position (see plate 1 and 2). They were coded as follows: drift sampler 1 with a 100 µm mesh size DR1 (100 µm), DR2 (250 µm), DR3 (500 µm), DR4 (100 µm), DR5 (250 µm) and DR6 (500 µm). The first set of samplers consisting of DR1 to DR3 were placed in a riffle biotope while the second set (DR4 – DR6) were placed in a pool biotope during the first day of sampling as indicated in Figure 2. The distance between the two sets of drift samplers was maintained at 50 m to avoid inducing drift during sampling. In order to assess whether drift sampler position had any effect on drift densities, the samplers were purposively placed at the right, middle and left banks in both biotopes as indicated in Figure 3. Discharge passing through the drift samplers was determined by measuring velocity at the mouth of each sampler and multiplying the readings by the wetted area of the sampler. On day two (2) and three (3), the position of drift samplers was interchanged to accord each sampler an equal chance of being in the middle, right or left banks (see Figure 3 for details). Exposure time was set at intervals of 5, 10, 15, 20, 25 and 120 minutes based on (M'Erimba, 2004 ; M'Erimba, *et al.,* unpublished), and other scientists who have sampled at different times (Collier and Wakelin, 1992 ; Thornton, 2008 ; Kennedy *et al.,* 2014 ; Evan *et al.,* 2016).

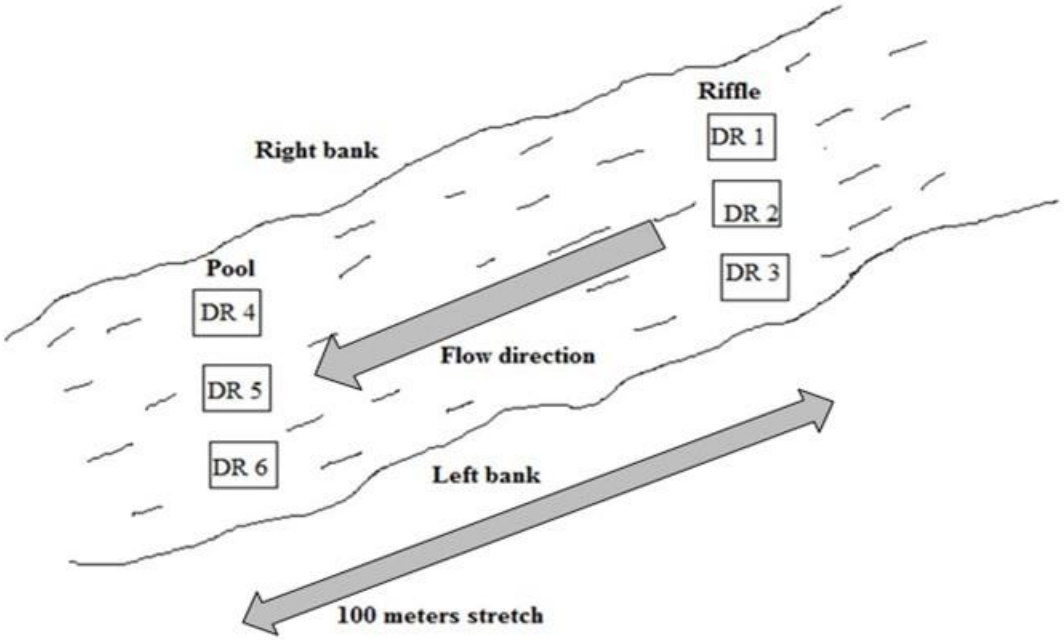

Figure 2 : Generalized schematic setup of drift samplers in the river; DR 1 = Drift sampler 1 (100 µm), DR 2 = Drift sampler 2 (250 µm), DR 3= Drift sampler 3 (500 µm), DR 4 = Drift sampler 4 (100 µm), DR 5 = Drift sampler 5 (250 µm) and DR 6= Drift sampler 6 (500 µm).

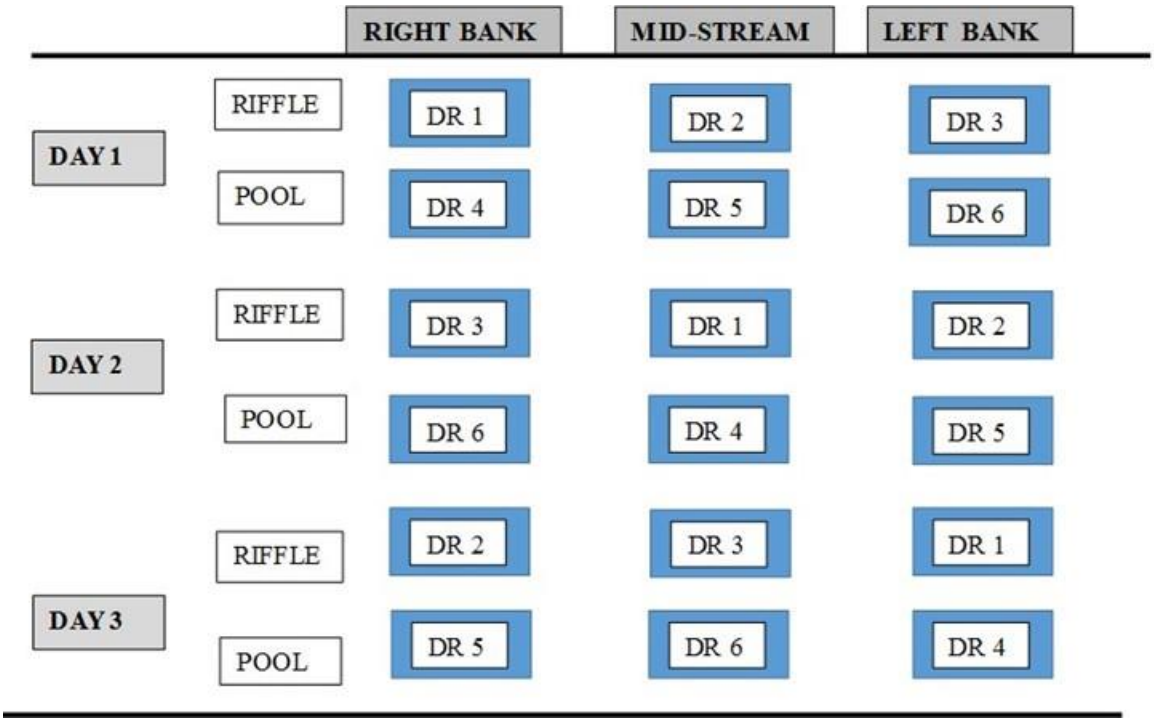

Figure 3: Systematic experimental setup of drift samplers of varying mesh size in riffle and pool biotopes during each sampling occasions.

All the drift samplers were simultaneously exposed on the stream bed on 23rd January 2017 in both biotopes (Table 1). Drift samples collected in the samplers' cup at the rear of the net were emptied in well labelled polythene bags and fixed with 4% formalin. Samples were taken to the laboratory at the end of each sampling occasion, and washed through a series of sieves to remove formalin and debris. The invertebrates were sorted under a dissecting microscope at × 400 magnification, enumerated and then identified to the lowest taxonomic level possible using keys by Gerber and Gabriel (2002). The total number of drift samples collected by the end of the experiment were 756, (Six drift samplers x 6 time intervals = 36 samples; 36 samples x 3 days = 108 samples and 108 samples x 7 sampling occasions = 756 drift samples, Table 1).

Table 1: Systematic experimental setup of drift samplers of varying mesh size in riffle and pool biotopes at different sampling dates.

Sampling occasion	Days	Sampling dates	Right bank	Mid-stream	Left bank
1	**Day 1**	23/01/2017	100 µm	250 µm	500 µm
	Day 2	24/01/2017	500 µm	100 µm	250 µm
	Day 3	25/01/2017	250 µm	500 µm	100 µm
2	**Day 1**	30/01/2017	100 µm	250 µm	500 µm
	Day 2	31/01/2017	500 µm	100 µm	250 µm
	Day 3	01/02/2017	250 µm	500 µm	100 µm
3	**Day 1**	06/02/2017	100 µm	250 µm	500 µm
	Day 2	07/02/2017	500 µm	100 µm	250 µm
	Day 3	08/02/2017	250 µm	500 µm	100 µm
4	**Day 1**	13/02/2017	100 µm	250 µm	500 µm
	Day 2	14/02/2017	500 µm	100 µm	250 µm
	Day 3	15/02/2017	250 µm	500 µm	100 µm
5	**Day 1**	20/02/2017	100 µm	250 µm	500 µm
	Day 2	21/02/2017	500 µm	100 µm	250 µm
	Day 3	22/02/2017	250 µm	500 µm	100 µm
6	**Day 1**	27/02/2017	100 µm	250 µm	500 µm
	Day 2	28/02/2017	500 µm	100 µm	250 µm
	Day 3	01/03/2017	250 µm	500 µm	100 µm
7	**Day 1**	06/03/2017	100 µm	250 µm	500 µm
	Day 2	07/03/2017	500 µm	100 µm	250 µm
	Day 3	08/03/2017	250 µm	500 µm	100 µm

3.2.3 Collection of benthic macroinvertebrates

Five random benthic samples for quantifying macroinvertebrates abundance and diversity as well as proportion of benthos in drift were collected from the two biotopes during each sampling occasion. All samples were collected quantitatively using a modified Hess sampler with an effective sampling area of 0.029 m^2 and mesh size 100 μm. The Hess sampler was placed randomly facing upstream and all sediments enclosed within the working area disturbed by hand for 30 seconds. The Hess sampler was carefully retrieved and all the samples obtained emptied into well-labelled polythene bags, fixed with 4% formalin and taken to the laboratory. At the laboratory, the samples were washed under tap water through a series of mesh sieves (1000, 500 and 100 μm) to remove debris, stones and formalin (Barbour *et al.*, 1999). Benthic macroinvertebrates samples were sorted, enumerated and identified to the lowest taxonomic level possible. This process was repeated for three consecutive days over seven (7) sampling occasions giving a total of 210 benthic samples. The data obtained was used for computation of proportion of benthos in the drift.

3.2.4 Determination of drift densities and proportions of benthos in the drift

Drift densities were determined as outlined by Leung *et al.* (2009) by first determining the amount of filtered water (Q, m^3s^{-1}) which was obtained by multiplying water depth (m), breadth (m) of sampler and the mean velocity (m s^{-1}). To determine drift densities (individuals per m^3) individual counts were divided by the throughflow.

The percentage proportions (P %) of the benthos in the drift were determined according to Elliott (1967) as follows (eqn 1):

$$P = (x\mathrm{D}.100)/(X - x\mathrm{D}) , \qquad \textbf{Equation 1}$$

where,

x = drift density (individuals per m^3),

D = average depth in metres (m), and

X = mean benthos density (individuals per m^2).

The percentages obtained in these calculations indicated the relative importance of benthos as an ecological driver of the structure of macroinvertebrate drift.

3.2.5 Determination of diversity and similarity indices

Shannon-Wiener diversity index (H′) (Shannon Wiener, 1963) and Jaccard coefficient (J) (Jaccard, 1908) were used to determine and compare diversity of invertebrates in drift and in benthos in both biotopes using Equation 2 and 3, respectively.

$$H' = -\Sigma(log_2 P_i) \quad P_i = \frac{ni}{N} \qquad \textbf{Equation 2}$$

where,

H′ = Shannon-Wiener diversity index,

P_i = relative abundance of each species,

n_i = number of individuals in each species, and

N= total number of all individuals.

Similarity in species abundance in the riffle and pool biotopes:

$$J = \frac{C}{A+B-C} \qquad \textbf{Equation 3}$$

where,

A = number of species in biotope 1,

B = number of species in biotope 2, and

C = number of species common in both biotopes

Shannon's Equitability index (E^H) was used to measure the evenness with which individuals of the biotopes community were divided among the taxa present as described by Shannon Wiener (1963) using Equation 4.

$$E^H = H'/Hmax \quad \text{where } Hmax = lnS \quad \text{hence } H'/lnS \qquad \textbf{Equation 4}$$

where; H′ = Shannon-Wiener diversity index and S = species richness (No. of species).

3.3 Data analysis

All statistical analysis were carried out using SPSS Statistical Software version 22. The data was tested for homogeneity of variance before the application of parametric tests. Any data that failed the test was log_{10} (x +1) transformed. Student's t-test was used to test for any significant differences in physico-chemical parameters between the riffle and pool biotopes, and also to test

the differences in mean abundance of drifting macroinvertebrates in the two biotopes at $p = 0.05$. It was also used to compare means of macroinvertebrates benthos densities between riffle and pool. One-way ANOVA was used to compare means of drift densities among the nets, time and position in each biotope. The same test was also performed to test the difference in mean proportions of benthos in drift per mesh size in the two biotopes. Two-way ANOVA was used to test interaction between drift mesh size and exposure time at each biotope. The same test was used to test any interactions between drift mesh size and net positions at the two biotopes. Interactions among exposure time, drift net position and mesh size on drift densities in the two biotopes was tested using the three-way ANOVA (Zar, 1999). Tukey's honestly significance difference (HSD, $\alpha = 0.05$) was applied for multiple mean comparisons for significant F-values.

Regression equations were applied to establish the time at which all the nets clogged in both biotopes as well as to predict drift densities after every half an hour intervals. Pearson Correlation analysis was conducted in order to find the relationship between the physico-chemical variables and drift densities in both biotopes. Principle component analysis (PCA) was conducted to determine related factor complexes from standardized data (correlation coefficients matrix) of the physico-chemical variables and drift densities in both biotopes. Significant associations were confirmed at 5% and 1% significance levels using Pearson correlation test.

CHAPTER FOUR

RESULTS

4.1 Physico-chemical variables in the riffle and pool biotopes

The mean (bolded) and range values (bracketed) of the selected physico-chemical variables in riffle and pool biotopes in the Njoro River are presented in Table 2. The lowest temperature recorded in both biotopes was 14 °C whilst the highest was 18.70 °C. Conductivity ranged between 146.40-295.00 µs cm^{-1} and dissolved oxygen mean was 7.8 mg l^{-1} in both biotopes. Most of the physico-chemical variables measured did not differ significantly between the two biotopes ($p > 0.05$) except discharge, velocity and water depth ($p < 0.001$). Discharge and velocity were significantly higher in the riffle than in the pool whilst water depth was significantly higher in the pool than in the riffle biotope.

Table 2: Physico-chemical variables in riffle and pool biotopes in the Njoro River. Bolded figures are means ± SE, n = 27. Range values are in parenthesis. p values: * = 0.05, ** = 0.01, *** = 0.001, n.s = not significant.

	Stream biotopes		
Stream variables	**Riffle**	**Pool**	**t-value**
Temperature (°C)	**15.72** ± 0.32 (13.86-18.70)	**15.62** ± 0.31 (13.88-18.28)	**0.214** n.s
Conductivity (µs cm^{-1})	**202.35** ± 17.43 (146.40-295.00)	**202.40** ± 17.56 (146.82-294.75)	**0.004** n.s
Dissolved oxygen (mg l^{-1})	**7.79** ± 0.12 (7.04-8.92)	**7.76** ± 0.06 (7.24-8.01)	**0.164** n.s
% Oxygen saturation	**92.24** ± 1.62 (80.00-103.80)	**92.72** ± 1.60 (82.00-104.22)	**0.220** n.s
pH	(7.54-9.24)	(7.64-9.36)	
Turbidity (NTU)	**20.72** ± 0.65 (17.60-25.92)	**20.26** ± 0.72 (17.72-25.78)	**0.521** n.s
Discharge (m^3 s^{-1})	**0.36** ± 0.04 (0.12-1.05)	**0.09** ± 0.01 (0.06-0.18)	**7.463*****
Velocity (m s^{-1})	**0.75** ± 0.05 (0.31-1.31)	**0.33** ± 0.05 (0.20-1.09)	**6.998*****
Water depth (m)	**0.08** ± 0.01 (0.01-0.17)	**0.31** ± 0.01 (0.10-0.49)	**14.611*****

4.2 Drift net throughflow in the riffle and pool biotopes

The amount of water filtered through the three drift nets differed significantly at the riffle (One-way ANOVA, $F_{(2,375)} = 3.141$, $p < 0.05$) and pool biotope (One-way ANOVA, $F_{(2,375)} = 5.787$, $p < 0.05$) as presented in Figure 4. *Post hoc* Tukey contrasts indicated that there was no significant difference in throughflow between the 100 µm, 250 µm and the 500 µm nets in the riffle biotope. In the pool biotope, the Tukey contrasts indicated that there was a significant difference between the 500 µm and 100 µm, 250 µm and 100 µm ($p < 0.05$), and in contrast the 250 µm net did not differ significantly with the 100 µm net ($p > 0.05$). The difference in the filtered water by the 100 µm and 250 µm nets between the two biotopes was not significant (t = 0.343, d.f = 250, $p > 0.05$) and (t = - 0.136, d.f = 250, $p > 0.05$), respectively. However, there was a significant difference in the water filtered through the 500 µm in the two biotopes (t = - 2.670, d.f = 250, $p < 0.05$) where the net placed in the riffle filtered less water.

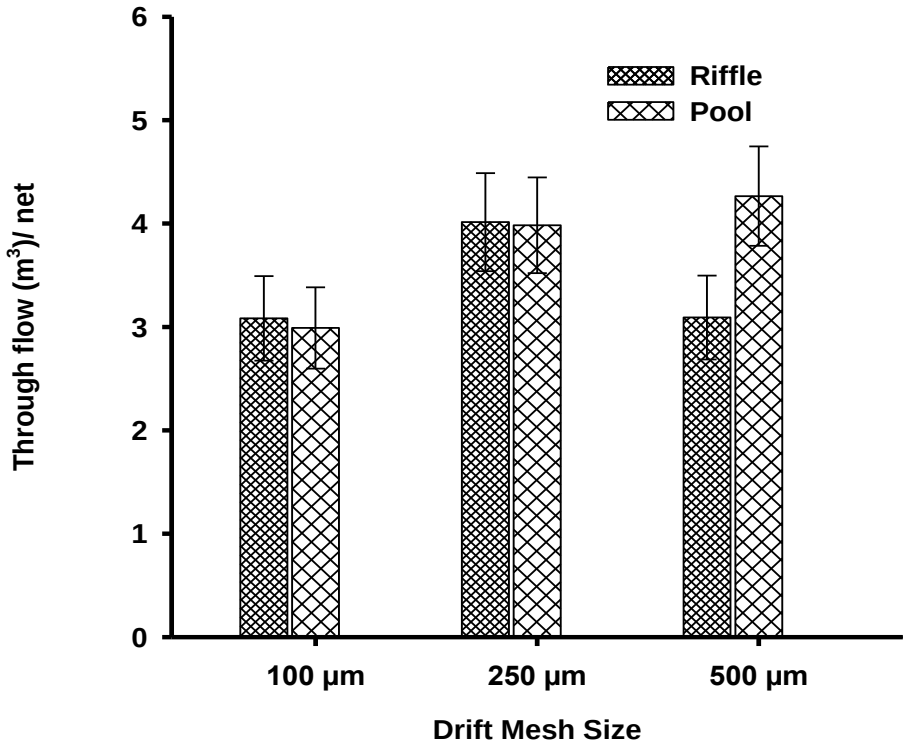

Figure 4: Amount of water filtered by the three nets during the course of the experiment in the two biotopes. Vertical bars are ± SE, n=756.

The throughflow in riffle biotope was apparently high in the left bank compared to the mid-stream and right bank, while in the pool biotope the flow was relatively uniform in all the positions (Figure 5). In the riffle the three nets filtered more than 4 $m^3$of water in the left bank than when placed at the mid and right banks. There was no significant difference among the three net positions in the riffle using the 100 µm net (One-way ANOVA, $F_{(2,123)} = 0.764$, $p > 0.05$) and 500 µm net (One-way ANOVA, $F_{(2,123)} = 1.481$, $p > 0.05$). In contrast, the 250 µm net returned a significant difference among the three net positions (One-way ANOVA, $F_{(2,123)} = 4.918$, $p < 0.05$). In the pool biotope, the three net positions did not have any significant difference in the amount of water filtered by the 100 µm (One-way ANOVA, $F_{(2,123)} = 0.761$, $p > 0.05$), 250 µm (One-way ANOVA, $F_{(2,123)} = 0.411$, $p > 0.05$) and 500 µm nets (One-way ANOVA, $F_{(2,123)} = 0.758$, $p > 0.05$).The amount of water filtered by the three nets was more than 4 m^3 at each position as presented in Figure 5.

When the amount of water filtered was considered against net exposure duration, there was an expected throughflow proportional trend (Figure 6). For instance, the 120 minutes exposure time translated to more water filtered in both biotopes. The 5 minutes exposure time recorded discharge of less than 1 m^3 in all the nets in both biotopes. There was a highly significant difference in the amount of water filtered during the 5, 10, 15, 20, 25 and 120 minutes exposure durations in the riffle and pool biotopes ($p < 0.001$).

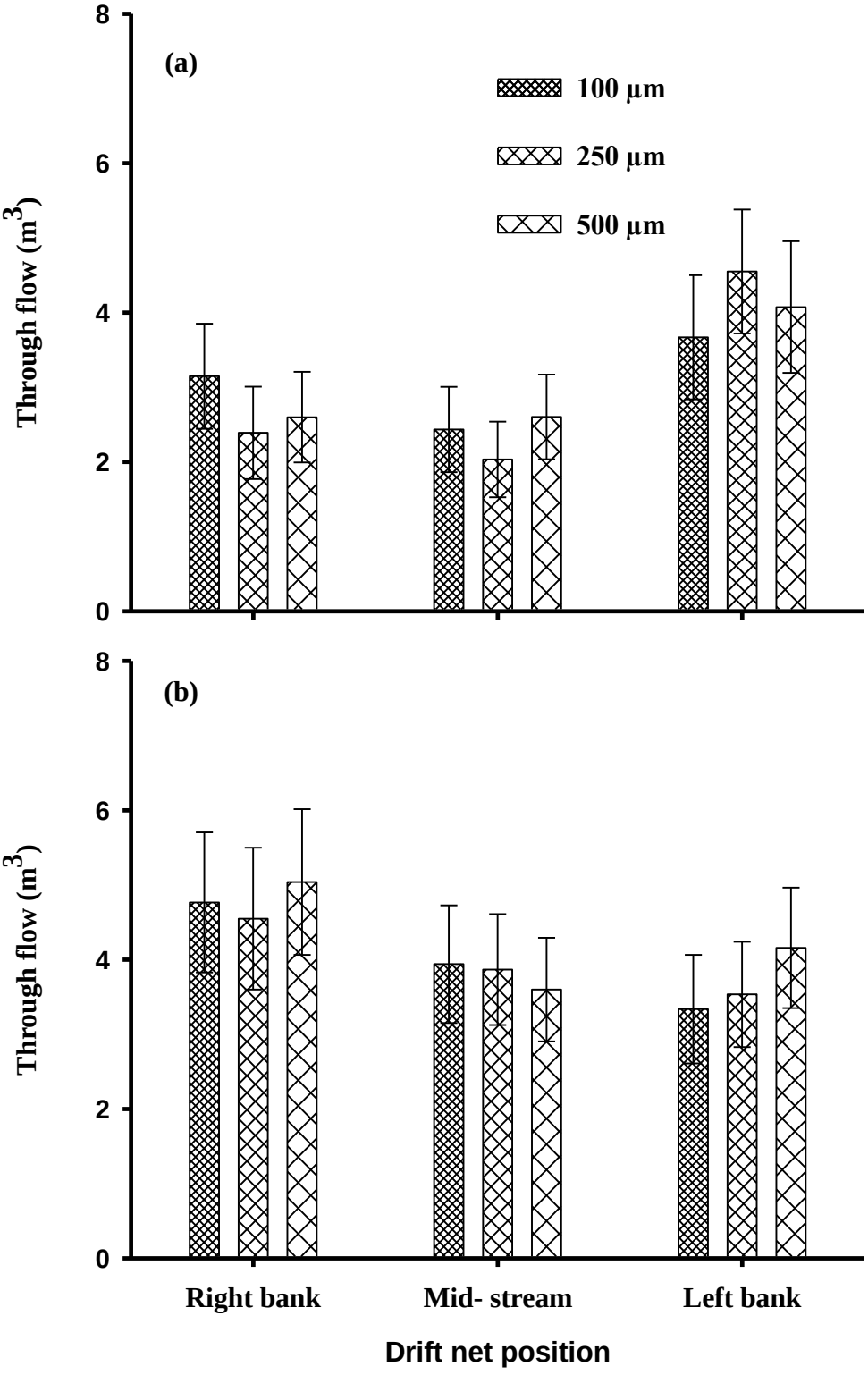

Figure 5: Amount of water filtered at different positions in (a) riffle and (b) pool biotopes in the Njoro River (pooled data). Vertical bars are ± SE, n= 756.

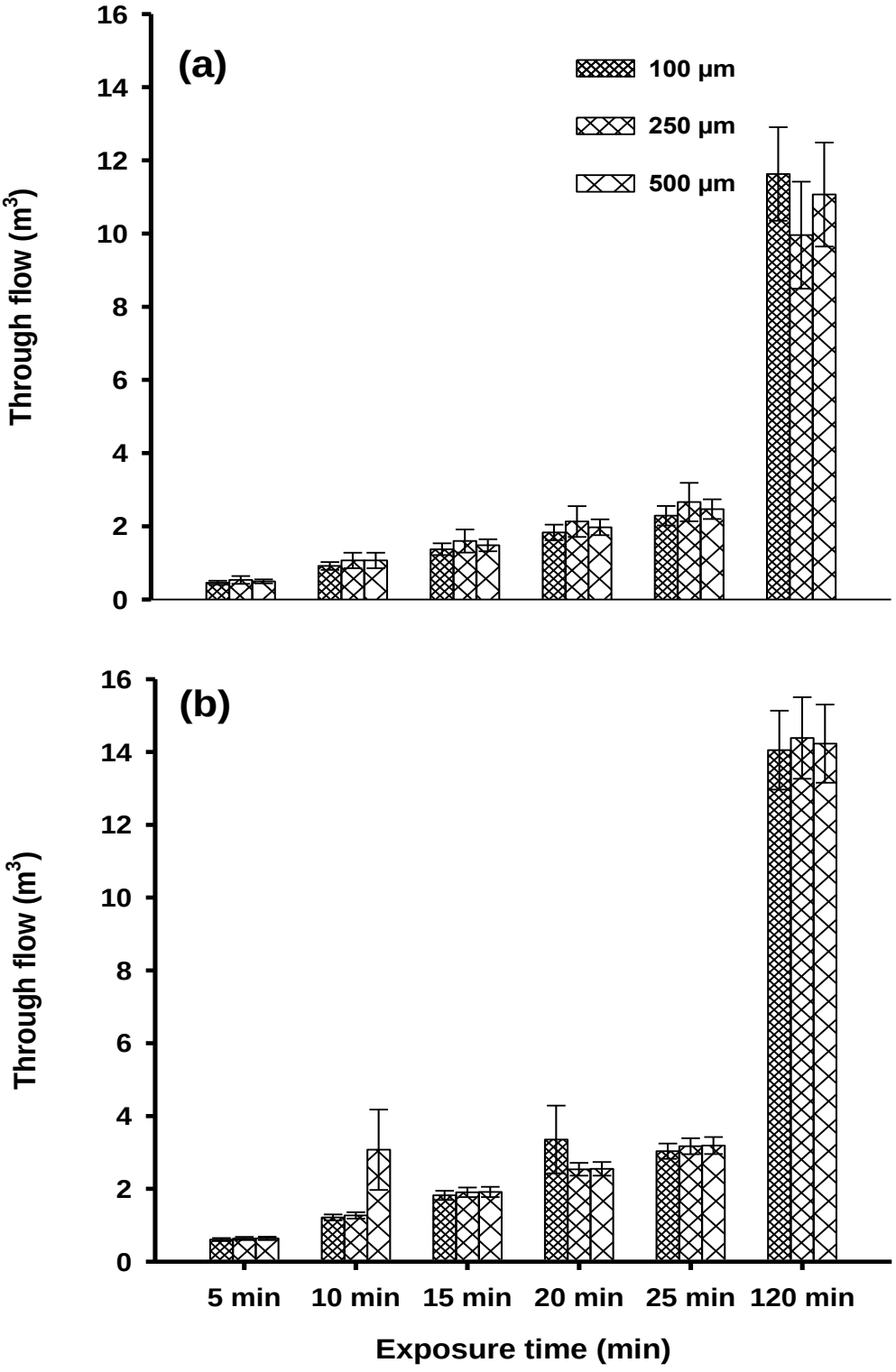

Figure 6: Amount of water filtered at different drift net exposure durations in (a) riffle and (b) pool biotopes in the Njoro River (pooled data).Vertical bars are ± SE, n= 756.

4.3 Drift of macroinvertebrates

4.3.1 Drift composition, diversity similarity index and evenness between riffle and pool biotopes

A total of 26 taxa were collected in the pool and riffle biotopes using 100 µm, 250 µm and 500 µm nets out of which 42% were captured by the three nets across the biotopes (Table 3). Aeshnidae was captured by the 100 µm and 500 µm nets in both the riffle and pool biotopes. Dixidae appeared once in the 250 µm net in the riffle biotope while Gyrinidae was captured in the 250 µm and 500 µm in the pool biotope. Hydrachnellae appeared once in the riffle in the 100 µm and 250 µm nets. Libellulidae, Sphaeriidae and Veliidae were captured only once in the 500 µm nets in the riffle biotope.

Table 3: Occurrence list of macroinvertebrate taxa collected from drift in a riffle and pool biotope in the Njoro River. (+) Taxon present, (-) Taxon not observed.

	Riffle			Pool		
Taxa	**100 µm**	**250 µm**	**500 µm**	**100 µm**	**250 µm**	**500 µm**
Aeshnidae	+	-	+	+	-	+
Baetidae	+	+	+	+	+	+
Caenagrionidae	+	+	+	+	+	+
Caenidae	+	+	+	+	+	+
Ceratopogonidae	+	+	+	+	+	+
Chironomidae	+	+	+	+	+	+
Culicidae	+	+	+	+	+	+
Dixidae	-	+	-	-	-	-
Elmidae	+	+	+	+	+	+
Gyrinidae	-	-	-	-	+	+
Helodidae	+	+	-	+	+	+
Heptageniidae	+	+	+	+	+	+
Hydrachnellae	+	+	-	-	-	-
Hydraenidae	-	-	-	-	+	-
Hydrophilidae	-	-	-	+	-	+
Hydropsychidae	+	+	+	+	+	+
Leptoceridae	+	-	+	+	+	+
Libellulidae	-	-	+	-	-	-
Muscidae	+	+	+	-	+	-
Oligochaeta	-	+	+	+	-	+
Psychodidae	-	+	-	-	-	+
Pyralidae	+	+	+	+	+	+
Simuliidae	+	+	+	+	+	+
Sphaeriidae	-	-	+	-	-	-
Tipulidae	-	+	-	-	+	-
Veliidae	-	-	+	-	-	-
Total	**16**	**18**	**18**	**16**	**17**	**18**

The diversity index (H′) of drifting macroinvertebrates in the riffle biotope was 1.77 while in the pool was 1.65, implying a higher diversity in the riffle compared to the pool biotope. The Jaccard index indicated 86% taxonomic similarity between the riffle and pool biotopes. The macroinvertebrates in drift in the riffle biotope were 54.42 % evenly distributed while in the pool evenness was 50.64 %.

Table 4 depicts the major taxonomic groups that were caught in the three nets during the entire sampling period. In the riffle, the 100 µm net caught 37.7% of the total macroinvertebrate in drift, while the 250 µm caught 37.1% of the total drifting individuals. The 500 µm net captured the least. In the same biotope, Chironomidae and Simuliidae dominated in the 100 µm net while in the 250 µm net, Chironomidae dominated with 15.3% followed by Baetidae comprising 13%. Simuliidae dominated in the 500 µm net at 13%. In the pool habitat, the 100 µm net captured 47.4% of the total macroinvertebrates that drifted, followed by 250 µm at 32% and finally the 500 µm net at 21%. Chironomidae dominated the other taxa at 24% in the 100 µm net, while Baetidae (12%) dominated in the 250 µm net and also the 500 µm at 9.5%.

Table 4: Relative abundance of the major macroinvertebrate groups caught by the three nets in each biotope. Chiron-Chironomidae, Baet-Baetidae, Simul-Simuliidae, Caen-Caenidae.

		Taxonomic groups					
Biotope	**Mesh size**	**Chiron.**	**Baet.**	**Simul.**	**Caen.**	**Others**	**Total (%)**
Riffle	**100 µm**	11.89	7.07	11.92	4.75	2.10	37.7
	250 µm	15.28	12.64	2.76	2.89	3.54	37.11
	500 µm	4.68	4.19	12.64	1.52	2.12	25.15
			Total				**100**
Pool	**100 µm**	23.67	12.12	5.20	3.12	3.25	47.36
	250 µm	11.26	12.03	3.19	3.57	1.97	32.02
	500 µm	4.62	9.46	1.65	3.06	1.83	20.62
			Total				**100**

4.3.2 Effect of varying mesh size on drift densities in the riffle and pool biotopes

The mean drift densities (pooled data) collected in the riffle and pool were 38.79 ± 5.15 individuals m^{-3} and 20.73 ± 0.10 individuals m^{-3}, respectively. The two values differed significantly ($t = 2.821$, $d.f = 754$, $p < 0.05$). The mean drift densities collected by the three nets (100 µm, 250 µm and 500 µm) are presented in Figure 7. The highest mean invertebrate drift density at the riffle was recorded in the 100 µm drift net, followed by the 250 µm net and the lowest densities were obtained using the 500 µm net. The difference in the mean drift densities among the three nets in the riffle was very highly significant (One-way ANOVA, $F_{(2,375)} = 26.75$, $p < 0.001$). Drift densities obtained from the 500 µm drift net were significantly lower than in 250 µm and 100 µm (Tukey's HSD test, $\alpha = 0.05$) whilst the densities in 250 µm and 100 µm nets did not differ ($p > 0.05$). The highest mean invertebrate drift density in the pool was recorded in the 100 µm drift net, with the least densities obtained in the 500 µm net. Drift densities differed significantly among the three nets in the pool habitat (One-way ANOVA, $F_{(2, 375)} = 30.36$, $p < 0.001$), with the 100 µm net having the highest drift density (Tukey's HSD test, $\alpha = 0.05$).

Drift densities of the major taxonomic groups is presented in Table 5. Among the taxa collected in the riffle biotope, simuliids contributed the highest drift densities in the 100 µm and 500 µm drift net while chironomids had the highest density in the 250 µm net. In the pool biotope, simuliids formed the highest drift densities in the 250 µm and 500 µm drift nets while chironomids formed the highest density in the 100 µm net. There was a highly significant difference ($p < 0.001$) among the four dominant taxa collected using the 100 µm, 250 µm and 500 µm mesh sizes in both biotopes.

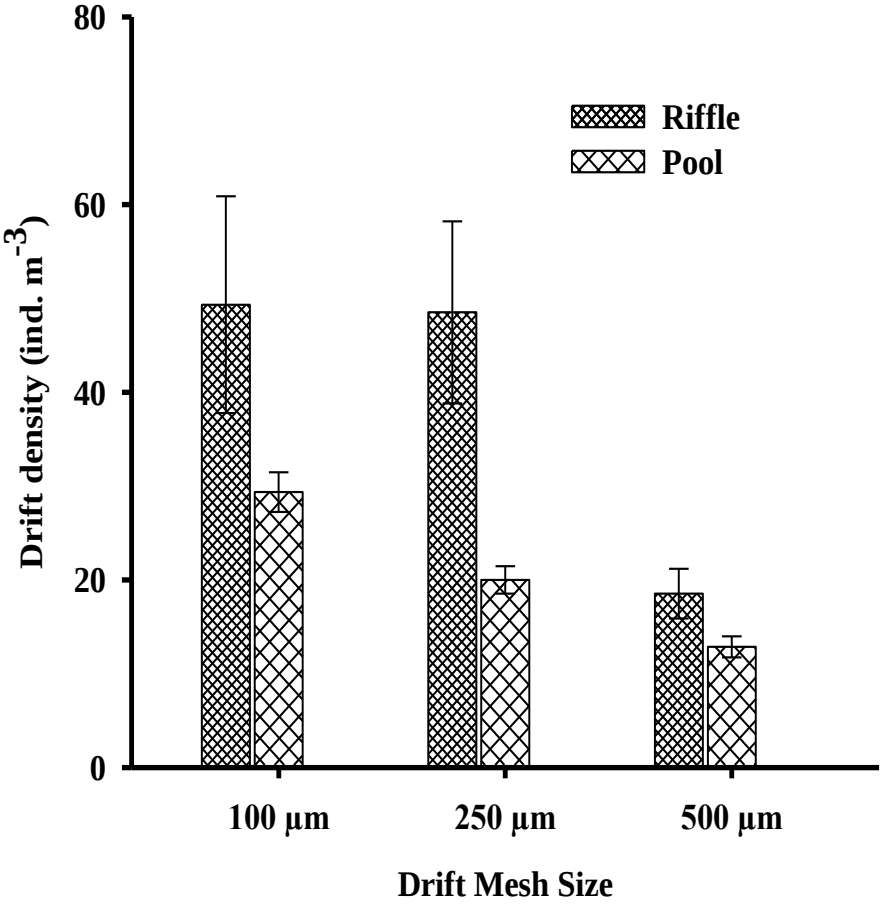

Figure 7: Mean drift densities in a riffle and pool biotopes using different drift net mesh sizes in the Njoro River. Vertical bars are ± SE, n = 756.

Table 5: Drift densities (ind.m^{-3}) of the dominant macroinvertebrate groups in the Njoro River biotopes. Bolded values are means, bracketed values are ± SE, n = 756; p values: * = 0.05, ** = 0.01, *** = 0.001, n.s = not significant.

		Taxonomic groups				
Biotope	**Mesh size**	**Chironomidae**	**Baetidae**	**Simuliidae**	**Caenidae**	**p-value**
Riffle	**100 µm**	**46.63**	**27.71**	**46.75**	**18.64**	**21.76*** **
		(22.5)	(4.33)	(22.5)	(4.39)	
	250 µm	**59.91**	**49.55**	**10.83**	**11.34**	**45.32*** **
		(15.92)	(16.82)	(5.47)	(2.26)	
	500 µm	**18.36**	**16.44**	**6.11**	**5.96**	**24.12*** **
		(5.33)	(4.24)	(2.72)	(1.45)	
Pool	**100 µm**	**44.31**	**22.69**	**9.73**	**5.84**	**88.90*** **
		(9.98)	(2.97)	(1.60)	(1.58)	
	250 µm	**21.08**	**22.53**	**5.96**	**6.69**	**63.85*** **
		(4.66	(2.52)	(1.34)	(1.69)	
	500 µm	**8.65**	**17.71**	**3.09**	**5.73**	**61.48*** **
		(2.85)	(2.05)	(1.53)	(1.60)	

4.3.3 Effect of varying exposure time on macroinvertebrates densities

Macroinvertebrate drift densities were highly significantly influenced by exposure time at the riffle (One-way ANOVA, $F_{(5, 372)} = 13.70$, $p < 0.001$) as well as in the pool biotope (One-way ANOVA, $F_{(5, 372)} = 22.09$, $p < 0.001$). Generally, the drift densities decreased with increase in exposure time. The mean drift densities at different net exposure time in the riffle and pool in the Njoro River are presented in Figure 8.

In the riffle biotope, the 100 µm mesh net recorded the highest drift densities at 5 minutes exposure (107.03 ± 58.07 individuals m^{-3}) and the lowest was at 120 minutes exposure duration (16.10 ± 3.68 individuals m^{-3}). The exposure time had a significant effect on invertebrate drift densities captured by the 100 µm mesh (One-way ANOVA, $F_{(5, 120)} = 5.19$, $p < 0.001$). Tukey contrasts indicated that the 120 minutes exposure differed significantly with the 5, 10 and 15 minutes ($\alpha = 0.05$). The 250 µm mesh net in the riffle, recorded the highest densities at 10 minutes exposure (73.19 ± 36.38 individuals m^{-3}) and the lowest was obtained at 120 minutes (16.88 ± 5.21 individuals m^{-3}). There was a highly significant difference among the exposure time (One-way ANOVA, $F_{(5, 120)} = 4.80$, $p < 0.001$) on invertebrate drift densities captured by

the 250 µm mesh net. Tukey contrasts indicated that there was no significant difference between the 5, 10, 15, 20, 25 minutes exposure. In contrast, the 120 minutes exposure differed significantly with the 5 and 10 minutes ($p < 0.05$). Using the 500 µm mesh net in the riffle biotope, the highest drift density was obtained at 5 minutes exposure duration (39.69 ± 10.44 individuals m^{-3}) while the least was obtained at 120 minutes (6.17 ± 1.2 individuals m^{-3}). There was a highly significant difference among the exposure time (One-way ANOVA, $F_{(5, 120)} = 6.636$, $p < 0.001$) on invertebrate drift densities captured by the 500 µm mesh net. *Post hoc* Tukey contrasts indicated that there was no significant difference between the 15, 20, 25 and 120 minutes exposure, and in contrast, the 5 minutes exposure differed significantly with the 15, 20, 25 and 120 minutes ($\alpha = 0.05$).

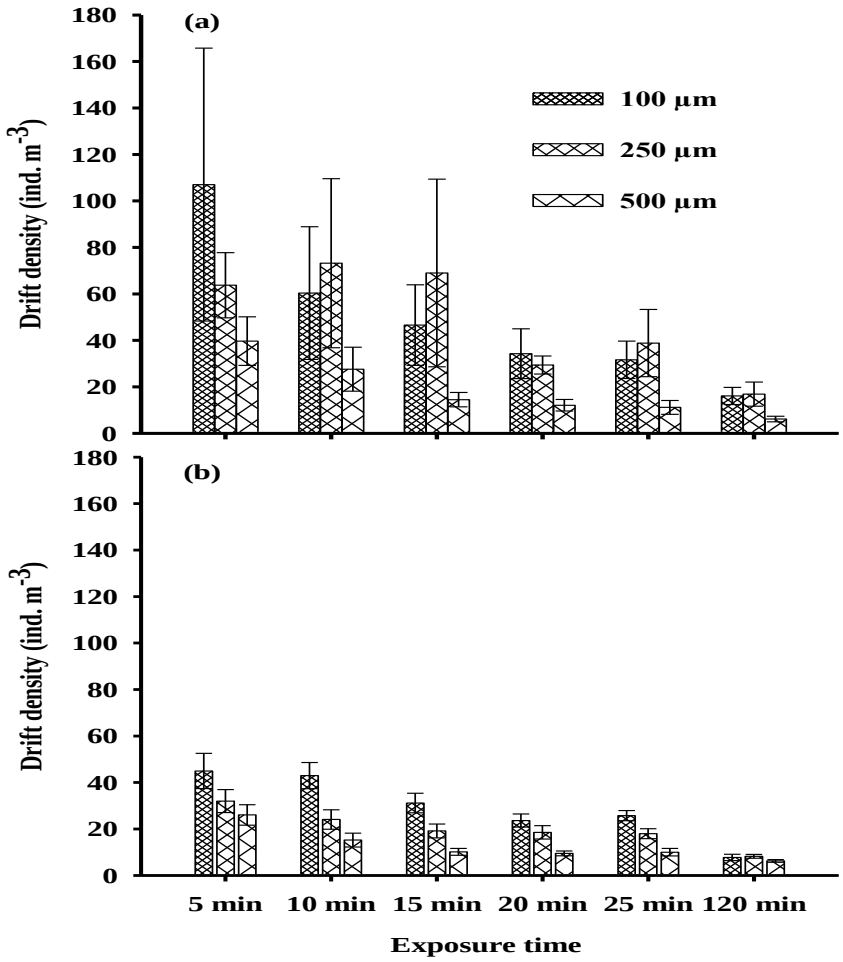

Figure 8: Mean drift densities at different net exposure times (5 – 120 min) in (a) riffle and (b) pool biotopes in the Njoro River. Vertical bars are ± SE, n = 756.

Generally, the highest drift densities in the pool biotope were recorded at 5 minutes and 10 minutes exposure time and decreased with net exposure time in all the three nets, with the lowest being obtained at 120 minutes. The 100 µm mesh net recorded the highest drift densities in the pool biotope at 5 minutes exposure (44.96 ± 7.73 individuals m^{-3}) and the lowest was at 120 minutes exposure duration (7.73 ± 1.38 individuals m^{-3}). The exposure time had a significant effect on invertebrate drift densities captured by the 100 µm mesh (One-way ANOVA, $F_{(5, 120)} = 21.26$, $p < 0.001$). Tukey contrasts indicated that the 120 minutes exposure time differed significantly with all the other exposure durations ($\alpha = 0.05$). The 250 µm mesh net in the pool recorded the highest densities at 5 minutes exposure (31.98 ± 4.95 individuals m^{-3}) and the lowest was obtained at 120 minutes (8.23 ± 0.84 individuals m^{-3}). There was a highly significant difference among the exposure times on invertebrate drift densities captured by the 250 µm mesh net (One-way ANOVA, $F_{(5, 120)} = 6.184$, $p < 0.001$). *Post hoc* Tukey contrasts indicated that there was no significant difference between the 5, 10, 15, 20, 25 minutes exposure time ($p > 0.05$). In contrast, the 120 minutes exposure differed significantly with all the other exposure times ($p < 0.05$). The highest drift density obtained from the 500 µm mesh net was at 5 minutes exposure duration (24.04 ± 4.41 individuals m^{-3}) whilst the least was obtained at 120 minutes (6.25 ± 0.18 individuals m^{-3}). There was a highly significant difference among the exposure times on invertebrate drift densities captured by the 500 µm mesh (One-way ANOVA, $F_{(5, 120)} = 7.10$, $p < 0.001$). *Post hoc* Tukey contrasts indicated that 5 minutes drift densities differed significantly with all the other exposure times except 10 minutes, while 120 minutes densities only differed significantly with 5 and 10 minutes ($p < 0.05$).

There was no significant interaction between drift mesh size and exposure duration in the riffle (Two-way ANOVA, $F_{(10,360)} = 0.379$, $p > 0.05$) whereas, in the pool biotope, there was a statistically significant interaction between the two factors (Two-way ANOVA, $F_{(10,360)} = 2.489$, $p < 0.01$) as presented in Table 6.

Table 6: Summary of two-way ANOVA on the interactions between drift mesh size and exposure time at the riffle and pool biotopes. Significant p values are in bold.

Source of Variation	DF	SS	MS	F	P
Riffle biotope					
Mesh size	2	10.48	5.24	31.57	**<0.001**
Exposure time	5	13.05	2.61	15.72	**<0.001**
Mesh size x Exposure time	10	0.63	0.06	0.38	0.955
Residual	360	59.77	0.17		
Total	**377**	**83.93**	**0.22**		
Pool biotope					
Mesh size	2	7.08	3.54	42.87	**<0.001**
Exposure time	5	11.54	2.31	27.95	**<0.001**
Mesh size x Exposure time	10	2.06	0.21	2.49	**0.007**
Residual	360	29.74	0.08		
Total	**377**	**50.42**	**0.13**		

4.3.4 Effect of drift net position on macroinvertebrate densities

The highest mean drift densities at the riffle biotope were recorded in the 100 µm mesh net placed at the left bank (103.39 ± 33.22 individuals m^{-3}) (see Figure 9). . The drift densities differed significantly with respect to net positions (One – way ANOVA, $F_{(2,375)} = 11.43$, $p < 0.001$). The highest mean drift densities at the pool biotope were recorded at the left bank (Fig 9) in the 100 µm mesh net (32.71 ± 3.97 individuals m^{-3}). In contrast, there was no significant difference in drift densities obtained from the right bank, mid-stream and left bank positions in the pool biotope (One – way ANOVA, $F_{(2,375)} = 0.839$, $p > 0.05$).

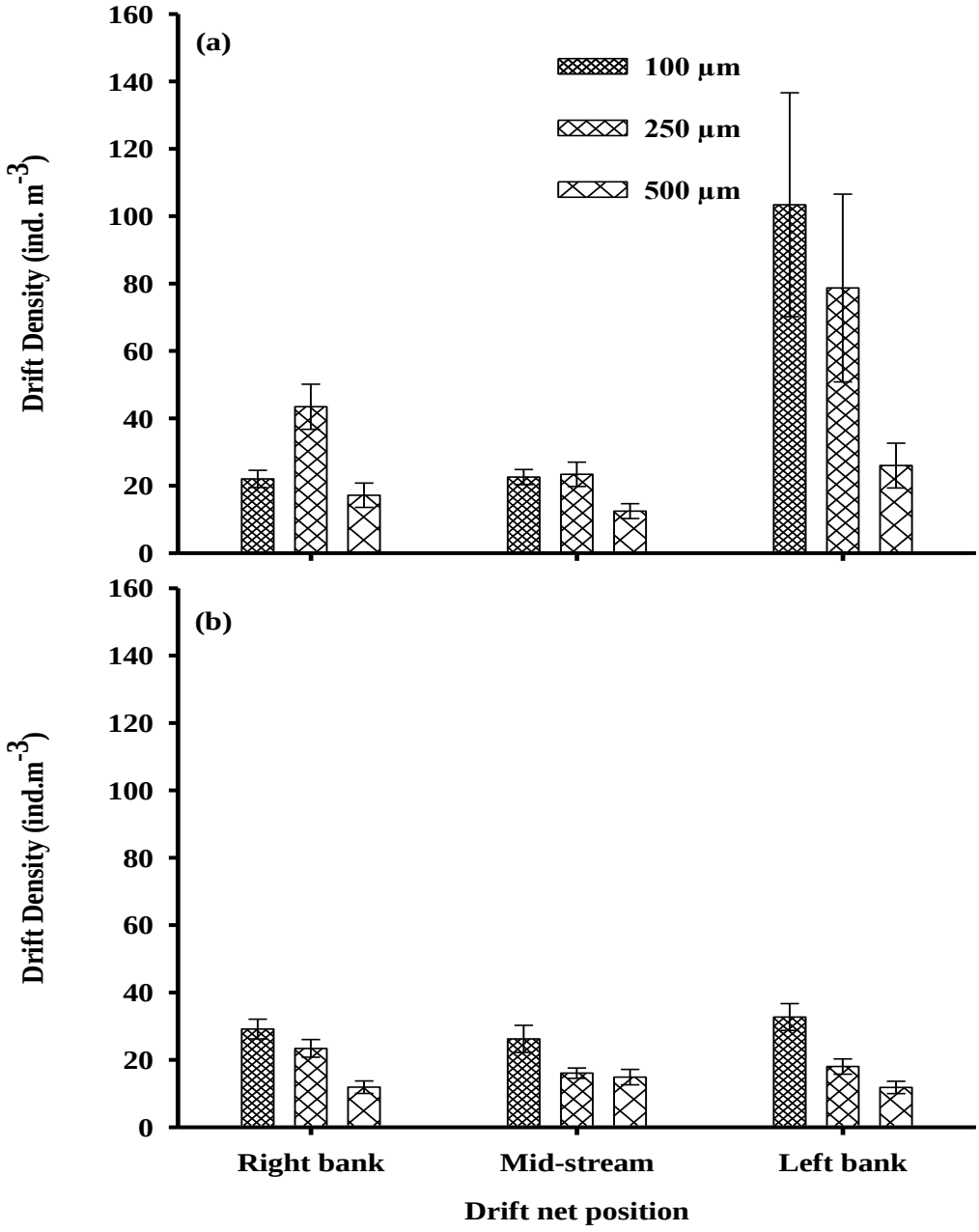

Figure 9: Mean drift densities at different positions in (a) riffle and (b) pool biotopes in the Njoro River. Vertical bars are ± SE, n = 756.

In the riffle biotope, the 100 µm mesh recorded the highest drift densities at the left bank (103.39 ± 33.22 individuals m^{-3}) and the lowest was at the right bank (22.03 ± 2.53 individuals m^{-3}). The net positions had a significant effect on invertebrate drift densities captured by the 100 µm mesh (One-way ANOVA, $F_{(2,123)} = 19.78$, $p < 0.001$). *Post hoc* Tukey contrasts indicated that the left

bank drift densities differed significantly with the mid-stream and right bank densities ($p < 0.05$) while the right bank and mid-stream did not differ significantly ($p > 0.05$). The 250 µm mesh net placed in the left bank of the riffle biotope recorded the highest densities (78.68 ± 27.87 individuals m^{-3}) and the lowest densities were obtained at mid-stream (23.39 ± 3.61 individuals m^{-3}). There was no significant difference among the net positions on invertebrate drift densities captured by the 250 µm mesh (One-way ANOVA, $F_{(2,123)} = 1.807$, $p > 0.05$). Using the 500 µm mesh net in the same biotope, the highest drift density was obtained at the left bank (25.97 ± 6.66 individuals m^{-3}) whilst the least was obtained at the mid-stream (12.47 ± 2.20 individuals m^{-3}). There was no significant difference among the net positions on invertebrate drift densities captured by the 500 µm mesh (One-way ANOVA, $F_{(2,123)} = 2.659$, $p > 0.05$).

The 100 µm mesh net recorded the highest drift densities at the pool biotope at the left bank (32.71 ± 3.97 individuals m^{-3}) and lowest at the mid-stream (26.21 ± 4.03 individuals m^{-3}). The net positions did not have significant effect on invertebrate drift densities captured by the 100 µm mesh net (One-way ANOVA, $F_{(2,123)} = 1.858$, $p > 0.05$). The 250 µm mesh in the pool recorded the highest densities at the right bank (23.39 ± 2.62 individuals m^{-3}) and the lowest at the mid-stream (16.06 ± 1.52 individuals m^{-3}). The net positions did not have significant effect on invertebrate drift densities retained by the 250 µm mesh (One-way ANOVA, $F_{2,123)} = 1.858$, $p > 0.05$). The highest drift density obtained from the 500 µm mesh was at the mid-stream (14.88 ± 2.30 individuals m^{-3}) whilst the least was obtained at the left bank (11.81 ± 1.823 individuals m^{-3}). There was no significant difference among the net positions (One-way ANOVA, $F_{(2,123)} = 0.659$, $p > 0.05$) on invertebrate drift densities captured by the 500 µm mesh.

There was a statistical significant interaction between drift mesh size and net position in the riffle (Two-way ANOVA, $F_{(4,369)} = 2.595$, $p < 0.05$) whereas in the pool biotope, there was no statistically significant interaction between the two factors (Two-way ANOVA, $F_{(4,369)} = 1.990$, $p > 0.05$) as shown in Table 7.

Table 7: Summary of two-way ANOVA on the interactions between drift mesh size and net positions at the riffle and pool biotopes. Significant p values are in bold.

Source of Variation	DF	SS	MS	F	P
Riffle biotope					
Mesh size	2	10.48	5.24	28.97	**<0.001**
Net position	2	4.83	2.41	13.34	**<0.001**
Mesh size x Net position	4	1.88	0.47	2.60	**0.036**
Residual	369	66.75	0.18		
Total	**377**	**83.93**	**0.22**		
Pool biotope					
Mesh size	2	7.08	3.54	30.96	**<0.001**
Net position	2	0.23	0.11	0.98	0.376
Mesh size x Net position	4	0.91	0.23	1.99	0.096
Residual	369	42.20	0.11		
Total	**377**	**50.42**	**0.13**		

4.4 Relationship between drift densities, exposure time and net positions in the two biotopes

4.4.1 Relationship between drift densities and exposure time in the two biotopes

The relationship between the drift densities and exposure time can be explained by a linear equation. The regression equations for the riffle and pool biotopes are as follows:

Riffle biotope

a) 100 µm mesh net: Drift density = 63.38-0.46 (exposure time)

b) 250 µm mesh net: Drift density = 61.55-0.40 (exposure time)

c) 500 µm mesh net: Drift density = 24.25-0.18 (exposure time)

Pool biotope:

a) 100 µm mesh net: Drift density = 38.17-0.27 (exposure time)

b) 250 µm mesh net: Drift density = 24.81-0.15 (exposure time)

c) 500 µm mesh net: Drift density = 15.90-0.09 (exposure time)

All the above equations were used to determine drift densities after 30 minutes, 60 minutes, 90 minutes and 180 minutes in both biotopes (Table 8). These relationships are demonstrated in Figures 10a and 10b, respectively.

Table 8: Drift densities (ind.m^{-3}) as predicted by the regression equation for the times 30, 60, 90, 150 and 180 minutes exposure time. – implies absence of drift densities beyond the indicated time.

Biotope		**Exposure time (minutes)**				
Riffle	**Mesh size**	**30**	**60**	**90**	**150**	**180**
	100 µm	49.58	35.78	21.98	-	-
	250 µm	49.55	37.55	25.55	1.55	-
	500 µm	18.85	13.45	8.05	-	-
Pool	**100 µm**	30.07	21.97	13.87	-	-
	250 µm	20.31	15.81	11.31	2.31	-
	500 µm	13.20	10.50	7.80	2.40	-

Table 8 indicates that the three nets collected drift densities in the range 18.85-49.58 in 30 minutes, 13.45-35.78 in 60 minutes, 8.05-21.98 in 90 minutes and thereafter clogging occurred beyond 120 minutes in the riffle biotope. Further, the ranges in the pool biotope were 13.20-30.07 in 30 minutes, 10.50-21.97 in 60 minutes, 7.80-13.87 in 90 minutes and thereafter beyond 120 minutes the nets started clogging.

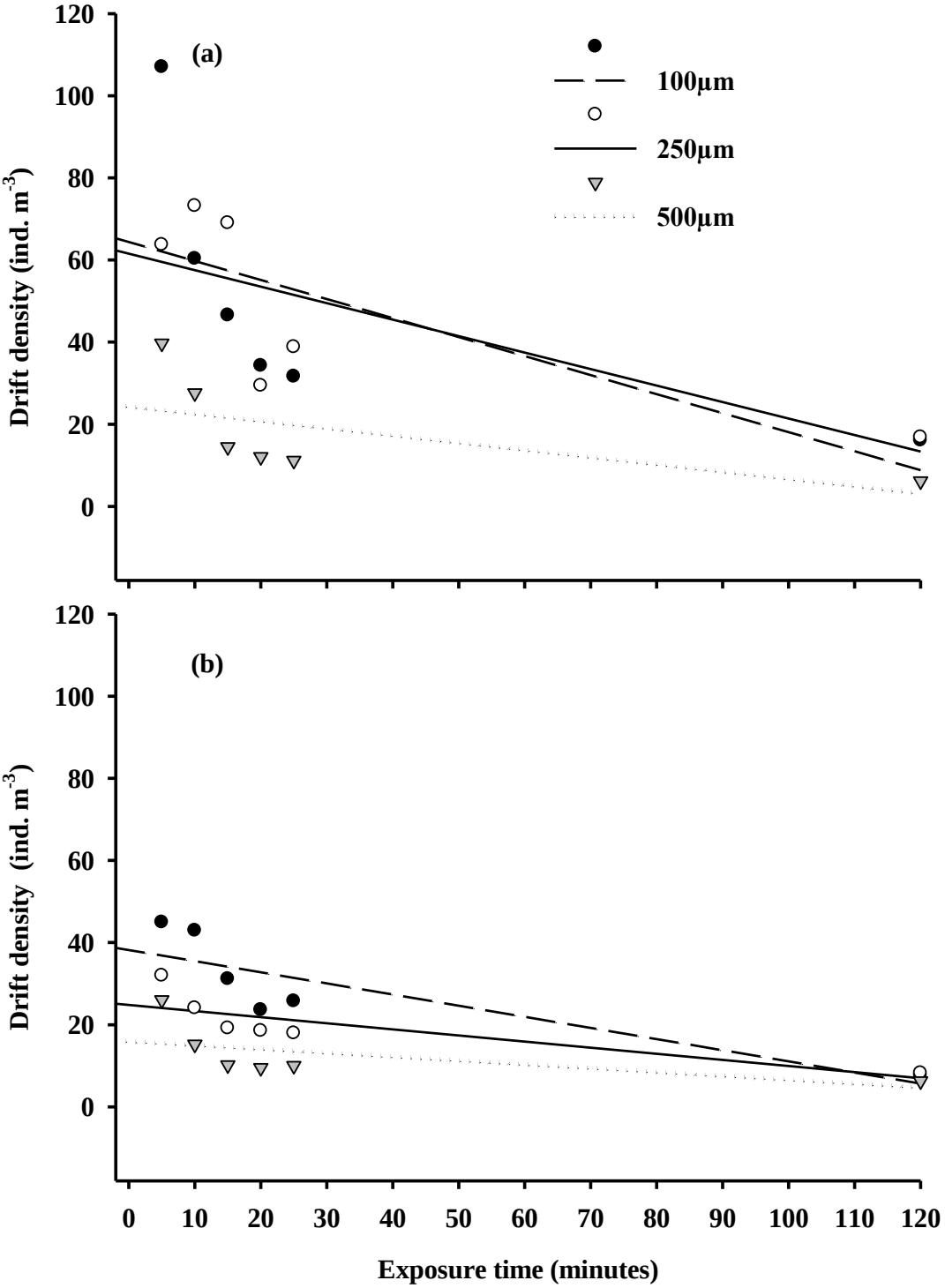

Figure 10: Regression lines of drift densities and exposure time (a) riffle and (b) pool biotopes in the Njoro River.

4.4.2 Interactions among mesh size, exposure time and net position in both biotopes

Homogeneity of variance using the Levene's test indicated that there was no significant difference on the variances of drift densities ($p > 0.05$). Hence three - way ANOVA was carried out. There was no significant interaction observed among drift net mesh size, drift net position and exposure time in the riffle (Three way- ANOVA, $F_{(20,324)} = 0.375$, $p > 0.05$) and pool (Three way- ANOVA, $F_{(20,324)} = 0.374$, $p > 0.05$) biotopes (Table 9).

Table 9: Summary of three-way ANOVA on the interaction among drift mesh size, exposure time and net position on drift densities at the riffle and pool biotopes. Significant p values are in bold.

Riffle biotope **Source of variation**	**DF**	**SS**	**MS**	**F**	**P**
Drift Mesh size	2	10.48	5.24	33.26	**<0.001**
Net position	2	4.83	2.41	15.31	**<0.001**
Exposure time	5	13.05	2.61	16.57	**<0.001**
Drift Mesh size x Net position	4	1.88	0.47	2.98	**0.019**
Drift Mesh size x Exposure time	10	0.63	0.06	0.40	0.946
Net position x Exposure time	10	0.82	0.08	0.52	0.875
Drift Mesh size x Net position x Exposure time	20	1.18	0.06	0.38	0.994
Residual	324	51.06	0.16		
Total	**377**	**83.93**	**0.22**		
Pool biotope					
Drift Mesh size	2	7.08	3.54	41.60	**<0.001**
Net position	2	0.23	0.11	1.32	0.269
Exposure time	5	11.54	2.31	27.12	**<0.001**
Drift Mesh size x Net position	4	0.91	0.23	2.67	**0.032**
Drift Mesh size x Exposure time	10	2.06	0.21	2.42	**0.009**
Net position x Exposure time	10	0.39	0.04	0.45	0.919
Drift Mesh size x Net position x Exposure time	20	0.64	0.03	0.37	0.994
Residual	324	27.58	0.09		
Total	**377**	**50.42**	**0.13**		

4.5 Relationship between drift densities and physico-chemical variables

4.5.1 Correlation between drift densities and physico-chemical variables

There was a positive significant correlation between drift densities with temperature and conductivity, in the riffle biotope ($p < 0.001$) whereas the correlations of drift densities with dissolved oxygen, pH, turbidity, velocity and discharge were not significant ($p > 0.05$). In the

pool biotope, there was a positive significant correlation between drift densities with dissolved oxygen and turbidity and negative significant correlation with conductivity and temperature ($p < 0.05$). However, the correlation between drift densities with pH, velocity and discharge were insignificant ($p > 0.05$).

4.5.2 Principle component analysis

The Principal component analysis (PCA) for water quality parameters in the riffle and pool biotopes were defined as in Table 10. The PCA was complemented by factor analysis of the retained components and comparison of the first two PCs (Figure 11 and 12). There were three principal components (PCs) which were extracted from 9 variables, whose Eigenvalues were greater than 1.0. Hence, the three components accounted for 76.23% and 67.51% of total variability in the riffle and pool respectively. Table 10 shows the three components extracted from PCA. PC1 in both biotopes, was principally associated with changes in pH, dissolved oxygen levels, conductivity, temperature and turbidity and explained 37.60% and 39.29% of the total variability in the riffle and pool respectively (Figure 11 and 12). There were positive relationship with pH, conductivity and temperature and negative relationship with dissolved oxygen levels and turbidity. This implied that the water quality variables mentioned above (pH, dissolved oxygen levels, conductivity, temperature and turbidity) had a major influence on drift densities.

PC2 in the riffle was characterized by a positive relationship of the 100 µm, 250 µm and 500 µm net mesh and explained 25.75% of the total variability. This component was linked to variation in drift net mesh sizes. PC2 in the pool biotope was characterized by the 100 µm mesh net and an inverse relationship with the discharge, explaining 15% of the total variability. PC3 at the riffle ascribed to discharge in the river and was explained by 12.88% of the total variability. This component increased with increasing discharge. In fact, based on the correlation of 0.940, this PC1 was primarily a measure of discharge. This suggests that variability in stream discharge had an effect on macroinvertebrates drift. In the pool biotope, PC3 was associated with variability in mesh-size (250 µm and 500 µm mesh) and explained 13.29% of the total variability. In general, the drift densities were mainly influenced by variability in discharge, mesh sizes and temperature and proportionately by changes in pH, dissolved oxygen, conductivity, and turbidity.

Table 10: Factor loading on principal components of water quality variables and drift densities from the riffle and pool biotope.

	Principal components					
	Riffle			Pool		
Parameter	**PCA 1**	**PCA 2**	**PCA 3**	**PCA 1**	**PCA 2**	**PCA 3**
pH	**0.846**	0.004	-0.172	**0.841**	0.255	-0.124
Dissolved oxygen	**-0.642**	0.146	-0.531	**-0.773**	0.217	0.102
Conductivity	**0.720**	-0.204	-0.024	**0.668**	-0.476	-0.044
Temperature	**0.879**	-0.145	0.104	**0.853**	-0.033	-0.149
Turbidity	**-0.747**	-0.116	-0.158	**-0.626**	0.533	-0.076
Discharge	-0.013	0.005	**0.940**	-0.145	**-0.779**	-0.046
Mesh-100 µm	-0.084	**0.908**	0.038	-0.288	**0.588**	0.213
Mesh-250 µm	-0.030	**0.881**	-0.058	0.015	-0.036	**0.893**
Mesh-500 µm	-0.095	**0.966**	-0.037	-0.256	0.273	**0.694**
Variance	3.38	2.32	1.16	3.54	1.35	1.19
Variance (%)	37.60	25.75	12.90	39.29	15.00	13.26
CV (%)	37.60	63.34	76.22	39.29	54.25	67.51

***CV=** Cumulative Variance. Factor loadings (correlation coefficients) in bold give the corresponding variable(s) considered in each principle component (PC).

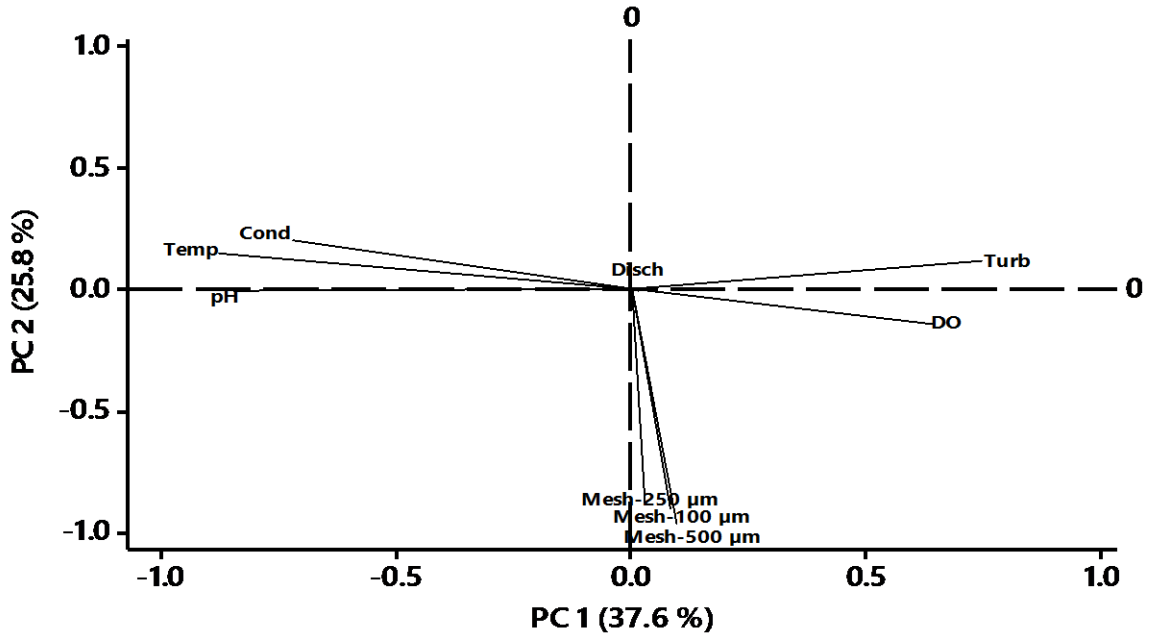

Figure 11: Principle component analysis of physico-chemical variables and drift densities for the first two PCs in the riffle biotope.

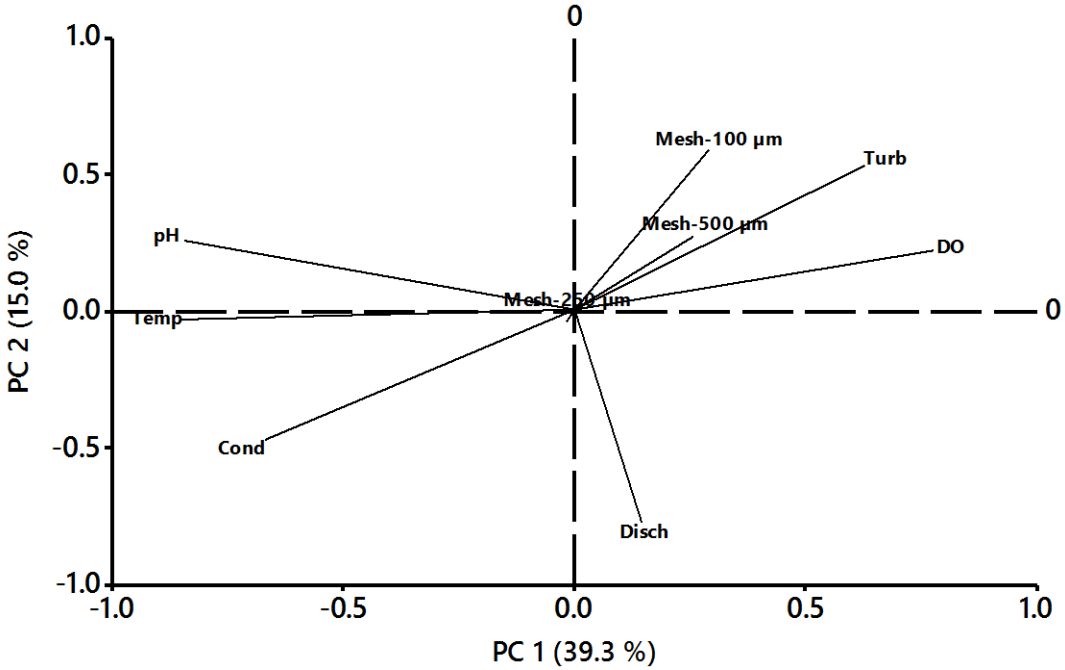

Figure 12: Principle component analysis of physico-chemical variables and drift densities for the first two PCs in the pool biotope.

4.6 The structure and composition of benthic macroinvertebrates

4.6.1 Benthic macroinvertebrate composition, abundance and diversity

A total of 17 benthic invertebrate taxa were collected in the riffle and pool biotopes, that is, 16 and 14 in the riffle and pool biotopes, respectively (Table 11). Libellulidae was not found in the riffle while Hydrophilidae, Pyralidae and Tipulidae were absent in the pool biotope. Chironomidae, Baetidae and Simuliidae were the most dominant groups, contributing about 80% of the total macroinvertebrates, with simuliids and chironomids dominating the riffle and pool biotopes respectively (Table 12). Macroinvertebrate densities collected in the riffle biotope had a mean of 1035.04 ± 612.77 individuals m^{-2} whereas the mean at the pool biotope was 348.70 ± 134.33 individuals m^{-2} (Figure 13). The difference in the densities of the macroinvertebrates between the two biotopes was, however not significant ($t = 0.176$, $d.f = 32$, $p > 0.05$).

Table 11: Occurrence of benthic macroinvertebrate taxa in riffle and pool biotopes in the Njoro River. (+) Taxon present, (-) Taxon not encountered.

	Stream biotopes	
Taxa	**Riffle**	**Pool**
Baetidae	+	+
Caenidae	+	+
Ceratopogonidae	+	+
Chironomidae	+	+
Culicidae	+	+
Elmidae	+	+
Helodidae	+	+
Heptagenidae	+	+
Hydrachnellae	+	+
Hydrophilidae	+	-
Hydropsychidae	+	+
Leptoceridae	+	+
Libellulidae	-	+
Muscidae	+	+
Pyralidae	+	-
Simuliidae	+	+
Tipulidae	+	-

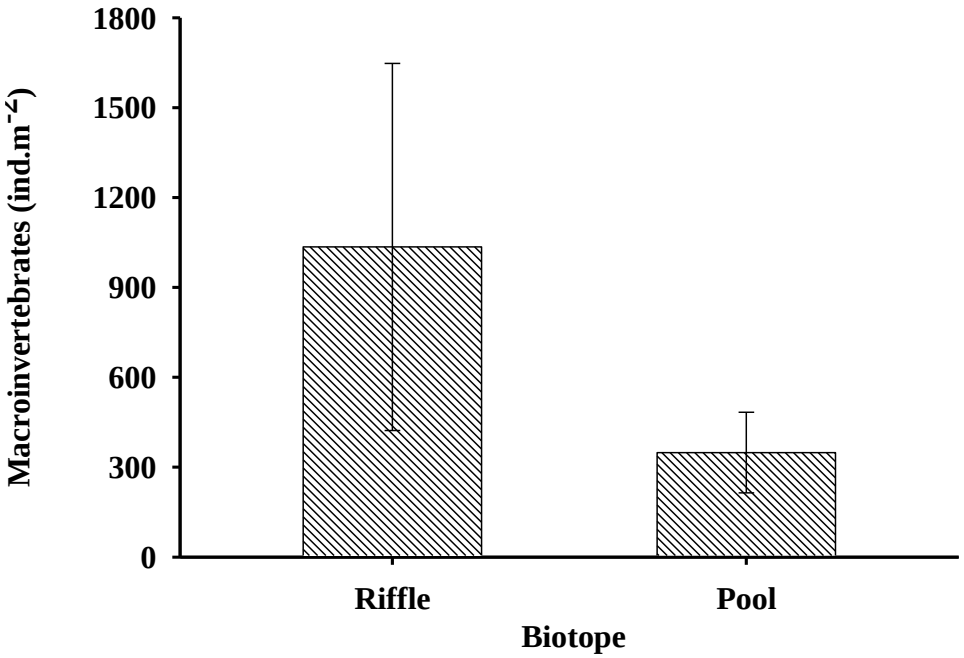

Figure 13: Benthic macroinvertebrate densities in the riffle and pool biotopes. Vertical bars are ± SE, n=210.

Table 12: Benthic macroinvertebrate densities (ind.m^{-2}) of the major groups in the two biotopes. Bolded values are means, bracketed values are ± SE, n=210.

	Taxonomic groups			
Biotope	**Chironomidae**	**Baetidae**	**Simuliidae**	**Others**
Riffle	**902.19**	**338.56**	**1964.26**	**314.11**
	(212.78)	(66.82)	(492.96)	(137.56)
Pool	**413.79**	**199.37**	**135.42**	**436.99**
	(56.47)	(29.38)	(74.73)	(105.83)

The diversity index of benthic macroinvertebrates in the riffle biotope was 1.26 while in the pool was 1.90. This implied that there was a higher diversity in the pool compared to the riffle biotope. The Jaccard index indicated a 76% taxonomic similarity between the riffle and pool biotopes. The macroinvertebrates in the riffle biotope were 49% evenly distributed while in the pool evenness was 72%.

4.6.2 The proportions of benthos in drift in the riffle and pool biotopes

The taxa collected in drift and benthos are presented in Tables 13. A total of 26 families occurred in drift while 17 families occurred in benthos. Nine additional families occurred in drift but not in benthos and included Aeshnidae, Caenagrionidae, Dixidae, Gyrinidae, Hydraenidae, Oligochaeta, Psychodidae, Sphaeriidae, Veliidae. About 65% of the families in benthos occurred in drift.

The percentage proportions of benthos in drift in the riffle and pool biotopes are shown in Figure 14. In the pool biotope, the percentage proportions of benthos in drift were double that of the riffle biotope. The range of the proportions of benthos in drift was 0.04 - 0.12 in the riffle biotope and 0.31 - 0.71 in the pool biotope. There was a highly significant difference between the proportions of benthos in drift in the riffle and pool biotopes ($t = -9.473$, $d.f = 106$, $p < 0.001$).

The proportions of benthos in drift in the different drift net mesh sizes were as follows: 100 µm > 250 µm > 500 µm in the riffle biotope. In the same biotope, there was a significant difference on the proportions of benthos in drift, among the 100 µm, 250 µm and 500 µm nets (One-way ANOVA, $F_{(2,51)} = 3.241$, $p < 0.05$). Similarly, in the pool biotope, the difference among the proportions of benthos in drift in the three nets was highly significant (One-way ANOVA, $F_{(2,51)} = 11.172$, $p < 0.001$). *Post hoc* Tukey contrasts indicated that there was a significant difference between the 100 µm versus 500 µm and 100 µm versus 250 µm ($\alpha = 0.05$).

Table 13: Occurrence of drift and benthic macroinvertebrate taxa in the Njoro River. (+) Taxon present, (-) Taxon not encountered.

	Drift		Benthos	
Taxa	**Riffle**	**Pool**	**Riffle**	**Pool**
Aeshnidae	+	+	-	-
Baetidae	+	+	+	+
Caenagrionidae	+	+	-	-
Caenidae	+	+	+	+
Ceratopogonidae	+	+	+	+
Chironomidae	+	+	+	+
Culicidae	+	+	+	+
Dixidae	+	-	-	-
Elmidae	+	+	+	+
Gyrinidae	-	+	-	-
Helodidae	+	+	+	+
Heptagenidae	+	+	+	+
Hydrachnellae	+	-	+	+
Hydraenidae	-	+	-	-
Hydrophilidae	-	+	+	-
Hydropsychidae	+	+	+	+
Leptoceridae	+	+	+	+
Libellulidae	+	-	-	+
Muscidae	+	+	+	+
Oligochaeta	+	+	-	-
Psychodidae	+	+	-	-
Pyralidae	+	+	+	-
Simuliidae	+	+	+	+
Sphaeriidae	+	-	-	-
Tipulidae	+	+	+	-
Veliidae	+	-	-	-
Total	23	21	16	14

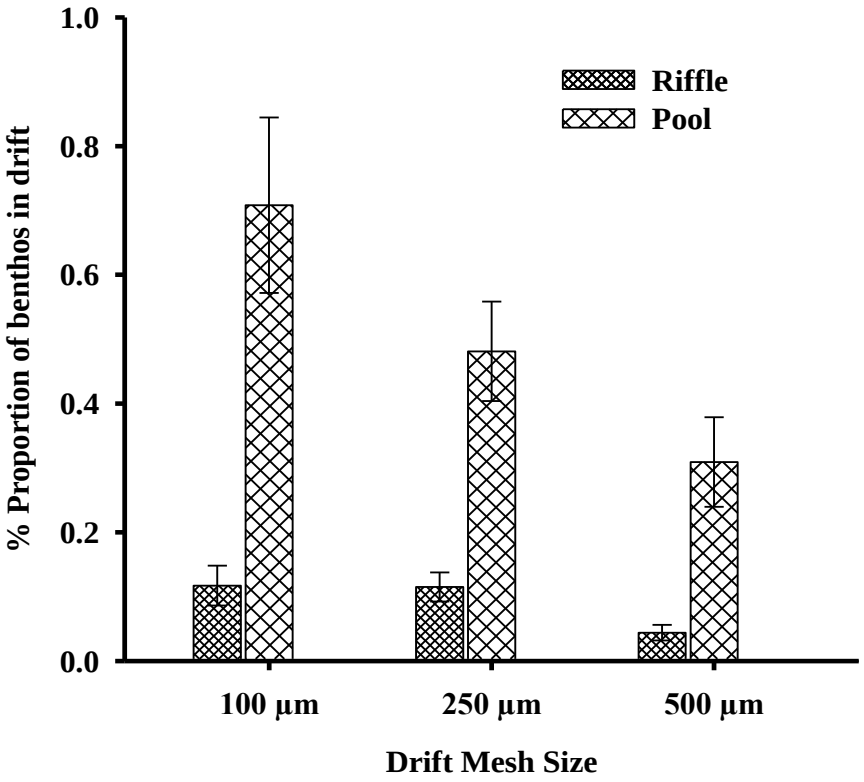

Figure 14: Percentage proportions of benthos in the different drift net mesh sizes in the riffle and pool biotopes in the Njoro River (pooled data). Vertical bars are ± SE, n=106.

Generally, the proportions of benthos in drift decreased with increase in net exposure time in both biotopes, whereby the 5 minutes and 120 minutes exposure duration had the highest and lowest drift densities, respectively (Figure 15). Percentage proportion of benthos in drift in relation to stream position in the riffle and pool biotopes are shown in Figure 16. The highest percentage in the riffle and pool biotopes were recorded at the left bank by the 100 µm mesh net.

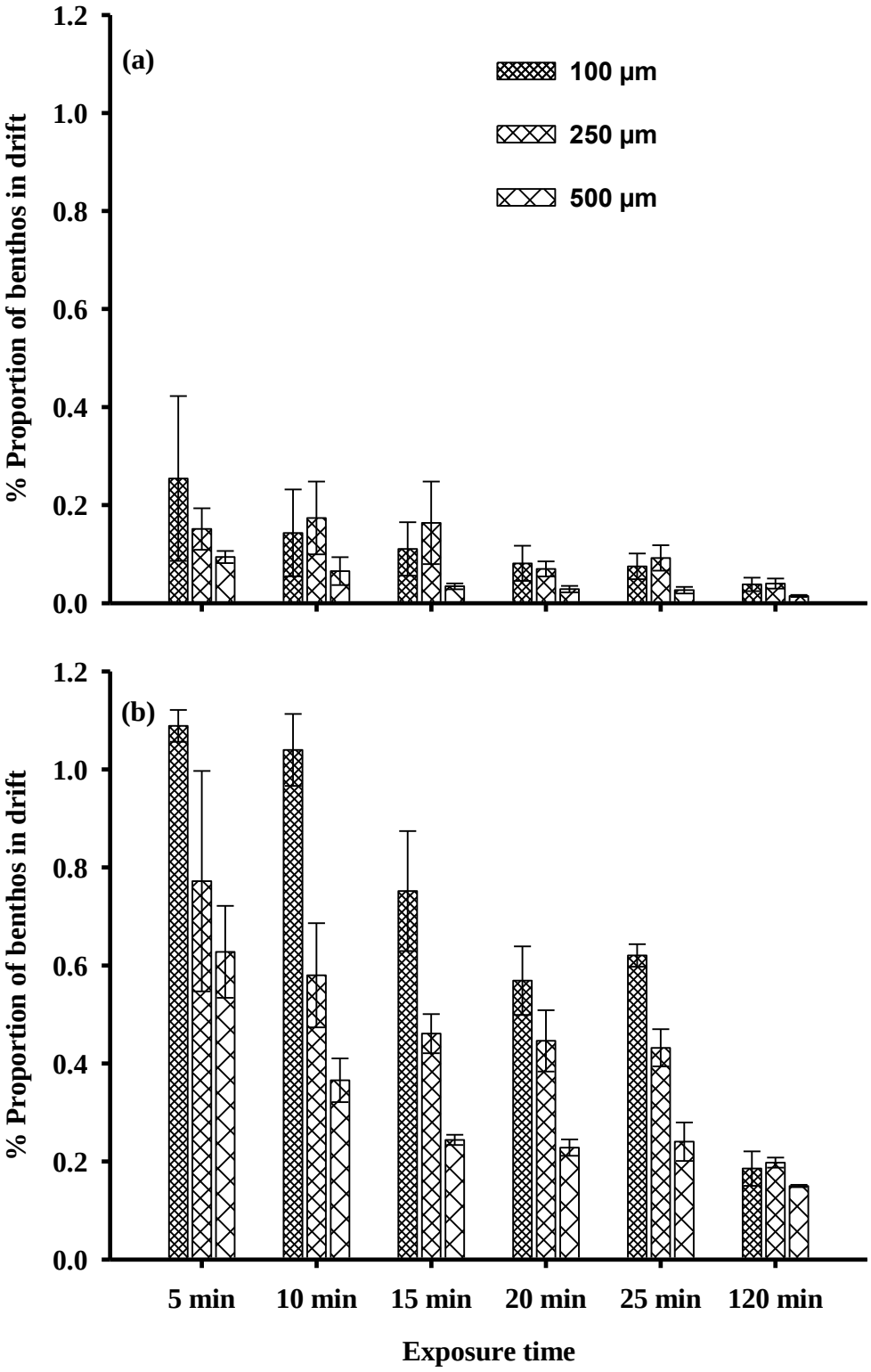

Figure 15: Percentage proportions of benthos in drift with time in (a) riffle and (b) pool biotopes in the Njoro River. Vertical bars are ± SE, n=106.

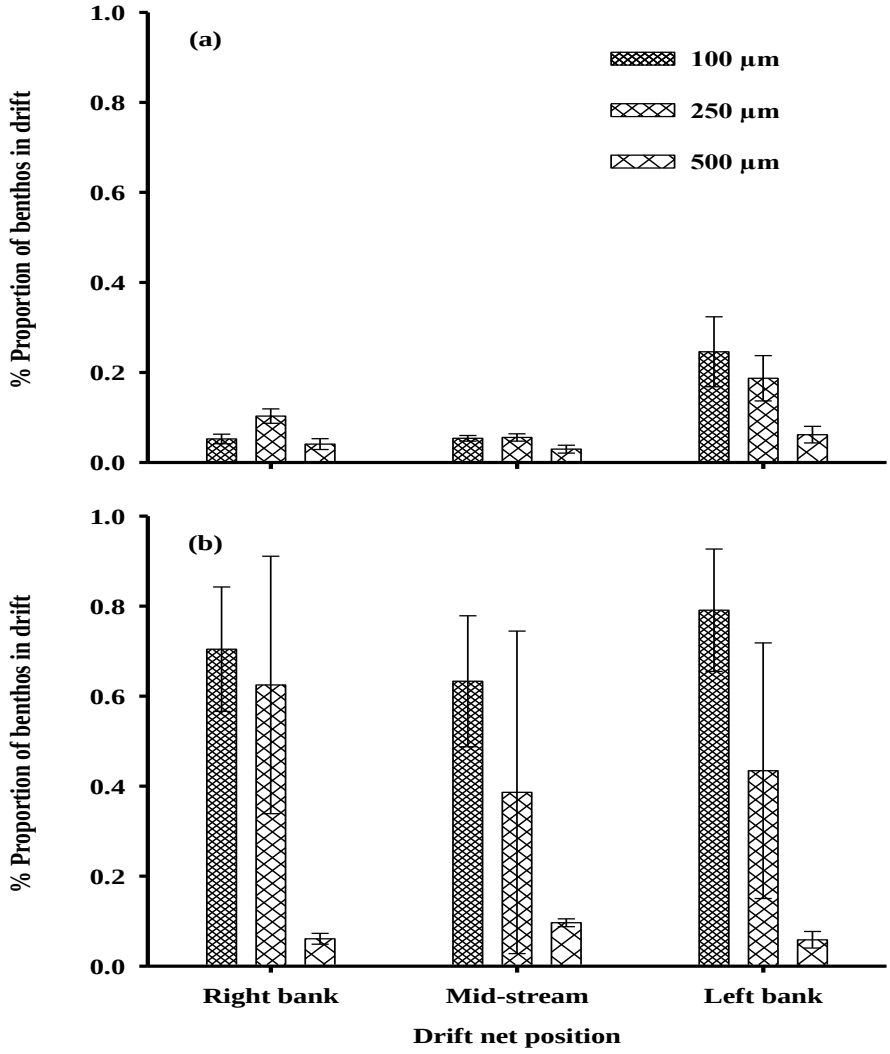

Figure 16: Percentage proportions of benthos in drift at different positions in (a) riffle and (b) pool biotopes in the Njoro River. Vertical bars are ± SE, n=106.

4.7 Macroinvertebrate drift and benthos

Table 14 shows the percentage abundance of the major macroinvertebrates groups in the riffle and pool biotopes in the Njoro River. Simuliids and chironomids contributed the highest densities in benthos and drift, respectively, while *Caenis sp.* had the lowest densities in both biotopes. The percentage abundance of chironomids, beatids and simuliids in the benthos were higher in the riffle than the pool biotope by 37%, 26% and 87%, respectively. However, *Caenis sp.* were higher by 73% in the pool biotope than in the riffle. In drift, the percentage abundance of all the major taxa was high in the riffle as compared to the pool biotope by chironomids-26%, baetids-20%, simuliids-54% and caenis-33%.

Table 14: Percentage abundance of the major macroinvertebrate groups in the benthos (ind.m^{-2}) and drift (ind.m^{-3}) in the Njoro River biotopes.

		Chironomidae				Baetidae				Simuliidae				Caenidae			
Biotopes	**Mesh size**	Benthos		Drift		Benthos		Drift		Benthos		Drift		Benthos		Drift	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Riffle	**100 µm**	902.19	33.33	46.63	37.33	338.56	33.33	27.71	29.57	1964.26	33.33	46.75	73.40	9.40	33.33	18.64	51.86
	250 µm	902.19	33.33	59.91	47.97	338.56	33.33	49.55	52.88	1964.26	33.33	10.83	17.01	9.40	33.33	11.34	31.54
	500 µm	902.19	33.33	18.36	14.70	338.56	33.33	16.44	17.55	1964.26	33.33	6.11	9.59	9.40	33.33	5.96	16.59
	Total	**2706.57**	**100.00**	**124.90**	**100.00**	**1015.68**	**100.00**	**93.70**	**100.00**	**5892.78**	**100.00**	**63.69**	**100.00**	**28.20**	**100.00**	**35.95**	**100.00**
Pool	**100 µm**	413.79	33.33	44.31	59.84	199.37	33.33	22.69	36.05	135.42	33.33	9.73	51.79	62.70	33.33	5.84	32.00
	250 µm	413.79	33.33	21.08	28.48	199.37	33.33	22.53	35.80	135.42	33.33	5.96	31.76	62.70	33.33	6.69	36.63
	500 µm	413.79	33.33	8.65	11.68	199.37	33.33	17.71	28.15	135.42	33.33	3.09	16.45	62.70	33.33	5.73	31.36
	Total	**1241.37**	**100.00**	**74.03**	**100.00**	**598.11**	**100.00**	**62.93**	**100.00**	**406.26**	**100.00**	**18.78**	**100.00**	**188.10**	**100.00**	**18.26**	**100.00**

CHAPTER FIVE
DISCUSSION

Studies on macroinvertebrates drift in Kenyan Rivers started way back in 1992 by Mathooko and Mavuti (1992) in the Naro Moru River using a net of 105 µm. This was subsequently followed by M'Erimba (2004), M'Erimba *et al.* (2014) and M'Erimba *et al.* (2017) in the Njoro and Ellegirini Rivers using a 100 µm mesh nets. The studies focused on drift densities over 24 hour period (diel periodicity). Currently, there is a paradigm shift in which ecologist use macroinvertebrate drift to explain some phenomenon in streams for instance, pollution and disturbances (Gimenez *et al.*, 2015). Majority of studies paid attention to effects of light (Thornton, 2008), discharge (Imbert and Perry, 2000), predators (Mathooko, 1996) and pollution (Lugthart *et al.,* 1990) on macroinvertebrate drift densities. Other angles of drift studies have been introduced for instance the influence of mesh-size (Slack *et al*., 1991) and siltation (Suren and Jowett, 2001) among others. This study focused on the effect of mesh size, exposure duration and drift net position on drift densities in the Njoro River.

5.1 Physico-chemical parameters in the riffle and pool biotopes

5.1.1 Variation of the selected physico-chemical parameters in the riffle and pool biotopes

Most of the physico-chemical parameters showed insignificant differences between the riffle and pool biotopes. Temperature, conductivity, dissolved oxygen, turbidity, water velocity and discharge values were higher in the riffle than in the pool biotope. Velocity and discharge recorded in the riffle was significantly higher than in the pool. This is in accord with the definitions of pools and riffles by Johnston and Slaney (1996), where pools and riffles have low and high current velocity, respectively. Discharge is a function of velocity and this could have attributed to the difference observed between the two biotopes. Discharge perhaps influenced drift densities obtained from the two biotopes. Imbert and Perry (2000), and Bruno *et al.* (2010) observed an increase in drift densities with increased discharge. In one of the studies to directly measure drift distances *in-situ* across different habitat configurations, Lancaster *et al.* (1996) found that reach-scale drift increased with mean velocity and decreased with the number of depositional microhabitats.

5.1.2 Throughflow in the riffle and pool biotopes

The amount of filtered water in riffle biotope showed high values in the left bank compared to the mid-stream and right bank, while in the pool biotope the flow was relatively uniform in all the positions. This translated to high drift densities at the left bank in both biotopes, hence indicating that the amount of water filtered had a significant effect on drift densities. This observation has been supported outside this study. For instance, increased drift may result both from increase in amount of flow (Robinson *et al.,* 2004) and from flow decreases (Barbero *et al.,* 2013). Brittain and Eikeland (1988) and Poff and Ward (1991) observed that rapid changes in streamflow often induce increases in drift rate or drift density. This is attributed to invertebrates being dislodged through the scouring effect as flow increases with stream discharge (Mackay,1992), and once entrained in the water column resettlement rates of drifting invertebrates are lower in swift water (Bond *et al*., 2000). Similarly, Kändler and Seidler (2013), working in Landwasser River (Germany), observed that benthic drift was strongly influenced by the hydraulic conditions of the river, and hence there was a positive correlation between drift density and flow velocity. The longer the nets were exposed the more the water filtered (Janáč and Reicharda, 2016). Nets placed in the pool filtered more water than those placed in riffle biotope. For instance, the 500 µm mesh net filtered significantly high amount of water in the pool than in the riffle while the 250 µm mesh net filtered equal amounts in both biotopes. Factors like mesh size (clogging effect), position of the net and streambed topography could have contributed to the observed disparities.

5.2 Drift of macroinvertebrates in the Njoro River

5.2.1 Drift composition and densities in riffle and pool biotopes

Macroinvertebrates that drifted in the riffle and pool biotopes in the Njoro River were mainly composed of Chironomidae, Baetidae, Simuliidae and Caenidae. Among the four major taxa chironomids contributed the highest drift densities. Similar observations were made by Bruno *et al.* (2010) and Kennedy *et al.* (2014) who sampled for 5 minutes and found that chironomids had the largest average drift concentrations than any other taxa. This observation has also been supported by other studies (Robinson *et al.,* 2002; Hieber *et al.,* 2003; Tonkin and Death, 2013) which observed that Diptera were particularly common in drift. This observation can be

attributed to factors such as high abundances of chironomids in benthos (Kibichii *et al.,* 2007; M'Erimba *et al.,* 2014; Mbaka *et al.,* 2015).

In this study, the mean drift densities obtained at both biotopes were 29.82 ± 2.65 ind.m^{-3}. M'Erimba (2004) found close to similar values of drift densities of 28.6 ± 2.7 ind. m^{-3} in the Njoro River. There was a higher diversity of drifting macroinvertebrates in the riffle than in the pool biotope. Moreover, drift densities were significantly higher in the riffle compared to the pool. This observation supports the findings by Rader (1997) and Leung *et al.* (2009) who used a 250 µm mesh size net in small and medium order streams of the northern hemisphere and found highest drift densities in riffles. Peterson and Rabeni (2001), studying an Ozark stream, found that drift abundances were higher in the riffle compared to the pool habitats. A plausible explanation could be that macroinvertebrates preferred riffle sections to pool sections because the increased flow over riffles provides more oxygen and food compared to slower flow in pools (Brown and Brussock, 1991). In addition, pools are the major sites of drift consumption and deposition with subsequent mortalities and decomposition (Waters, 1962).

Some macroinvertebrates may also prefer riffle habitats due to their filter-feeding techniques because fast water in riffles delivers a greater amount of available food than slow moving water in pools. As water depth increases, available food can settle to the bottom of a pool, becoming unavailable to filter-feeding macroinvertebrates (Witt, 2013). Another explanation for higher drift densities in riffle compared to the pool is that in this study, the riffle biotope was majorly composed of a bedrock while the pool was composed of sand and gravel. This observation concurs with the findings of Lytle (2000) who suggests that the bedrock in riffles is more physically stable than substrata in pools (sand and gravel) and the bed clusters act as refugia during floods (Matthaei and Huber, 2002). In addition, Principe (2008) reported that riffle habitats are more complex, offer numerous niches for streambed macroinvertebrates, act as refuges from flooding and predators, and exhibit greater food supply.

5.2.2 Drift densities in relation to mesh size

In this study, the highest mean drift density in both the riffle and pool biotopes was obtained using the 100 µm drift net followed by the 250 µm net and the lowest densities were obtained using 500 µm net. Assuming the 100 µm net captured a 100% of the drifting macroinvertebrates, the 500 µm net lost about 60% of the drifting macroinvertebrates whilst, 13% was lost by the

250 µm net. Mean invertebrate drift density decreased with increase in drift sampler net mesh size and differed significantly among the three nets. This demonstrates that drift samplers fitted with fine meshed nets had a propensity to collect more invertebrates than drift samplers fitted with coarse meshed nets. This could be attributed to loss of small sized invertebrates that pass through coarse meshed nets. For example, Mbaka *et al.* (2016) showed that use of coarse meshed sieves, i.e., 500 µm, led to exclusion of meiofauna from samples and had a significant effect on mean invertebrate density (See also Hwang *et al.,* 2007; Pinna *et al.,* 2014; Hartwell and Fukuyuma, 2015). A different study assessed the contribution of meiofauna to invertebrate drift in streams and found that meiofauna constituted a considerable portion (35%) of total invertebrate drift density (Perić *et al.,* 2014). Given that small sized fauna are likely to be lost from drift samples when using coarse meshed nets, it is important to use drift samplers fitted with fine meshed nets when characterizing invertebrates in stream ecosystems where the existing taxa are unknown.

A similar observation of increased drift densities with decrease in drift net mesh size was also reported by Mundie (1964) who averred that a 1000 µm mesh size would lead to samples being selective since the smallest adult insects would escape through the screen above the water. This finding was further supported by Slack *et al*. (1991) using a triple drift net sampler. A larger net mesh size is recommended in streams with high coarse particulate organic matter in order to avoid clogging which is encountered when using smaller mesh sizes (Janáč and Reicharda, 2016). Kennedy *et al*. (2014), working in Colorado River in Lees Ferry, used a finer mesh of 250 µm at 5 minutes exposure to capture small invertebrates of Chironomidae and to prevent backpressure and clogging associated with the smaller mesh size and obtained drift densities of 0.51 ± 3.2 ind. m^{-3}. Although fine meshed nets retain the small sized invertebrates, use of such nets increases the time needed for sorting and increases the rate of net clogging (Naman *et al.,* 2016; Muehlbauer *et al.,* 2017). In contrast, drift samplers fitted with coarse mesh nets do not retain the smaller invertebrates and may possibly lead to underestimation of invertebrate drift density and composition as observed in this study when using the 500 µm mesh net. However, coarse meshed drift nets may be more appropriate if the objective of the study is to analyze large sized invertebrate taxa. To use fine meshed nets, it is fundamental to determine the optimum time for sampling particular streams, to obtain representative samples and simultaneously avoid clogging.

5.2.3 Drift densities in relation to different exposure time

Previous studies that investigated invertebrate drift had different sampling times, such as between 5 minutes and 2 hours (Mathooko, 1996; Robinson *et al.,* 2004; Kennedy *et al.,* 2014; Naman *et al.,* 2016). In this study, the exposure time was maintained at intervals of 5, 10, 15, 20, 25, and 120 minutes. Drift densities were highest at the 5 minutes exposure time using the drift sampler fitted with a 100 µm mesh net and lowest at the 120 minutes exposure using the 500 µm mesh net in both biotopes. This implies that the drift sampler fitted with a fine meshed net was more appropriate for sampling invertebrate drift in the study river within the shorter sampling time frame. Modification of drift net filtering efficiency as a result of trapping coarse organic and sedimentary matter, i.e., clogging, has the impact of diminishing net entrance velocities, causing mistakes in the computation of sampled water volume, and consequently the invertebrate drift density (Faulkner and Copp, 2001).

Drift densities decreased with an increase in sampling time. This finding compared favorably with those of M'Erimba *et al.*(unpublished) who sampled drift in the Njoro River (polluted) and Kamweti River (unpolluted) during the day and night using a 100 µm drift net and exposure time of 5, 10, 15, 20 and 25 minutes. Their results showed that invertebrate drift was highest during the 5 minutes exposure time, nocturnal drift was higher than diurnal drift, and the drift densities were higher in the polluted river than in the unpolluted river. Contrasting findings have also been reported by some authors (Slack *et al.,* 1987; Faulkner and Copp, 2001) who reported that total taxa and abundance increase with length of sampling period. However, exposure time should be regulated to avoid clogging resulting from the suspended solids in stream water. Muehlbauer *et al.* (2017) performed a meta-analysis of 77 studies on the effect of drift net clogging on drift concentrations and found that drift nets clog in a non-linear fashion over time. Coarse suspended solids and net mesh size have a strong impact on clogging rates and the resultant drift data. Given that linear models are typically used in drift studies to derive the total volume of water filtered over a given drift net exposure time, invertebrate drift studies should consider the most appropriate model (e.g., inverse exponential, logistic) in which drift net clogging occur (Muehlbauer *et al.,* 2017). The non-linear fashion in which drift nets clog also suggest that the typically used method of calculating average water velocity from measurements taken only at the time when the experiment starts and at the end of invertebrates sampling brings in considerable error in invertebrate density values. This study established that a linear regression model can be

equally a good model of estimating drift densities if done progressively, that is, at intervals of 5 minutes. The same model predicted that the three nets would clog completely beyond 2 hours of exposure in the Njoro River.

Despite this, studies rarely take into consideration the most optimum sampling time for a drift net of a given mesh size and the suspended sedimentary and organic materials in a given lotic ecosystem. For example, Perić and Robinson (2015) investigated the spatio-temporal shifts of macroinvertebrate drift in glacial streams using drift samplers fitted with 100 µm mesh nets and found that sampling time could not exceed 30 minutes due to suspended matter. Overall, studies could overcome the problem of fine mesh nets clogging by sampling over short periods of time or modification of their sampling methods to avoid clogging without gross underestimation of invertebrate drift densities and composition.

5.2.4 Comparison of drift densities

Several studies in tropical and temperate streams have been conducted in different streams using different drift net mesh sizes and exposure time to quantify macroinvertebrate drift (Table 15). M'Erimba (2004) exposed a drift net of 100 µm for 15 minutes and found mean values of drift densities of 28.6 ± 2.7 ind. m^{-3} in the Njoro River, Kenya. In the current study the mean densities obtained at 15 minutes exposure using the 100 µm net mesh size were 38.85 ± 10.77 ind. m^{-3}. These densities differed probably due to variability in levels of disturbance over time (M'Erimba, 2014) or differences in the stream sections sampled. Mathooko and Mavuti (1994a) sampled the Naro Moru River, Kenya for 120 minutes using a 105 µm drift net mesh size and obtained densities of 0.19 - 0.42 ind. m^{-3}. In the current study the mean densities collected using a drift net mesh size of 100 µm at 120 minutes exposure was 11.91 ± 2.53 ind. m^{-3}. This could also be explained by the fact that the rivers had different levels of disturbances.

Leung *et al.* (2009) sampled in Husdon Creek in Canada for 5 minutes using a 250 µm drift net and found mean densities of 3.20 ± 1.58 ind. m^{-3} in the riffle and 1.51 ± 0.57 ind. m^{-3} in the pool habitats. In the current study the mean densities obtained by the same mesh size and exposure time were 63.73 ± 14.02 ind. m^{-3} in the riffle and 31.98 ± 4.95 ind. m^{-3} in the pool biotope. This demonstrates that generally high drift densities were in the riffle habitat. Collier and Wakelin (1992) exposed a 500 µm net for 120 minutes in Manganuiateao River in New Zealand, obtained drift densities of 0.18 - 1.51 ind. m^{-3}. In the current study drift densities obtained using the 500

µm drift net at 120 minutes exposure duration were 6.21± 0.89 ind. m^{-3}. The reason for the difference in densities is that the Manganuiateao River has its flow and water quality protected by a National Water Conservation Order (Collier and Wakelin, 1992) whilst the Njoro River is not protected. In Magpie River in Ontario, Evan *et al.* (2016) sampled for 15 minutes using a drift net of 500 µm and obtained a mean of 2.3 ± 0.16 ind. m^{-3} while in the current study drift densities obtained at the same exposure time using the same mesh size was 12.32 ± 2.28 ind. m^{-3}. The differences in densities could be probably due to the fact that Magpie River is regulated and also inter-habitat ecological and physical differences.

Table 15: Commonly used drift mesh sizes and exposure time in different rivers according to literature.

River	Country	Exposure (minutes)	Mesh size	Author
Manganuiateao	New Zealand	120	500 µm	Collier and Wakelin, (1992)
Naro Moru	Kenya	120	105 µm	Mathooko and Mavuti, (1994)
Spol	Switzerland	15-30	400 µm	Robinson *et al.*, (2004)
Njoro & Ellegirini	Kenya	15	100 µm	M'Erimba, (2004)
Alex's Creek	New Zealand	60	400 µm	Hansen and Closs (2007)
Murrumbidgee	Australia	10	250 µm	Thornton, (2008)
Husdon Creek	Canada	294-330	250 µm	Leung *et al.*, (2009)
Colorado	Arizona	5	250 µm	Kennedy *et al.*, (2014)
Magpie	Ontario	15-30	500 µm	Evan *et al.*, (2016)
Njoro	**Kenya**	**5 - 120**	**100 µm**	**Current study**
Njoro	**Kenya**	**5 - 120**	**250 µm**	**Current study**
Njoro	**Kenya**	**5 - 120**	**500 µm**	**Current study**

5.2.5 Drift densities in relation to net position

The highest mean drift densities in both biotopes were recorded in the 100 µm drift sampler placed at the left bank and the lowest were obtained at the right bank using the 500 µm drift sampler. The densities at the left bank differed highly significantly with those at the right bank and mid-stream in the riffle while there was no significant difference in drift densities obtained

from the three drift positions in the pool biotope. The high invertebrate drift density at the left bank could be attributed to the high hydraulic disturbance due to the tilting topography. This made the invertebrates more susceptible to drift. The current finding concurred with that of M'Erimba (2004) who found that drift densities increased with an increase in discharge in the Njoro and Ellegirini Rivers.

Elliott (1970) described experiments on spatial variation of drift by considering horizontal variation using seven nets. The whole water column across the stream was sampled and concluded that the differences in drift can be attributed to either random errors or differences in velocity between nets. Similarly, Neale (1999) examined spatial distribution of drift in the Bere Stream in Dorset and the results showed a high degree of heterogeneity in the cross-sectional drift that may be related to water velocity. Further, results by Faulkner and Copp (2001) showed that drift densities in a stream are spatially heterogenous especially if the sample is taken in a small net near the bed in the centre of the channel. The authors suggest that if a single net must be used, it should be placed to one side of centre in the stream since drift collections can be affected significantly by even quite small changes of bed sampling positions even within the cross-section. The observation of high drift densities at the left bank in this study stream was in accord with the findings of Weber (2006). The author observed that mean drift density near the channel banks is higher than that closer to the centre of the channel. He concluded that invertebrates either begin and end their drift more frequently near the banks or direct themselves from wherever they leave the bed towards the banks causing higher concentrations in the drift there.

High hydraulic disturbance at the benthic zone may also greatly increase drift of benthic organic matter, and consequently the drift rate of invertebrates due to reduction of refugia from predators, food and attachment surfaces. For example, Siler *et al.* (2001) investigated the effect of coarse organic matter reduction on invertebrate drift in streams and found that the stream deprived of detrital resources had significantly higher invertebrate drift presumably due to increased movements by the invertebrates in search of areas of abundant food resources and other habitat areas. This finding also concurred with that of Mbaka, *et al*. (2015) in the Njoro River where high coarse particulate organic matter input from the riparian vegetation resulted in increased macroinvertebrate density. Furthermore, O'Hop and Wallace (1983) reported a positive

relationship between macroinvertebrate drift and drifting detritus in a North Carolina Creek and inferred that detritus acted as a disturbance agent.

5.3 Relationship between physico-chemical variables and drift

In this study, temperature, conductivity, dissolved oxygen and turbidity correlated with drift densities whereas oxygen saturation, pH, velocity and discharge did not correlate with drift densities in the two biotopes. Some studies have also reported similar observations of insignificant correlations between velocity and drift densities (e.g. Hansen and Closs 2007). In contrast, Leung *et al.* (2009) observed that there was only a weak positive relationship between drift abundance and velocity at the mesohabitat scale. In addition, other studies found significant correlations between the two variables (Keeley and Grant, 1997; Nislow *et al.,* 1998; Rosenfeld *et al.,* 2000).

5.4 Benthic macroinvertebrate structure and composition

5.4.1 Benthic macroinvertebrates in the riffle and pool biotopes

Several studies on benthic macroinvertebrates have been conducted in the Njoro River (Shivoga, 2001; Makoba *et al.,* 2008; Makoba *et al*., 2010; Mbaka *et al.,* 2015). In the current study, the mean benthos densities obtained were 691.87 ± 373.55 individuals m^{-2}, with simuliids and chironomids (all dipterans) dominating the riffle and pool biotopes, respectively. A similar finding of dipterans dominating the benthos in the Njoro River was reported by Makoba *et al*. (2010). Higher macroinvertebrates densities of 1760.95 ± 308.27 individuals m^{-2} were reported in the same river by M'Erimba *et al.* (2014) during low discharge when the intensity of disturbances was high. The findings by the same authors that Oligochaetes were the most abundant group contrasted the findings in the current study.

Many authors have reported differences in macroinvertebrate community structure among stream habitats (Ramírez *et al.,* 1998; Armitage and Cannan, 1999; Tickner *et al.,* 2000; Baptista *et al.,* 2001; Bonada *et al.,* 2006; Principe *et al.,* 2007). Some studies reported the lowest values of diversity and richness in habitats characterized by fine substrate (Armitage and Cannan 1999; Tickner *et al.,* 2000; Fenoglio *et al.,* 2004), while the highest values were found in the most heterogeneous environments (Beisel *et al.,* 2000; Principe and Corigliano 2006). There was a higher diversity of benthic macroinvertebrates in the pool than in the riffle biotope, contrasting the findings of Grossman (2014) which indicated that riffles have higher macroinvertebrate

diversities than pool biotope. This occurrence could have been due to constant disturbances at the riffle biotope through, laundry/washing (personal observation) which were absent at the pool biotope.

There were higher benthic densities in the riffle than in the pool biotope in this study. The riffle biotopes are known to have stable substrates thus act as macroinvertebrate refugia from disturbances (Matthaei *et al.,* 2000). This could contribute to high local abundances in drift, while unstable areas may have low densities of benthic invertebrates and hence make a smaller contribution to the drift (Graesser, 1988). Furthermore, other studies have also found similar observations of higher densities in the riffle than in the pool biotopes (Brown and Brussock 1991; Halwas *et al.*, 2005) which may lead to higher drift (Hammock and Wetzel, 2013; Weber *et al.,* 2014). Each habitat unit of a lotic system is associated with a particular macroinvertebrate assemblages or guilds whose structure and composition are mainly dictated by substrate and flow type (Ramírez *et al.*, 1998; Tickner *et al.*, 2000).

5.4.2 Proportions of benthos in drift

There were nine additional taxa of macroinvertebrates in drift than in benthos. This could have been due to introduction of upstream, riparian and other allochthonous drifters into the study reach and into the channel (Pringle and Ramírez, 1998). Likewise, drift components may also differ from the benthic components because not all organisms have the same predisposition to drifting (Barbero *et al.,* 2013). The percentage proportions of benthos that drifted were higher in the pool biotope than in the riffle biotope, this implies that pools acts as traps to the drifting macroinvertebrates. In both biotopes drift and benthic community were dominated by insects and the most abundant orders were Ephemeroptera and Diptera. The same insect taxa showed high densities in drift and benthic community in neotropical streams (Ramírez and Pringle, 1998, 2001). In the present study the range proportions of benthos in drift was between 0.04 - 0.71%. Close to similar results were obtained by Mathooko (1996) (0.03-0.08%) in the Naro Moru River, Kenya. Inaddation, Moog and Heinisch (1991) also obtained closer ranges of 0.008 - 0.70% in Wagrainer Ache, Austria. However, M'Erimba *et al.* (2014) found relatively higher ranges of proportions, 0.04 - 22.43% in the Njoro River, Kenya. Other studies have found lower range of proportions of benthos in drift (e.g. Grzybkowska, *et al.,* 1993 ; Scarsbook and Townsend, 1993).

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

a) Riffles contribute high drift densities and diverse organisms in streams than pools. Drift is dominated by Diptera (Chironomidae and Simuliidae) and Ephemeroptera (Baetidae and Caenidae) in the Njoro River.

b) Drift in streams depends on the type of mesh-size used, the position of the nets, habitat type (biotope), as well as sampling duration among other factors.

c) Pools act as traps of benthos in streams as demonstrated by high proportions of benthos in the pool biotope in this study.

d) Drift could offer addition information that could easily be missed out if benthos are considered alone as was demonstrated in this study where additional nine taxa occurred in drift but not in benthos

6.2 Recommendations

a) Future studies should incorporate both drift and benthos in sampling in order to get more informative results, since this study obtained more macroinvertebrates in drift than in benthos. Hence, drift sampling should be included as a standard complementary tool to benthic sampling in bioassessment protocols of tropical streams.

b) Future studies should consider seasonality aspect as well as time of the day in addition to drift net mesh size, position, exposure duration and biotope.

c) Exposure time has a great effect on the reliable quantification of drift and studies should assess the most favorable time needed to obtain representative estimates of drift densities in streams of various categories.

d) Drift should be explored further as a possible rapid bio-assessment tool in streams in future studies

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APPENDICES

Appendix 1: Drift densities of the macroinvertebrate groups (ind.m^{-3}) in the Njoro River biotopes.

	Riffle			Pool		
Taxa	**100 µm**	**250 µm**	**500 µm**	**100 µm**	**250 µm**	**500 µm**
Aeshnidae	0.04	0.00	0.01	0.02	0.00	0.08
Baetidae	27.71	49.55	16.44	22.69	22.53	17.71
Caenagrionidae	0.04	0.16	0.04	0.06	0.03	0.13
Caenidae	18.64	11.34	5.96	5.84	6.69	5.73
Ceratopogonidae	0.68	4.23	0.53	1.95	0.22	0.20
Chironomidae	46.63	59.91	18.36	44.31	21.08	8.65
Culicidae	4.62	7.31	6.35	2.94	2.29	2.24
Dixidae	0.00	0.00	0.00	0.00	0.00	0.00
Elmidae	0.58	1.12	0.34	0.23	0.25	0.15
Gyrinidae	0.00	0.00	0.00	0.00	0.01	0.01
Helodidae	0.19	0.07	0.00	0.05	0.04	0.01
Heptageniidae	0.83	0.46	0.06	0.47	0.50	0.38
Hydrachnellae	0.02	0.08	0.00	0.00	0.00	0.00
Hydraenidae	0.00	0.00	0.00	0.00	0.01	0.00
Hydrophilidae	0.00	0.00	0.00	0.04	0.00	0.03
Hydropsychidae	0.91	0.22	0.85	0.12	0.18	0.06
Leptoceridae	0.21	0.00	0.05	0.02	0.04	0.01
Libellulidae	0.00	0.00	0.12	0.00	0.00	0.00
Muscidae	0.02	0.01	0.02	0.00	0.04	0.00
Oligochaeta	0.00	0.07	0.02	0.06	0.00	0.02
Psychodidae	0.00	0.03	0.00	0.00	0.00	0.02
Pyralidae	0.10	0.10	0.25	0.12	0.03	0.08
Simuliidae	46.75	10.83	6.11	9.73	5.96	3.09
Sphaeriidae	0.00	0.00	0.04	0.00	0.00	0.00
Tipulidae	0.00	0.03	0.00	0.00	0.05	0.00
Veliidae	0.00	0.00	0.03	0.00	0.00	0.00

Appendix 2: Species list and mean densities (ind.m^{-2}) of benthic macroinvertebrates collected in the riffle and pool biotopes.

Taxa	**Riffle**	**Pool**
Baetidae	1692.79	996.87
Caenidae	47.02	313.48
Ceratopogonidae	59.56	141.07
Chironomidae	4510.97	2068.97
Culicidae	53.29	125.39
Elmidae	507.84	316.61
Helodidae	3.13	31.35
Heptagenidae	75.24	984.33
Hydrachnellae	15.67	6.27
Hydrophilidae	3.13	0.00
Hydropsychidae	608.15	188.09
Leptoceridae	15.67	40.75
Libellulidae	0.00	34.48
Muscidae	9.40	3.13
Pyralidae	3.13	0.00
Simuliidae	9821.32	677.12
Tipulidae	169.28	0.00
Mean ± SE	1035.04 ± 612.77	348.70 ± 134.33

Appendix 3: Mean through flow (m^{-3}) at different positions in the riffle and pool biotopes in the Njoro River. Bracketed values are ± SE.

Biotope		**Net position**		
Riffle	**Mesh size**	**Right-bank**	**Mid-stream**	**Left bank**
	100 µm	**3.15** (0.70)	**2.43** (0.57)	**3.67** (0.83)
	250 µm	**2.39** (0.62)	**2.03** (0.51)	**4.55** (0.83)
	500 µm	**2.60** (0.61)	**2.60** (0.57)	**4.07** (0.88)
Pool	**100 µm**	**4.77** (0.94)	**3.94** (0.79)	**3.34** (0.73)
	250 µm	**4.55** (0.95)	**3.87** (0.74)	**3.53** (0.70)
	500 µm	**5.04** (0.98)	**3.60** (0.69)	**4.16** (0.81)

Appendix 4: Pearson's rank correlation matrix of the physico-chemical and drift densities for the riffle and pool biotopes. *Significant correlations at $p < 0.05$. ** Significant correlations at $p < 0.001$.

Riffle									
Variable	**pH**	**DO**	**EC**	**Temperature**	**Turbidity**	**Discharge**	**100 µm**	**250 µm**	**500 µm**
pH									
DO	**-0.34****								
EC	**0.44****	**-0.49****							
Temperature	**0.82****	**-0.55****	**0.52****						
Turbidity	**-0.46****	**0.51****	**-0.44****	**-0.53****					
Discharge	-0.06	**-0.33***	-0.03	0.15	-0.07				
100 µm	-0.06	0.15	-0.2	-0.214	0.01	0.02			
250 µm	-0.04	0.17	-0.18	-0.136	0.04	-0.04	**0.65****		
500 µm	-0.08	0.22	**-0.23****	**-0.23****	-0.03	-0.03	**0.87****	**0.80****	
Pool									
pH									
DO	**-0.47****								
EC	**0.46****	**-0.48****							
Temperature	**0.65****	**-0.73****	**0.49****						
Turbidity	**-0.42****	**0.51****	**-0.63****	**-0.40***					
Discharge	-0.2	-0.14	0.19	0.04	-0.249				
100 µm	-0.1	**0.31***	**-0.45****	**-0.28***	**0.35***	-0.16			
250 µm	-0.16	0.10	-0.05	-0.1	-0.05	-0.12	0.08		
500 µm	-0.17	**0.26***	**-0.31****	**-0.30***	**0.31***	-0.06	0.34	**0.36***	