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SOIL SURFACE-ACTIVE FAUNA IN DEGRADED AND RESTORED LANDS OF NORTHEAST BRAZIL

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ABSTRACT

Land degradation reducing vegetation cover may affect the soil surface-active fauna because both aboveground and belowground invertebrates depend on complex plant communities. In this study, we evaluated the effect of land degradation and restoration on soil fauna in northeast Brazil. Sites differed in degradation status: native vegetation, moderately degraded land, highly degraded land, and land under restoration for 4 years. Araneae and Coleoptera densities were significantly higher in natural vegetation and restored land (8 ± 4 ind./trap and 41 ± 21 ind./trap, respectively) than in degraded lands (−73% and −81%, respectively). The density of Formicidae was significantly higher in natural vegetation (206 ± 181 ind./trap) than in highly degraded land (32 ± 24 ind./trap), while restored land (51 ± 10 ind./trap) and moderately degraded land (37 ± 14 ind./trap) did not differ significantly from the other degradation levels. The density of Orthoptera did not follow the aforementioned patterns, while invertebrate groups mostly had highest densities in natural land and restored land. Linear regressions showed a strong negative relation between faunal density and soil bulk density, and a positive relation with soil organic matter due to an increase in plant cover. Our results indicate that land degradation simplifies soil surface-active invertebrate communities with pronounced decreases in the density of Araneae, Coleoptera, and Formicidae, but that land restoration practices may recover the density of soil fauna even after only 4 years. Araneae, Coleoptera, and Formicidae respond sensitively to land degradation and restoration practice and are suggested as indicator groups for restoration success. Copyright © 2013 John Wiley & Sons, Ltd.

KEYWORDS: indicator taxa; land degradation; monitoring; pitfall traps; restoration practices; soil arthropods

INTRODUCTION

The land surface affected by anthropogenic degradation is increasing. Approximately 23% of all arable land of the planet is being affected by land degradation, and, at the end of the last century, approximately 910 Mha were under moderate to extreme degradation (Oldeman, 1994). In Brazil, slash-and-burn practices combined with diamond-mining activities have caused land degradation (Almeida-Filho & Carvalho, 2010; Thomaz & Luiz, 2012; Souza Braz *et al*., 2013). In addition, high temperatures and evapotranspiration associated with a short rainy period with high precipitation in this region and fragile soils may intensify the effects of anthropogenic land degradation.

The Brazilian Government has invested about U$ 1 million for the purpose of recovery of degraded land. The main goal is to restore soil properties and increase the vegetation cover as important strategies for the recovery of soil productivity and sustainability (Araujo *et al*., 2013). The restoration process involves the use of conservation practices, such as building terraces for water storage and the sowing of plant species, such as grasses and legumes. Previous studies found increasing vegetation cover to improve the chemical and physical properties of soils (Silva *et al*., 2012; Trabaquini *et al*., 2013) as well as soil microbial biomass and enzyme activity (Nunes *et al*., 2012; Wu *et al*., 2013).

Despite the high density and biodiversity of soil-dwelling animals, limited knowledge exists of the consequences of land degradation and restoration on different groups of soil animals. Wall *et al*. (2010) recently concluded that conservation and management attempts to protect biodiversity from ecosystem degradation have mainly focused on the loss of aboveground species, while soil organisms may vanish unnoticed. As soil organisms drive many essential ecosystem processes (e.g., Wardle *et al*., 2004; Cerdà & Doerr, 2010; Cerdà & Jurgensen, 2011; García-Orenes *et al*., 2012), land management practices thus should also consider promoting soil biodiversity and high population densities of soil-dwelling organisms in order to improve sustainable crop production, soil fertility, and nutrient and water retention (Wall *et al*., 2010).

The soil surface-active fauna can provide important information on the degree of land degradation or restoration due to its strong dependency on vegetation properties (Scherber *et al*., 2010; Eisenhauer *et al*., 2013). We investigated land degradation and restoration effects on the densities of soil surface-active fauna in northeast Brazil across different seasons and years. We expected land degradation to strongly reduce the densities of many groups of invertebrates, and we were interested in the question if current restoration approaches are able to successfully reconstitute such invertebrate communities.

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Moreover, the identification of sensitive invertebrate indicator groups may inform rapid assessment approaches to evaluate the biological status of degraded and restored lands.

MATERIALS AND METHODS

Study Site

The study was conducted at Gilbués municipality (09°49′55″S and 45°20′38″W), northeast Brazil. The climate is tropical dry with a mean precipitation of 1,000 mm yr^{-1} (with rainfall from January through May) and an annual mean temperature of 31 °C, with minimum and maximum temperatures of 22 and 40 °C, respectively. According to the Brazilian soil survey, the dominant soils are classified as eutrophic red-yellow podzolic soils with low activity clay and granite, and gneiss as parental material. The following four selected sites (4,000 m^2 each) were studied: native vegetation (NAT), moderately degraded land (MDL), highly degraded land (HDL), and land under restoration (RES) (Table I).

The native vegetation is covered by trees, including *Cenostigma macrophyllum* Tul., *Tabebuia serratifolia* (Vahl) G. Nicholson, *Hymenaea courbaril* L., *Orbignya phalerata* Mart., *Combretum leprosum* Mart., *Guarea kunthiana* A. Juss, and *Lecythis pisonis* Camb. These trees cover between 80 and 90% of the ground surface and contribute approximately 1 kg m^{-2} of plant litter annually (Figure 1a). The MDL (Figure 1c) and HDL (Figure 1d) sites resulted from cutting of native vegetation for charcoal production in 2008 and 2004, respectively. Nowadays, the MDL site is dominated by herbaceous plant species (*Aristida sepfolia* L., *Cyperus uncynulatus* L., and *Tragus berteronianus* L.) that cover approximately 24% of the soil surface, while the HDL site has sparse vegetation cover (<5%). Land restoration at RES (Figure 1b) started in 2006 by shifting the degraded land by building terraces (approximately 500 m^2) for water storage, fertilization of the soil with 50, 100, and 200 kg ha^{-1} yr^{-1} of N, K_2O, and P_2O_5, respectively. The fertilizers are applied annually by spreading on the soil surface. Afterwards, the RES site was re-vegetated with *Crotalaria juncea* L. and *Panicum maximum* Jacq. at densities of 2,500 and 3,000 plants ha^{-1}, respectively. The annual input of litter (air-dried) from the catch crops is approximately 1.5 kg m^{-2} on the soil surface.

Sampling of Soil Surface-Active Fauna

Surface-active soil fauna was evaluated in March (wet season) and September (dry season) of 2010 and 2011 using pitfall traps, consisting of plastic containers of 10 cm height and 10 cm in diameter with 50% ethanol to about 1/3 of its volume. These traps were buried leaving its opening at ground level, spaced 20 m in the form of a transect towards the central part of each area, where they remained for 7 days. At each site, we brought out six traps to cover some spatial heterogeneity. The soil fauna was identified and quantified with a binocular microscope and grouped to order or family level.

Site Properties

Soil organic matter (SOM) was determined by the wet combustion method using a mixture of potassium dichromate and sulfuric acid under heating (Yeomans & Bremner, 1988). Soil bulk density (SBD) was determined using a volumetric sampling tool that had a relief cutting tip of 50 mm diameter, which screwed on to a 150 mm long cylinder. The cylinders were inserted by hand using gentle pressure and were not used if any compaction occurred during insertion. SBD was calculated according to Logsdon & Karlen (2004). Vegetation cover was estimated by assessing the percentage of the ground that it was covered by the existing vegetation.

Statistical Analyses

Data were log_{10}-tranformed to meet the requirements for parametric statistical tests. Only those invertebrate groups

Table I. Main characteristic of the evaluated sites: native vegetation, moderately degraded land, highly degraded land, and land under restoration for 4 years

Characteristic	NAT	RES	MDL	HDL
Longitude	45°20′42·7″W	45°20′32·2″W	45°20′41·1″W	45°20′29·2″W
Latitude	09°52′32·1″S	09°52′49·6″S	09°52′33·0″S	09°52′48·3″S
Altitude (m)	441	449	460	452
Slope (%)	2-5	5-9	5-9	5-9
Vegetation	zTrees[a]	Herbs[b]	Herbs[c]	Herbs[d]
Clay (g kg^{-1})	510·2	510·8	500·4	520·1
Silt (g kg^{-1})	90·7	100·3	100·5	90·8
Sand (g kg^{-1})	390·1	370·9	390·1	380·1
SBD[e] (g cm^{-3})	1·15	1·23	1·38	1·40
SOM[f] (g kg^{-1})	22·6	10·4	5·8	2·1
Vegetation cover (%)	100	100	24	4

NAT = native vegetation, MDL = moderately degraded land, HDL = highly degraded land, RES = restored land.
[a]Caneleiro (*Cenostigma macrophyllum* L.), pau d′arco (*Tabebuia serratifolia* L.), jatobá (*Hymenaea courbaril* L.), palmeira de babaçu (*Orbignya phalerata* L.), mofumbo (*Combretum leprosum* L.), jitó (*Guarea kunthiana* L.), and sapucaia (*Lecythis pisonis* L.).
[b]*Crotalaria juncea* L. and *Panicum maximum* L.; 24% total plant cover
[c]*Aristida sepfolia* L., *Cyperus uncynulatus* L., and *Tragus berteronianus* L.; 5 % total plant cover
[d]herbs (*Tragus berteronianus* L.).
[e]SBD, soil bulk density
[f]SOM, soil organic matter (compared with native vegetation).

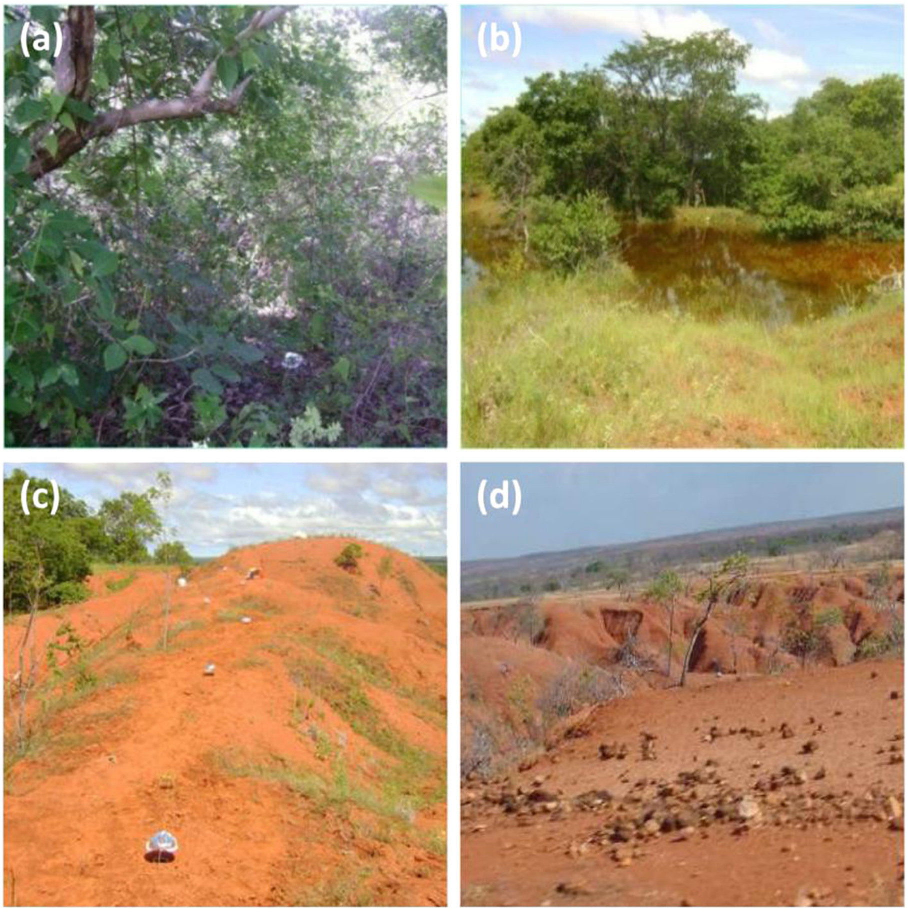

Figure 1. The study sites. (a) Natural vegetation dominated by trees covering between 80% and 90% of the ground surface. (b) Restored land; land restoration started in 2008 by shifting the degraded land by building terraces (approximately 500 m^2) for water storage. (c) Moderately degraded land and (d) highly degraded land resulting from cutting of native vegetation for charcoal production in 2008. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

were analyzed that met the statistical assumptions, were available in high numbers and for which the sampling method was adequate (i.e., Araneae, Coleoptera, Formicidae, Orthoptera). Generally, soil-dwelling organisms (e.g., Collembola, Acari) are extracted from soil cores by heat (Macfadyen, 1961; Kempson *et al*., 1963), Heteroptera and Homoptera live in the vegetation and are investigated using sucking methods or spoon nets (Sanders & Entling, 2011), whereas flying organisms are trapped with further techniques depending on their behavior (e.g., stick and pheromone traps). Therefore, most of the taxa were not assessed adequately with pitfall traps and are excluded from further analyses. The means and standard deviations of these groups are nevertheless given in Table II. We used repeated measures analysis to investigate land degradation and seasons on the densities of soil surface-active fauna. In addition to repeated measures analyses, we performed comparisons of means using Tukey's honestly significant difference tests.

Linear regressions were calculated using data on SBD ($g\,cm^{-3}$) and SOM (%). Data on bulk density were log-transformed, and for SOM data, we used arcsin-transformation. All statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

RESULTS

In general, we found very strong effects of land degradation on the density of Araneae (mainly vagrant species; $F_{3,20} = 20{\cdot}29$, $p < 0{\cdot}001$), Coleoptera (mainly Scarabaeidae; $F_{3,20} = 85{\cdot}15$, $p < 0{\cdot}001$), and Formicidae (only *Atta* spec.; $F_{3,20} = 4{\cdot}93$, $p = 0{\cdot}01$), but less so in Orthoptera (only Gryllidae; $F_{3,20} = 2{\cdot}49$, $p = 0{\cdot}09$; Figure 2). Araneae and Coleoptera densities were significantly higher in natural vegetation and restored land than in degraded lands (Figure 2, graphs a and b). Similarly, the density of Formicidae was significantly higher in natural vegetation than in strongly degraded land, while restored land and moderately degraded land did not differ from the other degradation levels (Figure 2c). The density of Orthoptera did not differ significantly between degradation levels, their densities remained stable, and did not follow the aforementioned trend to decrease with increasing degradation level (Figure 2d).

Densities of Araneae, Coleoptera, Formicidae, and Orthoptera differed significantly with time and the interaction of time and degradation level; however, consistent patterns were not observed (Tables III and IV). For instance, Araneae (and other taxa) were most often highest in NAT and RES plots compared with MDL and HDL but differed between seasons. Depending

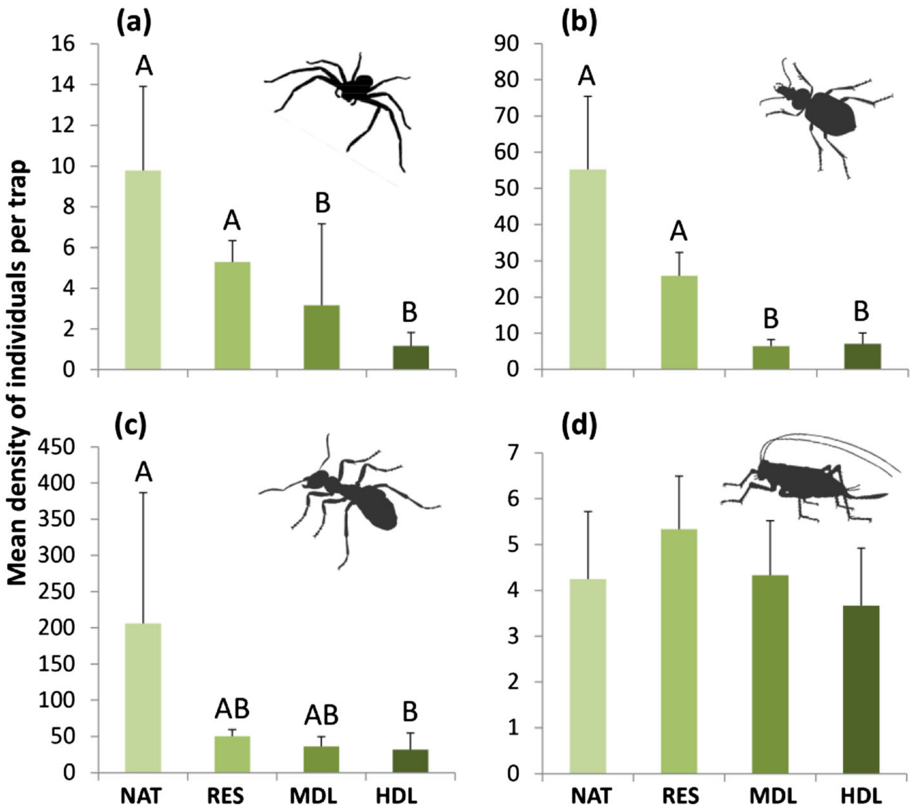

Figure 2. Soil surface-active fauna [(a) Araneae, (b) Coleoptera, (c) Formicidae, (d) Orthoptera] as affected by land degradation; MDL = moderately degraded land; HDL = highly degraded land), land restoration (RES) in comparison to natural vegetation (NAT). Bars with different letters vary significantly (Tukey's honestly significant difference test, $p < 0{\cdot}05$). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

on the year, densities were higher in the dry or the wet season. In addition, in plots with native vegetation during the dry season of 2011, densities of Araneae were about 400% higher than the overall mean of the remaining dates. Similar results were observed for Formicidae but not for Coleoptera and Orthoptera (Table III). Linear regression revealed strong relationships of bulk density and SOM with densities of Araneae, Coleoptera, and Formicidae, whereas Orthoptera were not significantly affected (Table V). Densities of soil surface-active fauna decreased with increasing SBD, whereas the opposite was true for SOM.

DISCUSSION

In the present study, we investigated the response of soil surface-active fauna to explore the consequences of land degradation for soil fauna. In addition, we suggest indicator groups for restoration success. We focused on the most abundant taxa Araneae, Coleoptera, Formicidae and Orthoptera, which were adequately assessed in the present study and showed relatively high population densities. With the exception of Orthoptera, these taxa were strongly affected by land degradation and their densities declined significantly with increasing land degradation, (Lavelle *et al*., 2001) likely because of the loss of vegetation cover and thus an adequate habitat (Menta *et al*., 2011). The planting and fertilization of degraded lands successfully restored plant cover, which in turn allowed the recovery of invertebrate communities.

Densities of Araneae and Coleoptera in restored land did not differ significantly from land with native vegetation indicating a general recovery of densities and note that we did not assess faunal diversity. In detail, spiders respond to changes in microclimatic conditions (Pearce *et al*., 2004), depend on structural complexity of the vegetation (Uetz, 1991; Langellotto & Denno, 2004), and prey occurrence (Wise & Chen, 1999; Cunha Neto *et al*., 2012). The latter is also supported by our data with overall lower densities of invertebrates in degraded lands.

The increase in the densities of beetles, mainly Scarabaeidae, in restored lands compared with degraded land may also correspond to an overall resource increase as they live on carrion, dead and living plant material, and are generally linked to higher organic matter availability (Kim, 1993; Fagundes *et al*., 2011).

All ants in our pitfall traps belonged to the genus *Atta*, which have a mutualistic association with fungi, which are grown in specific fungus gardens delivering food for the ants (Weber, 1966). Although *Atta* cuts plant leaves for maintaining the fungus gardens, the net effect on the vegetation often is positive with higher vegetation cover in the presence of ants (Trager *et al*., 2010). Thus, increased ant densities may be due to higher resource availability in restored lands.

All Orthoptera in pitfall traps were Gryllidae. This group did not respond significantly to land degradation suggesting no strong relationship to vegetation cover. Gryllidae are omnivorous scavengers feeding on a wide range of organic

Table II. Means ± standard deviation of invertebrate densities in pitfall traps (four sampling campaigns in 2 years)

	NAT			RES			MDL			HDL		
	Mean		SD	Mean		SD	Mean		SD	Mean		SD
Araneae	**9·79**	±	**4·11**	**5·29**	±	**1·04**	**3·17**	±	**3·99**	**1·17**	±	**0·66**
Pseodoscorpionidae	0·42	±	0·30	0·50	±	0·63	0·25	±	0·32	0·04	±	0·10
Acari	1·75	±	0·97	2·54	±	1·90	2·88	±	2·43	9·17	±	3·79
Diplopoda	0·00	±	0·00	0·28	±	0·33	0·39	±	0·39	0·61	±	0·33
Collembola	7·38	±	3·81	11·58	±	5·50	113·79	±	242·21	10·00	±	7·42
Thysanura	0·00	±	0·00	0·00	±	0·00	0·25	±	0·27	0·00	±	0·00
Blattodea	0·83	±	0·41	1·04	±	1·60	0·00	±	0·00	0·04	±	0·10
Isoptera	1·96	±	2·12	0·17	±	0·20	0·04	±	0·10	0·00	±	0·00
Orthoptera	**4·25**	±	**2·01**	**5·33**	±	**1·28**	**4·33**	±	**1·87**	**3·67**	±	**1·16**
Heteroptera	0·50	±	0·55	0·58	±	0·30	0·58	±	0·52	0·08	±	0·13
Homoptera	6·63	±	2·13	2·33	±	0·80	0·79	±	0·51	0·96	±	0·62
Coleoptera	**55·29**	±	**20·19**	**25·92**	±	**6·43**	**6·42**	±	**1·85**	**7·08**	±	**3·00**
Hymenoptera	0·63	±	0·65	0·29	±	0·25	1·54	±	0·91	0·54	±	0·46
Formicidae	**206·00**	±	**180·48**	**50·33**	±	**9·06**	**36·29**	±	**13·35**	**31·67**	±	**23·17**
Lepdidoptera	0·00	±	0·00	0·17	±	0·41	0·17	±	0·41	0·17	±	0·41
Diptera	22·00	±	10·61	12·21	±	4·53	1·71	±	1·42	2·83	±	1·92

Taxa are given in bold which are illustrated in Figure 1. For these taxa densities were sufficiently high to perform statistical analyses, and the sampling method was adequate. Results for other taxa should be treated with caution.

SD = standard deviation, MDL = moderately degraded land, HDL = strongly degraded land, RES = restored land, NAT = natural vegetation.

Table III. Means ± standard deviation of soil surface-active animal densities trapped with pitfall traps in two seasons (rain and dry) in 2 years (2010 and 2011)

			Araneae			Coleoptera			Formicidae			Orthoptera		
			Mean		SD	Mean		SD	Mean		SD	Mean		SD
2010	**rain**	**NAT**	3·83	±	1·17	58·67	±	15·07	29·17	±	11·44	7·33	±	4·89
		RES	8·33	±	3·88	24·50	±	9·91	65·50	±	25·19	5·67	±	5·16
		LDL	1·50	±	1·05	5·17	±	5·27	46·17	±	26·10	4·17	±	2·64
		HDL	0·67	±	0·82	6·33	±	4·32	18·83	±	14·96	2·50	±	0·55
	dry	**NAT**	7·50	±	2·43	65·33	±	21·68	19·83	±	7·41	2·50	±	3·08
		RES	5·33	±	2·94	21·50	±	4·59	68·83	±	27·97	6·83	±	2·48
		LDL	2·83	±	2·56	14·33	±	6·53	38·00	±	19·05	10·17	±	7·00
		HDL	0·33	±	0·52	16·67	±	10·13	31·00	±	12·25	5·33	±	3·44
2011	**rain**	**NAT**	3·33	±	2·16	95·83	±	58·20	24·33	±	12·77	5·00	±	2·90
		RES	2·17	±	1·72	27·50	±	13·13	24·17	±	13·63	6·83	±	5·49
		LDL	7·00	±	11·83	5·83	±	5·27	39·17	±	25·61	2·33	±	3·01
		HDL	0·33	±	0·52	4·67	±	3·93	11·17	±	5·46	5·67	±	3·01
	dry	**NAT**	24·50	±	17·47	1·33	±	1·51	750·67	±	709·23	2·17	±	1·47
		RES	5·33	±	2·34	30·17	±	21·02	42·83	±	11·65	2·00	±	1·67
		LDL	1·33	±	1·86	0·33	±	0·52	21·83	±	15·70	0·67	±	1·21
		HDL	3·33	±	2·34	0·67	±	0·52	65·67	±	87·70	1·17	±	1·60

MDL = moderately degraded land, HDL = highly degraded land, RES = restored land, NAT = natural vegetation, SD = standard deviation.

Table IV. ANOVA table of repeated measures analysis for densities of soil surface-active fauna in degraded lands and the respective interaction

	DEG		Time		DEG × Time	
	$F_{3,20}$	P	$F_{3,60}$	P	$F_{9,60}$	P
Araneae	20·29	<0·0001	6·51	0·0007	5·52	<0·0001
Orthoptera	2·49	0·0894	11·92	<0·0001	3·05	0·0046
Coleoptera	85·15	<0·0001	46·04	<0·0001	10·12	<0·0001
Formicidae	4·93	0·0101	8·17	0·0001	7·41	<0·0001

DEG; with natural vegetation, restored land, moderately degraded land and highly degraded land), time (wet and dry season in 2010 and 2011.

Table V. Linear regressions of soil surface-active fauna with soil bulk density (g m^{-3}) and soil organic matter (%)

	Bulk density			SOM		
	R^2	$T_{1,22}$	P	R^2	$T_{1,22}$	P
Aranae	0·5676	−5·37	<0·0001	0·6525	6·43	<0·0001
Orthoptera	0·0375	−0·93	0·3646	0·0015	0·18	0·8562
Coleoptera	0·8148	−9·84	<0·0001	0·7863	9	<0·0001
Formicidae	0·4868	−4·57	0·0002	0·4318	4·09	0·0005

SOM = soil organic matter.

materials, e.g., dead animals, living and decaying plant material, seedlings, and fungi (Dettner & Peters, 2003). This food mixing makes them probably less sensitive to environmental changes (Hailey *et al*., 1998) and may explain their nonsignificant response to land degradation.

Overall, plants influence the soil surface-active fauna directly by providing a source of energy (i.e., carbon) in their surface litter and root inputs, and contribute indirectly by altering soil structure and hydrology, thereby influencing the microclimate experienced by soil organisms (Wolters, 2001). This is confirmed by linear regressions with SOM data. We observed a significant increase in the densities of soil surface-active soil fauna with increasing SOM content. In this context, an increase in SOM corresponds to an increase in plant biomass as indicated by higher plant cover with decreasing degradation level, i.e., high availability of food resources, and habitat. This is in line with previous studies on soil microorganisms reporting significant relationships between land degradation, reductions in soil pore structure, increased soil erosion, decreased SOM, and decreased soil microbial activity (García-Orenes *et al*., 2010; Guénon *et al*., 2013; Wu *et al*., 2013). Moreover, the relationships between SBD and soil surface-active fauna may indicate the importance of soil pores for the foraging behavior of some Araneae, Coleoptera, and Formicidae taxa, as well as that soil fauna may influence soil structure through burrowing activity (García-Orenes *et al*., 2010; Oo *et al*., 2013).

Although we grouped the focal taxa very roughly (order level), we were able to identify three possible indicator taxa reflecting the success of restoration practices. The assessment of indicator taxa is most often less destructive and labor-intensive than investigating whole communities at the species level (Niemelä & Baur, 1998), which is why such rapid ecosystem assessments may be an easy monitoring tool to evaluate the consequences of, for instance, land degradation and restoration. Nevertheless, further studies in restored and degraded lands are needed to inspect if aggregation of soil surface-active species information into order level is appropriate and how the diversity of the focal taxa vary with land degradation and restoration.

CONCLUSION

Our results indicate that land degradation strongly decreases the density of Araneae, Coleoptera, and Formicidae, but that land restoration practices may increase the density of soil surface-active fauna even after only 4 years. The rapid assessment of these invertebrate groups may thus represent a powerful tool to evaluate the biological status of degraded and restored lands.

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