



Litter processing and shredder distribution as indicators of riparian and catchment influences on ecological health of tropical streams



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ABSTRACT

Terrestrial plant litter is the main source of energy for food webs in forest headwater streams. Leaf litter quality often changes when native tree species are replaced by exotic ones and land use change in the watershed can alter physico-chemistry and functional composition of invertebrate communities, ultimately impairing associated ecosystem processes. We used the composition of invertebrate functional feeding groups (FFGs) and the ecosystem process of leaf breakdown as structural and functional indicators, respectively, of ecosystem health in upland Kenyan streams. During dry and wet conditions, invertebrates were sampled in 24 streams within forest (10), mixed (7) and agriculture (7) catchments. Five forest and five agriculture streams were subsequently used for leaf litter breakdown experiments using two native (*Croton macrostachyus* and *Syzygium cordatum*) and one exotic (*Eucalyptus globulus*) species differing in quality. Coarse- and fine-mesh litterbags were used to compare microbial (fine-mesh) with shredder + microbial (coarse-mesh) breakdown rates, and by extension, determine the role of shredders in litter processing in these streams. Seasonal influences on water quality were observed across catchment land uses. Total suspended sediments, turbidity and total dissolved nitrogen were consistently higher during the wet than dry season. However, seasonal influences on FFGs were inconsistent. Catchment land use influenced invertebrate functional composition: 21 taxa, including eight shredders, were restricted to forest streams, but abundance was a poor discriminator of disturbance. Breakdown rates were generally higher in coarse- compared with fine-mesh litterbags for the native leaf species and the relative differences in breakdown rates among leaf species remained unaltered in both agriculture and forest streams. Shredder and microbial breakdown of leaf litter displayed contrasting responses with shredders relatively more important at forest compared with agriculture streams. However, these patterns were inconsistent across leaf species over the dry and wet seasons. Overall, shredder mediated leaf litter breakdown was dependent on leaf species, and was highest for *C. macrostachyus* and lowest for *E. globulus*. This suggests that replacement of indigenous riparian vegetation with poorer quality *Eucalyptus* species has the potential to reduce nutrient cycling in streams, with foodwebs becoming more reliant on microbial processing of leaf litter, which cannot support diverse consumers and complex food webs.

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1. Introduction

Developing landscapes to meet human needs has altered surface water hydrology, geomorphology and physico-chemistry, impacting the ecology of streams (Allan, 2004; Dudgeon et al., 2006; Vorosmarty et al., 2010). Land-use changes in catchments and along riparian corridors have replaced natural forests with agriculture,

pastures and exotic forestry species (Ferreira et al., 2006a; Hladyz et al., 2011). Loss of natural riparian corridors alters stream light and temperature regimes and the timing, quality and quantity of inputs of leaf litter and dead wood (Elosegi and Johnson, 2003; Wantzen et al., 2008), in turn increasing nutrient inputs and primary production (Scarsbrook and Halliday, 1999; Baxter et al., 2005). These changes typically reduce habitat complexity and biodiversity, and affect organic matter dynamics, nutrient cycling, water purification and erosion processes (Palmer and Filoso, 2009; Acuña et al., 2013).

Riverine ecosystems exhibit extreme heterogeneity in environmental conditions at multiple temporal and spatial scales ranging from microhabitats to whole landscapes (Frissell et al., 1986; Poff,

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1997). Tropical streams and rivers are highly dynamic and water quality is influenced by both catchment land use, and riparian and in-stream activities (Jinggut et al., 2012; Minaya et al., 2013; Silva-Junior et al., 2014). For example, elevated concentrations of nutrients and sediments have been recorded in streams draining agricultural catchments during the wet season due to run-off from unpaved roads, footpaths and farmlands (Kilonzo et al., 2013). In rural catchments, in-stream human activities (water abstraction, bathing, washing and watering of livestock) are influenced by weather conditions, being more common during the dry season (Mathooko, 2001; Yillia et al., 2008). The quality and quantity of leaf litter inputs into these streams is also seasonally variable and dependent on catchment and riparian conditions (Wantzen et al., 2008).

Assessing anthropogenic disturbances on streams relies mostly on monitoring metrics of aquatic communities and physico-chemistry (Barbour et al., 1999; Bonada et al., 2006). The relative abundances of various taxa and functional feeding groups (FFGs) of stream benthic invertebrates have been used as structural indicators (Rosenberg and Resh, 1993; Barbour et al., 1999), while functional components (Gessner and Chauvet, 2002; Young et al., 2008) have tended to be neglected. Structural and functional indicators are not necessarily concordant, highlighting the need to consider both during bioassessment (Gessner and Chauvet, 2002; Bonada et al., 2006). Breakdown of leaf litter is an important functional indicator that links riparian vegetation, environmental conditions, microbial and invertebrate activities (Vannote et al., 1980; Hladyz et al., 2010; Woodward et al., 2012). However, while the use of leaf litter breakdown as a measure of ecosystem functioning is receiving increased attention in temperate streams (Gessner and Chauvet, 2002; Young et al., 2008; Woodward et al., 2012), studies in the tropics are limited (Jinggut et al., 2012; Silva-Junior et al., 2014), and the influence of seasonality is not well understood. Moreover, variability of leaf litter decomposition is likely across climatic regions that differ in environmental factors and invertebrate functional composition (Pozo et al., 2011; Pérez et al., 2011).

Despite under-representation in the literature, the functioning of freshwater tropical ecosystems is highly impacted by human disturbance (Dudgeon et al., 2006). For Africa, balancing increased demands for economies, food production, clean water and environmental quality is an increasing challenge (McClain, 2013; McClain et al., 2014). Many catchments in East African montane forests and high potential agro-ecological zones have lost extensive areas of native vegetation to exotic forests, farming, settlement and grazing (Mati et al., 2008; Maitama et al., 2009). Many landscapes are criss-crossed with unpaved roads and footpaths with extensive areas under grazing and farmlands of mainly fast maturing crops. This risks increased soil erosion and sediment loading to streams and rivers; most notably during the rainy season. Indigenous vegetation along streams and rivers in agriculture catchments is increasingly replaced by exotic *Eucalyptus* species. Even though *Eucalyptus* spp. belong to the same group (Family: Myrtaceae) as *Syzygium cordatum* that is endemic and dominant along riparian areas (Mathooko and Kariuki, 2000), *Eucalyptus* leaves are highly sclerophyllous (Graça et al., 2002). As a result, most leaf litter that enters agriculture streams is refractory and high in polyphenolic compounds. This can significantly alter microbial, fungal and invertebrate communities that colonize leaves, leaf-litter breakdown rates, and the higher trophic levels supported by allochthonous resources (Graça et al., 2002; Ardón and Pringle, 2008). Partitioning effects of pressures on stream biota at different spatial and temporal scales is often lacking, but necessary to guide management and safeguard ecosystem services. With few exceptions, data on ecosystem functioning and the extent of anthropogenic influences on East African streams remain limited (Masese and McClain, 2012; Masese et al., 2014).

Leaf litter breakdown in streams is driven by resource quality, activity of consumers and environmental conditions (Tank et al., 2010; Kominoski and Rosemond, 2012). The chemical composition and physical structure of leaf litter influence preferences of shredders and microbial colonization rates (Graça et al., 2001; Ligeiro et al., 2010). Nutrient enrichment of streams can accelerate leaf litter breakdown by stimulating microbial activities and invertebrate consumption (Rosemond et al., 2002; Gulis and Suberkropp, 2003), but the stimulation effect is also dependent upon the quality of leaf litter (Ardón et al., 2006; Ferreira et al., 2006b; Gulis et al., 2006). However, land use influences on the diversity and abundance of shredders, which are more sensitive to nutrient pollution compared with microbes (Hieber and Gessner, 2002; Pascoal et al., 2003), imply that contrasting responses to resource quality among microbes and shredders might be expected. In the tropics, higher temperatures stimulate fast rates of microbial breakdown of litter and may reduce food availability for shredders (Irons et al., 1994; Boyero et al., 2011a). Despite the narrow temperature range in the tropics, agriculture streams are warmer and with higher electrical conductivity, suspended sediments and dissolved nutrients compared with forest streams (Kasangaki et al., 2008; Kilonzo et al., 2013; Minaya et al., 2013). Effects of these changes on ecosystem functioning are poorly understood in Afrotropical streams where land use change has been linked to terrestrial biodiversity loss and changes in the natural flow regimes of rivers (Maitama et al., 2009; Mango et al., 2011; McClain et al., 2014).

In this study, we compared the use of functional and structural indicators to detect changes in land use. We used leaf litter breakdown as a functional indicator and the composition of invertebrates FFGs as structural indicators to assess the influence of rural land use and riparian conditions on ecosystem functioning of Kenyan highland streams. Wet and dry season functional organization of benthic invertebrates were characterized in 24 streams distributed among forest, mixed and agriculture catchments. Leaf breakdown experiments were conducted using two native (*Croton macrostachyus* and *S. cordatum*) and one exotic (*Eucalyptus globulus*) leaf species in five forest and five agriculture streams. The two native species represent nearly the extremes of the litter quality range of native riparian trees in the study area, and the exotic species used has lower litter quality and is common along farm edges, and planted as woodlots in riparian areas as well as in commercial plantations. We hypothesize that: (1) the influence of land use and riparian disturbance on invertebrate structural and functional organization are accentuated by seasonality, (2) breakdown rates of all plant species will be higher in agriculture streams than in forest streams, (3) the relative importance of invertebrates shredders on litter breakdown will be lower in agricultural than in forest streams, and (4) breakdown rates will be species-specific with the nutrient poor species displaying the slowest response to land use.

2. Materials and methods

2.1. Study area

The study was conducted in mid-altitude (1900–2300 m a.s.l.) first to third order streams draining the western slopes of the Mau Escarpment within the Kenyan Rift Valley. A total of 24 sites were selected in the headwaters of the Mara River, which flows to Lake Victoria. The river drains the extensive tropical moist broadleaf Mau Forest Complex (MFC) that is a source of rivers draining into Lakes Baringo, Nakuru and Victoria (Fig. 1). Vegetation in the MFC is diverse, with over 95 tree species (Blackett, 1994). Catchment and sub-catchments were delineated and land use categorized using a combined digital elevation model, remote-sensing images (Landsat 5 Thematic Mapper data of 2008, 30 m resolution) and topographic

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