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Analysis of environmental factors determining the abundance and diversity of macroinvertebrate taxa in natural wetlands of Southwest Ethiopia

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ABSTRACT

In Ethiopia, wetland resources play a vital role in the lives of adjacent communities by helping them to achieve food security and livelihoods. However, many wetlands throughout the country are facing degradation as high population growth rate increases the need for more fertile agricultural land. Lack of awareness and logistic constraints are important reasons for the weak consideration of wetland ecosystems by the country's development planners. In this paper, we set out to develop methods for predicting species–environment relationships. Decision tree models and Canonical Correspondence Analysis (CCA) were used to identify factors influencing macroinvertebrate community structure in natural wetlands of Southwest Ethiopia. The models were based on a dataset of 109 samples collected from 57 sites located in eight different wetlands. Sixteen macroinvertebrate taxa were selected based on their frequency of occurrence to determine the status of the wetlands. It was found that Corixidae, Baetidae and Hydrophilidae had the highest predictive model performance. This indicates that these taxa have clear requirements regarding their environmental conditions. The low Kappa value combined with the high number of Correctly Classified Instances of Chironomidae may be related to their high frequency of occurrence, so that their presence is of little predictive power. This was also further illustrated by the Canonical Correspondence Analysis (CCA) where the family of Chironomidae, common at nearly every sampling station in the wetlands, was plotted in the centre of the CCA axis. Vegetation cover, water depth, and conductivity were the most important variables determining the presence or absence of macroinvertebrate taxa. These variables were selected in more than 80% of the classification tree models and played a critical role in the ordination analyses. The sensitivity analysis, based on the regression tree models, also showed that vegetation cover and conductivity were affecting the abundance of some macroinvertebrate taxa. Information on habitat quality and environmental factors preserving a high diversity are essential to develop conservation and management programs for wetlands and their related ecosystem services in Ethiopia, where wetland resources are being lost at a high rate, and continue to be at high risk due to expansion of agricultural and other development activities.

1. Introduction

Wetlands are one of the most biologically productive natural ecosystems on earth (Dixion and Wood, 2003; Rolon and Maltchik, 2006). While they occupy about 6% of the world's land surface, they contribute up to 40% of the annual globe's ecosystem services (Bonell et al., 1993; Costanza et al., 1997). Wetlands perform a wide variety of ecological functions including nutrient cycling (Bunn et al., 1999), carbon storage (Adhikari and Bajracharaya, 2009), flood reduction (Hey and Philippi, 1995) and provisioning of habitat for wildlife (Jacobs et al., 2009). Moreover, wetlands play a vital role in ensuring water supply, food security and livelihoods for millions of people living in developing countries (Shewaye, 2008; Teferi et al., 2010). Understanding the economic value of nature and the services it provides to humanity has become increasingly important for local, national, and global policy and decision making. Quantifying and integrating ecosystem services into decision making will be crucial for sustainable development (Turner et al., 2010). Costanza et al. (1997) calculated that wetland values can contribute worldwide up to $15,000 per hectare per year. The majority of the value of services are currently outside the market system, but should be included in the future. Several of these services include gas regulation, disturbance regulation, waste treatment and nutrient cycling (Costanza et al., 1997). The value of these regulating services derives from the benefits they protect and are, as described by the Millennium Assessment, often related to water quality (Simonit and Perrings, 2011). With

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respect to water quality and drinking water production, potential costs in wastewater treatment can be reduced, because tertiary treatment by wetlands may save costs for alternative treatment (Costanza et al., 1997). The threats posed by climate change and the increase in global population predicted to reach nine billion by 2050, resulting in increasing pressures on water resources, urge the need to maximise these benefits (Ramsar, 2010).

Despite the fact that many scientific studies highlight the importance of wetlands for ecosystem services, most wetlands worldwide have suffered from extensive exploitation in the past century (Xu et al., 2011). Studies have shown that about 50% of the world's wetlands have disappeared in the last century due to agriculture and urban development (Mitsch and Gosselink, 1993; Shine and Klemm, 1999). Drainage for agriculture has been recognized as the primary cause of global wetland loss (Xu et al., 2011). In Ethiopia, rapid population growth triggers expansion of agricultural areas, resettlement of landless people, and exploitation activities in wetland areas (Shewaye, 2008). Consequently, several wetlands either disappeared or are on the verge of drying out (Shewaye, 2008), while others rapidly decline in water quality. In response to the rapid degradation of wetlands in Ethiopia, a number of studies on wetland hydrology (Dixion, 2002; Dixion and Wood, 2003) and socio-economic aspects (Solomon, 2004) have been initiated. However, little is known about the overall ecological condition of wetlands in Ethiopia. The diversity and abundance of macroinvertebrates are known to provide considerable information on ecosystem impairment (Feio et al., 2007; Liston et al., 2008). Analysing the health and diversity of these wetlands, based on the presence of macroinvertebrates, could therefore indicate the state of the ecosystem and the related services (Feld et al., 2010). In the present study, we therefore set out to identify the major environmental factors governing the macroinvertebrate communities inhabiting wetlands in a region in Ethiopia that is relatively rich in wetlands, but is under severe pressure by rapidly increasing land use intensity.

Macroinvertebrates represent a diverse group of long living sedentary species that react strongly and often predictably to human influences on aquatic systems (Cairns and Prall, 1993). They are considered very appropriate subjects for the assessment of the ecological condition of wetlands, since they are abundant, readily surveyed, and taxonomically rich (Dodson, 2001). Furthermore, they play an important role in the overall functioning of wetland ecosystems as they occupy a central position in the food web of wetlands (Batzer et al., 1999). Macroinvertebrate community characteristics can reflect primary production and the ability of a wetland to support vertebrate wildlife (e.g. fish) and remove pollutants (Batzer et al., 2006). A better understanding of the factors driving changes in macroinvertebrate community structure along perturbation gradients at several taxonomic levels is therefore important to predict the potential changes in the ecological conditions of wetlands (Trigal-Domínguez et al., 2009).

In order to predict the habitat requirements of wetland macroinvertebrate communities, there is a clear need for models quantifying species–environment relationships to support decision making (Broekhoven et al., 2006). Modelling the distribution of taxa as a function of the abiotic environment, often called habitat suitability modelling, has been recognized as a significant component of conservation planning (Guisan and Zimmermann, 2000). Habitat suitability models combine occurrence and/or abundance of species with environmental variables, both biotic and abiotic factors, judging on the habitat quality or predicting the effect on species occurrence of environmental changes within the habitat (Anderson et al., 2003; Store and Kangas, 2001). These models are typically developed by identifying statistical relationships between the occurrence and/or the abundance of the species and the biochemical and physical properties of a given site (Store and Kangas, 2001). In this regard, many approaches including multivariate analysis (Robertson et al., 2001) and modelling techniques such as decision trees (Boets et al., 2010; Dakou et al., 2007; Goethals et al., 2002; Hoang et al., 2010), artificial neural networks (Dedecker et al., 2007; Goethals et al., 2007; Park et al., 2003), fuzzy logic (Broekhoven et al., 2006; Mouton et al., 2009) and Bayesian belief networks (Adriaenssens et al., 2004) have been applied.

The aim of the present study was to analyse the relationship between habitat quality and the occurrence and diversity of macroinvertebrates in Wetlands in Southwest Ethiopia. Therefore, we developed habitat suitability models using decision tree models and used multivariate data analysis in order to analyse the macroinvertebrate community structure in these natural wetlands. The information obtained from this study can be used to inform on environmental factors that are important for community structure of macroinvertebrates and as a guideline for habitat conservation of wetlands and their related ecosystem services.

2. Methods and materials

2.1. Study area

The data used for the present study were collected from wetlands located in the Gilgel Gibe watershed, Southwest Ethiopia (Fig. 1). Six permanent (Koffe, Kitto, Boye, Haro, Bulbul and Balawajo) and two temporary (Haro1 and Haro 2) wetlands located along the Gilgel Gibe river were included. The studied wetlands are varying in size ranging from 5 ha to a few hundred hectares. These wetlands serve as a source of drinking water, as breeding grounds for birds and as grazing land (Yimer and Mengistou, 2009). All permanent wetlands except Bulbul are riverine, connected upstream and downstream to the rivers flowing into the Gilgel Gibe River and finally to the Gilgel Gibe hydro power dam. The temporary and Bulbul wetlands are created by a meandering floodplain. These temporary wetlands are characterised by high fish and waterfowl abundance. The major threats from human activities around and in these wetlands include intensive livestock grazing, brick making, vegetation clearance, land conversion to cropland, drainage, municipal waste discharge and cultivation. Maize (*Zea mays*) cultivation is a common practice in and around these wetlands.

2.2. Data collection

A total of 57 sampling stations were monitored. Fifty two permanent sampling sites were sampled both during the dry (March to May, 2010), and the wet (August to September, 2010) season, whereas five temporary wetland sampling stations were sampled only during the wet season. In this way, 109 samples were available.

2.2.1. Abiotic habitat characteristics

Abiotic habitat characteristics at each sampling station over a 500-meter reach were assessed using the USEPA wetland habitat assessment protocol (Baldwin et al., 2005). The physical features measured included vegetation cover, water depth, hydromorphological settings and adjacent land use patterns (grazing, cultivation/ploughing, clay mining, drainage and waste dumping; see Table 1).

Dissolved oxygen, electric conductivity, pH and water temperature were measured in the field using a multi-probe meter (HQ30d Single-Input Multi-Parameter Digital Meter, Hach). Chlorophyll a concentration was measured on site using a fluorometer (Turner Design Aquafluor). At each site 2 l of water was collected and stored on ice until return to the Laboratory of Environmental Health at Jimma University, where samples were analysed for total nitrogen (TN), total phosphorus (TP), five day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), orthophosphate, ammonium and nitrate concentration according to the standard methods as prescribed by APHA et al. (1995).

2.2.2. Biotic habitat characteristics

Macroinvertebrates were collected at each sampling station using a rectangular frame net (20×30 cm) with a mesh size of 300 μm. Each