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Ants as indicators of soil-based ecosystem services in agroecosystems of the Colombian Llanos

Catalina Sanabria [a,b], Patrick Lavelle [a,b], Steven J. Fonte [a,c,*]

[a] International Center for Tropical Agriculture (CIAT), Cali, Colombia
[b] UMR IESS-Paris, Université Paris 6 UPMC, Paris, France
[c] Department of Plant Sciences, University of California, Davis, USA

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ABSTRACT

Ants represent a widespread and functionally diverse taxonomic group that are both sensitive to land management and serve as important regulators of key soil processes. Building upon this idea, we sought to understand the impacts of agricultural management on ant communities in the Orinoco River Basin of eastern Colombia and to identify species that could be used as indicators of soil-based ecosystem services. Ants were collected and identified from the soil and litter layer within 75 fields (nine TSBF subsamples along a transect in each field) divided among five common agricultural land uses in the region: 1) annual crops (maize, soy and rice), 2) rubber plantations, 3) oil palm plantations, 4) improved pastures (based on *Brachiaria* spp.), and 5) semi-natural savannas. As expected, land management was found to greatly influence ant communities. Improved pastures showed the highest species richness (6.9 species per transect) and semi-natural savanna the greatest abundance of ants (145 individuals per transect). Within each of these fields a suite of soil and agroecosystem characteristics were measured and combined into synthetic indicators of five soil-based ecosystem services: 1) nutrient provision, 2) water storage and regulation, 3) maintenance of soil structure, 4) climate regulation services and 5) soil biodiversity and biological activity. Ant species were then associated with these synthetic indicators using the IndVal method to identify indicator species for each of the five consolidated ecosystem services measured. In total, 14 indicator species were identified and found to be significantly associated with either the high or low provision of each of the five services. The development of such bioindicators offers a rapid and relatively inexpensive tool to facilitate land management and policy decisions in this biologically diverse and rapidly changing region of Colombia.

1. Introduction

Tropical savannas cover approximately 15% of the total land area in South America (Rippstein et al., 2001) and are of critical importance for agricultural production and a range of other ecosystems services in the region. In Colombia, these savannas occupy much of the eastern plains (locally referred to as the Llanos Orientales), a rapidly developing part of the Orinoco River Basin that has been traditionally managed under extensive livestock and low-input agriculture. Recent investment in the region has focused on large-scale agricultural intensification involving the conversion of semi-natural savanna to annual crops of rice, maize and soybean, perennial crops such as oil palm and rubber, and improved pastures (typically sown with Brachiaria species and fertilized every few years). This conversion usually involves high inputs of fertilizer and lime combined with deep and rather intensive tillage. Such intensification has generated much concern, as soils and ecosystems of the region are generally fragile and comprise a patchwork of agricultural land uses mixed with semi-natural savanna and riparian forests, both critical landscape components in regulating regional water quality and biodiversity (Goosen, 1971; Correa et al., 2005; Lavelle et al., 2014).

Soils are involved in the provision of many ecosystem services that are of great importance for the maintenance of ecosystem functioning and human societies, with farmers primarily responsible for the management of this resource (Millennium Ecosystem Assessment, 2005; Wall et al., 2012). Soils are also considered a large reservoir of

* Corresponding author. Present address: One Shields Avenue, Department of Plant Sciences, University of California, Davis, CA 95616, USA. Tel.: +1 530 574 3958.
E-mail address: sjfonte@ucdavis.edu (S.J. Fonte).

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biodiversity that has received less attention relative to above ground communities (Brussaard et al., 1997). Deforestation and the conversion of natural systems to intensified agriculture can have devastating impacts on both above- and below ground biodiversity (Lawton et al., 1998; Lavelle and Lapied, 2003). This biodiversity is highly vulnerable to management changes, but also critical to maintaining key ecosystem functions and contributing to the long-term sustainability of agroecosystems (Wall et al., 2012).

Soil macrofauna, in particular, represent an important part of agroecosystem biodiversity and some groups have received considerable attention as ecosystem engineers that fundamentally influence the nature and functioning of soils they inhabit (Lavelle et al., 2006). Past research indicates that the loss of soil macroinvertebrate diversity degrades soil structure and diminishes nutrient cycling (Blanchart et al., 1997; Velásquez et al., 2012). Ants, in particular, fulfill key roles in the maintenance of energy and material flow in soils. Among the many functions performed by ants is a constant rearrangement of soil particles, favoring the movement of organic matter and more rapid mineralization of litter and organic residues (Folgarait, 1998; Wagner et al., 2004). Ants also contribute to improving soil aggregation and aeration by creating macropores and subterranean galleries constructed with a mixture of organic matter and mineral soil, formed into biogenic structures. Ants have also been shown to modify soil chemical processes via modifications to pH (Hölldobler and Wilson, 1990; Lafleur et al., 2005; Frouz and Jilková, 2008) and enhancement of microbial activity (Dauber et al., 2001). In addition to their fundamental role as ecosystem engineers, ants have been proposed as valuable indicators of soil quality (Lobry de Bruyn, 1999; Paoletti, 1999), since they are involved in many below ground functions, are highly sensitive to changes in management, and respond quickly and consistently to environmental alterations (Philpott et al., 2010).

The aim of this study was to to identify indicator species for key soil-based ecosystem services and evaluate the impact of land use on soil-dwelling ant communities in the Llanos region of Colombia. This represents a strategic objective since farmers have little access to many of the costly and complex scientific techniques for measuring ecosystem services, nevertheless generally possess considerable knowledge of plants and invertebrates that occur in their fields (Rousseau et al., 2013). Indicator species identified by scientists and validated by farmers (with support from trained technicians) could thus be used to evaluate the provision of ecosystem services on farms, and allow farmers to be more active participants in land management decision-making.

2. Materials and methods

2.1. Study region and design

This research was carried out in the Meta Department of eastern Colombia. At roughly 200 m in elevation, the region experiences a humid tropical climate, with an average annual temperature of 26 °C, rainfall averaging 2500 mm year^{-1}, and a marked dry season between December and March (Decaëns et al., 2001). Sampling was conducted along a 200 km transect extending from Puerto

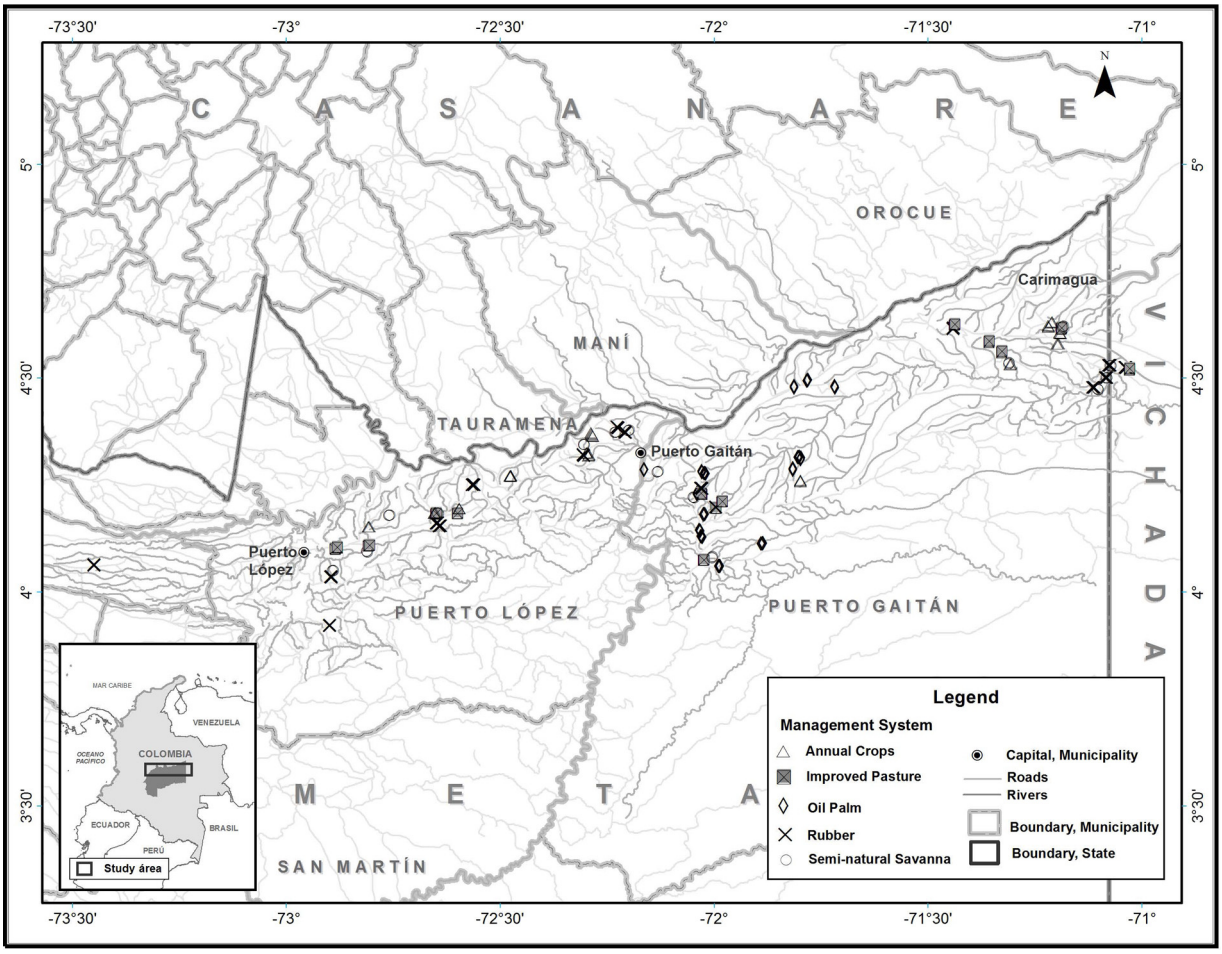

Fig. 1. Location of the 75 plots and associated land use sampled between June and July 2011, in the Meta Department, Colombia.