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Development of a plant based riparian index of biotic integrity (RIBI) for assessing the ecological condition of highland streams in East Africa

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A B S T R A C T

The study of riparian plant communities along running streams offers information on the state of habitat and can help increase our knowledge on the use of bioindicators. We developed a riparian index of biotic integrity (RIBI) to evaluate the conditions of highland streams in response to anthropogenic disturbances in the southwest Ethiopian highland. To construct RIBI, we evaluated 22 potential plant metrics. Disturbance was quantified for each site using information on canopy openness, ground area without vegetation and exposed mineral soil. Five core metrics (floristic quality indexes, average C, native tree/shrub species, riparian status species and Shannon diversity index) were found to respond to anthropogenic disturbances. These metrics were significantly differentiated among sample sites categorized as low and high disturbance sites ($p < .001$). The core metrics and RIBI scores for this data set were also significantly correlated with environmental variables including riparian buffer width, dissolved oxygen, water temperature, turbidity, total suspended sediment, nitrate and orthophosphate. These findings provide support for the continued use of plants as indicators of highland stream condition in the East Africa, providing that the responses of plant based metrics to disturbances. Thus, the RIBI could be useful tool for the assessment and monitoring of stream ecosystems and evaluating the effect of stream restoration in the East African highland in the future.

1. Introduction

Natural riparian vegetation are distinct, diverse, and are among the most valuable ecosystems on the globe (Gonçalves and Callisto, 2013). Besides high level of biodiversity, riparian zones supply numerous services such as nutrient control (Yuan et al., 2009), bank stabilization (Berges, 2009), shading effect and social aspects (Meek et al., 2010).

However, the importance of riparian areas is disproportionate to their physical extent on landscape, especially in the tropical regions such as East African highland (Mathooko and Kariuki, 2000; Mathooko, 2001; Senzota and Mbago, 2010). In many tropical countries anthropogenic activities such as deforestation, siltation, channelization of streams and rivers have resulted in extreme ecological degradation of freshwater ecosystem (Demissie et al., 2013) and there is an increase in the agricultural land with the expense of riparian vegetation (Abate and Lemenih, 2014) which accelerate deterioration of stream water quality (Lu et al., 2014).

The existence of riparian vegetation is related exclusively to the water chemistry. Developing riparian plant based indices as indicator method has thus been an objective for surveying water quality and stream condition (Thiébaut et al., 2006). Biological indicators integrate the spatial and temporal effects of biological and environment factors on streams (Haury et al., 2006; Thiébaut et al., 2006), and are appropriate for evaluating the potential effects of many aspects of changes in aquatic ecosystems (Grasmück et al., 1995; Robach et al., 1996).

The use of biological indicators including macroinvertebrates (Barbour et al., 1996; Extence et al., 2013), birds (Gregory et al., 2003), fish (Lyons, 2006), and macrophytes (Carbiener et al., 1990; Nichols et al., 2000; Clayton and Edwards, 2006; Triest, 2006) has been applied broadly in ecological research to evaluate freshwater ecosystem conditions. Such indices have been applied to ecosystems throughout the world including in the United States (Miller et al., 2006; Lane and Brown, 2007), Europe (Robach et al., 1996; Thiebaut et al., 2002; Lang and Murphy, 2012) and recently in East Africa highlands (Ambelu

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et al., 2010; Mereta et al., 2013; Moges et al., 2016).

Riparian plant communities are strong causal linkages between biodiversity and ecosystem functioning (Cavaillé et al., 2013). Such linkages can be systematically assessed using metric based on diversity (Junyan et al., 2014; Pourbabaei et al., 2014; Řepka et al., 2015), floristic quality (Bowers and Boutin, 2008; McIndoe et al., 2008; Malik et al., 2012) and indicator species (Johnston, 2003; Jovan and Mccune, 2006). As such, little information is available on plant based biological assessment tools in the southern tropical African rivers (Kennedy et al., 2015) and so far none in East Africa. Thus, the current study develops a plant based bioassessment tool for assessment and monitoring of highland streams. The main objectives of the present study were to (1) develop Riparian Index of Biotic Integrity (RIBI) for highland streams; (2) identify attributes of the riparian vegetation community of highland streams that responded predictably to human disturbance.

2. Methods and materials

2.1. Study area

The Gilgle Gibe catchment is located in Jimma zone, south western Ethiopia (latitude 7°25′–7°55′N and longitude 36°30′–37°22′E) (Fig. 1) and the altitude ranges from 1096 m above sea level in the lowland to 3259 m in the headwater (Ambelu et al., 2010).

The region was once covered with tropical sub-humid vegetation and coffee forest (Keddi and Moges, 2016), but is now dominated by cropland (wheat, barley, faba bean, sorghum and maize) and to a lesser extent grazing land and certain segment covered by riparian vegetation (Demissie et al., 2013). The climate of the study area is classified as tropical humid and belongs to the high altitude cool tropic area of the country; this is also the wettest part with an average rainfall of 1550 mm per year and an average temperature of 19 °C (Demissie et al., 2013).

2.2. Site selection

Satellite images were used to delineate stream and quantify land use in the study area. Remote sensing data and Arial photographs scale of 1:50,000 were used in addition to digitalise the study stream and sub watersheds. Before actual data collection, a preliminary field survey had been conducted to get a general view on the physical conditions of the area, such as the vegetation cover and to locate streams showing different land use categories.

Based on this, eighteen permanent streams ranging from 1st to 3rd order were selected according to the classification by (Rosgen, 1985). Data derived from the GIS covers were compared with field observation and potential sites were randomly positioned on the land use map. The selected streams were representatives of the catchment in terms of botanical composition, management scenario and geo-morphological diversity. Thirty-five sampling sites were chosen at various locations to encompass the range of a priori land use categories (forest, mixed, plantation and agriculture). Hereafter, riparian embedded in primary forest are called forest sites, riparian embedded in primary mixed of pasture and bushland are called mixed sites, riparian embedded in primary eucalyptus plantation are called plantation sites, and riparian embedded in primary agricultural land are called agricultural sites. Sites were sampled in agriculture (15), mixed (9), eucalyptus plantation (4), and forest (7) land use categories. The altitude of the study streams ranged from 1638 m above sea level in the downstream to 2116 m in the headwater. All map manipulations and spatial analyses were performed using ESRI ArcGIS 10.3 and Erdas Imagine 10.0 software.

2.3. Riparian vegetation sampling

Following Burton et al. (2005) 20-m transects were established on both sides of the selected streams that extended from the stream edge to the uplands perpendicular to the stream. Successive transects were located 100 m apart in the downstream direction from the first transect. Within each transect, rectangular plots, 100 m^2 (5 m × 20 m) with a long face, parallel to the stream were placed at 10 m distances. Within each plot, all woody vegetation stands were recorded. Plot numbers varied from one to two per transect depending on the width of the riparian zone. Herbaceous plant species were collected within a 1 m by 1 m (1 m^2) plot, which was placed at the center of the main plot. Adjacent land-use and any evidence of human disturbance (grazing, cutting, and firewood collection) were noted. The local plant name of the specimens were recorded in the field. All specimens were then pressed and taken to Jimma University, where they were identified using key books of Bekele (2007), and Fichtl and Magana (1994), and published flora of Ethiopia and Eritrea. However, some specimens which were difficult to identify using these keys were taken to the national herbarium (ETH), Addis Ababa University for further identification (by comparing with authentically identified) specimens. Taxa were determined to be native or alien to the southwestern Ethiopia using published volumes of flora of Ethiopia (Hedberg and Edwards, 1989; Hedberg, 1989; Edwards, 1995, 1997; Tadesse, 2000; Hedberg, 2003, 2006). Finally, the voucher specimens were deposited at Herbarium of Jimma University.

2.4. Water quality sampling strategy and analytical procedure

Thirty-five sampling sites were selected (Fig. 1), and water samples were collected during two different seasons: the wet season (September 2014) and the dry season (January 2015). The dataset collected in this study includes eight water quality parameters. At each site, water temperature, pH, dissolved oxygen (DO), and electrical conductivity (EC)were measured using a multi-probe meter (HQd4 Single-Input Multi-Parameter Digital Meter, HACH) and turbidity was measured using a Wagtech turbidity meter (Wag-WT3020). The total suspended sediment (TSS), nitrate and orthophosphate were measured in the laboratory according to the standard methods of APHA et al. (1995).

2.5. Floristic quality index

The floristic quality index (FQI) is one of the assessment means that may show habitat condition of an area. The FQI uses measure of ecological conservatism and species richness to figure out habitat quality of an area and ecological conservatism is showed numerically as a coefficient of conservatism (Bowers and Boutin, 2008). The values of conservatism (C) range from 0 (exotic taxa and native taxa that act as opportunistic invaders, includes species that commonly occur in disturbed ecosystems) to 10 (taxa with high degrees of fidelity to a narrow set of stable ecological conditions) see also Alemu et al. (2017). Species with low value of C score were considered tolerant of many disturbances, whereas species with high values of C scores were considered to occur within a narrow set of stable ecological conditions (Freyman et al., 2016). The FQI score for an individual site was calculated as:$I' = \Sigma\ (CC_i)/\sqrt{(N_{allspeciesrichness})}$ where I' = the modified FQI score, CC_i = the coefficient of conservatism of plant species *i*, and $N_{allspecies}$ = the total number of species both native and non- native (Andreas et al., 2004; Taft et al., 2006).

2.6. The disturbance gradient

Numerous methods of quantifying a human disturbance gradient have been used in parallel with biotic indices to test the precision (consistency and bias) of the assessment method (Ferreira et al., 2005; Miller et al., 2006; Stewart and Mallik, 2006). In this study, disturbance gradient (DG) used to test RIBI metrics was derived from index of disturbance severity (IDS) within a proportional area of the 100 m^2. We used field data on canopy openness, ground area without vegetation and exposed mineral soil into a quantitative index of disturbance

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