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Mapping multiple ecosystem services indicators: Toward an objective-oriented approach

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ABSTRACT

Quantifying and mapping ecosystem services (ES), their indicators and their relationships is of crucial importance for environmental management. In this article, we analyze the spatial distribution of multiple-ES indicators at three locations on the pioneer fronts of the Brazilian Amazon. We identify trade-offs and synergies between six ES indicators for soil, vegetation and biodiversity characterization. We also propose spatial representations of multiple-ES indicators (vegetation carbon stocks, rates of water infiltration into soil, soil chemical quality, soil carbon stocks, biodiversity and richness in Sphingidae). Finally, we discuss three different methods to map them depending on the goals of the maps, arguing that maps lean on objective-oriented approaches. The study is based on remote sensing and sampling data from 135 sampling points. We created multiple-ES indicators maps based on Principal Component Analysis (PCA), a score of ES richness, and discrimination of land cover units. PCA is an appropriate tool for showing high correlations between indicators, nevertheless has notable limitations for visual communication. The scoring method may help mapping ES hotspots, however it fails to consider relationships among them. The land-cover-based method has the advantage of being simple and easy to interpret, still it may not consider important indicators not related to land-cover changes. We discuss the interests and limitations of these different ways to map multiple-ES indicators, regarding the final goals of the maps.

1. Introduction

Since the Millennium Ecosystem Assessment (MEA – MEA, 2005) and due to the diffusion of remote sensing practices, ecosystem services (ES) mapping techniques have generated great interest in recent literature (*e.g.* Naidoo et al., 2008; Kienast et al., 2009; Rutledge et al., 2010; Nedkov and Burkhard, 2012; Bagstad et al., 2014). Because mapping provides spatial information about the state of ES, it helps targeting areas where it is necessary to implement and monitor environmental policies. Maps also facilitate understanding of the real impacts of current environmental policies on ecosystems and the services they provide.

Ecosystems always provide multiple ES that are related to one another. The benefits of studying ES trade-offs to facilitate policy making is well demonstrated (Bennett et al., 2009; Carpenter et al., 2009; Raudsepp-Hearne et al., 2010). For example, a policy that would target only a single individual ES could therefore have unintended consequences on other ES and consequently on human well-being (Bennett et al., 2009; Viglizzo et al., 2012).

Because ES are simultaneously provided by the ecosystems and are in constant interrelations (Bennett et al., 2009), it is necessary to study these interrelations. As a matter of facts, much effort has been made in recent years to understand better relationships between ES and the environmental factors that influence them. One way that would give major benefits for environmental management is the quantification and maps of multiple-ES (i.e. map that presents multiple ecosystem services – Van Jaarsveld et al., 2005; Egoh et al., 2007). However, the number of multiple-ES maps is small (Seppelt et al., 2011; Crossman et al., 2013), most likely due to the many

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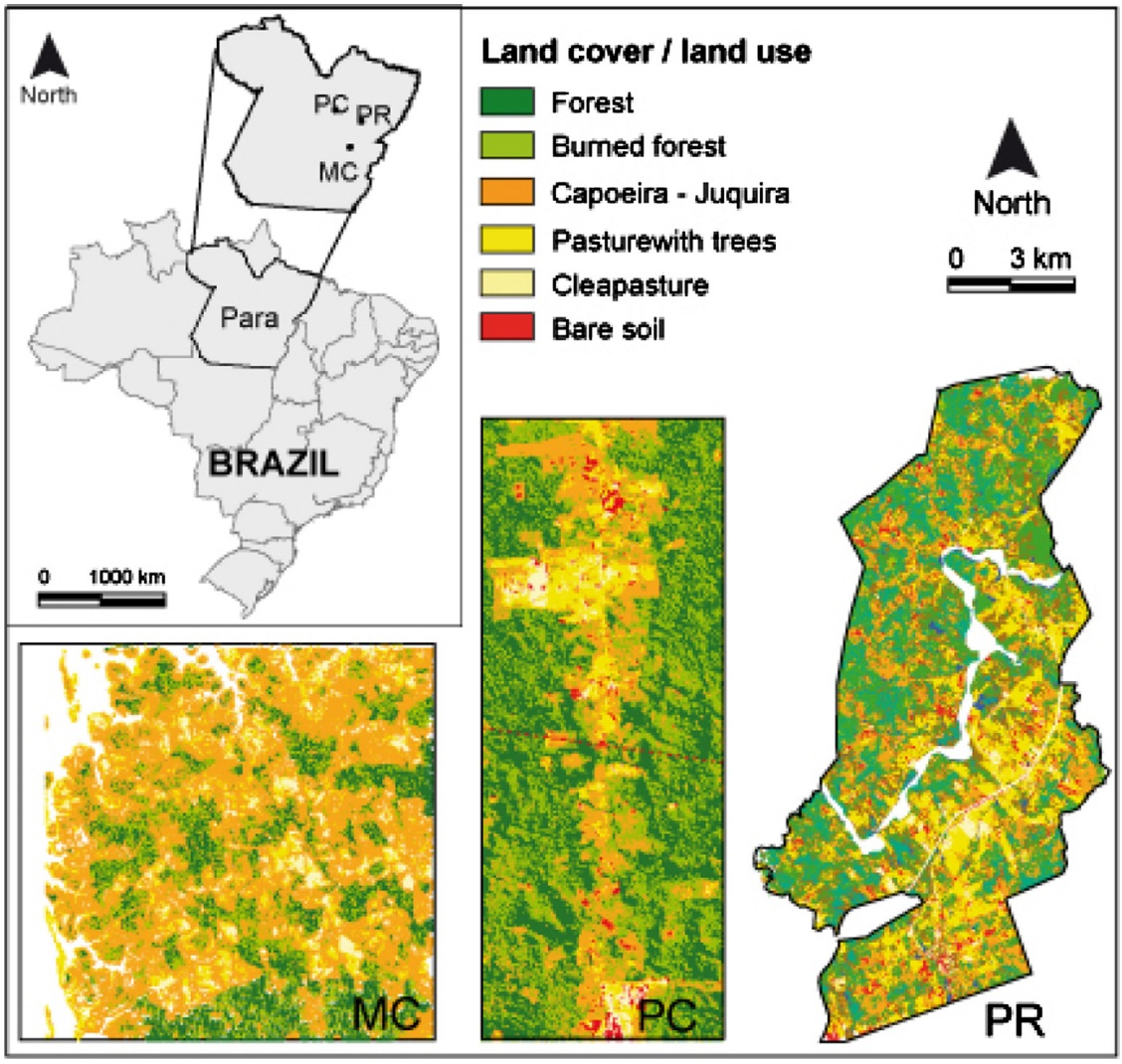

Fig. 1. Location of Pará State and the study sites of Macaranduba (MC), Pacajá (PC), and Palmares II (PR). Colored maps represent land use of the study sites in 2007.

challenges involved in mapping multiple ES or multiple-ES indicators. Creating multiple-ES (indicators) maps addresses thematic issues that are important for decision making and methodological concerns, such as the data used to model multiple ES or multiple-ES indicators.

A brief review[1] of current scientific literature demonstrates the methodological difficulties in current multiple ES mapping methods. For example, it illustrates the difficulty to map a large number of ES indicators in biophysical values. Indeed, some of ES are more frequently studied, mainly the regulation ES (43%), while others are not taken into account. Moreover, the understanding and the consideration of their interrelations are often still lacking. Some studies represent the correlations between only two ES by qualitatively classifying Spearman's rank correlation or overlapping ES hotspots (Anderson et al., 2009; Eigenbrod et al., 2010). These methods thus do not promote full understanding of the multiple relationships of ES.

However, if methodological problems linked to ES mapping are often highlighted, the non-neutral dimension of maps as a powerful tool is rarely underlined. Yet, in this article, we aimed to generate several multiple-ES indicators maps including 6 ES indicators (vegetation carbon stocks, rates of water infiltration into soil, soil chemical quality, soil carbon stocks, biodiversity and richness of Sphingidae). These multiple-ES indicators maps are produced from a diverse and large dataset obtained in three different geographical areas of the pioneer fronts of the Brazilian Amazon (Pará State). We first meant to identify trade-offs and synergies between the six ES indicators. Afterwards we proposed three spatial representations of multiple-ES indicators. Finally, we discussed the three different mapping methods regarding the objectives they could fulfill (educational, policy making. . .), concluding that ES mapping should be considered as an oriented-objective approach.

According to previous scientific studies, we defined the different words relative to multiple maps (Bennett et al., 2009; Mouchet et al., 2014; Scröter and Remme, 2015): ES associations are the relations between ES, negative or positive; trade-offs are the relationships between ES when they co-vary negatively; synergies are the relationships between ES when they co-vary positively and ES hotspots are the areas with a high production of one or few ES. Conversely, a coldspot is an area where ES providing is low. To consider more than one ES, in their interrelations or through their hotspots or associations, we use the expression "multiple-ES indicators" in opposition to the study of only one ES indicator, called "individual-

[1] We searched the Web of Science® to identify recent research involving multiple-ES maps. We searched all scientific articles published from 1990 to 2014 using the terms "ecosystem service" (both plural and singular) and "mapping" or "map(s)" as topics.