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Development of a multimetric plant-based index of biotic integrity for assessing the ecological state of forested, urban and agricultural natural wetlands of Jimma Highlands, Ethiopia

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ABSTRACT

Wetlands are vital natural resources thereby providing ecological and socio-economic benefits to the people. However, anthropogenic activities have seriously changed the ecological conditions of wetlands worldwide, especially in developing nations like Ethiopia. Predominantly, the absence of biomonitoring tool greatly hampers the protection and management of wetlands. Therefore, the objective of this research is to develop a plant-based index of biological integrity for facilitating the management of wetlands. Accordingly, 122 plant species belonging to 37 families were collected and identified from forested, urban and agricultural wetland types and included in the analysis of the plant metrics. Initially, we reviewed and screened 35 potential metrics. Then, we selected four core metrics (% cover of native species, sensitive plant species richness, tolerant plant species richness and% of shrub species richness) using the decrease or increase responses to human disturbances, Mann-Whitney *U* test and redundant metric test. A trisect-quartile range system using box plots of the reference or impaired sites of wetlands was established to provide values for each core metrics. Then after, we combined the core metrics to develop the plant-based index of biological integrity. Finally, we validated the index by comparing the index response to different wetland types. Additionally, the index was validated based on the measured environmental variables that characterize the human disturbance gradient of wetlands. We found that the plant-based index is robust to discriminate the reference wetlands from impaired wetlands and can also be used as an effective tool for evaluating the long term natural wetland conditions of the Eastern African wetlands in the future.

1. Introduction

Wetlands are critical natural resources in developing countries of Tropical Africa including Ethiopia, where they do diverse ecological services and provide numerous socio-economic benefits to local communities. Particularly, where there are less human impacts, wetlands are fundamental in conserving biodiversity; regulating pollution, runoff, waste discharges and climate change, and in being natural reservoirs of water (Millennium Ecosystem Assessment (MA), 2005; Ramsar Convention Secretariat, 2011).

Vegetation is also vital in improving water quality through the uptake of nutrients, metals and other contaminants (U.S. EPA, 2002). Especially, wetland vegetation is used to differentiate ecological stressors including hydrological alterations, nutrient enrichment, excessive siltation and other human disturbance (Philippi et al., 1998; Bourdaghs and Gernes, 2005). According to Miller et al. (2006), the aquatic plant community is susceptible to physical, chemical and biological changes in the surrounding environment. In addition to their direct response to environmental change, the aquatic plants also offer many other advantages for bioassessment including their immobility, ease of sampling, identification (Beck and Hatch, 2009), quantification and their long life-span. Plants are, therefore, excellent indicators of the biological integrity of wetland ecosystems (U.S. EPA, 2002; Miller et al., 2006).

Wetlands have been degraded mainly due to anthropogenic factors such as the use of agrochemicals (Virbickas et al., 2011), drainage for cultivation, water extraction, climate changes (MA, 2005), urbanization/settlement, waste discharges (Soni and Bhatt, 2008), clay mining for brick-making, grazing and harvesting. Specif-

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ically, lack of appropriate bioassessment tools (Miller et al., 2006), poor management and misconception of people towards wetlands have aggravated the wetland problems. Thus, to show all kinds of degradation and cumulative influence of an (aquatic) ecosystem, biological indices of biotic integrity (IBI) of aquatic ecosystems were more preferred to physicochemical assessment methods (Mandaville, 2002; Muralidharan et al., 2010). This is because biological data are more directly related to ecological health of aquatic ecosystems than that of the (physico-) chemical data (Campbell, 2004). Moreover, bioassessment indices, specifically plant-based indices of biotic integrity (PIBIs) are popular and robust methods to prioritize wetlands for protection, management or restoration efforts (U.S. EPA, 2002; DeKeyser et al., 2003; Miller et al., 2006) in developed nations such as U.S.A. However, till now, very few efforts have been made to use plants as biological indicators (Mack et al., 2000; Miller et al., 2006) despite their robust efficacy for assessing the wetland conditions.

In Ethiopia, about 2% total area of the country was covered with wetlands (Hailu, 2007), and the majority of them have been degraded due to various anthropogenic factors (Hailu, 2007; Getachew et al., 2012; Mereta et al., 2013). Moreover, although some efforts have been made for the past decades to identify the extent of impairment of freshwater ecosystems using mainly physicochemical parameters and/or very few biotic indices developed for other countries, the ecological assessments of wetlands have also been hindered due to the absences of biological indices, particularly plant-based indices. To the best of the authors' knowledge, to date, not a single plant-based index of biotic integrity (PIBI) developed as an alternative management tool in Ethiopia and even in Africa as a whole except few fauna-based indices of biotic integrity (IBIs) (e.g., Yimer and Mengistou, 2009; Mereta et al., 2013 in Ethiopia; Bird, 2010 in South Africa). Therefore, to fill these gaps, this study targeted to develop an effective, rapid and easily applicable plant-based bioassessment tool (PIBI) for wetlands of Ethiopia and of Eastern Africa as well. Accordingly, the objectives of this study were 1) to develop a multimetric PIBI for the assessment of the biological integrity of wetlands, and (2) to validate and determine the reliability of the expected efficiency of the PIBI. Thus, we proposed the alternative hypothesis that the plant-based selected metrics or the developed PIBI could discriminate well the impaired sites from the reference sites.

2. Methods and materials

2.1. Study area

Wetlands are situated in Jimma Highlands with latitude of 7°15′N and 8°45′N and longitude of 35°30′E and 37°30′ E (Fig. 1). Jimma Zone covers a total area of about 18, 412.54 km^2, of which 15% is covered with highlands. The altitudes of the Zone range from 880 to 3340 ma.s.l. The mean annual rainfall of Jimma is between 1800 and 2300 mm with heavy rainfall months from June to September. The temperature of the study area also ranges from 8 to 28 °C with an annual mean of 20 °C so that the area has characteristics of sub-humid, warm to hot climate.

2.2. Wetland selection

Bonchie, Duda, Agaro, Boye, Haro and Merewa were the study wetlands of Jimma Highlands selected during the preliminary surveys (Table 1) based upon reference maps and literature. The study wetlands were selected based on their accessibility to the road and locations, and the availability of reference/forested wetlands (U.S. EPA, 2002). The study six wetlands are located from 1656 to 2028 ma.s.l. and ranged from about 1.5–70 ha in size. The six study wetlands were grouped into two forested/reference wetlands, two agricultural and two urban impaired wetlands based on their catchment land uses and human disturbance scores (HDS) (Table 1) using the protocol of Gernes and Helgen (2002).

2.2.1. Agricultural impaired wetlands

Merewa and Haro wetlands were selected as agricultural impaired wetlands (Table 1), and are located in the rural catchments, where cultivation, grazing and brick-production were common activities. Haro is permanently flooded, but Merewa is a semi-permanently wetland. However, some parts of both wetlands were drained for cultivation during dry season and hence the wetlands have been degraded. Particularly, such highland wetlands have subjected to drainage during dry season for maize cultivation in most parts of the southwestern Ethiopia (Woldu and Yeshitela, 2003).

2.2.2. Urban impacted wetlands

Boye and Agaro wetlands were wetlands influenced by urban-human practices from the towns of Jimma and Agaro, respectively (Table 1). Kitto and Awetu streams, crossing Jimma town, receive urban sewage and storm water, and then drain to Boye wetland. Thus, the wetland received untreated wastes generated by the community of Jimma. Additionally, overgrazing, plantation, urbanization and grass-harvesting were the main causes of wetland degradation. Likewise, a stream called Birr-Gedele carries the urban wastes from the Agaro town to Agaro wetland. Generally, despite wetland disturbance by cultivation and urban landscapes (Miller et al., 2006), these sites support a well developed plant community.

2.2.3. Reference/forested wetlands

Bonchie and Duda wetlands were selected as reference wetlands because for developing a biotic index, establishing reference sites is mandatory (Barbour et al., 1996). Thus, repeated surveys were necessary to locate reference wetlands due to diminished natural resources (particularly wetlands) caused by human activities. Hence, it was too difficult to find natural reference wetlands with large area size and close proximity to the impaired ones. This was the limitation we encountered during site selection despite their insignificant impact in the number of core metrics or in the PIBI development (see Section 3.1). Based on survey, therefore, we found two reference wetlands with relatively small area

Table 1
Locations and characteristics including HDS of wetlands surveyed in Jimma Highlands.

District	Name of wetlands	Wetland type	Locations		Altitude (m.a.s.l.)	HDS	Wetland area (~ha)
			Easting	Northing			
Jimma	Boye	Urban	7°38′56″	36°52′09″	1705	73	60.00
Gomma	Agaro	Urban	7°50′57″	36°35′14″	1656	75	2.00
Kersa	Merewa	Agricultural	7°41′01″	36°54′01″	1822	81	70.00
Jimma	Haro	Agricultural	7°36′47″	36°49′58″	1712	65	7.00
Gera	Bonchie	Forested	7°44′49″	36°15′18″	2028	15	4.00
Gera	Duda	Forested	7°45′47″	36°16′21″	2010	18	1.50