Biological Conservation 192 (2015) 378–386

Contents lists available at ScienceDirect

Biological Conservation

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

National and regional relationships of carbon storage and tropical biodiversity

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ARTICLE INFO

Article history:
Received 7 April 2015
Received in revised form 25 September 2015
Accepted 24 October 2015
Available online xxxx

Keywords:
Ecosystem services
REDD
Conservation
Planning
Colombia

ABSTRACT

Tropical forests host the highest levels of biodiversity and maintain some of the largest carbon stocks of all terrestrial ecosystems. Policies resulting from the United Nations Framework Convention on Climate Change (UNFCC) for forest-based climate change mitigation (e.g., Reducing Emissions from Deforestation and forest Degradation (REDD+)) have been considered win–win solutions for both C storage and biodiversity conservation. Win–win solutions are indeed apparent when there is geographical overlap of high carbon density forests with high biodiversity, as suggested by many global studies. However, strong congruence between high carbon storage and biodiversity at the national and subnational levels is less obvious. To improve national policies and expectations of REDD+ outcomes, it is necessary to account for the potential risks of relocating deforestation activities from high-carbon areas to low-carbon areas, as such relocation may negatively affect high-biodiversity habitats. Using a combined dataset of global and national biodiversity and C storage, we examined whether the optimization of carbon and biodiversity is, as suggested, a win–win situation. We identified hotspots of C storage and of biodiversity within Colombia and the demographic and land use factors that affect the spatial distribution of the current patterns of biodiversity and C. We also identified and mapped two additional forest carbon and biodiversity relationships (areas with high carbon and low biodiversity and areas with low carbon and high biodiversity) that represented relevant conservation trade-offs at national and subnational levels. Our results suggest that, although C storage and biodiversity hotspots still overlap nationally and subnationally, the relationship between these two types of hotspots is weaker than that at the global level. Additionally, areas where high carbon and high biodiversity do not overlap are more extensive than potential win–win areas. Simultaneous carbon and biodiversity conservation is not as straightforward as it appears to be at the global level. Countries must swiftly identify areas where unintentional negative biodiversity consequences may result from national REDD+ strategies, and future research should identify the factors that affect C storage and biodiversity both at the national and subnational levels.

1. Introduction

Tropical forest ecosystems host the highest level of biodiversity on the planet (Gardner et al., 2012; Myers et al., 2000) and also play a vital role in balancing global greenhouse gas (GHG) emissions due to their ample above- and below-ground carbon storage (Houghton, 2005). Despite their importance, tropical forests are highly threatened by land-use changes that result in species loss, habitat loss, and forest fragmentation and degradation. The loss of tropical forests would destroy many unique habitats and may induce a mass species extinction (Wright and Muller-Landau, 2006). Furthermore, the issue of deforestation relates directly to both biodiversity loss and climate change: together, tropical deforestation and forest degradation have been recognized as the second largest source of carbon emissions to the atmosphere, accounting for almost 20% of human origin GHG emissions (Gullison et al., 2007). Despite the dual role of tropical forests as repositories of both biodiversity and carbon (C), both of which are essential for climate change mitigation, these two roles have rarely been examined simultaneously (Baraloto et al., 2014; Thomas et al., 2012). Similarly, biodiversity and climate change policies are rarely simultaneously addressed in tropical countries (Díaz et al., 2009).

Some recent studies have suggested that, at least at the global scale, conserving tropical forests may safeguard both C stocks and biodiversity (Strassburg et al., 2010). Conversely, other global studies indicate that there is limited geographic overlap between least-cost areas for retaining forest C and protecting biodiversity (Siikamäki and Newbold, 2012). Policies that aim to reduce the drivers of forest change might benefit from incorporating assessments of both carbon storage and biodiversity conservation (Kissinger et al., 2012). International programs that aim to reduce emissions from deforestation and to increase atmospheric GHG removal by forests (e.g., REDD+) are also viewed as

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http://dx.doi.org/10.1016/j.biocon.2015.10.014

potential opportunities to foster biodiversity in developing countries (Gardner et al., 2012; Thomas et al., 2012; Venter et al., 2009). However, not all forests are equally beneficial to biodiversity conservation, and trade-off situations may arise in which the most biodiverse regions may not also store the most C. For example, the Cerrado in Brazil is a highly diverse ecosystem with an aboveground biomass of less than 13 Mg/ha (Pivello, 2011). Such a conflict might result in unintended negative consequences for biodiversity conservation if policies focus exclusively on C storage (Phelps et al., 2012). Indeed, REDD+ activities that will be implemented at the national level are also recognized as a potential threat to biodiversity (Dickson and Kapos, 2012) when the role of biodiversity conservation is not properly framed within those activities. Thus, there has been some discussion of the risk of shifting deforestation activities from areas with high C content to areas with lower C content but that are also vital for biodiversity conservation (Gardner et al., 2012; Jones et al., 2012).

A lack of adequate monitoring data at the national level is, in part, caused by the paucity of studies on the relationship of C stocks and biodiversity in tropical countries. To combat this shortage, a three-tiered approach was proposed to integrate biodiversity concerns into assessment frameworks for national REDD+ programs (Gardner et al., 2012), including a combination of globally derived data with nationally generated remote sensing data and ground-based forest and biodiversity surveys (Vihervaara et al., 2014). Colombia is an extremely biodiverse country, with high C stocks (Arbeláez-Cortés, 2013; Asner et al., 2012). Therefore, it is a perfect model for understanding the effect of downscaling congruencies between biodiversity conservation and C storage at the national level. Furthermore, Colombia contains highly contrasting natural regions and a wide range of geographical characteristics. In this study, we have three objectives. First, we wanted to determine the relationship between C storage and biodiversity and to determine whether this relationship changes when examined on a national versus a subnational level. Second, we examined the direct and indirect factors that affect the C storage and biodiversity patterns that we identified. Finally, we described three potential conservation scenarios: the creation of 1) win–win areas, where biodiversity hotspots overlapped with C storage hotspots; 2) areas with high C storage and low biodiversity; and 3) areas with low C storage and high biodiversity.

2. Material and methods

2.1. Study area

The study was conducted in Colombia, a tropical country located at the northwestern tip of the South American continent (with borders at 12°26′46 North, 4°13′30 South, 66°50′54 East and 79°02′33 West). Colombia encompasses an area of more than 1.1 million km^2, and it is the only country in South America with both Caribbean (in the North) and Pacific (in the West) coastlines. Colombia borders Venezuela and Brazil to the east and Peru and Ecuador to the south. Colombia is located near the equator yet possesses a wide range of temperature and precipitation because of the presence of the Andes Mountains and the associated variations in elevation. Although western Colombia is mostly mountainous (45% of this area) and densely populated, a major part of the country consists of plains lying below 500 m. This country is a perfect place to undertake this study due to its high heterogeneity; its geography is divided into five distinct regions, based on climate, topography and soil type: the Amazon, the Andes, the Caribbean, the Orinoco and the Pacific regions. These five natural regions were analyzed separately throughout the manuscript. In terms of biodiversity, Colombia is a megadiverse country, with 34 different biomes and 132 natural ecosystem types (Rodríguez et al., 2015). The natural ecosystems are diverse, but in 2010, 53% (60.507.592 ha) of the Colombian territory was forests (IDEAM, 2011). The numbers of species reported are 1889 for birds, 763 for amphibians and 479 for mammals (IAVH, 2012).

2.2. Datasets

To analyze the distribution of forest C stocks within the entire country, we spatially estimated the distribution of above-ground natural forest C storage using data obtained from a national official project, "Scientific and institutional capacity building to support Reducing Emissions from Deforestation and Degradation (REDD) projects in Colombia" (IDEAM, 2011), where forest is defined as an area of at least 1 ha covered with trees or woody vegetation of at least 5 m in height and at least 30% crown cover. These original data were collected from 2791 forest and floristic inventories in permanent and temporary plots located throughout the country over the past two decades (Phillips et al., 2011). From this project, we used the C values reported for the natural forests of Colombia that were estimated by allometric equations for natural forest types and classified according to Holdridge Life zones. Values ranged from 48.1 t C/ha in dry tropical forests to 128.8 t C/ha in lowland tropical humid forests. We converted the C data to a 10 × 10 km grid (with a total of 11,537 cells) and assigned a value to each cell that corresponded to the total C per cell by adding the values for each forest type present and weighting it according to the relative area of each forest type (Fig. 1A).

To obtain a spatial dataset for species richness in Colombia, we combined the spatial global datasets of bird, mammal and amphibian distributions (IUCN, 2010) with data from the national biodiversity information system (IAVH, 2012). These three groups were selected to represent biodiversity in Colombia because more information was available for these taxa than any other. Records from the national system that did not have coordinates were georeferenced to WGS84. Overall, we compiled data for 743 species of amphibians (29,458 georeferenced locations), 449 species of mammals (35,237 locations) and 1690 species of birds (413,032 locations) in Colombia. For each cell in the 10 × 10 km grid, we assumed a species was present if the cell met one of the following criteria (Fig. 1): a) the cell contained a known georeferenced location from the national dataset or b) the cell was located within the species' range polygon from the global IUCN dataset. As a measure of richness, the total number of species per group was calculated by counting the number of species in each cell (Fig. 1B–D). We also calculated the combined species richness of all groups, as an overall measure of biodiversity.

Of the total cells with data, we excluded from our analysis those cells with more than 70% of the area under transformed ecosystems (i.e. crops or pastures or degraded areas), with a final dataset of 9759 cells for the analysis describe below. To examine the factors that affected C storage patterns (Fig. 1A) biodiversity (Fig. 1B–D), we used environmental, demographic and land-use information from a previously organized GIS database (Armenteras et al., 2011, 2013a). For each cell of the 10 × 10 km grid, we calculated the following variables: (i) mean annual temperature, (ii) annual precipitation; (iii) altitude, (iv) rural population density in 2005, (v) roads, (vi) pasture area in 2005, (vii) agricultural area in 2005, (viii) forest area in 2005, and (ix) deforestation rate between 1990 and 2005.

2.3. Analyses

We determined the relationship of biodiversity and C storage in separate analyses for the whole country and for each of the five natural regions. To do so, we calculated the Pearson's correlation coefficient for C and biodiversity (all groups together and birds, mammals and amphibians, individually).

We used general linear models (GLMs) to analyze the effects of demography (i.e., rural population density, roads), land use (i.e., agricultural and pasture areas and deforestation rate) and the physical environment (i.e., temperature, precipitation, altitude, forest area) on biodiversity (i.e., the species richness of birds, mammals and amphibians, each taxon separately and as a group) and C storage. Whenever necessary, variables were transformed to improve the normality of the