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Future impacts of drivers of change on wetland ecosystem services in Colombia

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ABSTRACT

Wetlands are among the most valuable ecosystems in the world due to their delivery of ecosystem services (ES), but they are particularly vulnerable to drivers of land-use change. However, little is known about how different wetlands respond to drivers of land-use change and how that impacts their delivery of ES. After extreme floods hit Colombia in 2010–2011, negative impacts from these storms heightened the interest of Colombian policy-makers in understanding and recognizing the importance of wetlands. Here, we present a map with 19 wetland types for Colombia and assess the ES that these wetlands deliver and how those ES are impacted by drivers of land-use change. We based our spatial analysis on the Corine Land Cover data for Colombia and combined that with spatial indices derived from knowledgeable experts using the matrix approach and participatory mapping (PGIS). The most vulnerable wetland types identified were floodplain forests, riparian wetlands, freshwater lakes and rivers. The region of Magdalena-Cauca has been identified as the most vulnerable to the impacts of land-use change, until 2025. We discuss our results in light of the current Colombian policy-debate which concerns the designation of wetlands as strategic ecosystems. This designation implies necessary restrictions or prohibition of harmful activities in wetlands, principally mining and industrial agriculture.

1. Introduction

Extremely damaging floods in 2010–2011 in Colombia highlighted the importance of wetlands for hydrological regulation, in particular, the amelioration of flooding and reduction of erosion and mud slides, among governmental decision makers. Approximately 31% of the country and 3.2 million people were affected (7% of the national population) by the floods, with the cost of damages amounting to USD 6052 million (CEPAL, 2012). These societal and economic losses indicate that Colombia is vulnerable to the impacts of extreme climactic events. As a result, wetlands are beginning to be recognized in Colombia as strategically important ecosystems and the consequences of land-use changes that affect wetlands are receiving broader attention.

The importance of wetlands for delivering ecosystem services (ES) is widely recognized (de Groot et al., 2006; Maltby and Acreman, 2011). However, the variability among different wetland types in ES delivery is less understood (MEA, 2005). Moreover, different wetland types, due to their location (e.g. coastal versus inland), are affected by different drivers of change, and therefore require tailored approaches to address human impacts (Zedler and Kercher, 2005). Thus, analyzing how different wetland types deliver ES and how these are affected by various drivers of land-use change is highly relevant for the development and implementation of wetland management plans and policies.

ES mapping is becoming a powerful decision-making tool (Burkhard et al., 2013; Crossman et al., 2013). Previous studies have shown how ES maps can be combined with predicted land-use changes to inform local decision-making (Bateman et al., 2013; Daily et al., 2009; Goldstein et al., 2012; Raymond et al., 2009). Tailored approaches of land cover based mapping methods and participatory mapping of ES (PGIS) by scientists and decision-makers may facilitate the introduction of an ES framework into environmental policies. However, most previous PGIS studies have produced ES maps at local or regional scales, while only a few studies have mapped ES at the national level

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(Brown and Fagerholm, 2015). Moreover, drivers of land-use change are usually not incorporated in ES mapping approaches, limiting the utility of ES maps for decision-making.

Given current population growth and economic development, Colombia will undoubtedly experience future land-use changes affecting wetland ecosystems. To inform policy and minimize ES loss, it is essential to understand how and where drivers of land-use change will affect wetlands, and which ES would be degraded across wetland types.

With this understanding, our specific aims were to: (1) assess and map ES delivered by different wetlands types in Colombia, (2) assess and map the major drivers of land-use change and proximate causes considered to have the greatest impact on ES delivery, and (3) identify vulnerable wetlands; that is, those with the highest capacity to deliver ES, but also with a high probability of being affected by drivers of land-use change in the future. This work is part of a national research project on wetlands (Alexander von Humboldt Biological Resources Research Institute and Adaptation Fund, Project No 13-014), which was proposed as a part of the actions required to strengthen the capacity of Colombia to cope with climate variability and increased vulnerability.

2. Study area

We focused on the continental area of Colombia, which covers 1.1 million km^2 (Fig. 1). The high variance in topography (altitude ranges from 0 to 5775 m asl) and climate (temporal and spatial distribution of rainfall caused by the migration of the Intertropical Convergence Zone – ITCZ, and of the El Niño Southern Oscillation – ENSO), provides the environmental conditions for the biological diversity that places Colombia among the world's megadiverse countries (Mittermeier et al., 2011). Approximately 27% of the country is covered by wetlands (Flórez et al., 2014). Wetland diversity is high, ranging from peatlands, lakes and riparian wetlands in the Andes, to the flooded forests and palm swamps in Amazonia, the flooding savannas in Orinoco, and the coastal swamps, lagoons and mangroves in the Caribbean and Pacific sea. The national territory is divided into five major hydrological watersheds (Fig. 1): Caribbean (102,786. 68 km^2), Magdalena-Cauca (271,118.09 km^2), Orinoco (347,208.26 km^2), Amazon (341,991.29 km^2), and Pacific (77301.82 km^2), which are then further divided into 38 hydrological zones (IDEAM, 2013). Of these, 23 hydrological zones were affected by damaging floods in 2010–2011, encompassing 31% of the national territory (353,930.9 km^2).

Ample evidence supports increasing recognition that Colombia is affected by urban development practices, population growth and resource consumption that has occurred since the mid-20th Century (McAlpine et al., 2009; Meyfroidt et al., 2013). These developments are the underlying driving forces behind wetland loss and conversion in Colombia and are similar to those reported worldwide (MEA, 2005; van Asselen et al., 2013). However, the environment in Colombia has also suffered from complex issues related to being a resource-rich (e.g. mining) country, involved in an internal armed conflict for more than 70 years (Caselli et al., 2015). Since the middle of last century, Colombia and other countries in South America, have experienced a remarkable landscape transformation, especially with the expansion of urban areas (Etter et al., 2008), where approximately 75% of the population (45.5 million) resided in 2010 (DANE and DANE, 2005). The main settlements are located in the Andean and Caribbean regions, but recent landscape assessments have also shown increasing development in the Orinoco and Amazon regions (Etter et al., 2008).

Major proximate causes or economic activities that impact wetland ES mostly through land-use changes are cropping (coffee, sugar cane, oil palm, coca, and rubber), cattle ranching, and mining (coal, oil, gold); gold mining and oil palm cultivation are the fastest growing activities in the last decade. These activities are responsible for the transformation of 45% of the natural land cover (Etter et al., 2006) and have led to violent clashes over land ownership and social marginalization. Land-use change has led to the degradation of large wetland complexes, thus reducing their delivery of ES, including their capacity to buffer drastic and unpredictable storms, precipitation and floods (Camargo, 2012; Marquez, 2001; Ricaurte et al., 2012).

3. Material and methods

We based our spatial analysis on the Corine Land Cover data for Colombia (CLC—Colombia map) (IDEAM, 2010a), combined with spatial indices (Table 1) derived from knowledgeable experts in accordance with methodological approaches such as the matrix approach and participatory mapping (PGIS) for future impacts of drivers of land-use change (Brown and Fagerholm, 2015; B A Bryan et al., 2010; Burkhard et al., 2012; Jacobs et al., 2015; Palomo et al., 2013; Petter et al., 2013). For a detailed methods description, see Appendix in Supplementary materials.

The CLC-Colombia map was organized into six hierarchical levels and 97 land cover classes, 17 of which related to coastal, inland and artificial wetlands. These classes were expanded into 19 to better represent wetland specificities. For data management, a Geodatabase was created and all data were projected using the MAGNA Colombia Bogota System, with general mapping undertaken using ArcGIS 10.1 (ESRI, 2013) and IDRISI Selva 17.0 (Clark Labs, 2013).

Given the lack of ES data for different wetland types for Colombia and worldwide (Gallo and Rodriguez 2010,2011,2011; Ricaurte et al., 2012,,2014), and given the science-policy nature of this study (due to the political attention and policy momentum that the 2010–2011 floods raised), we decided to use expert knowledge to assess ES and drivers of land-use change at a national level (Palomo et al., 2014; Plieninger et al., 2013; Ramirez-Gomez et al., 2015). Data were collected through two, 1-day participative workshops organized in Bogota, Colombia in February 2014, with 58 participants, including scientists, policy and sectoral officers from governmental institutions, universities and private organizations. Participants were chosen on the basis of their cutting-edge knowledge and expertise on tropical wetlands, with an emphasis on aquatic ecology, botany, hydro-geomorphology, fisheries, environmental policy, agriculture, mining and transportation. The interdisciplinary character of the group was seen as a way of ensuring the quality of the information. In order to avoid bias in responses and to facilitate participation, the participants were split into groups of 8–9 people, with different professional backgrounds or research fields.

On the first day, participants were provided with a list of the 19 wetland types that would be used to develop the wetland map (Fig. 1). Then, participants were asked to individually assess the capacity of the 19 wetlands to provide ES from a prioritized list that was developed or provided during the workshop. Later, the same exercise was performed at the group level (8–9 people) to achieve a consensus. Scoring in the prioritization and consensus matrices was accomplished using a 1–5 scale with 5 being the most valuable to each ES.

On the second day of the workshop, participants assessed how drivers of land-use change might impact each of the 19 wetland types. Based on the wetland evaluation in the frame of the Millennium Ecosystem Assessment (MEA, 2005) and Política nacional para la gestión integral de la biodiversidad y sus servicios ecosistémicos de Colombia (MADS, 2012), we selected three drivers of land-use change that were the most critical to understand in Colombian wetlands: (1) land-use change and habitat loss, (2) water demand, and (3) water pollution. Accordingly, we identified a set of proximate causes of major importance in Colombia related to land-use change: (1) agriculture (rice, coffee, sugar cane, oil palm, greenhouse vegetable and fruit crops, other crops), (2) cattle ranching (pasture grasses, forage shrubs, pastures mixed with agriculture, pastures with trees), (3) mining (surface and underground mining, mixed mining), (4) water infrastructure (inland and marine aquaculture, channels, hydropower dams, other artificial water systems), and (5) road infrastructure (principal and other roads).

Participants were first provided with the respective explanations of