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National ecosystems services priorities for planning carbon and water resource management in Colombia

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ABSTRACT

The modelling and mapping of ecosystem services (ES) are important components of any programme of land management planning, as they help evaluate the potential benefits that ecosystems provide to society. The objective of this paper is to evaluate ES for setting priorities and planning carbon and water resource management in Colombia. By using information related to provision and regulation services for water, carbon storage and protection services against extreme events such as landslides, we have evaluated the spatial distribution of ES and identified geographical hotspots. The results are presented for two levels of analyses: (1) natural regions and (2) watersheds. We found differences in the distribution and range of values for ES and observed that each region and watershed tends to maximise one or two services, with the exception of the Caribbean region, which presents low values for most services. The services of water resources provision, regulation of water flow and carbon storage in the above-ground biomass presented high correlations among them, with the Pacific and Amazonian regions presenting the highest average values for these ES. The Andean region was important for the prevention of landslides and the amount of carbon in the soil. At the watershed level, the Amazon watershed and those associated with transition areas (piedmont) between the Andes and the lowlands of the Amazonian, Orinoquia and Pacific regions were the areas where the greatest number of hotspots was concentrated. These results provide valuable information on how better use official institutional information to quickly define and prioritise ES, to guide management actions within the country's recent policies on integrated water resources management and on biodiversity and ES.

Introduction

The concept of ecosystem services (ES), defined as the benefits that human beings obtain from ecosystems (MA, 2005), has become a key tool for different stakeholders interested in linking natural, human and economic systems (Armsworth et al., 2007; Bryan et al., 2010; Muradian and Rival, 2012). There is an increasing interest in incorporating ES into environmental planning policies (de Groot et al., 2010; Muradian and Rival, 2012; Viglizzo et al., 2012) and into the design of objectives and strategies for landscape management, with the aim of improving the provision of these services to society (Daily and Matson, 2008; Farrell and Anderson, 2010; Kroll et al., 2012).

In the past decade, many publications have synthesised discussions around the ES concept and their classification system (de Groot et al., 2002; Wallace, 2007; Costanza, 2008; Braat and de Groot, 2012), payment for ES (PES) (Van Hecken and Bastiaensen, 2010; Wünscher and Engel, 2012) or the link between ecosystem processes, biodiversity, climate change, land use and ES (Egoh et al., 2007; Fu et al., 2012; Armstrong et al., 2012; Mace et al., 2012). However, there is still a lack of information and empirical data on the distribution, service fluxes and trade-offs between different landscape functions and how these ES change over time and across different spatial scales (de Groot et al., 2010; Haines-Young et al., 2012; Mace et al., 2012).

One of the requirements to apply the ES concept and decision-making is the quantification and mapping of services (Braat and de Groot, 2012; Burkhard et al., 2012; Maes et al., 2012a). Mapping ES is the initial step for the subsequent analyses of ecological, social

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and economic processes associated with ES (TEEB, 2010). Both processes help answer questions related to the state and trends of ES for society, the drivers that affect them and the priorities of conservation and restoration strategies (Maes et al., 2012b). The mapping and modelling methods are varied, depend on the research objectives, type of service and working scale, and are still undergoing development and validation (Nedkov and Burkhard, 2012). The current trends in mapping and modelling include research on biodiversity, species functions, habitat structure, ecosystem processes, ecological production functions and landscape function analyses (Lavorel and Grigulis, 2012; Maes et al., 2012a; Nedkov and Burkhard, 2012; Bastian, 2013).

Generally, information on ES mapping and modelling focuses on the distribution of services, especially food and water provision and regulation (UNEP-WCMC, 2011), and the majority of this research consists of studies conducted at different spatial scales (Maes et al., 2012a). China, South Africa, USA, the Netherlands and Australia are the countries in which most of the research is conducted for this subject (Egoh et al., 2008, 2012; Costanza and Kubiszewski, 2012). Ecosystem functions, such as inputs for mapping, are generally linked through models or indicators from the primary data by relating these functions to maps of land use/cover, eco-regions or habitat maps (Burkhard et al., 2012; Haines-Young et al., 2012; Maes et al., 2012b). The capacity of the ecosystem capacity to supply certain ES and the actual usage by people varies considerably (Bastian, 2013) because ecosystem functions depend mainly on biophysical conditions and land use (de Groot et al., 2010; Burkhard et al., 2012).

In Latin America (LA), between the years 2001 and 2004, the Millennium Ecosystem Assessment initiative catalysed the increase in studies related to ES. Chile, Costa Rica, Colombia, Perú, Argentina and Brazil have conducted sub-global evaluations (MA, 2005), with differences among the studies that reflect each country's context, needs and pressures regarding their natural resources. In the region, studies have focused on quantifying carbon- and water-related services, and the payment for ecosystem services (PES) has received considerable attention (Corbera et al., 2007; Pagiola et al., 2007; Quintero et al., 2009), but trade-offs analyses are scarce (Balvanera et al., 2012). The review by Balvanera et al. (2012) on the state of knowledge on this subject is noteworthy, concluding that there are imbalances in the focus of interest and information availability for each country and that the diversity of ecosystems and people in LA should be taken into consideration for interventions and future scenarios. However, most countries have official information that can be the basis for a national inventory of their ES and prioritise ES conservation areas. In Colombia, research on ES is limited, and with the exception of the first evaluation of ES within the MA (2005) study (Armenteras et al., 2005), current interest revolves around PES related to hydrological services and biodiversity and pastoral systems (Murgueitio et al., 2011; Moreno-Sanchez et al., 2012). Studies focusing on mapping and trade-offs are also scarce in Colombia (but see Tallis et al., 2012). Recently, Colombia has incorporated ES in its biodiversity policy (MADS, 2012), the actions of which should be based on the knowledge and availability of spatial information on the state and trends of the ecosystems and ES at different scales for decision-making.

Herein, we present the first national mapping of ES in Colombia, which is a country with high geographic heterogeneity and several sources of environmental information that are often underused by decision makers. The general objective of this study is to carry out an evaluation of ecosystem services in Colombia for setting priorities and planning carbon and water resource management. We have based this study on two levels of analysis: five natural regions and 41 watersheds. The study is interesting because it shows the suitability of using available official information and how to use it as a surrogate to quickly map ES in tropical countries where data are often collected at different scales and are limited in its availability. Currently, attention on ES is focused on tropical countries. We have formulated the following questions: (1) What is the spatial distribution for ES? (2) To what extent are ES correlated on both national and watershed levels? (3) What geographical areas maximise the different ES production (i.e., what are the ES hotspots)? Using available public information related to water resources, forests, soils and the use of geographic information tools, we have evaluated the following five ES in Colombia: water provision, regulation of water flow, carbon storage in the above-ground biomass and in the soil and finally landslide prevention.

Methods

Study area

Colombia is located in north-western South America and is considered to be a mega-diverse country, with 34 different biomes and 132 natural ecosystem types (IDEAM et al., 2007). The country covers approximately 1,142,000 km^2 in continental area and has five natural regions that are associated with 41 watersheds (Fig. 1), which are used as units of analysis in this study: the Andean (including the three Andes ranges, the Inter-Andean valleys and the Magdalena-Cauca watersheds), the Caribbean, the Amazonian, the Pacific and the Orinoco. These regions have contrasting hydroclimatic, geomorphologic, topographic, edaphic and land use/cover conditions as well as different levels of socio-economic development (Poveda et al., 2011; Armenteras-Pascual et al., 2011). The country is characterised by a high water yield with fluvial discharge that varies from 100 mm per year into the Caribbean to over 6000 mm per year into the Pacific. The water volume in Colombia is 2084 km^3, which is distributed in five big hydrological regions that are divided into the 41 aforementioned watersheds also used as level of analysis and that are currently monitored (MADS, 2010). The population density of the country is 40 people/km^2, distributed irregularly, with ca. 85% of the population concentrated in urban centres of the Andean region, with 3500 people/km^2, in contrast with the southern and western parts of the country, with less than 1 person/km^2 (http://www.dane.gov.co). More than one-third of the territory has been transformed, with the current predominant land use being agriculture, including pasture in the Andean and Caribbean regions, tropical humid forests in the Amazonian and Pacific regions and savannahs in the Orinoquia region. The natural ecosystems are diverse, and although forests covered approximately 57 million hectares in 2005, deforestation rate has been estimated to be 273,334 ha per year between 2000 and 2005 (Cabrera et al., 2011). Moreover, in the past decade Colombia has experienced a five-fold increase in foreign investment, especially in mineral extraction (e.g., oil, carbon and gold) (Banco de la República, 2012), a trend that is foreseen to be maintained and to affect some of the basic services for people because many of these projects are planned to be developed in high biodiversity areas that are strategic for the conservation of water resources. Large projects aiming to produce biofuels are also being developed, together with a continuous encroachment of forests due to the progression of the agricultural frontier in the Amazonian and Orinoquia regions.

Methods and databases used to estimate the ES

We evaluated the spatial distribution of five ES: water provision, regulation of water flow, carbon storage in the above-ground biomass and carbon in the soil, and landslide prevention. These ES were selected because of their relevance to environmental management and planning and also for the availability of their data for the whole country. Our approach uses the hierarchical classification of