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Low-cost strategies for protecting ecosystem services and biodiversity

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ABSTRACT

The selection of priority areas for nature conservation must balance the costs and benefits of conserving biodiversity, protecting ecosystem services, and permitting human activities or resource use. In this study, we selected priority areas for conservation in a seasonally dry tropical forest in Brazil and analyzed changes in the protection of ecosystem services and the conservation of plant biodiversity upon excluding areas with high opportunity costs (e.g., where income would be lost if natural areas were protected) and high population density. We identified two types of protected areas: sustainable use (SU) and strict protection (SP). Plant biodiversity (181 species) and supporting services (water balance, net primary productivity, and soil fertility) were used to determine the optimal locations of both types of protected areas. Provisioning services (water supply, fodder, and genetic resources) were used to determine SU priority areas, while regulating services (water purification, carbon storage, and erosion prevention) were used to determine SP areas. The selection of lowly populated or costly areas was associated with a small decrease in the representation of biodiversity (4% loss in SP and 6% loss in SU) and a large decrease in the representation of supporting (36% loss in SP and 31% loss in SU), regulating (41% loss in SP), and provisioning services (7% loss in SU). Our results reveal that selecting priority areas with low population density and low opportunity costs would decrease the overall representation of ecosystem services in protected areas but would still improve the cost efficiency of biodiversity conservation efforts.

1. Introduction

Over the last several decades, the role of protected areas has expanded to include the protection of social and cultural diversity and the maintenance of ecosystem services in addition to the conservation of species and ecosystems (Watson et al., 2014). Ecosystem services are valuable resources for human populations and include natural resources and ecological processes. These services provide a link between nature and human populations and support quality of life (Pascual et al., 2017). In particular, humans obtain numerous benefits from nature and from the protection or conservation of ecosystem services. For example, the conservation of a native forest can guarantee the persistence of endemic species and the delivery of clean water to surrounding human populations.

The conservation of biodiversity is compatible with the conservation of ecosystem services in some cases (Balvanera et al., 2001). However, conservation choices based on biodiversity alone may be unsuccessful in protecting ecosystem services when a spatial mismatch between biodiversity and ecosystem services is present at a large scale (Thomas et al., 2013). Even when biodiversity and ecosystem services are spatially correlated, protected areas may not conserve these to the same extent (Manhães et al., 2016). Therefore, to combine the conservation of biodiversity and ecosystem services, conservation planning strategies should consider both measures as independent features (Chan et al., 2006; Thomas et al., 2013; Wickham and Flather, 2013).

At the same time, the benefits of nature conservation must be balanced with socioeconomic activities developed in same priority areas. In this context, opportunity cost describes the foregone revenue when nature conservation is prioritized rather than other forms of land use (e.g., agriculture and urbanization; Adams et al., 2010). Also, as nature conservation is generally subjected to a restricted budget, accounting for the overall benefits and costs of conservation can improve the efficiency of resource allocation and the selection of priority areas for conservation (Bottrill et al., 2008). The spatial relationship between

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socioeconomic costs and conservation benefits can help us to understand how these co-occur at a large scale (Naidoo et al., 2006). If benefits are negatively correlated with costs, the inclusion of costs will have a small effect on the selection of priority areas; yet, if benefits are positively correlated with costs, priority areas will change because of spatial co-occurrence (Naidoo et al., 2006). All these possibilities complicate the selection of high-priority conservation areas for decision makers and managers (Gerber, 2016).

Vulnerability to human impact is another important variable considered in systematic conservation planning and in setting priority areas for conservation (Brooks et al., 2006). Vulnerable areas may present threats to biological conservation in the long term and require greater investment in surveillance by environmental agencies, thereby imposing a higher conservation cost. The vulnerability of potential conservation sites can be assessed in different ways and can be based on, for example, land tenure, the presence of threatened species, or expert opinions (Wilson et al., 2005). Human population growth and density can also represent threats to biodiversity and can be used to assess the vulnerability of potential conservation sites (Cincotta et al., 2000). Thus, vulnerability and opportunity costs should both be considered during the selection of priority areas based on low-cost strategies for conservation. A consideration of these variables would support decision makers in balancing socioeconomic losses with conservation benefits.

A low-cost scheme using opportunity cost in nature conservation can reduce spatial correlation between potential conservation areas and agricultural areas. On the other hand, a low-cost strategy based on vulnerability can decrease the pressure on the conservation of species and services, which occur in areas with high population density. However, reduction of agricultural areas in the selection of priority areas may lead to a lower representation of species-specific conservation areas when these areas are spatially correlated (Dobrovolski et al., 2011). Moreover, the selection of non-vulnerable areas during this process would mitigate future biodiversity loss by avoiding areas that could suffer future human impacts (Wilson et al., 2005). Nonetheless, in some cases, vulnerable areas should be prioritized, for example, when numerous target species (i.e., endemic or endangered species) co-occur in highly threatened areas (Cincotta et al., 2000), even though this would lead to a highly vulnerable conservation scheme.

Multiple-scenario analyses balance the benefits and costs of conservation and support decision makers and conservationists in prioritizing and planning conservation areas (Di Minin et al., 2013; Dobrovolski et al., 2014; Dobrovolski et al., 2011; Faleiro and Loyola, 2013). In the present study, we used a multiple-scenario approach to designate priority conservation areas based on the representation of biodiversity and ecosystem services in potential conservation areas and on the inclusion of vulnerability and opportunity costs in different conservation prioritization scenarios. We applied this approach to determine two types of priority areas, sustainable use (SU) and strict protection (SP) areas, and to make relevant recommendations on the establishment of protected areas in Brazil.

2. Methods

2.1. Study site

We identified priority areas for conservation in the Caatinga, a seasonally dry tropical forest located in the semi-arid region of Brazil (Fig. 1). Caatinga vegetation is mostly formed by deciduous trees and shrubs and is characterized by an annual herbaceous plant layer that only grows during the rainy season (Bellefontaine et al., 2000). The corresponding semi-arid region covers 11% of Brazil (nearly 826,411 km^2). Rainfall in the Caatinga ranges from 240 to 1500 mm per year, yet rainfall is less than 100 mm in the five- to six-month dry season (Pennington et al., 2009). Overall, the rate of evapotranspiration in the Caatinga is three times higher, on average, than the rate of rainfall, causing a severe water shortage in this region throughout the year (Pennington et al., 2009).

Ongoing deforestation and human activities coupled with dry conditions are currently causing desertification and leading to biological impoverishment in the Caatinga (Marinho et al., 2016; Ribeiro et al., 2015). Agriculture and livestock production are the main economic activities in this region. These productive lands have higher opportunity costs for conservation because of the revenue lost by local people following the establishment of protected areas. Accordingly, these high-cost areas along with the presence of densely populated areas might lead to future conflicts in the establishment of protected areas.

As a proxy for estimating opportunity costs, we used the agricultural gross domestic product (GDP) per municipality (available at http://www.ibge.gov.br) in Brazilian currency (BRL; in August of 2017, 1.0 BRL = 0.32 USD). To estimate vulnerability, we used a population density map based on the number of persons per square km (data retrieved from http://sedac.ciesin.columbia.edu). To highlight areas with high vulnerability (high population density) and high opportunity costs (high agricultural GDP) in the Caatinga, we selected the pixels corresponding with the upper 5th quintile of both variables (Fig. 1).

Currently, the selection of priority areas for conservation in the Caatinga is gaining increasing attention within the conservation community because only 7.4% of this severely threatened environment is currently under protection (Hauff, 2010) (Fig. 1). According to Brazilian environmental legislation (SNUC, 2000), protected areas (PA) are categorized into two broad types of management: strict protection (SP), wherein the direct use of natural resources is closely regulated (PA I – IV categories of the International Union for Conservation of Nature [IUCN]), and sustainable use (SU), wherein local livelihoods and activities are allowed under sustainable management plans (Dudley, 2008).

2.2. Conservation features

2.2.1. Biodiversity

To estimate plant biodiversity, we used 103,437 presence records of 769 tree species within the Caatinga boundaries that were retrieved from the NeoTropTree database, which contains presence records for woody plant species throughout the entire Neotropical region (Oliveira-Filho, 2014). With these presence records, we used the Maximum Entropy (MaxEnt) software to generate models that inferred the geographical distribution of each species.

MaxEnt uses presence records of species and environmental variables of the background landscape to estimate habitat suitability for species (Elith et al., 2011). We used the country of Brazil as the background landscape and considered the following environmental variables: climatic variables from the Worldclim database (http://www.worldclim.org), soil type variables (http://mapas.ibge.gov.br), and height above nearest drainage (HAND; http://www.dpi.inpe.br) from the database of the Brazilian National Institute for Space Research (INPE, for its acronym in Portuguese). We selected the HAND variable because of its high correlation with plant composition (Schietti et al., 2014). We used pairwise Pearson correlation tests to select only uncorrelated environmental variables with coefficient values below 0.7. Following this criterion, we then ran the MaxEnt models using ten environmental variables (mean diurnal range, isothermality, mean temperature of the warmest quarter, precipitation of the wettest quarter, precipitation of the driest quarter, precipitation of the warmest quarter, precipitation of the coldest quarter, altitude, HAND, and soil type).

Of the 769 tree species recorded in the Caatinga, we only selected those species whose distribution covered more than half of Caatinga's area. We used this cutoff to select species that were specifically associated with this biome; most species in Caatinga are widely distributed and also present in other biomes, such as the Cerrado, Amazon, and Atlantic Forest in Brazil (JBRJ, 2016). Following this criterion, 181 species were used to generate habitat suitability maps and to therefore