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INFLUENCE OF FOREST DISTURBANCE ON EARTHWORM (OLIGOCHAETA) COMMUNITIES IN THE WESTERN GHATS (SOUTH INDIA)

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Summary—In the Western Ghats (South India), the natural evergreen forest has been highly disturbed and fragmented for 150 years. The resultant vegetation is a mosaic of more or less disturbed forests, pastures, and crops (mainly paddy fields). This paper aims to assess the effects of anthropic disturbance on earthworm communities. Earthworms were collected at the end of the rainy season in a wide range of milieux distinguished by their vegetation, soil properties and topography. The earthworms found belong to the families Octochaetidae, Megascolecidae and Moniligastridae. Densities ranged from 35.3 to 545.3 ind m^{-2}. Biomasses ranged from 2.35 to 52.56 g m^{-2}. There was no clear relationship between these community characteristics and the vegetation, soil properties or topography as pastures and forests supported high or low densities (or biomasses). Nevertheless, some species were restricted to pastures, some species to forests and some species are found in all milieux. © 1997 Elsevier Science Ltd

INTRODUCTION

Forest disturbance linked to human activity is a worldwide problem, its importance depends on different points of view (mainly ecological and economical). Causes of this disturbance are diverse, and consequences are strong modifications of soil and vegetation and thus of system functioning.

This present study is a part of a programme aimed at assessing the relationship between human activities and the environment in a small area (20 km^2) located in the Western Ghats (Karnataka State). This region harboured a vast tract of pristine forest 150 or 200 years ago, but is now mostly a mosaic of degraded forest patches interspersed with pastures, *Acacia auriculiformis* and *Casuarina equisetifolia* plantations, paddy fields, gardens and pockets or large areas of natural evergreen forests. From 1975 to 1992, the deforestation rate was *ca.* 0.42% y^{-1} (Puyravaud *et al.*, 1994); by 1992, 44% of the total surface was disturbed.

This study assesses the effect of forest ecosystem disturbance on earthworm communities which are poorly studied in this area. A few studies on earthworms were carried out in other parts of the Western Ghats (Jamieson, 1977; Kubra Bano and Kale, 1988; B. Ferry, unpub. PhD thesis, University of Nancy, 1992).

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MATERIALS AND METHODS

Study area

The study was conducted in the Western Ghats in the Karnataka State, Shimoga Division, Sagar Forest Range, on the western side of the Lingannamaki Reservoir (14°00′N, 74°45′E). The climate is tropical monsoon determined by the south west monsoon. This region has 6–7 dry months (from October to April) and receives an annual rainfall of 5000 mm. The monsoon peak is June–July. Mean annual temperature is *ca.* 22°C with maxima in April and October and a minimum in December–January. In winter, minimum temperature may be less than 10°C and maximum temperature more than 30°C. Soils are ferrallitic soils (Bourgeon, 1988; E. Peterschmitt, unpub. PhD thesis, University of Nancy, 1991). The forest vegetation has been broadly described as *Dipterocarpus indicus-Diospyros candollena oocarpa* type (Pascal, 1988).

Study sites

Earthworms were collected in 29 sites characterized by different vegetation types, slopes and elevation (from 420 to 1000 m a.s.l.): 12 more or less disturbed forests, five edges between forests and pastures, two *Acacia auriculiformis* plantations (2- and 8- years-old), one thicket (200 m^2, crossed by cattle), 1 altitude (natural?) grassland, two pastures with high density of *Phoenix humilis* (called Phoenix pastures), six pastures without *P. humilis* (called pastures).

Earthworm sampling

On each site, earthworms were hand-sorted from three soil monoliths (50 × 50 × 20 cm) placed at the apices of a 10 m side triangle. Specimen were kept in formalin, then identified, counted and weighed. Earthworms were sampled at the end of the rainy season in October 1991 and in October 1992. Shannon diversity indices ($H' = -\Sigma p_i \log_2 p_i$ where p_i is the relative abundance of the species i) and evenness ($E = H'/\log_2 S$, where S is the number of species) (Barbault, 1992) were calculated for each site, on a weight basis (Cousins, 1991).

Soil analyses

On 26 sites, soil samples were taken from each of the three monoliths (0–10 and 10–20 cm), mixed and then analysed. We analysed soil organic carbon (SOC) (carmhograph), total nitrogen (Kjeldhal method), sum of cations and cation exchange capacity (CEC).

RESULTS

Species

A total of 5326 earthworms were collected. Only 68 individuals were not identified. Twenty-eight species were identified (Table 1) belonging to three families (Moniligastridae—genus Drawida—7 species, Megascolecidae—3 species and Octochaetidae—18 species) including three new genera (Octochaetidae) and 16 new species. The new taxa will be soon published. Only *Drawida paradoxa and Lennoscolex* sp. were never found in forests or edges. Six species were restricted to forests. Nineteen species were never collected in pastures or Phoenix pastures. Seven species were found both in pastures and forests. Thirteen species were collected in one, two or three sites (of a total of 29 sites), eight species in four to ten sites and seven species were collected in more than 10 sites.

Number of species (species richness)

The number of species ranged from two in an 8-year-old Acacia plantation to 11 in an undisturbed forest and 10 in an altitude grassland (Fig. 1). On average, pastures had a significant lower number of species than forests and edges (respectively, 3.7, 7.1 and 7.6) (Table 2). Acacia plantations and Phoenix pastures also had low numbers of species.

Densities

Densities ranged from 35 ind m^{-2} in a Phoenix pasture to 545 ind m^{-2} in a thicket (Fig. 1). On average, there was no significant differences between pastures, edges and forests (respectively, 165, 193 and 160 ind m^{-2}) (Table 2). Phoenix pastures had a low density (mean = 53 ind m^{-2}). Acacia plantations had a mean density of 200 ind m^{-2}.

Table 1. Presence of earthworm species in different habitats

	Pastures	Altitude grassland	Phoenix pastures	Thicket	Acacia plantations	Edges	Forests
MONILIGASTRIDAE							
Drawida paradoxa Rao	*	*	*		*		
Drawida sp. (nr. thurstoni Gates)				*		*	
D. ampullacea Gates		*		*	*	*	*
Drawida sp1		*					*
Drawida sp2	*				*	*	*
D. kanarensis Stephenson							*
D. sulcata Michaelsen							*
MEGASCOLECIDAE							
Megascolex sp. (nr. konkanensis Fedarb)				*		**	
Lennoscolex sp.		*					
Perionyx sp.						*	*
OCTOCHAETIDAE							
Konkadrilus tirthahalliensis Julka	*	*	*			*	*
Konkadrilus sp1 (nr. zicsii Julka)	*	*		*	*	*	*
Konkadrilus sp2 (nr zicsii Julka)	*		*		*	*	*
Konkadrilus sp3 (nr. bahli Soota and Julka)					*		
Hoplochaetella sp1 (nr. karnatakensis Julka)					**		
Hoplochaetella sp2 (nr karnatakensis Julka)		*			*		
Hoplochaetella sanvordemensis Julka						**	
Hoplochaetella H. Gates							*
Mallehulla indica Julka and Rao				*		*	
Karmiella karnatakensis Julka	*				*	*	
Karmiella sp1							*
Genus A sp1		*				*	*
Genus A sp2							*
Genus B sp1							*
Genus C sp1	*		*		*	*	*
Genus C sp2	*					*	*
Genus C sp3		*		*			*
Wahoscolex sp	*		*			*	*

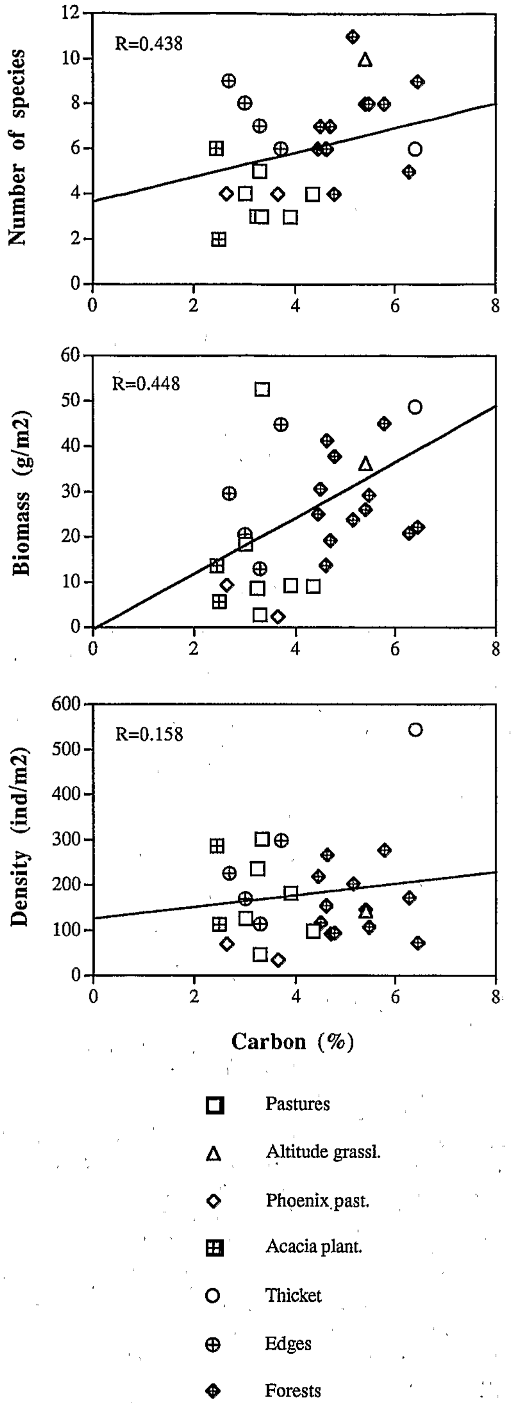

Fig. 1. Relationship between soil organic carbon (0–10 cm) and earthworm (i) number of species, (ii) biomass and (iii) density in 29 sites.

Biomasses

Biomasses ranged from 2.35 g m^{-2} in a Phoenix pasture to 52.56 in a pasture (Fig. 1). On average, forests and edges had higher values than pastures, Phoenix pastures and plantations (respectively 27.92, 23.44, 16.79, 5.86 and 9.67) (Table 2). These differences were not significant, mainly due to the high biomass value observed in a pasture. Except for this value, biomasses observed in forests were higher than that of pastures, Phoenix pastures and Acacia plantations.

Dominant species

On average, *D. paradoxa* represented 86% of pasture biomasses, 93% of Phoenix pasture biomasses, 46% of pasture densities and 70% of Phoenix pasture densities. *D. ampullacea* represented 31% of forest biomasses and 33% of forest densities, 47% of altitude grassland biomass and 55% of altitude grassland density. *Konkadrilus* sp 1 represented 40% of biomass and 72% of density in thicket.

Species diversity and evenness

Shannon species diversity indices ranged from 0.397 in a pasture to 2.539 in a forest. On average, pastures had lower indices than forests and edges (respectively 1.128, 2.025 and 2.032) (Table 2). On a weight basis, diversity indices in pastures, forests and edges were respectively 0.822, 1.982 and 2.171. Evenness ranged from 0.250 in a pasture to 0.940 in a forest. On average, pastures had lower indices than edges and forests (respectively, 0.610, 0.696 and 0.730). Evenness was not correlated with number of species, biomass or density. Evenness in pastures, edges and forests were, respectively, 0.449, 0.748 and 0.718.

Earthworms/soil properties relationship

Soil organic carbon (SOC) and the sum of cations in forests, edges, thickets and altitude grassland were twice to threefold that in pastures and Acacia plantations. There was a good correlation between SOC (0–10 cm) and the number of species and SOC and biomass [$R = 0.438$ ($P < 0.05$) and $R = 0.448$ ($P < 0.05$), respectively]. There was no correlation between SOC and earthworm density ($R = 0.158$) (Fig. 1).

DISCUSSION AND CONCLUSION

The modification of vegetation linked to forest disturbance led to strong modification of soil properties: impoverishment of SOC, nitrogen content, sum of cations, CEC and clay content. Acacia plantations cultivated on pastures have almost the same characteristics as pastures. Altitude grasslands characterized by a thick humus layer protected by vegetation was close to forests and thickets regarding soil properties. These vegetation and soil changes lead to strong modifications of earthworm communities.

In forests, communities were characterized by a high species richness, a high species diversity and a relatively high biomass. Edges which make the tran-

Table 2. Characteristics of earthworm communities in different habitats (mean and confidence interval $P < 0.05$)

Number of sites	Forests 12	Edges 5	Thicket 1	Acacia plantations 2	Phoenix pastures 2	Altitude grassland 1	Pastures 6
Number of species	7.08 ± 1.13	7.60 ± 1.14	6	4	4	10	3.67 ± 0.73
Biomass (g m^{-2})	27.92 ± 6.23	23.44 ± 18.27	48.71	9.67	5.86	36.34	16.79 ± 20.93
Density (ind m^{-2})	160.5 ± 45.4	193.2 ± 71.3	545	200	53	144	165.2 ± 107.4
Diversity (H')	2.025	2.032	1.206	1.445	1.285	2.154	1.128
Evenness (E)	0.730	0.696	0.466	0.829	0.642	0.648	0.610

sition between forests and pastures had almost the same characteristics as forests. The thicket studied had high biomass and density, low species richness and species diversity and medium evenness due to the relative dominance of *Konkadrilus* sp1. The altitude grassland had high species richness, species diversity, biomass and medium density. Evenness showed a good partitioning between species. Pastures were characterized by low species richness, species diversity and biomass. Evenness was generally high. Phoenix pastures had similar characteristics as other pastures. Acacia plantations which present a grass and a tree cover showed the same characteristics as pastures. The partition of total density was good between the different species (high evenness).

Thus we could say that the transition from a forest to a pasture in this area essentially leads to a reduction in species diversity and biomass. Actually the variations among the same habitats, linked to different system functionings which did not appear in our study, are important. These variations might relate to the date of pasture installation, since forest plots have been regularly cleared for 150 years, or to the intensity of cattle grazing. Saunders *et al.* (1991) stressed the importance of the size of habitat "islands" and of the modification of microclimates depending on the habitat size and on the connectivity of habitats. It is thus possible that earthworm communities are affected by the size, shape and position in the landscape of their habitats. Forests also show earthworm communities variations from one site to another but this is not linked to the intensity of disturbance given by phyto-ecologists (Puyravaud *et al.*, 1994). Altitude grassland was shown to be naturally occurring by phytoecologists using the presence of *Ischaemum semisagittatum* (Graminaea), an endemic species (Puyravaud *et al.*, 1994). These grasslands supported earthworm communities whose characteristics are close to those of forests yet are different to those of anthropic pastures. One species *Lennoscolex* sp. was only found in this habitat which may reinforce the theory of a natural origin for these grasslands.

Facing an increasing deforestation rate in this area, it is hypothetized that forest will completely disappear in one or two centuries, leading to a decrease in biodiversity. In conclusion, this study allowed the discovery of new species and genera and thus contributes to a better knowledge of earthworm fauna from India and of earthworm ecology.

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