Ecological Indicators 32 (2013) 116–122

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Scale-dependent effects of rural activities on benthic macroinvertebrates and physico-chemical characteristics in headwater streams of the Mara River, Kenya

Veronica Minaya[a,*], Michael E. McClain[a,b], Otto Moog[c], Fred Omengo[a], Gabriel A. Singer[d]

[a] UNESCO-IHE Institute for Water Education, Westvest 7, 2611AX Delft, The Netherlands
[b] Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands
[c] BOKU – University of Natural Resources and Life Sciences, Vienna, Austria
[d] Department of Limnology, University of Vienna and WasserCluster Lunz Biological Station, Austria

ARTICLE INFO

Article history:
Received 10 September 2012
Received in revised form 25 February 2013
Accepted 3 March 2013

Keywords:
Macroinvertebrates
Tropical streams
Catchment scale
Reach scale
Mau Forest
Bioindication
Scale-dependency
Human pressure

ABSTRACT

We studied streams in a rural landscape mosaic of the upper Mara River basin (Mau Forest, Kenya), where native forest has been converted to land uses dominated by various kinds of farming, agriculture and rural human settlements. We investigated scale-dependent effects of these anthropogenic rural activities on macroinvertebrates and physico-chemical variables by separately testing for effects of reach-scale disturbance and catchment-scale land use. Physico-chemical variables like conductivity, turbidity and total suspended solids reacted equally well to reach-scale disturbance and catchment-scale land use, demonstrating the high spatial integration potential of these variables and calling for farsighted large-scale water resource management. In contrast, macroinvertebrates reacted more sensitively at the reach-scale than at the catchment-scale, suggesting a stronger influence of local habitat conditions. These results highlight the importance of local stream ecosystem management, e.g., the restoration and protection of stream banks, to protect against agriculture-driven biodiversity losses. However, we also found responses of selected taxa to catchment-scale land use, suggesting that localized management efforts may not suffice to maintain full stream ecosystem integrity and regional biodiversity. Our results also suggest that macroinvertebrates may allow a scale-specific assessment of stream ecosystem integrity and pressures by a scale-dependent bioindicatory approach.

1. Introduction

Streams are hierarchically organized ecosystems (Frissell et al., 1986) affected by anthropogenic land use change through multiple mechanisms operating over a range of spatial and temporal scales (Allan, 2004). Land use conversion (e.g., forestry to agriculture) or management practices (e.g., riparian buffer rehabilitation) can initiate cascades of effects ultimately impacting a stream's physico-chemistry or biota at different spatial scales (Burcher et al., 2007; Sponseller et al., 2001). Discharge, solute and seston load integratively respond to land use and landscape physiography at catchment-scale; while stream hydraulics, sediment, light and organic inputs tend to be more sensitive to reach-scale geomorphology, riparian zone conditions and proximate land use (Snelder and Biggs, 2002; Allan, 2004). Impacts from land use change may act simultaneously at either of these scales or differentially, thus affecting ecosystem processes and integrity in a scale-dependent manner.

Understanding the influences of catchment-scale versus reach-scale land use on aquatic ecosystem condition is important in resource management, especially where humans depend on aquatic ecosystem services. In East Africa rural communities depend on stream ecosystems for direct and indirect services such as drinking water supply and provision of food and traditional medicines (Mathooko et al., 2009; Terer et al., 2004). Degradation of ecosystem function caused by land use change can undermine livelihoods and hinder sustainable development (Mathooko et al., 2009). Conversion of forests to agricultural land and settlements is the prevailing form of land use change on the African continent, with particularly strong impacts – massive losses of forest and savannas – predicted for sub-Saharan Africa (Tilman et al., 2001; Foley et al., 2005). Research in East African catchments with intense land cover conversion documented alterations of flow regimes, degradation of habitats, loss of biota and changes in ecosystem function (Masese et al., 2009; Masese and McClain,

* Corresponding author. Tel.: +31 68 189 1440.
E-mail addresses: minay1@unesco-ihe.org, verominaya81@hotmail.com (V. Minaya).

1470-160X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecolind.2013.03.011

2012; Mathooko, 2001). Management is needed to address the declining status of stream ecosystems in these rural settings, with scientific guidance to identify the scale of intervention being one of the highest priorities.

The Mara headwaters are situated in the Mau Forest, the largest (416,450 ha) of Kenya's remaining forests and a major water tower. This forested portion of the Mara River Basin hosts two perennial tributaries: Nyangores and Amala, whose catchments extend above 2000 m above sea level and typically receive 1400 mm precipitation per year, concentrated in two rainy seasons (March–May 'long rains', October-November 'short rains'). Various agricultural activities including livestock raising, cultivation of tea, coffee, maize and small-scale horticulture, fruit and root crops abound in the highlands. Thus, over the past 30 years the Mau Forest area decreased by 25% (Owino, 2009) due to conversion to agricultural use and spreading of rural settlements. With the human population in Kenya annually increasing by 3% (United Nations Educational, Scientific and Cultural Organization, 2011) and a 55% increase in agricultural land in the last 14 years, the Mau Forest is under pressure and interdisciplinary modelling efforts have predicted increased water demands and continued alteration of flow regimes for the future (Mango et al., 2011; Melesse et al., 2008; Mutie et al., 2006).

This study investigates the dependence of physico-chemical and biotic characteristics on land use-associated factors at catchment-scale and at reach-scale in headwaters of the Kenyan Mara River. We investigate stream integrity based on readily measurable physico-chemical variables, macroinvertebrate community composition and popular biotic indices. We then separately test for effects on these response variables by two factors expressing the intensity of agriculturally motivated activities at catchment- and reach-scale. Our results suggest scale-dependent sensitivity of various response variables and help to identify appropriate spatial scales for future management and mitigation measures.

2. Materials and methods

Sampling in the Nyangores and Amala tributaries of the Mara River was done during November and December 2009. 25 streams from 1st to 5th order replicated one of 3 catchment-scale land uses: (a) forest (FOR; sparse human intervention, $n = 13$), (b) agriculture (AGR; tea, coffee, maize and livestock grazing, $n = 6$), and (c) mixed (MIX; forest fragments and small-scale agriculture, $n = 6$) (Fig. 1). Catchment delineation and land use categorization were done prior to field sampling combining a digital elevation model, remote-sensing images (Landsat 5 Thematic Mapper data of 2008, 30 m resolution) and topographic maps (1:50,000 survey of Kenya 1971). At reach-scale, sites were assigned to one of 3 levels of riparian and in-stream disturbance (low, intermediate, high) associated with agriculture and settlements in the site's immediate vicinity. Disturbance was assessed for a 100 m upstream reach using a standardised field survey (Rankin, 1995) integrating site observations and interviews with local people. Briefly, 'low' disturbance sites had no local communities within 1 km and natural riparian vegetation without noticeable effects of grazing or human activities. Intermediate disturbance sites had occasional signs of streambank erosion, grazing, riparian vegetation loss, water harvesting and bathing or washing activities. Highly disturbed sites exhibited obvious degradation signs, daily in-stream presence of cattle and frequent human activities.

Dissolved oxygen concentration (DO), electrical conductivity (EC), temperature, pH and turbidity were measured in-situ with a YSI Professional Plus meter (YSI Inc., USA) and a portable turbimeter (Hach 2100P ISO, USA). Well-mixed water samples from the thalweg were immediately filtered through pre-weighed glass-fibre filters (Whatman GF/F, pre-combusted at 450 °C/4 h). Filtrate was transported in 500 ml PET bottles at 4 °C pending lab-analysis within 8–48 h NH_4–N and PO_4–P were determined using United States Environmental Protection Agency Standard Methods (350.2 and 4500-P) and a Hitachi U-2000 spectrophotometer. Total suspended solids (TSS) were determined from GF/F filters gravimetrically after drying (60 °C) to constant weight.

Benthic macroinvertebrates were sampled with a multi-habitat approach (Hering et al., 2004; Moog, 2007). 10 subsamples were taken over a 100 m reach in proportion to macrohabitats (mineral: mud, silt, sand, stones; biotic: floating macrophyte, submerged macrophyte, bank vegetation, living and fallen wood, algae/periphyton) (Moog, 2009). Subsamples were collected in upstream direction with a hand-net (500 μm mesh) while manually disturbing upstream located patches (25 × 25 cm) for 1 min, pooled to a composite sample and fixed (formaldehyde, 4% final concentration). Sorted macroinvertebrates were identified to genus (Trichoptera, Coleoptera), subfamily (Chironomidae) or family level (all other taxa) using the Aquatic Invertebrates of South African Rivers Field Manual (Gerber and Gabriel, 2002). Among the calculated macroinvertebrate metrics were the total number of taxa/families, total individuals, and the percentages of taxa of EPT (Ephemeroptera, Plecoptera and Trichoptera), COPTE (Coleoptera + Odonata + EPT), Coleoptera and Chironomidae. The South African Scoring System (SASS) was also used to assess site condition (Dickens and Graham, 2002) using SASS5, the average score per taxon (ASPT), SASS 6-15 for sensitive and SASS 8-15 for most sensitive taxa. From among the many biotic indices available SASS was selected because, apart from being the only Africa-based currently available biotic index, it is gaining prominence in the region and on the whole continent as one of the most appropriate indices for assessing ecological condition and assessment of environmental flow requirements in rivers (O'Keeffe and Dickens, 2008; LVBC & WWF-ESARPO, 2010).

Our study design involves the two independent factors catchment-scale land use (3 rank-ordered levels: AGR, MIX and FOR) and reach-scale disturbance (3 rank-ordered disturbance levels: low, intermediate and high). We understand both factors as expressions of (potential) influence of agriculture and human settlements on stream ecosystems at two different spatial scales, i.e., both factors are essentially the same identical factor "rural activity" but defined at 2 different spatial scales. Therefore, instead of using a two-way statistical testing design, we tested for effects of both factors separately, as the dependence between the two factors certainly prevents their simultaneous assessment. We henceforth refer to catchment-scale land use as *catchment* and reach-scale disturbance as *reach*. Non-parametric, rank-based *H*-tests (Kruskal-Wallis ANOVAs) were used to test for effects of *catchment* and *reach* on physico-chemical parameters and macroinvertebrate metrics. *H*-tests were more appropriate due to moderate sample sizes and distributional properties of the data. Significant *H*-tests were followed by Tukey multiple comparisons as post-hoc tests. To compare the strengths of *catchment*- and *reach*-effects on various response variables, we used the factor levels AGR vs. FOR, and low vs. high disturbance (as extreme end-members of the two rank-ordered factors) and computed percentages of increase from the non-impacted end-member to the impacted end-member mean as a unit-free "effect size".

Non-metric multidimensional scaling (NMDS) based on a Bray-Curtis (BC) dissimilarity matrix computed from relative taxa abundances was used for ordination of sites with regard to macroinvertebrate community composition (MCC) (Anderson, 2006; Legendre and Legendre, 1998). NMDS is considered a robust non-parametric ordination method for datasets with moderate sample sizes and a high number of variables, and the BC dissimilarity is among the most widely used dissimilarity measures for abundance