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Modeling the impact of highland settlements on ecological disturbance of streams in Choke Mountain Catchment: Macroinvertebrate assemblages and water quality

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ABSTRACT

Human disturbances of waterways in Ethiopian highlands have increased throughout the last century due to population growth and increased land use. Despite this, there is a lack of knowledge on macroinvertebrate responses to human disturbances and the application of biological monitoring in tropical highland waterways in general. In this study, we have evaluated the human impact on the ecological integrity of the Chemoga River catchment in the Choke mountain watershed in the northwestern region of the Ethiopian Blue Nile highlands. During wet and dry seasons the water quality and macroinvertebrate assemblages were assessed. Multivariate statistics and Canonical Correspondence Analysis (CCA) were used to identify factors influencing macroinvertebrate community structures in highland streams in the northwest regions of Ethiopia. A total of 66 taxa of benthic macroinvertebrates were recorded, among which Diptera (38%) and Coleoptera (21%) were the most dominant. The results revealed a severe decrease in the ecological integrity of the Chemoga River in terms of macroinvertebrate composition at higher altitude. The ordination and cluster analysis clearly indicates extremely low macroinvertebrate diversity at sites where human impact is severe and a strong effect of altitude. These results highlight the need to protect the highland waterways of the Blue Nile area and that of similarly degraded watersheds in the Ethiopian highlands.

1. Introduction

The Ethiopian Highlands have been home to humans from the very dawn of the species. In the past decades, however, increasing population growth and the associated expansion of farming and grazing activities across nearly the entire highland landscape have led to high rates of environmental degradation (Vlek and Denich, 2012; Birhanu, 2014), testing the resilience of highland ecosystems to human-induced pressures. Environmental degradation is an ever-worsening problem (Aerts et al., 2007), with erosion and loss of soil fertility headwaters regions posing a particular threat (Zeleke and Hurni, 2001). Improper agricultural practices, over grazing and deforestation all contribute to the problem (Simane et al., 2012). In addition, the quantity and quality of surface water resources in such areas are highly affected. As a result of many years of improper land use, the majority of the Ethiopian highlands contain degraded ecosystems affecting the quality and quantity of surface water resources and diversity of aquatic organisms (Ambelu et al., 2010).

The Choke Mountain watershed are primary headwaters of the upper Blue Nile River (Teferi et al., 2010; Simane et al., 2012). However, human settlement in this area negatively affects the rivers and streams of the watershed. Human populations and their use of land have already threatened habitats and degraded most of the terrestrial and aquatic ecosystems in the area (Ellis, 2011). Land use modifications and small scale irrigation are the most common practices of farmers in the watershed. Such activities around drainage areas are one of the potential causes of pollution

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of the aquatic systems (Beyene et al., 2009; Ambelu et al., 2010). In addition, the current agricultural policy of Ethiopia encourages farmers to use fertilizers without any measure of preventing the washout water pollution. Similarly, stream diversion for irrigation purposes is becoming a common practice which leads to reduction of water level in the downstream watercourse (Ambelu, 2009). Such activities are common in Choke Mountain watershed for small scale irrigation activities. The reduction of stream flow in the natural watercourse limits macroinvertebrate habitats and causes elevated concentrations of pollutants, disturbs species interactions and reduces species richness (Poff et al., 1997; McIntosh et al., 2002; Niraula, 2012).

Highland streams also face non-point source discharges from domestic activities, grazing fields and agricultural runoff (Beyene et al., 2009; Ellis, 2011). In addition, due to high degree of elevation of the watershed, the water sources are highly exposed to sedimentation as a result of ecological degradation of the surrounding watershed. The presence, absence or composition of macroinvertebrate assemblages has been suggested as an index of human activity (Ambelu et al., 2010). Other studies conducted in some tropical highland African countries like Ndaruga et al. (2004), Kasangaki et al. (2008), Beyene et al. (2009) and Ambelu (2009) have shown that anthropogenic disturbances affect the presence or absence of aquatic macroinvertebrate species. However, no studies have been conducted in tropical African countries in general and East Africa in particular looking at the effect of human impacts on macroinvertebrate assemblages at higher altitudes. Therefore, a better understanding of the specific factors driving changes in water quality and the macroinvertebrate community structure along perturbation and settlement gradients is needed in order to generate knowledge and identify focus areas for sustainable environmental conservation approaches in highland watersheds. Similarly, effective environmental decision-making requires models that quantify species-environment interactions affecting macroinvertebrate communities in highland streams. Therefore, the main aim of the present study was to identify and evaluate the ecological disturbance of highland settlements on macroinvertebrate assemblages and water quality in a representative watershed of the Blue Nile highlands.

2. Methods and materials

2.1. Study area

The Choke Mountain watershed is located in the Upper Blue Nile (Abay River) highlands of Ethiopia. The watershed span a significant elevation gradient, with the highest peaks reaching 4200 m above sea level and the lowest confluence with the Blue Nile located at approximately 800 m above sea level (Zaitchik et al., 2012). The agro-ecology of the watershed is extremely varied from *kola* (hot) to *wurch* (afro-alpine) and with the physiographic, ecology, agriculture, socio-cultural and climatic conditions being quite different in appearance at the different elevations. Choke Mountain serves as a water tower of the region and headwater source of the Upper Blue Nile (Abay) river basin. Many of the rivers and tributaries of the Upper Blue Nile originate from this mountain range. There are about 59 rivers and many springs that originate from Choke Mountain watershed (Teferi et al., 2010).

The Chemoga River catchment is one of the main mesoscale catchments in Choke Mountain watershed. This catchment is exposed to extreme land use pressure in which the ecology is being alarmingly threatened by direct human interference as a result of rapid population growth (Bewket, 2002; Simane et al., 2012; Zaitchik et al., 2012). The catchment is characterized by overexploitation and overgrazing resulting from a large number of human settlements (CSA, 2007), high livestock loads, low agricultural productivity, severe land degradation, decreasing quality and volume of surface water flow (Simane et al., 2012). Therefore, there is no longer a significant natural forest cover in this catchment. However, the top moorland area of the Chemoga catchment is sparsely covered with giant lobelias (*Lobelia synchopetala*), lady's mantle (*Alchemilla humania*), Guassa grass (*Festuca* spp.) and other grasses. Small areas of natural woody plant cover (*Erica arborea* and *Hypericum revolutum)* are found in patches. Bamboo (*Arundinaria alpine)* is found as homestead/farmstead plantation as well as part of the natural vegetation cover in the area, though it is very sparsely and under threat. *Eucalyptus globules* is extensively grown in plantation in the watershed (Teferi et al., 2010; Simane et al., 2013).

The Chemoga catchment includes all traditionally classified agro-ecological zones, which are *wurch, dega, woyna dega,* and *kola*. The rainfall in the watershed is associated with the movement of the Inter-tropical Convergence Zone (ITCZ) with high rainfall during the rainy season (May-October) (Zaitchik et al., 2012; Simane et al., 2013). The highest elevations of the Chemoga catchment fall into the *wurch* agro-ecosystem, characterized by cold, moist conditions, average rainfall in excess of 2200 mm/year and the average annual temperature is less than 11.5 °C. However, at lower elevation of the catchment, the temperature increases successively from *dega* to *woyna dega* and then to *Kola* with average annual temperature of 11.5–17.5 °C, 17.5–20.0 °C, and 20.0–27.5 °C respectively (Zaitchik et al., 2012).

The location of the Chemoga River within the Blue Nile River headwaters gives it a special relevance, both because of the well-known transboundary tensions associated with the Blue Nile River and because the Blue Nile basin is the home of the Grand Ethiopian Renaissance Dam (GERD). The GERD, which is currently under construction, is a major development priority for Ethiopia, and it has raised appreciation for the importance of biomonitoring studies and tools that can contribute to ecological river management and the sustainable use of water resources.

2.2. Data collection

Macroinvertebrates and environmental data were collected at 36 sampling sites in the streams of the Chemoga River in the Choke Mountain watershed during the wet and dry seasons from September 2014 through May 2015 (Fig. 1). Depending on sampling site, one to five samples were taken. Throughout this period, 118 samples were collected using the kick sampling method as described by Gabriels et al. (2010). In short a D-frame net having a mesh size of 300 μm diameter was used for collection during 5 min sampling period. Samples were collected from each meso-habitat such as boulders and vegetation within a 10 m stretch. Macroinvertebrates were then sorted alive onsite and preserved in 70% ethanol for subsequent identification at family level following Gerber and Gabriel (2002) and Bouchard (2004).

Physical features of the streams that could have a direct or indirect influence on the macroinvertebrate community and water quality were recorded at the sampling sites. The habitat of each sampling reach was characterized using the USEPA rapid physical habitat classification format (Barbour et al., 1999). At each sampling site, anthropogenic activities were carefully registered based on six main human activities: *tillage, irrigation, grazing, land slid, tree removal* and *other activities* (cloth washing, swimming, and sand dredging). Each human disturbance activity was quantified based on its intensity in the studied streams as indicated by Wang et al. (1998) and Mereta et al. (2013). A class of one was given for no or minimal disturbance, 2 for medium and 3 for high disturbance (Table 1). The overall disturbance index score is based on the scores of the six variables and hence the total disturbance score could potentially range from 1 to 18. The higher the score,