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Relations between the design and management of Senegalese orchards and ant diversity and community composition

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ABSTRACT

Although agriculture is a major factor in environmental change, the level of its impact is likely to vary with farming practices. Thus, we sought to determine how farming practices might affect the natural compartment of agroecosystems and the sustainable use of land. In particular, we examined ant biodiversity and community composition as related to orchard design and management practices in the mango- and citrus-based orchard agroecosystems of Senegal. Ants were collected using pitfall traps in 49 orchards classed in four types based on their design and management. The results showed that the effect of practices was significant, albeit weak, and a typology of orchards based on design and management practices was congruent with a typology based on the composition of ant communities. The different types of orchard were seen to differ in the richness and diversity ant species. Moreover, ant richness and diversity was positively correlated with tree richness. We were also able to identify some ant species as being related to agricultural practices. For instance, *Monomorium salomonis* (L.) was closely associated with high irrigation, fertilization and pesticide use, whereas *Paltotyreus tarsatus* was associated with greater tree richness, high local ground coverage by the tree canopy, more leaf litter and great variation in the local tree planting density. This study appears to be the first attempt to characterise the relations existing between orchard design and management practices and the functioning of Sahelian fruit-based agroecosystems thereby furthering the goal of providing recommendations for sustainable management strategies.

1. Introduction

Agricultural activities are responsible for most landscape degradation, including the loss of plant and animal biodiversity. The simplification and destruction of natural habitats in agroecosystems are usually the main factors of such landscape degradation (Matson et al., 1997; Altieri, 1999; Benton et al., 2003; Burel et al., 2013). According to Philpott and Armbrecht (2006), intensive agricultural practices accelerate the loss of biodiversity. Changes in vegetation complexity, such as simplification or a decrease in biotic resources, commonly lead to a change in species interactions and ecosystem processes (Tilman et al., 1997; Hooper and Vitousek, 1997) and this can have potentially drastic consequences for ecosystem services. Nowadays, studies of ecosystem functioning are increasingly being used in efforts to promote biodiversity conservation. Examples include studies of the impact of human management practices on ecological processes in cropping systems (Weibull and Östman, 2003). In Senegal, it is known that orchard agroecosystems are very diverse in their varietal composition, their planting design and their management practices (Vannière et al., 2004; Grechi et al., 2013),

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but no prior study has examined the relations existing between orchard design and management practices and underlying ecological processes.

Biodiversity is known to have important functions in agroecosystems, affecting the stability, productivity, and sustainability of farms (Giller et al., 2009; Vandermeer et al., 2010), and the management of crop resources can have a major impact on the environment (Wardle et al., 2001; Hooper et al., 2005). To reduce that impact, it is necessary to understand the effect of orchard design and management on animal communities, including arthropods.

In Senegalese orchards, it was necessary to identify ecological indicators in order to understand how orchard design and management might impact ecological processes. An ecological indicator can be defined as any species "that demonstrates the impact of a stressor on biota or that monitors longer term stressor-induced changes in biota" (Mcgeoch, 1998). Soil organisms, such as earthworms and ants, are often used as ecological indicators. They play a crucial role in organic decomposition, soil nutrient balancing, soil formation and the renewal of soil fertility (Thomsen et al., 2012; Folgarait, 1998). Ants have been studied in many climate zones (Hoffmann and Andersen, 2003; Perfecto and Armbrecht, 2003) and have been successfully used as ecological indicators in a wide range of land-use situations (Andersen et al., 2002; Andersen and Majer, 2004). Ant communities have been investigated in studies of land management systems, natural systems, rehabilitation processes and changing agroecosystems (New, 2000). The robustness of ants as ecological indicators has been demonstrated, and is supported by an extensive understanding of their community dynamics in relation to disturbance (Andersen and Majer, 2004; Andersen et al., 2004). Moreover, ants can provide invaluable information, e.g. for detecting (1) invasive species; (2) trends affecting threatened or endangered species, (3) impacts on keystone species and also for (4) evaluating land management actions, and (5) assessing the impact of long-term ecosystem changes in disturbed habitats. All can be done in a relatively short time and for a low cost (Underwood and Fisher, 2006). Ant communities have been shown to respond quickly to changes in vegetation stages (Wike et al., 2010). In addition, ants are good biodiversity indicators because their diversity is representative of overall diversity and the assemblage composition of other groups, and can be characterised in a specified area relatively quickly and easily (Majer et al., 2007).

The consequences of ant activity and diversity for pest and disease control, and thus for agriculture, can be beneficial or detrimental depending on the local context and the identity of the ants. High ant activity has a top-down effect reducing communities of herbivorous arthropods in agroforest systems (Philpott and Armbrecht, 2006; Philpott et al., 2004). This is particularly true for dominant ants that have a marked predatory behaviour. However, high ant activity can also reduce communities of predatory arthropods (James et al., 1999), and thus be detrimental to agriculture. A beneficial effect of ant diversity on pest control is not well established, but is expected because, for instance, the more diverse a community is, the more chances it has of including a predator of a particular pest (Philpott and Armbrecht, 2006; Gove, 2007).

No prior studies have examined ant communities in Senegalese orchards. The agroecosystems, which are in the semi-arid climatic zone, possibly require specific ecological indicators that differ from those used in temperate or tropical zones. Thus, our aim was to identify representative ant communities, if any, in a wide range of Senegalese orchard types and then find out whether ants in general or specific ant species could be used as bioindicators of the impact of orchard design and management on their diversity, richness and community composition. To do this, we tested the hypotheses that ant diversity, ant richness and ant community composition are related to (i) orchard design and (ii) human management practices in orchard agroecosystems.

2. Materials and methods

2.1. Study area

The study was carried out in 49 orchards which were widely dispersed across the whole study area, were easily accessible and encompassed the diversity of orchard design and management found within the study area. They were located in four localities: 'Notto', 'Ndoyenne', 'Pout' (Pout town and Pout sigelec) in the *Niayes* region and 'Thiès' (Thiès East and Thiès West) in *Plateau de Thiès* region (Fig. 1). The two regions belong to the same semi-arid agroecological zone. The favourable climate mitigated by a cool and humid trade wind during the hot season makes the regions the major fruit and vegetable production areas of Senegal. Both regions are characterized by ferralic arenosols and a Sudano-Sahelian climate with unimodal rainfall from July to September (between 600 mm and 750 mm per year between 2008 and 2012). 'Ndoyenne' and 'Notto' benefit from oceanic winds that lower the ambient temperature for longer periods than in 'Pout' and 'Thiès'.

2.2. Orchard sample and characterisation of orchard types based on design and management practices

In a previous study carried out on 64 orchards sampled within the *Niayes* and *Plateau de Thiès*regions, an orchard typology was built based on 26 variables describing orchard design and management practices (Grechi et al., 2013). Orchard typology was obtained by a Hierarchical Multiple Factor Analysis (HMFA) performed on the variables of the 'orchard design' and 'orchard management' groups (Table 1). This HMFA was followed by an Agglomerative Hierarchical Clustering (AHC) with the Euclidean distance metric and Ward's agglomeration method. It resulted in four main orchard categories. These orchards were also characterized with seven additional variables classed in a third group regarding 'orchard vegetation state' (Table 1). These variables were not used for the cluster analysis but to describe the categories instead. Of the 49 orchards analysed in the present study, we used 31 from the previous study (we could not use the 64 for logistical reasons) and we added 18 new ones in order to have approximately the same number of orchards for each locality. Orchard categories for the remaining 18 new orchards were defined based on a same approach. For these additional orchards, HMFA was performed on the variables of the 'orchard design' and 'orchard management' groups. Then, the 18 additional orchards were assigned to the category for which the Euclidian distance between orchard coordinates and the category barycentre was minimal on the principal components of the HMFA.

The four orchard categories resulting from the HMFA and AHC analyses were: (1) 'no-input mango diversified orchards', (2) 'low-input mango orchards', (3) 'medium-input citrus-predominant orchards' and (4) 'medium-input large mango- or citrus-predominant orchards'.

Types 1 and 2 consisted of orchards with a large proportion of mango trees (86% on average), and a high diversity in mango cultivars for those of type 1. They were mostly planted with polyembryonic mango cultivars, such as cv. Boucodiékhal, and were dedicated to the local market or subsistence production. None of the type 1 orchards was managed or supplied with water, fertilizers and pesticides. The type 2 orchards displayed only low management levels. Vegetation in the type 1 orchards was dense. Type 3 consisted of orchards with a large proportion of citrus trees