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Tropical wetland ecosystem service assessments in East Africa; A review of approaches and challenges

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ABSTRACT

East African wetlands are hotspots of ecosystem services, particularly for climate regulation, water provision and food production. We review the ability of current approaches to ecosystem service assessments to capture important social-ecological dynamics to provide insight for wetland management and human wellbeing. We synthesise evidence of human influences on wetlands and gauge the suitability of models and tools for simulating spatial and temporal dynamics, and land management on multiple ecosystem functions and services. Current approaches are largely unsuitable for advancing knowledge of social-ecological system dynamics and could be greatly improved with inter-disciplinary model integration to focus upon interactions between multiple ecosystem functions and services. Modelling can alleviate challenges that tropical wetland ecosystem services management faces and support decision-making of land managers and policymakers. Better understanding of social-ecological systems dynamics is crucial in East Africa where societies are vulnerable to poverty and climate variability, whilst dependent upon agrarian-ecological based economies.

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1. Introduction

Wetlands are the interface of aquatic and terrestrial ecosystems, forming specialised ecosystems where complex ecological processes occur due to the interactions between water, vegetation and soils (Naiman and Henri, 1997). Globally, wetlands cover 5.7 ± 0.3 M km^2 (mean annual maximum extent 1993–2007 ± standard deviation) (Prigent et al., 2012), approximately 6% of the earth's surface (Lehner and Döll, 2004). Tropical wetlands, located between 30°S and 30°N, cover 2.6 M ± 0.2 M km^2 and account for approximately 46% of global wetland coverage (Prigent et al., 2012). Estimates suggest that upwards of 50% of wetlands globally have been lost, but data on wetland land use change in Sub-Saharan Africa is sparse (Davidson, 2014; Leemhuis et al., 2016; Russi et al., 2013; UNWWAP, 2003). The provision of a range of goods and benefits to local populations from wetlands is well documented, particularly in areas of high rural poverty, such as East Africa (IWMI, 2014; Maltby and Acreman, 2011; McCartney et al., 2010; Naiman and Henri, 1997; Rebelo et al., 2009; Russi et al., 2013; Sellamuttu et al., 2008). Population pressures, demands for food and energy and limited natural resource management have driven an expansion of cultivation in wetlands across the tropics (McCartney et al., 2010, 2005). The extent of agricultural impacts on wetland ecosystem health is not well understood, particularly in Africa (Davidson, 2014; Joosten, 2010; Owino and Ryan, 2007). Between 1999 and 2008, agricultural expansion in wetland areas in Uganda averaged 410 ha^{-1} y^{-1}, (NEMA, 2010) yet little is known about the effects of anthropogenic influences on wetland functions and, more importantly, ecosystem services (ES) and impacts on wellbeing in local communities.

There is growing recognition of the value of wetland ES, particularly with regard to climate mitigation and adaptation (Duraiappah et al., 2013; Kolka et al., 2016; Russi et al., 2013). Increasing demand for climate-led wetland protection and restoration by public and private sectors may lead to increased investment in wetland management through government policy and market based mechanisms, such as carbon markets and water funds (Bonn et al., 2014; Kumar et al., 2011; Worrall et al., 2009). As a result, climate change action may become an important future driver of wetland management, with impacts effecting multiple ES (beyond just carbon) and wetland dependent communities. To understand the future impact of wetland management on wellbeing, disaggregated assessments of ES are vital for informed decision making in respect to poverty alleviation (Daw et al., 2011; Maltby and Acreman, 2011; Rodríguez et al., 2006). Awareness of the value of ES has increased, with progress largely due to the restructuring of existing knowledge into new frameworks (e.g. (Maltby and Acreman, 2011)). This has generated a better understanding of the important components of social-ecological systems, particularly the need to identify trade-offs, the role of management and policy, and plurality of societal values (Bennett et al., 2009; Daw et al., 2011; Reyers et al., 2013). Further examination of these systems is required to confirm suppositions and advance understanding of ES dynamics. Modelling and field experiments, as the primary tools for informing and developing understanding about systems, are essential for creating useful predictions and insights to expand understanding of wetland social-ecological systems dynamics, and evaluate the impact of wetland management on wellbeing.

Setting the focus of this review in the context of arguably two of East Africa's most significant anthropogenic and environmental challenges, rural poverty and climate change, we focus upon wetland ES that are central to these challenges; food production, and climate and water regulation. Against this background this paper sets out the critical social-ecological dynamics that wetland ES assessments need to capture. The paper then provides a synthesis of knowledge of the current interactions between wetland functions, and anthropogenic influences on ES based on a review of existing literature. A selection of models and tools commonly used for assessing ES and simulating wetland processes are reviewed to assess their ability to capture these important dynamics for wetland ES assessments. The review is set in an East African context, drawing upon perspectives from Uganda. This allows us to highlight the regional importance of wetlands, and current and potential future management options to reduce greenhouse gas (GHG) emissions and ensure food security against a background of poverty and an increasingly variable climate.

2. Requirements for wetland ecosystem services modelling

Ecosystem services are the manifestation of complex interactions between biophysical properties, ecological functions and human interventions (Bennett et al., 2015; Reyers et al., 2013). Wetland systems are amongst the most anthropogenically influenced ecosystems in the world, with modifications to hydrology, vegetation and soil (Carpenter et al., 2011; Prigent et al., 2012). Wetland land use change for agriculture in Uganda has typically involved the installation of crude drainage infrastructure to lower water tables, tilling wetland soils, replacing natural vegetation with crops and grazing pastures, and adding agrochemicals for soil management and pest and disease control (Andriesse, 1988; Holden, 2004; Mwita et al., 2013; Owino and Ryan, 2007; Schuyt, 2005). Understanding the influence of different land management practices (such as precision agriculture or improved water management) on ecological function and ES is required to evaluate and design alternative land use systems (Gordon et al., 2008; McCartney et al., 2010, 2005; Rebelo et al., 2009). This knowledge can further establish best practice techniques such as setting sustainable rates for biomass fibre extraction and processing (Jones et al., 2016).

Spatial interactions play an important role in the provision of wetland ES, particularly hydrological pathways between upstream activities which can influence wetland properties and have multiple downstream impacts on a range of ES (IWMI, 2014). Wetlands are highly sensitive to temporal dynamics, such as seasonal variations in hydrology and vegetation. Over longer temporal scales there are important system dynamics, such as compound changes, i.e. year on year declines in soil fertility, inflection points in ecological functions due to climatic thresholds, and the role of legacy impacts such as the long-term irreversible effects of peatland drainage (Bennett et al., 2015; Crépin et al., 2012; Drexler et al., 2009; Gordon et al., 2008; Rodríguez et al., 2006). Wetlands will be heavily influenced by future climate change and variability, hence it is important to understand the impacts of these on ES for future management (Erwin, 2009; Millennium Ecosystem Asssessment, 2005).

Assessments of wetland ES require simulation of multiple processes that act over a range of spatial and temporal scales in a useful and meaningful way to inform ecosystem management whilst being sensitive to the role of climate and anthropogenic influences on wetland functions and ES (Bennett et al., 2015; Burkhard et al., 2014; van Oudenhoven and de Groot, 2013). Due to limited empirical studies and data on tropical African wetlands, the data requirements for wetland ES assessments is critical to their application (Sjögersten et al., 2014; Joosten, 2010). This review evaluates ES assessment approaches against these important dimensions; anthropogenic influences on ecosystem functions, spatial and temporal dynamics, and data requirements.