Ecological Indicators 89 (2018) 250–259

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Using vegetation attributes to rapidly assess degradation of East African wetlands

Kai Behn[a,*], Mathias Becker[a], Sonja Burghof[b], Bodo M. Möseler[a], Daniel Kyalo Willy[c], Miguel Alvarez[a]

[a] *University of Bonn, Institute of Crop Science and Resource Conservation, Department of Plant Nutrition, Karlrobert-Kreiten-Str. 13, 53115 Bonn, Germany*
[b] *University of Bonn, Steinmann Institute of Geology, Mineralogy and Paleontology, Nussallee 8, 53115 Bonn, Germany*
[c] *University of Bonn, Institute of Food and Resource Economics, Nussallee 21, 53115 Bonn, Germany*

ARTICLE INFO

Keywords:
Assessment
Index of biological integrity (IBI)
Land use
Monitoring
WET-Health

ABSTRACT

Wetlands in East Africa harbor a large biodiversity and provide diverse ecosystem services. Also, wetlands are highly suitable for crop production due to generally fertile soils and water availability. As a result of rising demand for cropland that is driven by population growth, degradation of upland areas and changing food demand patterns, wetlands are increasingly used for agricultural production. Such land use changes can negatively affect biodiversity and the provision of ecosystem services, especially when formerly little-disturbed wetlands are converted into croplands. For evaluating wetlands and developing land use or conservation strategies, we require methods to assess disturbance and degradation of wetlands. For instance, many indices of biological integrity for wetlands using vegetation attributes have been developed especially in the USA, but to date, no comparable assessment schemes are available for East Africa. To develop such a scheme, we sampled four different wetland localities, covering both floodplain and inland valley wetlands in Kenya, Rwanda, Tanzania and Uganda. A total of 198 wetland plots were characterized regarding land use and evaluated in terms of geomorphology, hydrology, vegetation and water quality regarding their deviation from a theoretical natural reference state without human disturbances and given respective impact scores using the WET-Health approach. Additionally, nine variables characterizing vegetation attributes were recorded. The impact scores were rescaled from 0 to 1 and used as response variables in multiple linear regression models. The predictor variables were selected for each regression model out of the nine vegetation attributes in a stepwise process. The regression models for the different response variables differed strongly regarding their accuracy. The root mean square prediction error (RMSPE) ranged between 0.14 for the “vegetation disturbance” and 0.27 for the “hydrological modification” regression model. However, we conclude that vegetation attributes such as “absolute cover of perennial species” or “average height of vegetation” are generally useful to estimate anthropogenic impacts on East African wetlands as assessed with the WET-Health approach. The presented approach can hence be a pragmatic addition to the WET-Health approach as a cost-efficient and rapidly applicable method. Furthermore, it may also be useful for *ex-post* application to historic data and vegetation surveys.

1. Introduction

Wetlands are widespread ecosystems in East Africa (Denny, 1993) that cover up to 167.000 km^2 in Kenya, Rwanda, Tanzania and Uganda (Stevenson and Frazier, 1999). They supply diverse ecosystem services such as the provision of food and medicine, water regulation, water purification and carbon sequestration (MEA, 2005). They are also important habitats for plant and animal species (Denny, 1994). On the other hand, wetlands have a large potential for agriculture due to generally fertile soils and water availability (Sakane et al., 2011). Over the last decades, this potential has been increasingly exploited (Dixon and Wood, 2003; Sakane et al., 2011) with the rising demand for cropland driven by population growth, lack of arable land and alternative livelihoods (Namaalwa et al., 2013). Degradation of upland fields (Symeonakis and Drake, 2010**)** and increasing rainfall variability in the context of climate change (Boko et al., 2007**)** also drive farmers into the wetlands (Sakane et al., 2011). Governmental policies have been promoting wetlands for agricultural use to supply local as well as export markets (Dixon and Wood, 2003). On the other hand, policies protecting wetlands have often been weakly enforced (Mombo et al.,

---

[*] Corresponding author.
E-mail address: kaibehn@uni-bonn.de (K. Behn).

https://doi.org/10.1016/j.ecolind.2018.02.017
Received 19 January 2017; Received in revised form 5 February 2018; Accepted 7 February 2018

2011; Namaalwa et al., 2013). Resulting land use changes, especially conversions of formerly little-disturbed wetlands to croplands, can entail negative effects on biodiversity and on providing and regulating ecosystem services (Shuyt, 2005; Wood et al., 2013).

Information gained about a wetland's condition becomes increasingly important for supporting and evaluating management decisions to mitigate wetland destruction and loss of functions (Miller et al., 2006; U.S. EPA, 2002). Despite major difficulties in assessing quantitatively the current state of a wetland, methods have been developed to assess their biological integrity or to quantify degradation and disturbance in different regions and for different types of wetland ecosystems. Biological integrity is hereby referring to conditions compared with wetlands without anthropogenic impact (Anderson 1991) or to a condition being comparable to the natural habitat in terms of species composition, diversity and functional organization (Karr and Dudley, 1981). For instance, the WET-Health approach has been developed to assess impacts of human activities on wetlands in South Africa (Kotze et al., 2012; Macfarlane et al., 2009) and was adapted to a finer scale for assessing East African wetlands by Beuel et al. (2016). Another way of assessing wetland conditions is using indices of biological integrity (IBI) which are also known as indices of biotic integrity. Originally proposed by Karr (1981) for the evaluation of aquatic environments using fish community attributes, they became popular, especially in the USA. In East Africa, IBIs were developed for river habitats in Kenya by Aura et al. (2010, 2017); Masese et al. (2009) and Raburu et al. (2009) and for wetlands in the Jimma Highlands of Ethiopia by Moges et al. (2016). Indices of biological integrity use a variety of metrics that are weighted in different ways and subsequently summed up to a total score, indicating the state of the wetland. In different approaches, plants and vegetation, macro-invertebrates or fish are being used as indicators (U.S. EPA, 2002). Vascular plants and vegetation attributes such as proportion of annual species, cover of invasive species or floristic quality indices (DeBerry, 2015) have frequently been regarded as suitable indicators and have been applied to assess wetland ecological states or levels of anthropogenic disturbance (Mack, 2007; Miller et al., 2006; Reiss, 2006). They are sensitive to human disturbances and easy to record and to quantify (Miller et al., 2006). However, unlike for the USA, where they were developed for several states and for different habitat types (e.g. Mack, 2007; Miller et al., 2006; Reiss, 2006), such indices are not yet available for wetlands in East Africa, apart from the study of Moges et al. (2016).

In this study, we combined the WET-Health approach (Kotze et al., 2012) and the concept of IBIs. We developed multiple linear regression models to predict impact scores assessed with the WET-Health approach and used vegetation attributes such as “vertical structure”, “absolute cover of perennial species”, “average height of vegetation” or “relative cover of monocots” as predictors. Our approach is intended to serve as an addition to WET-Health that can be easily, rapidly and efficiently applied in different wetland types along with any vegetation sampling. Additionally, an ex-post application to already recorded data or historical datasets may be possible.

2. Material and methods

2.1. Study sites

Data were collected in four wetland localities distributed across four East African countries, namely Kenya, Uganda, Rwanda, and Tanzania (Fig. 1, Table 1). The sites were selected based on them being national priority areas for research, development or conservation (MOE, 2016; MOWE, 2016; NEMC, 2016; REMA, 2016; SAGCOT, 2016). They comprise the two major freshwater wetland types in East Africa, namely inland valleys and floodplains, and differ strongly in their geomorphological and hydrological attributes as well as bioclimatic properties (Beuel et al., 2016). Further, the studied wetlands feature different land uses and use intensities, ranging from intensively cropped plots to little-disturbed patches of natural vegetation.

The Rumuruti wetland site in Kenya represents a highland floodplain (1800 m a.s.l.) formed by the Ewaso Narok river on the Laikipia plateau. It is underlain by thin alluvial sediments on crystalline basements, composed of volcanic phonolites (Heinrichs, 2001). The wetland has been modified by partial large-scale drainage, and these parts are intensively used for crop cultivation and domestic ruminant grazing. Wetland segments unaffected by drainage are largely undisturbed and characterized by *Cyperus papyrus* L. (Thenya, 2001). Stands of fever trees (*Acacia xanthophloea* Benth.) are common along the drier fringes. According to the classification of Köppen-Geiger, the Rumuruti site is included in the transition between the bioclimates “Tropical Savanna” and “Temperate with Dry and Warm Summer” (Peel et al., 2007). Derived from the interpolated climate surface based on observations from 1950 to 2000, available in the WorldClim database (Hijmans et al., 2005), the average annual temperature is 17 °C and the mean annual rainfall 714 mm. The Kampala wetlands in Uganda consist of many small inland valleys north of the capital city at an altitude of 1100 m a.s.l. The area is underlain by gneisses and granitoides (GTK Consortium, 2009). The wetlands are located along a gradient from urban to rural areas and from intensively cultivated to less disturbed inland valley bottom lands. The latter ones are dominated by swamp forests (Lind et al., 1974) and papyrus marshes, as common in the headwaters of the Nile River (Denny, 1993). The site is located within the transition between the bioclimates “Tropical Rainforest” and “Tropical Monsoon” (Peel et al., 2007), with an average annual temperature of 22 °C and an annual rainfall of 1291 mm (Hijmans et al., 2005).

The Kigali site in Rwanda comprises both the Nyabarongo floodplain in the south, and several small inland valleys in the north of Kigali City at around 1500 m a.s.l. The area is underlain by micaschists and quartzites (IGNB, 1981). The area is densely populated and most wetlands are intensively used for cultivating crops. Unused patches are mostly found in the Nyabarongo floodplain and are characterized by papyrus marshes. The bioclimate according to Peel et al. (2007) is “Tropical Savanna”. The average annual temperature is 20 °C and the annual rainfall 990 mm (Hijmans et al., 2005).

Finally, the Ifakara site in Tanzania is part of the Kilombero river floodplain at around 250 m a.s.l. It is characterized by thick fluvial sediments (Geological Survey of Tanganyika, 1962) and the floodplain is widely used for cultivating rainfed lowland rice during the wet season. Unlike the other study sites, undisturbed areas of the seasonally flooded center are characterized by edaphic grasslands with *Hyparrhenia* spp., *Panicum fluviicola* Steud. and *Phragmites mauritianus* Kunth. With decreasing duration and depth of flooding towards the fringes of the floodplain, woodlands gradually replace the grasslands (Hood et al., 2002). The Ifakara site belongs to the “Tropical Savanna” bioclimate with 25 °C and 1427 mm of annual rainfall (Hijmans et al., 2005).

2.2. Sampling strategy

Sampling was done in randomly selected tiles (Beuel et al., 2016) of 250 m by 250 m within the wetland area, however adjusted to the survey's time frame (around two weeks per site) and the accessibility of plots (conditions of roads, requirements for permissions, etc.). Each tile was subdivided into assessment units that were characterized by homogeneous vegetation cover and similar land use (Beuel et al., 2016). Within the assessment units, plots of 10 m by 10 m were preferentially selected (Dengler et al., 2008) for vegetation sampling. The size of 100 m^2 was chosen to have sampling area suitable for all occurring vegetation types (Dengler et al., 2008) while still being manageable regarding the time frame. Settlement units were not sampled. In total, 198 plots in 48 tiles were sampled, 30 plots (in 7 tiles) in Rumuruti (Kenya), 73 (13) in Kampala (Uganda), 56 (18) in Kigali (Rwanda), and 39 (10) in Ifakara (Tanzania). The distribution of the plots in the respective study site is available in the attached kml-file.