Invertebrate Drift Densities in the Njoro and Kamweti Rivers in the Kenyan Highlands that Differ in the Level of Anthropogenic Disturbances

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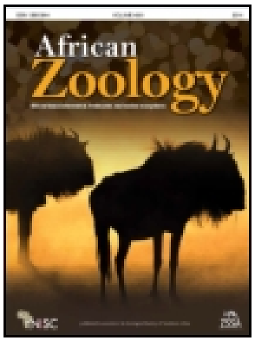

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Invertebrate drift densities in the Njoro and Kamweti Rivers in the Kenyan highlands that differ in the level of anthropogenic disturbances

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Invertebrate drift is one of several fundamental ecological processes in streams. However, little is known about the dynamics of invertebrate drift in Kenyan streams. In this study, we assessed invertebrate drift in two rivers, i.e. Njoro and Kamweti, that differ in the level of anthropogenic disturbances, between February and March, 2016. The aim was to evaluate the effect of river sampling duration (5, 10, 15, 20 and 25 min) and sampling period (day or night) on invertebrate drift densities. The 5-minute sampling period resulted in significantly higher mean drift densities than the other time intervals in both rivers. The highest mean drift density (2.0 ± 0.9 individuals m^{-3}) was recorded at the Njoro River during the day, whereas the lowest drift density (0.3 ± 0.2 individuals m^{-3}) was recorded at the Kamweti River during the day. A strong nocturnal drift pattern was noted at the less disturbed river (Kamweti). The present results suggest that anthropogenic perturbations influence invertebrate drift densities, and sampling duration and sampling period are important factors to consider when sampling invertebrate drift.

Keywords: anthropogenic impacts, drift, Kenya, sampling duration, sampling period

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Introduction

Invertebrate drift, the downstream movement of organisms in the water current, is an ecologically important phenomenon in stream ecosystems (Brittain and Eikeland 1988; Allan 1995). Drift plays a key role in spatial distribution of stream invertebrates, aiding recolonisation of stream sections after disturbances (Williams and Hynes 1976). Drift is a way for invertebrates to avoid predation pressure, and is a source of food for drift-feeding fishes (Mathooko 2000; Akbaripasand et al. 2014; Naman et al. 2016). In addition, the composition of drift in low-order streams typically reflects the benthic community and is a useful means of evaluating the composition of benthos (Ramírez and Pringle 2001). Invertebrate drift can be caused by accidental displacement from the substrates, change in abiotic factors (e.g. high discharge and photoperiod), biotic factors (e.g. benthic density), anthropogenic disturbances (pesticides input and physical disturbances) or as a behavioural mechanism occurring during foraging or when escaping from predators (Brittain and Eikeland 1988; Lauridsen and Friberg 2005; Henn et al. 2014; Naman et al. 2016). For example, Kennedy et al. (2014) sampled invertebrate drift, for 5 min, to evaluate the relationship between drift, discharge and benthic densities in a large regulated river. The authors found that an increase in discharge caused increased drift densities of invertebrates such as *Gammarus* sp., *Potamopyrgus* sp. and Chironomidae. On the other hand, drift densities of the blackfly larvae (*Simulium* sp.) decreased, by over 80%, as discharge increased. Drift of invertebrate taxa was positively correlated to benthic invertebrate density. Grzybkowska et al. (2004) sampled invertebrate drift, over a period of 10 min, and found that drift densities were highest in riffle habitats, compared with that of pools, and in spring and autumn in comparison to winter. An additional study investigated the factors influencing invertebrate drift in small forest streams, by sampling hourly, and found low drift rates and no clear diel patterns (Kerby et al. 1995). The authors suggested that the low drift rates may have been caused by the low flow discharge experienced during the study period. Winkelmann et al. (2008) evaluated the effect of benthivorous fish on stream invertebrate and found that the presence of gudgeon (*Gobio* sp.) and stone loach (*Barbatula* sp.) reduced the nocturnal drift of Ephemeroptera (*Baetis* sp.). The authors suggested that the observed drift patterns were caused by behavioural changes of invertebrates due to the presence of predator fish. In addition, anthropogenic disturbances in the areas near a stream, and instream, have an effect on the composition and densities of invertebrates in benthos and drift (Mathooko 2000; Hoover et al. 2007).

Anthropogenic disturbances in riparian areas affect the link between terrestrial and aquatic ecosystems (Naiman and Décamps 1997). For example, clearance of vegetation produces a cascade of effects in adjacent stream ecosystems, including increased sediment load, modified stream hydrology, increased physical disturbances by

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humans and domestic animals, and changes in primary and secondary productivity (Michaelis 1984; Hartman et al. 1996; Stone and Wallace 1998). Consequently, these factors affect the invertebrate drift dynamics in streams.

Despite the vast amount of information on drift, this phenomenon has received relatively little attention in Kenyan rivers, with most studies focusing primarily on invertebrates in benthos (e.g. Mathooko and Mavuti 1992; Mathooko 1998; Aura et al. 2011). The aim of the current study, therefore, was to investigate the effect of sampling duration and sampling period (day or night) on the densities of drifting invertebrates in two Kenyan rivers with different levels of anthropogenic disturbances.

Materials and methods

Study area and sites

The study sites were located at two reaches of the Njoro and Kamweti rivers (Table 1). The Njoro River is a second-order stream that emanates from the Eastern Mau Hills in the Rift Valley region of Kenya. The river discharges into Lake Nakuru, a Rift Valley soda lake. The Kamweti River originates from Mount Kenya in Central Kenya and is a tributary of the Tana River. In the Njoro River, the left bank has lower vegetation density than the right bank, and livestock are brought to the river to drink water (Figure 1). The left bank borders the road leading to Nakuru town, whereas the right bank borders a small-scale farm. On the Kamweti River, the left bank has lower vegetation density compared with that of the right bank (Supplementary Figure S1). However, no humans or livestock were observed coming to the river during the study period.

Habitat assessment and invertebrate samples collection and processing

Habitat assessment and sampling was undertaken four times between 27 February and 28 March 2016, at the Njoro River, and five times between 1 March and 29 March 2016 at the Kamweti River (Supplementary Table S1). Temperature, pH and dissolved oxygen concentration were measured *in situ* using portable sensors. A tape measure and a graduated rod were used to determine river width and depth, respectively. Current velocity was determined at 60% of the total water depth using a flow meter. The velocity, width and depth measurements were used in the calculation of water discharge following Gordon et al. (2004). The vegetation density cover and river substrates composition were evaluated visually (Bain and Stevenson 1999; Paletto and Tosi 2009). Water samples were analysed in the laboratory for nitrites, nitrates, ammonium and total phosphorous following the American Public Health Association (APHA 1992).

Invertebrates were sampled using two drift samplers (mouth size: 0.1 m^2) placed side-by-side at the middle of the river and fitted with flow-meters (Elliott 1970) and 100 μm mesh-size nets. The flow-meters were used to measure the flow velocity at the aperture of each sampler, to calculate the volume of water filtered by the net. The drifting invertebrates were sampled consecutively at 5, 10, 15, 20 and 25 min intervals, during the day (11:00–13:00) and night (20:00–22:00). Two replicates, one from each net, were collected during each time interval and the invertebrates collected at the rear end of the drift sampler's nets were emptied into labelled polythene bags and preserved using 4% formalin solution. The samples were taken to the laboratory and washed through two sieves (500 μm and 2 mm), to separate invertebrates from stones and coarse particulate organic matter. The invertebrates were identified and counted under a dissecting microscope to the lowest possible taxonomic level (Gerber and Gabriel 2002). Invertebrate density was expressed as individuals per cubic metre (Brittain and Eikeland 1988).

Data analysis

The effect of sampling duration (5, 10, 15, 20 and 25 min), sampling period (day and night) and stream on invertebrate drift density was evaluated using linear mixed-effect models (LMMs), with sampling duration, sampling period and stream as fixed factors, and stream as an interaction term with sampling duration and period. The Holm

Table 1: Summary of the geographical location and habitat characteristics of the study sites on the Njoro and Kamweti rivers. Values in parentheses are the SE

	Njoro River	Kamweti River
Latitude	00°22.39′ S	00°03.18′ N
Longitude	35°56.06′ E	37°12.25′ E
Altitude (m)	2 255	2 163
Vegetation cover (%)	30	50
pH	8.1 (0.1)	7.7 (0.08)
Temperature (°C)	18.3 (0.2)	16.7 (0.07)
Dissolved oxygen (mg L^{-1})	6.7 (0.07)	8 (0.04)
Discharge (L s^{-1})	0.003 (0.004)	0.005 (0.0007)
Total suspended solids (mg L^{-1})	11.6 (0.1)	9.2 (0.2)
Nitrites (mg L^{-1})	0.18 (0.006)	0.01 (0.001)
Nitrates (mg L^{-1})	1.4 (0.06)	0.03 (0.001)
Ammonium (mg L^{-1})	0.1 (0.001)	0.06 (0.004)
Total phosphorus (mg L^{-1})	0.02 (0.005)	0.05 (0.003)
Substrate composition	Sand and mud (80%), cobbles (10%), organic matter (10%)	Sand and mud (40%), boulders (5%), cobbles (20%), gravel (10%), organic matter (25%)

correction method was used to adjust *p*-values for multiple testing (Holm 1979), and we report the corrected *p*-values. All models were inspected visually following Zuur et al. (2009). Models that were statistically significant were compared using Tukey contrasts (Hothorn et al. 2008). All statistical tests were carried out using R 2.14.2 software (R Development Core Team 2012).

Figure 1: The reach sampled at the Njoro River

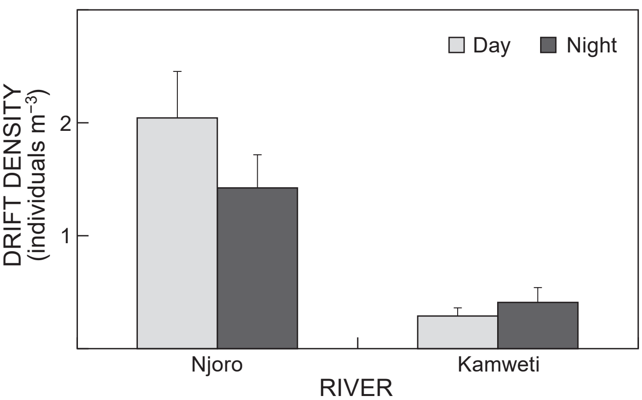

Figure 2: Mean invertebrate drift densities (individuals m^{-3}) in the Njoro and Kamweti rivers during day and night sampling time intervals. Vertical bars indicate the SE (n = 180)

Table 2: *F*-ratio and *p*-values for the mixed-effects models evaluating the effects of sampling duration, sampling period and stream on invertebrate drift density. Significant values ($p < 0.05$) are highlighted in bold. df = degrees of freedom, MS = mean squares

Effect	df	MS	*F*-ratio	*p*-value
Sampling duration	4	6.9	17.7	**0.0007**
Sampling period	1	0.8	2.1	0.5
Stream	1	69.2	176.6	**0.0007**
Sampling duration × Sampling period	4	0.05	0.1	1
Sampling duration × Stream	4	2.4	6.1	**0.0007**
Sampling period × Stream	1	4.7	12.1	**0.003**
Sampling duration × Sampling period × Stream	4	0.3	0.8	1

Results

Invertebrates

The highest mean stream invertebrate drift density (2.0 ± 0.9 individuals m^{-3}) was recorded at the Njoro River, whereas the lowest (0.3 ± 0.2 individuals m^{-3}) mean invertebrate drift density was recorded at the Kamweti River (Figure 2). Invertebrate drift density was significantly influenced by sampling duration, stream and sampling duration × stream and sampling period × stream (Table 2). However, sampling period, sampling duration × sampling period and sampling duration × sampling period × stream had non-significant effects on invertebrate drift (Table 2).

In the Njoro River, drift samples were dominated by Chironomidae and Baetidae (Figure 3), and mean invertebrate density was highest, by up to 0.7 fold, during the day. In the Kamweti River, drift samples were dominated by Baetidae (Figure 4) and mean invertebrate density was highest, by up to 1.4 fold, at night. Generally, Baetidae and Chironomidae were the most commonly encountered invertebrates in both rivers. The mean densities (individuals m^{-3}) of drifting invertebrate taxa at the Kamweti and Njoro rivers are presented in Supplementary Tables S2 and S3.

In the Njoro River, mean invertebrate drift density (individuals m^{-3}) was highest (day: 3.6 ± 0.7; night: 2.5 ± 0.6) and lowest (day: 1.1 ± 0.2; night: 0.8 ± 0.1) during the 5 min and 25 min sampling durations, respectively (Figure 5). In the Kamweti River, mean invertebrate drift density was also highest (day: 0.57 ± 0.2; night: 0.87 ± 0.3) during the 5 min sampling duration compared with those of the 10, 15, 20 and 25 min sampling durations (Figure 6).

Habitat conditions

The altitude (metres above sea level) of the study sites varied from 2 163 m (Kamweti River) to 2 255 m (Njoro River). The Kamweti River study site had higher (50%) vegetation cover intensity compared with that at the Njoro River site (30%). Mean water temperature ranged from

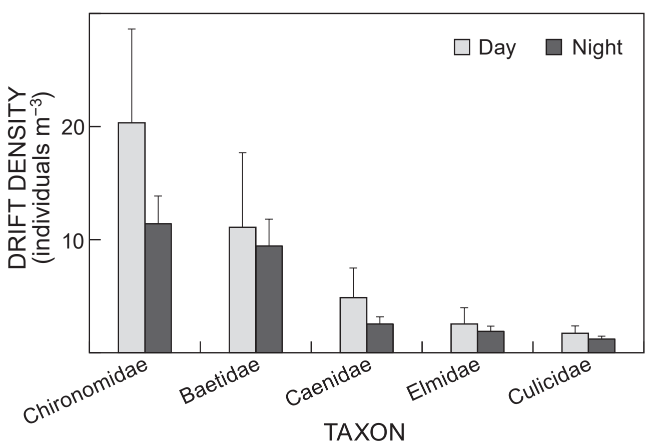

Figure 3: Mean invertebrate drift densities (individuals m^{-3}) of the major invertebrate taxa during day and night sampling time intervals at the Njoro River. Vertical bars indicate the SE (n = 180)

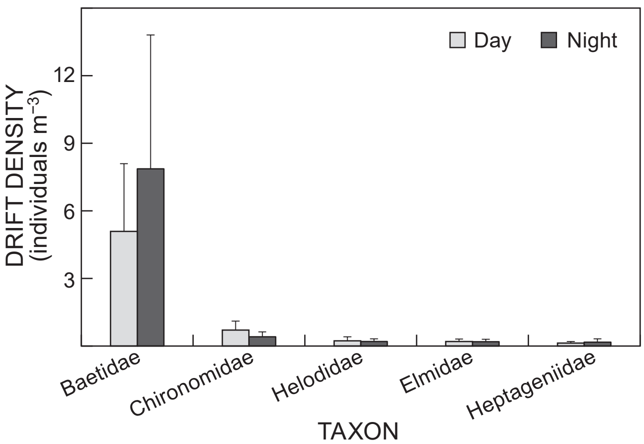

Figure 4: Mean invertebrate drift densities (individuals m^{-3}) of the major invertebrate taxa during day and night sampling time intervals at the Kamweti River. Vertical bars indicate the SE (n = 180)

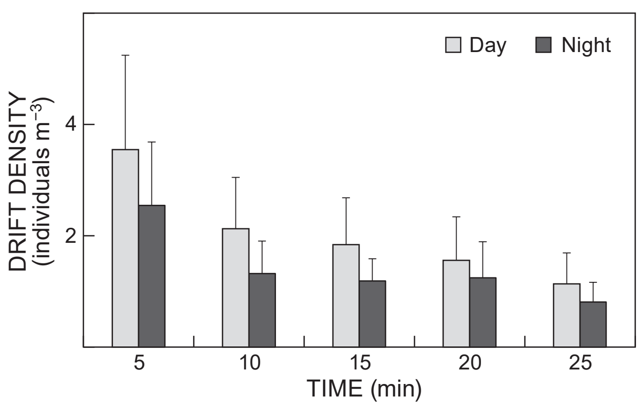

Figure 5: Mean invertebrate drift densities (individuals m^{-3}) during day and night time intervals (0–25 min) at the Njoro River. Vertical bars indicate the SE (n = 180)

18.3 °C (Njoro River) to 16.7 °C (Kamweti River). The most common substrate type at the Njoro River was sand and mud (80%), whereas the Kamweti River had lower fine substrates content (40%). Mean dissolved oxygen content ranged from 6.7 mg L^{-1} (Njoro River) to 8.0 mg L^{-1} (Kamweti River). The pH, discharge, total suspended solids, nitrates, ammonium and total phosphorus ranged from 8.1 (Njoro River) to 7.7 (Kamweti River), 0.003 L s^{-1} (Njoro River) to 0.005 L s^{-1} (Kamweti River), 9.2 mg L^{-1} (Kamweti River) to 11.6 mg L^{-1} (Njoro River), 0.03 mg L^{-1} (Kamweti River) to 1.4 mg L^{-1} (Njoro River), 0.06 mg L^{-1} (Kamweti River) to 0.1 mg L^{-1} (Njoro River) and 0.02 mg L^{-1} (Njoro River) to 0.05 mg L^{-1} (Kamweti River) (Table 1).

Discussion

Invertebrates

The highest mean invertebrate drift density was recorded at the Njoro River during the day, in contrast to the Kamweti River where the highest mean density was recorded at

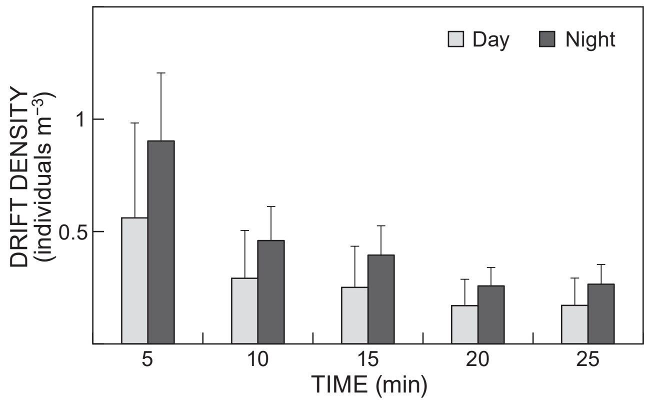

Figure 6: Mean invertebrate drift densities (individuals m^{-3}) during day and night time intervals (0–25 min) at the Kamweti River. Vertical bars indicate the SE (n = 180)

night. The high mean density of drifting invertebrates at the Njoro River during the day is likely attributable to the physical anthropogenic disturbances (e.g. cattle drinking water; Figure 1) observed at the site (see Mathooko 2001). Physical disturbance of stream bed substrates can induce accidental invertebrate drift by reducing invertebrate refugia, through sediment compaction and reduced organic matter, and by increasing fine sediments (e.g. sand and mud; Table 1) (Borchardt 1993). For example, Suren and Jowett (2001) investigated the effect of deposited sediment on invertebrate drift and found that input of fine sediment caused invertebrate drift to increase significantly. Similarly, Borchardt (1993) investigated the effect of flow and woody debris on drift loss of benthic invertebrates and showed that increase in flow caused the drift of *Ephemerella* sp. and *Gammarus* sp. to increase significantly. On the other hand, an increase in woody debris caused the drift of invertebrates to decrease significantly, presumably due to increased refugia from predators. The comparatively high invertebrate drift at the Njoro River also may be attributed to the relatively high concentrations of nutrients (e.g. ammonium and nitrites; Table 1) recorded at the site. O'Callaghan et al. (2015) demonstrated that the addition of nutrients and sediment to a system induced an increase in invertebrate drift.

Increase in the concentration of nutrients in aquatic ecosystems have been reported to have deleterious effects on aquatic invertebrate communities (Yuan 2010; Ashton et al. 2014; Alexander et al. 2016). For example, invertebrates have been shown to respond to runoff from agricultural areas through augmented drift (Olsen and Watzin 2009). Drift enables invertebrates to escape adverse environmental conditions and colonise new stream habitats (Naman et al. 2016). The observed higher drift densities in the Njoro River may have been caused by other factors, such as increased temperature, input of pesticides or physical dislodgement from the substrates (Wojtalik and Waters 1970; Davies and Cook 1993; Naman et al. 2016).

The higher invertebrate drift densities at the Kamweti River during the night has also been recorded in other streams (e.g. Flecker 1992; Ramírez and Pringle 1998;

Romaniszyn et al. 2007). For example, Romaniszyn et al. (2007) investigated invertebrate drift in southern Appalachian Mountain streams, USA, and showed that drift densities were highest in spring and early summer and that drift rates were highest at sunset. Ramírez and Pringle (1998) assessed invertebrate drift in a neotropical stream, Costa Rica, and found that drift was strongly nocturnal. An additional study of neotropical streams found that drift was primarily nocturnal in streams with fish (Flecker 1992). The high drift densities at night are found in streams where diurnal predators, such as fish, are present (Flecker 1992). In these streams, and in the current study, drift was mainly dominated by mayflies and dipterans (e.g. Chironomidae) (Flecker 1992; Pringle and Ramírez 1998; Callisto and Goulart 2005). In particular, the high noctural drift densities of baetids may be due to a behavioural adaptation to avoid drift-feeding fish that are active during the day, as has been demonstrated in other studies (Tikkanen et al. 1994; Huhta et al. 2000; Winkelmann et al. 2008). The high densities of chironomids and baetids could also be as a result of high densities of these taxa in benthos (e.g. Kibichii et al. 2007; Mbaka et al. 2014; M'Erimba et al. 2014). Studies conducted elsewhere also established a link between invertebrate drift rates and benthic densities (e.g. Fonseca and Hart 1996).

Studies that investigated invertebrate drift have had different sampling times, such as between 5 min and 1 h (e.g. O'Hop and Wallace 1983; Culp et al. 1994; Kerby et al. 1995; Kennedy et al. 2014). In the current study, we investigated the effect of sampling duration (i.e. 5, 10, 15, 20 and 25 min) on invertebrate drift. Invertebrate drift densities were significantly higher during the 5 min sampling than during the other sampling intervals. This suggests that 5 min is the optimal time for rapid bioassessment of invertebrate drift in the Njoro and Kamweti rivers. Sampling duration has a considerable impact on the reliable quantification of drift and studies should assess the most favourable time needed to obtain representative estimates of drift densities in streams. Depending on the level of suspended solids in stream water, sampling duration should be regulated to avoid clogging of the net because clogged nets have lower filtration efficiencies and may introduce biases in the resultant drift data (Muehlbauer et al. 2017). For example, Perić and Robinson (2015) investigated invertebrate drift in glacial streams and found that net clogging by glacial flour prevented sampling beyond 30 min.

Habitat conditions

The low (30%) vegetation cover at the Njoro River, compared with that at the Kamweti River (50%), may be attributed to the increased human activities, such as clearance of riparian vegetation and grazing of livestock along river banks. A previous study on the Njoro River established that human-related activities such as grazing led to reduction in riparian vegetation cover and that the effect was especially severe around livestock watering points (Mathooko and Kariuki 2000). Removal of riparian vegetation cover results in higher mean water temperature and has been demonstrated by Bowler et al. (2012) through meta-analysis. The high mean values of nitrites, nitrates and ammonium in the Njoro River, compared with those of the Kamweti River, may be attributed to human-related perturbations, such as livestock grazing and farming near the river, that may introduce dissolved substances in runoff (e.g. Moss 2008; Roche et al. 2013). Such perturbations may also lead to soil erosion and transport of fine sediment into streams and increase the content of suspended solids.

Conclusions

In conclusion, sampling duration and stream had significant, and dependent, effects on invertebrate drift densities and higher drift densities may be encountered in anthropogenically disturbed streams. Future studies should consider sampling different habitats (e.g. pools and riffles) and seasons.

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References

Akbaripasand A, Ramezani J, Lokman PM, Closs GP. 2014. Can drifting invertebrates meet the energy requirements of drift-feeding fish? A case study on *Galaxias fasciatus. Freshwater Science* 33: 904–914.

Alexander AC, Culp JM, Baird DJ, Cessna AJ. 2016. Nutrient–insecticide interactions decouple density-dependent predation pressure in aquatic insects. *Freshwater Biology* 61: 2090–2101.

Allan JD. 1995. *Stream ecology: structure and function of running waters*. London: Chapman and Hall.

APHA (American Public Health Association). 1992. *Standard methods for examination of water and waste water* (18th edn). Washington, DC: APHA.

Ashton MJ, Morgan RP, Stranko S. 2014. Relations between macroinvertebrates, nutrients, and water quality criteria in wadeable streams of Maryland, USA. *Environmental Monitoring and Assessment* 186: 1167–1182.

Aura CM, Raburu PO, Herrmann J. 2011. Macroinvertebrates' community structure in Rivers Kipkaren and Sosiani, River Nzoia basin, Kenya. *Journal of Ecology and the Natural Environment* 3: 39–46.

Bain MB, Stevenson NJ. 1999. *Aquatic habitat assessment: common methods*. Bethesda, MD: American Fisheries Society.

Borchardt D. 1993. Effects of flow and refugia on drift loss of benthic macroinvertebrates: implications for habitat restoration in lowland streams. *Freshwater Biology* 29: 221–227.

Bowler DE, Mant R, Orr H, Hannah DM, Pullin AS. 2012. What are the effects of wooded riparian zones on stream temperature? *Environmental Evidence* 1: 3.

Brittain JE, Eikeland TJ. 1988. Invertebrate drift — a review. *Hydrobiologia* 166: 77–93.

Callisto M, Goulart M. 2005. Invertebrate drift along a longitudinal gradient in a neotropical stream in Serra do Cipó National Park, Brazil. *Hydrobiologia* 539: 47–56.

Culp JM, Scrimgeour GJ, Beers CE. 1994. The effect of sample duration on the quantification of stream drift. *Freshwater Biology* 31: 165–173.

Davies PE, Cook LSJ. 1993. Catastrophic macroinvertebrate drift and sublethal effects on brown trout, *Salmo trutta*, caused by cypermethrin spraying on a Tasmanian stream. *Aquatic Toxicology* 237: 201–224.

Elliott JM. 1970. Methods of sampling invertebrate drift in running water. *Annales de Limnologie* 6: 133–159.

Flecker AS. 1992. Fish predation and the evolution of invertebrate drift periodicity: evidence from neotropical streams. *Ecology* 73: 438–448.

Fonseca DM, Hart DD. 1996. Density-dependent dispersal of black fly neonates is mediated by flow. *Oikos* 75: 49–58.

Gerber A, Gabriel MJM. 2002. *Aquatic invertebrates of South African rivers: field guide*. Pretoria: Department of Water Affairs and Forestry, Resource Quality Services.

Gordon ND, McMahon TA, Finlayson BL, Gippel CJ, Nathan RJ. 2004. *Stream hydrology: an introduction for ecologists* (2nd edn). New York: Wiley.

Grzybkowska M, Dukowska M, Figiel K, Szczerkowska E, Tszydel M. 2004. Dynamics of macroinvertebrate drift in a lowland river. *Zoologica Poloniae* 49: 111–127.

Hartman GF, Scrivener JC, Miles MJ. 1996. Impacts of logging in Carnation Creek, a high-energy coastal stream in British Columbia, and their implication for restoring fish habitat. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 237–251.

Henn M, Nichols H, Zhang Y, Bonner TH. 2014. Effect of artificial light on the drift of aquatic insects in urban central Texas streams. *Journal of Freshwater Ecology* 29: 307–318.

Holm S. 1979. A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics* 6: 65–70.

Hoover SER, Shannon LGW, Ackerman JD. 2007. The effect of riparian condition on invertebrate drift in mountain streams. *Aquatic Sciences* 69: 544–553.

Hothorn T, Bretz F, Westfall P. 2008. Simultaneous inference in general parametric models. *Biometrical Journal* 50: 346–363.

Huhta A, Muotka T, Tikkanen P. 2000. Nocturnal drift of mayfly nymphs as a post-contact antipredator mechanism. *Freshwater Biology* 45: 33–42.

Kennedy TA, Yackulic CB, Cross WF, Grams PE, Yard MD, Copp AJ. 2014. The relation between invertebrate drift and two primary controls, discharge and benthic densities, in a large regulated river. *Freshwater Biology* 59: 557–572.

Kerby BM, Bunn SE, Hughes JM. 1995. Factors influencing invertebrate drift in small forest streams, south-eastern Queensland. *Marine and Freshwater Research* 46: 1101–1108.

Kibichii S, Shivoga WA, Muchiri M, Miller SN. 2007. Macro-invertebrate assemblages along a land-use gradient in the upper River Njoro watershed of Lake Nakuru drainage basin, Kenya. *Lakes and Reservoirs: Research and Management* 12: 107–117.

Lauridsen RB, Friberg N. 2005. Stream macroinvertebrate drift response to pulsated exposure of the synthetic pyrethroid lambda-cyhalothrin. *Environmental Toxicology* 20: 513–521.

Mathooko JM. 1998. The effect of continuous physical disturbance on mayflies of a tropical stream: an experimental approach. *Hydrobiologia* 362: 209–216.

Mathooko JM. 2000. Artifical physical disturbances on streambed sites of a Kenyan mountain stream: effects of inter-disturbance intervals on mayfly densities. *Limnologica* 30: 331–339.

Mathooko JM. 2001. Disturbance of a Kenyan Rift Valley stream by the daily activities of local people and their livestock. *Hydrobiologia* 458: 131–139.

Mathooko JM, Kariuki ST. 2000. Disturbances and species distribution of the riparian vegetation of a Rift Valley stream. *African Journal of Ecology* 38: 123–129.

Mathooko JM, Mavuti KM. 1992. Composition and seasonality of benthic invertebrates, and drift in the Naro Moru River, Kenya. *Hydrobiologia* 232: 47–56.

Mbaka JG, M'Erimba CM, Mathooko JM. 2014. Impacts of benthic coarse particulate organic matter variations on macroinvertebrate density and diversity in the Njoro River, a Kenyan highland stream. *Journal of East African Natural History* 103: 39–48.

M'Erimba CM, Mathooko JM, Ouma KO. 2014. Macroinvertebrate distributions in relation to human and animal-induced physical disturbance on the sediment surface in two Kenya tropical Rift Valley streams. *African Journal of Aquatic Science* 39: 337–346.

Michaelis FB. 1984. Possible effects of forestry on inland waters of Tasmania: a review. *Environmental Conservation* 11: 331–344.

Moss B. 2008. Water pollution by agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363: 659–666.

Muehlbauer JD, Kennedy TA, Copp AJ, Sabol TA. 2017. Deleterious effects of net clogging on the quantification of stream drift. *Canadian Journal of Fisheries and Aquatic Sciences* 74: 1041–1048.

Naiman RJ, Décamps H. 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics* 28: 621–658.

Naman SM, Rosenfeld JS, Richardson JS. 2016. Causes and consequences of invertebrate drift in running waters: from individuals to populations and trophic fluxes. *Canadian Journal of Fisheries and Aquatic Sciences* 73: 1292–1305.

O'Callaghan P, Jocqué M, Kelly-Quinn M. 2015. Nutrient and sediment-induced macroinvertebrate drift in Honduran cloud forest streams. *Hydrobiologia* 758: 75–86.

O'Hop J, Wallace JB. 1983. Invertebrate drift, discharge, and sediment relations in a southern Appalachian headwater stream. *Hydrobiologia* 98: 71–84.

Olsen DA, Watzin MC. 2009. Do agricultural pollutants affect competition between filter-feeding caddis fly larvae? Results of laboratory microcosm experiments. *Freshwater Biology* 54: 406–416.

Paletto A, Tosi V. 2009. Forest canopy cover and canopy closure: comparison of assessment techniques. *European Journal of Forest Research* 128: 265–272.

Perić MS, Robinson CT. 2015. Spatio-temporal shifts of macro-invertebrate drift and benthos in headwaters of a retreating glacier. *Hydrobiologia* 751: 25–41.

Pringle CM, Ramírez A. 1998. Use of both benthic and drift sampling techniques to assess tropical stream invertebrate communities along an altitudinal gradient, Costa Rica. *Freshwater Biology* 39: 359–373.

Ramírez A, Pringle CM. 1998. Invertebrate drift and benthic community dynamics in a lowland neotropical stream, Costa Rica. *Hydrobiologia* 386: 19–26.

Ramírez A, Pringle CM. 2001. Spatial and temporal patterns of invertebrate drift in streams draining a neotropical landscape. *Freshwater Biology* 46: 47–62.

R Development Core Team. 2012. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Roche LM, Kromschroeder L, Atwill ER, Dahlgren RA, Tate KW. 2013. Water quality conditions associated with cattle grazing and recreation on national forest lands. *PLoS ONE* 8: e68127.

Romaniszyn ED, Hutchens JJ, Wallace JB. 2007. Aquatic and terrestrial invertebrate drift in southern Appalachian Mountain streams: implications for trout food resources. *Freshwater Biology* 52: 1–11.

Stone MK, Wallace JB. 1998. Long-term recovery of a mountain stream from clear-cut logging: the effects of forest succession on benthic invertebrate community structure. *Freshwater Biology* 39: 151–169.

Suren AM, Jowett IG. 2001. Effects of deposited sediment on invertebrate drift: an experimental study. *New Zealand Journal of Marine and Freshwater Research* 35: 725–737.

Tikkanen P, Muotka T, Huhta A. 1994. Predator detection and avoidance by lotic mayfly nymphs of different size. *Oecologia* 99: 252–259.

Williams DD, Hynes HBN. 1976. The recolonization mechanisms of stream benthos. *Oikos* 27: 265–272.

Winkelmann C, Petzoldt T, Koop JHE, Matthaei CD, Benndorf J. 2008. Benthivorous fish reduce stream invertebrate drift in a large-scale field experiment. *Aquatic Ecology* 42: 483–493.

Wojtalik TA, Waters TF. 1970. Some effects of heated water on the drift of two species of stream invertebrates. *Transactions of the American Fisheries Society* 99: 782–788.

Yuan LL. 2010. Estimating the effects of excess nutrients on stream invertebrates from observational data. *Ecological Applications* 20: 110–125.

Zuur AF, Ieno EN, Walker NJ, Saveliev AA, Smith GM (eds). 2009. *Mixed effects models and extensions in ecology with R. Statistics for Biology and Health*. New York: Springer Science.

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