Biological Conservation 169 (2014) 248–257

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Dung beetles as indicators of tropical forest restoration success: Is it possible to recover species and functional diversity?

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ARTICLE INFO

Article history:
Received 7 August 2013
Received in revised form 13 November 2013
Accepted 14 November 2013

Keywords:
Active restoration
Atlantic forest
Chronosequence
Functional traits
Pasture
Scarabaeinae

ABSTRACT

Tropical forest restoration is becoming increasingly more applied to offset biodiversity loss and maintain ecosystem processes, but knowledge about its efficacy is still limited. We evaluated the success of tropical forest active restoration using dung beetles (Coleoptera: Scarabaeinae) as bioindicators and combining measures of species diversity, composition and functional diversity. We assessed patterns of dung beetles community assembly along a restoration chronosequence and also compared restoration areas with reference (primary and old secondary forest) and degraded (pasture) ecosystems. Species composition in the restoration areas was clearly progressing towards the preserved forests and deviating from the pasture with increasing restoration age. We also found a turnover of open environment specialists and habitat generalists to forest generalists and forest specialist species along the restoration chronosequence. However, the majority of individuals in the older restored habitats were typically forest generalists. Biomass was the only variable that increased with restoration age. Species richness, number of individuals, biomass and functional richness in the restored areas were similar to, or even smaller, than in pastures and substantially lower than forest reference sites. Rarefied richness, functional evenness and functional dispersion did not vary between the habitats. We found that while restored areas have the capacity to host forest-restricted species, 18 years since active restoration has not been long enough to recover a stable and diverse dung beetle assemblage. Our study also demonstrates that measures of composition, species diversity and functional diversity can complement each other and contribute to a better understanding of the efficacy of restoration practices.

1. Introduction

The maintenance of tropical forest biodiversity and ecosystem processes depends on the development of effective conservation efforts, which remains a great challenge to conservationists (Gardner et al., 2009; Rands et al., 2010). Ecological restoration has been considered one of the major strategies to mitigate the ongoing biodiversity crisis and is being increasingly applied worldwide (Bullock et al., 2011; Montoya et al., 2012; Rands et al., 2010). Restoration practices are based on intentional activities that aim to recover the physical structure, biodiversity and ecological functions of a degraded ecosystem (Galatowitsch, 2012). However, this is not an easy task, especially when it comes to restoring complex systems, such as tropical forests (Goosem and Tucker, 1995).

The assessment of restoration progress is a critical step in the application and refinement of restoration strategies, enabling the identification of constraints to success and the prediction of restoration outcomes (Matthews and Spyreas, 2010). The typical approach used is through comparisons of the restored sites with undisturbed reference systems and degraded systems (Matthews and Spyreas, 2010; Rey Benayas et al., 2009). However, most studies taking this approach have focused on plants, largely disregarding faunal recovery (Brudvig, 2011; Majer, 2009). This botanical bias arose because it was assumed that fauna would return with vegetation development (Majer, 2009). However, recent studies investigating faunal recovery have shown that other variables besides vegetation per se can influence its return (e.g. connectivity, composition of the surrounding landscape, regional species pool, biotic factors) (Brudvig, 2011; Grimbacher and Catterall, 2007; Majer, 2009). Even less is known about the recovery of ecological

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0006-3207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2013.11.023

functions provided by biological diversity (Brudvig, 2011; Cadotte et al., 2011). Therefore, to truly determine restoration effectiveness and create self-sustainable functioning ecosystems it is critical to monitor not only plants, but also the return of fauna and functions associated with biodiversity (Cadotte et al., 2011; Majer, 2009).

Functional diversity is being increasingly advocated in the literature as a metric by which to evaluate the success of restoration programmes (e.g. Brudvig, 2011; Cadotte et al., 2011; Montoya et al., 2012), because it reflects aspects of the relationship between biological diversity, ecosystem functioning and environmental constraints (Díaz and Cabido, 2001; Mouchet et al., 2010). Indices of functional diversity are based on species traits found in a community and express the extent of functional differences among species in multidimensional space (Mouchet et al., 2010; Petchey and Gaston, 2006; Villéger et al., 2008). High functional diversity can result in greater resilience of the ecosystem to disturbance and higher levels of ecosystem functioning (Cadotte et al., 2011; Montoya et al., 2012). This type of information is not obtained when measuring only species diversity and composition, which are traditionally used to assess recovery in the restoration studies (Mayfield et al., 2010; Mouchet et al., 2010; Mouillot et al., 2013). Therefore, incorporating functional diversity metrics into restoration studies will aid in evaluations of restoration strategy effectiveness and decision-making (Cadotte et al., 2011; Montoya et al., 2012).

Monitoring the species and functional diversity of all fauna in restored areas is typically not logistically feasible, particularly in highly diverse systems like tropical forests. One approach is to select a group of organisms that serve as bioindicators, i.e. taxa that indicate environmental conditions (Gerlach et al., 2013). Dung beetles (Coleoptera: Scarabaeinae) have been widely proposed as cost-effective bioindicators because they are sensitive to ecosystem changes, easily sampled, broadly distributed, and their taxonomy and ecology are relatively well known (Gardner et al., 2008; Halffter and Favila, 1993; McGeoch et al., 2002; Nichols et al., 2007; Spector, 2006). They are also an ideal taxon for biodiversity monitoring because they rely on a large range of resources including rotten fruit, carcasses and feces of other animals (Spector, 2006). In addition, dung beetles are important components of terrestrial ecosystems, providing a set of ecological functions such as nutrient cycling, secondary seed dispersal, soil turbation, fertilization and biological control of vertebrate parasites (Nichols et al., 2008). Thus, dung beetle assemblages can both indicate and influence the success of restoration efforts.

Here we evaluate the efficacy of tropical forest restoration using dung beetles as bioindicators, combining measures of species diversity, composition and functional diversity. To assess restoration progress we evaluated patterns of dung beetle community assembly along a tropical forest restoration chronosequence. Additionally we compared restoration areas with reference (primary and old secondary forest) and degraded (pasture) ecosystems to assess restoration success. Specifically, we asked (1) Does dung beetle species composition shift with increasing time since restoration? (2) Do species richness, number of individuals, biomass and functional diversity increase with restored forest age? (3) Are restoration areas progressing towards the reference system and deviating from the degraded system based on these parameters?

2. Materials and methods

2.1. Study area

The study was conducted in the south of Bahia state, Brazil, covering the municipalities of Eunápolis, Porto Seguro, Belmonte and Itagimirim. This region was originally dominated by tropical lowland rainforest and is in the Atlantic Forest domain (IBGE, 2012). Atlantic Forest is considered one of the five biodiversity hotspots, is internationally recognized for its high levels of biodiversity and endemism (Myers et al., 2000). Although the region south of Bahia still holds large remnants of Atlantic Forest (Ribeiro et al., 2009), most of the original forest was cleared during the 1960s and 1970s mainly for timber exploitation, pastures and plantations of exotic tree monocultures (Carvalho et al., 1994; Nascimento et al., 2009; Oliveira et al., 1997). In 1990, <7% of the original Atlantic Forest remained (Carvalho et al., 1994).

According to the Köppen classification (Kottek et al., 2006), the regional climate is Af (tropical rainforest climate), without a dry season and with rains well distributed throughout the year. Mean annual temperature is 22.6 °C and is fairly constant over the year, with a range of 18.9–27.9 °C. Average elevation of the region is 180 m, and mean annual precipitation is 1600 mm (Veracel, 2007).

2.2. Sampling sites

Since 1994, Veracel Cellulose SA company has been restoring Atlantic rainforest vegetation in areas of degraded pasture in the south of Bahia. This company has an enormous influence in the study region, owning ~210 000 hectares of land in 10 municipalities. Of this total, more than 105 000 ha is set aside for conservation and protection of native vegetation and 90 453 ha is planted with *Eucalyptus* sp. In 2004 the company started to restore a minimum of 400 ha per year, and at the end of 2011 it had replanted a total of 4300 hectares of Atlantic Forest (Veracel, 2011), offering an excellent opportunity to assess tropical rainforest restoration success.

The restoration techniques employed by Veracel consist of active planting of Atlantic rainforest tree species (1111 seedlings per hectare) mainly in valleys, riversides, steep slopes and other protected areas. Initially ants are controlled using formicide baits, and grasses and herbaceous weeds are controlled with herbicide if they occur in high densities (2 kg/ha). Manual mowing is implemented in areas with weeds ⩾1 m tall and subsoiling is used to reduce soil compaction. The restored area is also fertilized before seedlings are planted. Monitoring of planting success is frequent in the first 3 years of the restoration process and after this period, it is conducted every 5 years.

Dung beetle sampling was conducted in 15 forest restoration areas of varying ages (with size of restored area in parentheses): 0 years (2 months since planting – 64 ha), 1 year (400 ha), 2 years (64 ha), 3 years (15 ha), 4 years (191 ha), 5 years (7 ha), 8 years (106 ha), 9 years (5 ha), 11 years (36 ha), 12 years (3 ha), 13 years (54 ha), 14 years (14 ha), 15 years (3 ha), 17 years (9 ha) and 18 years (11 ha). The restoration areas included in the study were typically separated by ⩾500 m. We also sampled reference and degraded sites in order to quantify restoration success. We considered primary Atlantic Forest and old secondary forest (>40 years old) as the reference sites, representing the desired end point of restoration. Areas that have been converted by humans to pastures were considered degraded sites, representing the starting point of restoration. Collections were carried out in five areas of each of these systems (primary forest, old secondary forest and pasture). The sampled areas of primary and old secondary forest were located in the Veracel Station Private Reserve of Natural Heritage (RPPN Estação Veracel), one of the largest private reserves in the Atlantic Forest with an area of 6069 ha and a continuous mosaic of primary and secondary forest in advanced stages. Each of the reference and degraded sampled areas were ⩾1 km from each other.

One sampled restoration area (15 years) was located inside RPPN at a distance of 5 m from the preserved rainforests, but >1 km from the sampled primary and secondary forest sites. The