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Unsustainable landscapes of deforested Amazonia: An analysis of the relationships among landscapes and the social, economic and environmental profiles of farms at different ages following deforestation

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ABSTRACT

In Amazonia, our knowledge of the trade-offs and possible thresholds in the relationships among social, economic and environmental parameters remains quite limited and hinders the design of sustainable socio-environmental systems. To fill this gap, we analyzed relationships among landscape metrics, socio-economic patterns, biodiversity and soil-based ecosystem services within a total of 51 farms located at 6 sites of the Colombian and Brazilian Amazon. Farms were representative of an initial set of 274 and they represented colonization ages from 10 to 80 years and a range of public policies found in the region.

Cluster analysis separated farms in 7 types of production systems according to 5 main criteria (size of the farm, human capital, incomes, farm products and production intensity) selected from an initial set of

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Biodiversity
Ecosystem services
Social wellbeing
Economic efficiency

18 criteria. Biodiversity was summarized into a composite index *Bd* built with data from 8 different groups: trees, shrubs, grasses and forbs, birds, Saturnidae and Sphingidae moths, Drosophilidae, earthworms and ants. Provision of ecosystem services was quantified by a composite indicator of 6 sub-indicators of soil hydrological functions, C storage and chemical fertility. Increasing intensity of production systems was linked to a significant decrease of indicators of natural capital biodiversity (Bd) and soil based ecosystem services (*Es*) with 20% and 37.3% variance explained, respectively. No relationship was observed between production systems and an indicator of human wellbeing (*Sb*) based on a set of 5 criteria identified with the farmers. Findings indicate that early colonizers migrate when a certain level of development has been achieved (as a result of their activities) and are replaced by wealthier populations.

An overall indicator of sustainability (*Su*) – that combines production efficiency (*Ep*), *Sb*,*Bd* and *Es* indices (ranging from 0.1–1.0) – decreases significantly with the landscape intensification (*Li)* with 18.7% variance directly explained by this relationship. *Su* was also significantly related to production systems (36.4% variance explained): while this indicator remained relatively stable with a value of 0.5 across the early and intermediate phases following deforestation, it dropped down considerably (0.2) for production systems based on cattle ranching on highly degraded pastures with less than 2% forest cover remaining. Restoration with sylvopastoral systems allowed some farms of this former group to increase sustainability to a value of 0.35 after less than 5 years. Agroforestry systems on sites deforested at the same time maintained values around 0.5, as they allowed the maximum production efficiencies and maintained relatively high values of the Biodiversity (*Bd*) and Ecosystem services (*Es*) indexes. This is evidence that beyond the general negative trade-off between human development and natural capital observed in Amazonia, agro ecological options to revert the trend are quite promising. A general methodological approach for the reconstruction of sustainable landscapes in farms of the deforested Amazonian region is proposed as a conclusion.

1. Introduction

With nearly 70% of forest cover remaining intact, the Amazon region houses unrivalled levels of species diversity for a number of taxonomic groups of plants, vertebrates and invertebrates (Da Silva et al., 2005). It is emblematic of the challenges faced by human development in a context of global environmental degradation and climate change (Millennium Ecosystem Assessment, 2005). Experts state that forest conservation is necessary to minimize regional climatic disturbances and limit global temperature increase to 2 °C at the end of the century (Lenton, 2011). They express concern about possible effects of climate change on the integrity of this region (Giles, 2006). Others still consider this vast and little populated area as a possible new frontier for expanding food production (Simon and Garagorry, 2005; Morton et al., 2006). Much emphasis has been placed upon creating large conservation areas to prevent irreversible biodiversity losses that this option would trigger (Peres, 2005; Walker et al., 2009; Gibson et al., 2011). However, the threat of deforestation leading to an irreversible shift to savanna has been expressed (Nepstad et al., 2008; Lawrence et al., 2007; Staver et al., 2011). Decision support strategies for conservation planning are now increasingly discussed (Game et al., 2013; Gardner et al., 2009), while considerably less effort has been directed towards improving land-use efficiency in already cleared lands by trying to understand trade-offs among ecosystem services and landscape organization (Godar et al., 2012; Kareiva et al., 2007; Steffan-Dewenter et al., 2007). In Amazonia, deforested lands comprise a gradient from early phases of settlement (with relatively high levels of forest cover) to more mature stages, where extensive livestock production and/or intensive agriculture may sustain development for a few decades before starting to decline (Rodrigues et al., 2009). Although natural forests may be present, they have all suffered some degree of perturbation.

Theory predicts that the socio-economic conditions prevailing in the region and the production systems that are selected determine the land cover mosaic of deforested landscapes as well as biodiversity and provision of ecosystem services (Gunderson and Holling, 2002; Mattison and Norris, 2005; Nelson et al., 2009). However, very few data have been collected thus far to test and quantify these relationships in Amazonia and facilitate the design of policies that simultaneously address the economic, environmental and social aspects of development (Carvalho et al., 2001; Grieg-Gran et al., 2005; Boerner et al., 2007; Foley et al., 2007). In addition, linkages between the decrease in social and economic performance, often observed after 3–4 decades following forest colonization, and an overall impairment of natural capital have not been clearly demonstrated (Rodrigues et al., 2009).

In order to fill these important gaps, we analyzed the relationships and trade-offs among the different social, economic and environmental components of farming landscapes, while testing the following hypotheses (Fig. 1).

H1. The production systems selected by farmers following deforestation determine the subsequent composition and structure of landscape and landuse intensity. Depending on resources available (labor, finances, knowledge, equipment) farmers convert forest to different types of agroecosystems and determine the nature, size, and shape of managed plots and their distribution in the farm landscape.

H2. Production systems, defined by human and financial resources available, commodities produced on the farm and incomes generated, directly affect production efficiency.

H3. Production systems also affect social wellbeing, such that well-equiped and well-trained farmers are expected to have a better chance to implement production systems with a high productivity and/or commercial value and fit in competitive marketing chains.

H4. Well performing production systems are therefore expected to result in satisfactory levels of well being.