Earthworm populations in *Eucalyptus* spp. plantations at Embrapa Forestry, Brazil (Oligochaeta)

Wagner Maschio, Fabiane M. Vezzani, and George G. Brown

Abstract. We compared earthworm populations (density, biomass and species richness) in five *Eucalyptus* plantations at Embrapa Forestry in Colombo, Parana state, southern Brazil: a 28 yr old *Eucalyptus benthamii* (EB) on a dystrophic oxisol, a 26 yr old mixed *Eucalyptus* spp. plantation (EM) and three plots with *Eucalyptus dunnii* (EDI, EDII, EDIII) 30 to 31 years, on dystrophic cambisols. The survey was carried during the summer rainy season (February 2010 and January 2012). Six species were found: *Pontoscolex corethrurus* (Müller, 1857), *Amynthas gracilis* (Kinberg, 1867), *Amynthas corticis* (Kinberg, 1867), *Metaphire schmardae* (Kinberg, 1867), *Fimoscolex* n. sp. and *Glossoscolex* n. sp. Earthworm populations, consisting of mainly native species (*Glossoscolex* and *Fimoscolex*) were found only in EB. In *E. dunnii* plantations *P. corethrurus* represented >90% of all individuals collected. *M. schmardae* appeared in EM, EDI and EDII but was not found in EDIII and EB. *A. gracilis* and *A. corticis* appeared in EM, EDII and EDIII. Prevalence of these exotic/peregrine earthworms was probably due to prior agricultural use of the area. As observed in other locations, *Eucalyptus* plantations tended to benefit *P. corethrurus* and exotic species while native species were less frequent.

Key words. Forestry management, *Eucalyptus benthamii*, *Eucalyptus dunnii*, terrestrial oligochaetes, biodiversity, soil quality.

Introduction

Forest plantations play an important role in Brazil's economic development : in 2010, the area occupied by plantations of exotic *Eucalyptus* and *Pinus* spp. in Brazil totaled 6.5 million ha, with 73% of the area corresponding to *Eucalyptus* species. Between 2005 and 2010, the area planted with these species increased 23% (ABRAF 2011), mainly to feed the demands for pulpwood and, above all, energy. However, few economically important *Eucalyptus* species are adapted to the colder, sub-tropical climate (Cfb, Koppen) in Southern Brazil (PALUDZYSZYN FILHO et al. 2006). Among these are *E. benthamii* and *E. dunnii*.

It is known that forestry plantations influence (result in changes in) soil fertility and biodiversity, causing a loss of native endemic species as well as the emergence and dominance of a few, generally invasive or exotic species (DECAËNS et al., 2006, GONZÁLEZ et al. 2006). Furthermore, planting and harvesting generally involves major soil disturbance, which can also negatively affect soil fauna (SAUTTER 2001). However, most forestry companies are gradually replacing intensive tillage with minimum soil preparation, to reduce nutrient and organic matter losses (QUADROS et al. 2002). These techniques can benefit soil fauna, which in turn can provide important ecosystem services (BLOUIN et al. 2013). Nevertheless, only few studies have evaluated soil fauna in *Eucalyptus* plantations in Brazil and worldwide, and even in fewer studies the collected earthworms have been identified (DANGERFIELD 1990,

Tomáš Pavlíček, Patricia Cardet, Maria Teresa Almeida, Cláudia Pascoal, Fernanda Cássio (Eds.): Advances in Earthworm Taxonomy VI (Annelida: Oligochaeta). – Proceedings of the 6th International Oligochaete Taxonomy Meeting (6th IOTM), Palmeira de Faro, Portugal, 22- 25 April, 2013.
ISBN 9783-925064-69-2 © Kasparek Verlag, Heidelberg

SOARES & COSTA 2001, WARREN & ZOU 2002, MBOUKOU-KIMBATSA et al. 1998, 2007). For instance, SOARES & COSTA (2001) found mainly soil insects (and a few earthworms) in one *Eucalyptus* plantation, and a predominance of lumbricid earthworms in one *Pinus* plantation in the region of Santa Maria -RS.

Earthworms are good indicators of environmental disturbance due to their high sensitivity to a wide range of soil and environmental properties and to management adopted by humans (PAOLETTI 1999). At Embrapa Forestry, many experimental tree plantations have been established since 1978, including native and exotic tree species such as *Araucaria angustifolia, Pinus elliottii* and various *Eucalyptus* spp. In a recent study by DA SILVA (2010) and LIMA (2011) more abundant exotic earthworm populations (*Pontoscolex corethrurus, Amynthas gracilis*) were found in *Pinus* plantations than in *Araucaria* plantations and native forest at Embrapa Forestry. In the present study we evaluated earthworm abundance and species richness in various *Eucalyptus* species plantations at Embrapa Forestry, and their possible relationships with soil physical-chemical parameters. The hypothesis to be tested was that the earthworm community in these *Eucalyptus* plantations is composed of mainly exotic earthworm species, with a predominance of *P. corethrurus*.

Material and Methods

Study sites. The study was conducted at Embrapa Forestry in Colombo county, Paraná State Brazil, in the metropolitan region of Curitiba (25.19°S, 49.09°W), at an altitude of ~938 m. The regional climate is humid subtropical (Köppen Cfb), with most of the annual precipitation (1400-1500 mm) in summer (Dec.-March), and August being the driest month (71 mm). Mean monthly temperatures range from a maximum of 16.7°C in February to 8.4°C in July.

Five *Eucalyptus* stands were selected:

- Stand 1. *E. benthamii* (EB) plantation, occupying an area of 0.67 ha. Average tree spacing was 5 x 3 m. The trees were ~41 m tall and 45 cm in diameter at breast height (DBH). The plantation was established in 1984 from seedlings planted in 3 x 3 m spacing.
- Stands 2-4. Three plantations of *E. dunnii* (ED), the first covering an area of 1.59 ha (EDI), the second 0.34 ha (EDII) and the third 0.18 ha (EDIII). Average tree spacing at the sampling points was 6 x 6 m (EDI), 5 x 5 m (EDII) and 3 x 2 m (EDIII). The trees were 43, 45 and 31 m tall and 59, 45 and 29 cm DBH, respectively, in EDI, EDII and EDIII. These plantations were established in 1981-1982 from seedlings planted in 2 x 2 (EDI), 3 x 3 (EDII) and 3 x 2 m spacing (EDIII).
- Stand 5. Mixed *Eucalyptus* (*E. dunnii+E. grandis+E. benthamii*) plantation (EM) covering an area of 0.82 ha, and with tree spacing of 3 x 3 m. The trees were 32 m tall and had DBH of 35 cm. The plantation was established in 1986 with 3 x 3 m seedling spacing.

The difference between the tree density in the current plantations and the density of planted seedlings in some stands is the result of thinning. The grassy vegetation in the understory has been mowed approximately 3-4 times per year. In the past (up to 1978), the currently forested areas had been used for annual cropping of wheat, rice and potatoes in a conventional system. Therefore, the soil had been tilled, fertilized and limed to correct pH in the past (>30 yrs ago). The areas with steeper slopes had suffered from severe erosion. Beginning in 1978 with the establishment of Embrapa Forestry several plots of *Pinus*, *Eucalyptus* and *Araucaria* were installed on station for genetic improvement of these tree species for forestry practices in Brazil.

Samples of earthworms were collected in the five plantations during the rainy season in 2010 (February) and 2012 (January). Soils in the plantations were classified according to the Brazilian national soil classification system (EMBRAPA 2009) as: dystrophic brown latosol (oxisol) in EB,

Table 1. Selected properties of the soils in the *Eucalyptus* spp. plantations at Embrapa Forestry, Colombo, Paraná, Brazil (mean of five replicates). *LBd= dystrophic brown Latosol; CHd= dystrophic humic Cambisol; CXvd= dystrophic haplic Cambisol.

	Soil type*	pH $CaCl_2$	K	Ca	Mg	Al	H+Al	Organic C	P	Coarse sand	Fine sand	Clay	Silt	Texture
			$Cmol_c\ dm^{-3}$					$mg\ dm^{-3}$		%				
E. benthamii	LBd	4.46	0.11	1.3	0.64	0.84	10.18	31.5	2.04	19.7	31.3	44.8	4.2	Clay
Mixed *Eucalyptus*	CXvd	4.42	0.05	1.14	0.84	0.92	11.30	31.2	1.66	21.9	31.5	41.2	5.5	Clay
E. dunnii I	CHd	4.04	0.072	0.44	0.34	2.24	15.66	33.8	3.36	24.3	26.5	38.8	10.5	Clay
E. dunnii II	CHd	4.22	0.056	0.94	0.68	1.2	11.45	30.7	1.48	22.7	27.7	44.0	5.5	Clay
E. dunnii III	CHd	4.32	0.058	0.8	0.54	0.96	11.22	29.2	1.60	21.3	36.5	34.8	7.5	Clay
E. dunnii (mean)	CHd	4.19	0.062	0.72	0.52	1.47	12.78	31.2	2.14	22.8	30.2	39.2	7.8	Clay

Table 2. Earthworm density (mean no. indiv. m^{-2} ± standard error), species richness and no. species $monolith^{-1}$ collected in 2010 and 2012 in *Eucalyptus* plantations at Embrapa Forestry, Colombo, Brazil. *EB= *E. benthamii;* ED= *E. dunnii;* EM= Mixed *E. dunnii* + *E. grandis* + *E. benthamii.* Different letters in each plantation (EB, EM or ED mean) represent significant differences in *Pontoscolex* or total earthworm densities using ANOVA or Kruskal-Wallis, at P<0.05.

	Native species		Exotic species								
	Glossoscolex n. sp.	*Fimoscolex* n. sp.	*P. corethrurus*	Cocoons	*Pontoscolex* total	*A. gracilis*	*A. corticis*	*M. schmardae*	Total density	No. species	No. species $sample^{-1}$
Feb. 2010											
EB	15±15	0	4±4b	1±1	5±5b	0	0	0	20±20b	2	0.4
EM	0	3±3	125±10ab	19±106	151±43ab	0	0	1±1	155±101ab	3	1.2
ED I	0	0	339±146	25±13	364±158	5±4	0	1±1	370±161	3	1.2
ED II	0	0	404±58	21±14	425±51	0	0	3±3	428±51	2	1.2
ED III	0	0	44±25	53±46	96±68	0	0	0	96±68	1	0.6
ED (mean)	0	0	262±112a	33±28	295±116a	2±2	0	1±2	298±118a	2	1.0
Jan. 2012											
EB	0	5±4	5±2	0	5±2	0	0	0	10±3b	2	1-0
EM	0	0	39±37	0	39±37	1±1	1±1	0	41±37ab	3	0.8
ED I	0	0	228±92	24±12	251±95	0	0	0	252±95	1	0.8
ED II	0	0	173±56	9±5	181±59	0	1±1	0	183±59	2	1.2
ED III	0	0	21±11	24±10	45±18	3±3	1±1	0	49±21	3	1.2
ED (mean)	0	0	141±71	19±9	159±73	1±1	1±1	0	161±72a	2	1.1

Table 3. Mean biomass (g m^{-2} ± standard error) of the earthworm species collected in 2010 and 2012 in *Eucalyptus* plantations at Embrapa Forestry, Colombo, Brazil. *For meaning of abbreviations please refer to Table 2. Different letters in each plantation (EB, EM or ED mean) represent significant differences in *Pontoscolex* or total earthworm biomass using ANOVA or Kruskal-Wallis, at P<0.05.

	Glossoscolex n. sp.	*Fimoscolex* n. sp.	*Pontoscolex corethrurus*	Cocoons	*Pontoscolex* total	*A. gracilis*	*A. corticis*	*M. schmardae*	Total
February 2010									
EB	1.7±1.7	0	0.44±0.44b	0.06±0.06	0.44±0.44b	0	0	0	2.2±2.2b
EM	0	0.06±0.06	40.9±32.7ab	0.6±0.5	41.8±32.6ab	0	0	1.4±1.4	43.4±32.4ab
ED I	0	0	79.6±33.3	1.2±0.6	81.1±34.2	1.1±0.69	0	0.6±0.6	82.7±35
ED II	0	0	106±29.4	0.69±0.44	109±26.6	0	0	1.1±1.1	110±29.2
ED III	0	0	18±10	2.2±1.9	20.3±11.8	0	0	0	20.3±11.8
ED (mean)	0	0	68±30^{a}	1.4±1.06	70.4±30.4a	0.31±0.44	0	0.5±0.69	71.4±30.8a
January 2012									
EB	0	0.06±0.06	0.19±0.19b	0	0.19±0.19b	0	0	0	21.6±21.3b
EM	0	0	11.8±11.7ab	0	11.8±11.6	0.44±0.44	1,3±1,3	0	13.4±11.3ab
ED I	0	0	5.2±18.6	1.8±0.8	52.6±19.5	0	0	0	52.6±19.5
ED II	0	0	41.1±14.3	0.6±0.5	42.9±15.1	0	0,9±0,9	0	43.8±14.6
ED III	0	0	4.3±2.7	1±0.4	5.8±2.8	0.19±0.19	1,9±1,9	0	8.6±3.4a
ED (mean)	0	0	31.8±15.6a	1.1±0.6	33.8±16.2	0.06±0.06	0,9±1,1	0	34.9±15.8a

dystrophic humic cambisol in all three *E. dunnii* plots and dystrophic haplic cambisol in the mixed plantation (Table 1). All soils were clayey, had relatively high organic C contents, highly acid pH, low P and K^+ contents and base saturation. No significant differences were detected between soil samples representing the three plantations (EM, EB, ED mean; Table 1).

In each plantation, five 40 x 40 x 20 cm deep monoliths were dug at least 20 m apart. The samples were taken in a zigzag design in EDII, EDIII and EM plantations, and in an X-shape design in EDI and EB. Sampling was done always ≥10 m from the edge of the plantations to reduce border effects. Prior to digging up the soil, the litter in the 40 x 40 cm area was handsorted for earthworms. All earthworms present in the top 20 cm of the soil were removed and preserved in 4% formalin. In the laboratory worms were identified to genus or species level, quantified and weighed.

Soil samples from each monolith were removed, air-dried, ground and analysed following standard EMBRAPA (1997) procedures for chemical parameters (pH and concentration of C, P, K^+, Ca^{2+}, Mg^{2+}, Na^+, H+Al) and evaluation of texture. These parameters were then used to calculate Pearson's correlation coefficients with biomass and density of all earthworms and of each species collected in the samples, using Statistica v.7 software (STATSOFT 2004). Mean abundance values were compared between plantations by using ANOVA considering unequal number of samples for the three systems (n = 5 for EM and EB and n = 15 in total for *E. dunnii*) and/or nonparametric Kruskal-Wallis tests (when the data could not be normalized and/or when variances were not homogeneous), using Statistica v.7. Values for the three *E. dunnii* plantations were combined since there were no differences between the soil parameters in these plantations (Table 1). The H_0 hypothesis expecting no differences between compared parameters was regarded as rejected if $P<0.05$. The density and biomass of each earthworm species, along with soil physical and chemical properties were subjected to principle component analysis (PCA) to assess relationships between communities and species recorded in the different plantations by using CANOCO v. 4.5 (TER BRAAK & SMILAUER 2002). Soil parameters with colinearity and "inflation factors" greater than 20 were excluded from the analysis. Hence, exchangeable Al^{3+} and Ca^{2+} were eliminated using "forward selection" due to their colinearity with other variables.

Results

Earthworm density, biomass and species richness. On the first sampling (February 2010), 855 individuals were collected, of which 342 were from EDII, 296 from EDI, 124 from EM, 77 from EDIII and 16 from EB. Five species were identified: *Pontoscolex corethrurus* (Müller, 1857), *Amynthas gracilis* (Kinberg, 1867), *Metaphire schmardae* (Kinberg, 1867), *Fimoscolex* n. sp. and *Glossoscolex* n. sp. (Table 2). The latter two are new native species, whose description has been prepared and will be submitted for publication elsewhere (A. FEIJOO & G. G. BROWN unpublished data).

Total earthworm density (Table 2) was higher in ED plantations (mean 298 indiv. m^{-2}), intermediate in the mixed (155 indiv. m^{-2}), and lowest in EB (20 indiv. m^{-2}), with significant differences between the plantations of ED and EB. Total biomass of earthworms ranged from 2.2 (EB) to 110 $g.m^{-2}$ (EDII; Table 3) and again differed between ED and EB. The same was also observed for *P. corethrurus* biomass, that represented 96-100% of the total biomass in ED and EM; only in EB was the biomass of this species lower (20% of total), with dominance of *Glossoscolex* sp. (Table 3). All cocoons found were of *P. corethurus*, and their density ranged from 25-53 m^{-2} in ED plantations, 19 m^{-2} in EM and only 1.3 m^{-2} in EB (Table 2). Most individuals were found at 0-10 cm depth: 94% in EM, 63% in EB, and 73-92% in ED.

Table 4. Pearson correlation coefficients (R^2 values) and their significance (p values) resulting from linear regressions between selected chemical and physical soil properties and *P. corethrurus* abundance in *Eucalyptus* plantations at Embrapa Forestry. Levels of significance: *p<0.05; **p<0.01; ***p<0.001.

	Fine sand	Coarse sand	Al	P	pH
1st sampling (Feb. 2010)					
Density	-0.33***	0.43***	ns	ns	ns
Biomass	-0.23**	0.45***	ns	ns	ns
Total density (with cocoons)	-0.26**	0.39***	ns	ns	ns
Total biomass (with cocoons)	-0.22**	0.44***	ns	ns	ns
2nd sampling (Jan. 2012)					
Density	-0.27**	0.25**	0.13*	ns	-0.14*
Biomass	-0.28**	0.33***	ns	ns	-0.14*
Total density (with cocoons)	-0.25**	0.28**	0.14*	0.12*	-0.16*
Total biomass (with cocoons)	-0.27**	0.34***	0.12*	Ns	-0.14*

On the second sample date (January 2012), 536 individuals were collected: 252 in EDI, 183 in EDII, 49 in EDIII, 41 in EM and 10 EB. Four species were identified: *P. corethrurus*, *A. gracilis*, *A. corticis* and *Fimoscolex* n. sp., the latter species being found only in EB.

Total density (Table 2) was again greater in ED (mean 161 indiv. m^{-2}), intermediate in EM (41 indiv. m^{-2}) and significantly lower in EB (10 indiv. m^{-2}). Total biomass ranged from 21.6 (EB) to 52.6 g m^{-2} (EDI) (Table 3), being significantly lower in EB than in ED (mean) plantations. *P. corethrurus* biomass (+ cocoons) was also significantly higher in ED than EB. As observed in the first sampling date, most worms collected in Jan. 2012 were at 0-10 cm depth: 97% of the total in EM, 75% in EB and 65-75% in ED. Cocoons were all of *P. corethurus* and only found in ED plantations (8-24 m^{-2}; Table 2).

Species richness (Table 2) was low in all plantations, ranging from 1 to 3 species at most per site. Species richness per sample was also very low, ranging from 0.4 to 1.2, but no significant differences were observed between the plantations (Table 2). Exotic species dominated in almost all plots, while native species were present only in EB and EM. *M. schmardae* was found only on the first sampling in EM, EDI and EDII, while *A. corticis* was found only on the second sampling in EM, EDII and EDIII (in litter and soil). *A. gracilis* was found on both sample dates, but only in EDI and EDIII. *P. corethrurus* was the most abundant species, reaching densities >300 indiv. m^{-2} (Table 2) and biomass >80 g m^{-2} in February 2010 (Table 3). This species represented >95% of all individuals collected on the first date in all plantations except EB, where only ~4 indiv. m^{-2} were found and where *Glossoscolex* n. sp. predominated. In 2012, *P. corethrurus* again predominated, representing >97% of all worms collected, except in EB, where earthworm abundance was very low and it represented only 50% of the collected individuals.

Soil and earthworm relationships. Due to the low abundance of other species, relationship between various soil parameters and earthworm populations were only evaluated for *P. corethrurus*. Regressions between fine and coarse sand contents and the density and biomass of *P. corethrurus* were highly significant (Table 4). Abundance decreased with higher fine sand contents and increased with higher coarse sand contents. On the first sampling date

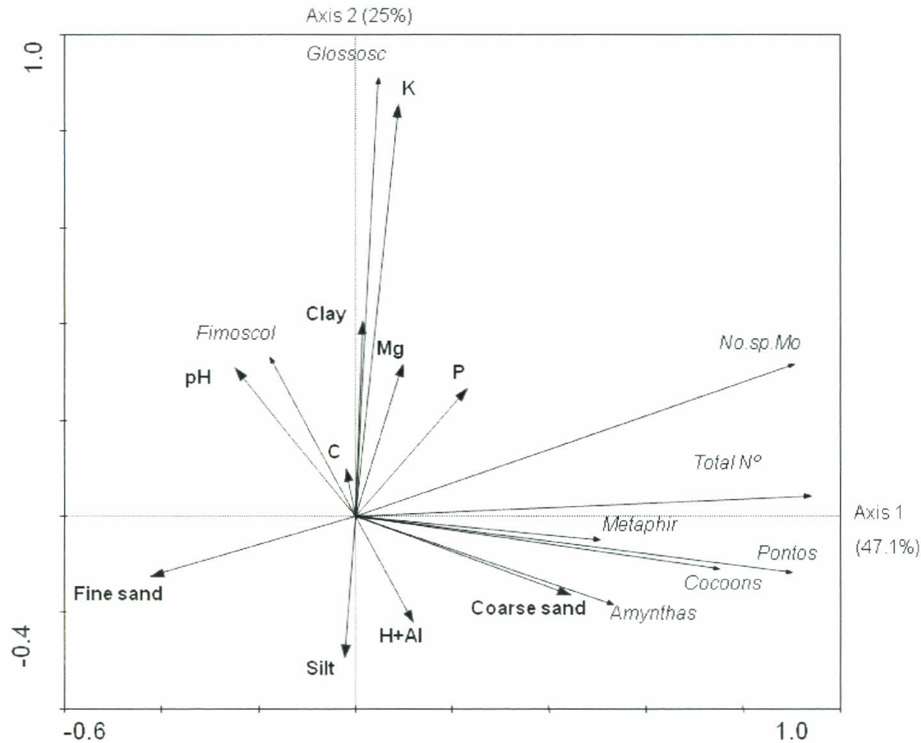

Fig. 1. Principal component analysis (PCA) showing Axes 1 and 2 (and % explained variance), using data on earthworm species abundance in Feb. 2010 (first sampling) and soil chemical and physical parameters as explanatory environmental variables. *Pontos* = *P. corethrurus*; *No.sp. Mo* = number species monolith^{-1}; *Metaphir* = *Metaphire schmardae*; *Fimosc* = *Fimoscolex* n. sp.; *Glossosc* = *Glossoscolex* n. sp.; *Amynthas* = *A. gracilis*; *Total N* = Total Abundance.

there were no significant relationships between soil chemical parameters and the abundance of *P. corethrurus*. However, on the second sampling date, significant correlations were found between *P. corethrurus* abundance and soil Al and P (positive) and pH (negative) although R^2 values were much lower than for coarse and fine sand contents (Table 4).

The Principal Component Analysis (PCA) using data from the first sampling (Fig. 1) again revealed positive relationships between exotic earthworms (*A. gracilis*, *M. schmardae* and *P. corethrurus*) and total earthworm abundance and richness (No. species monolith^{-1}) with coarse sand, exchangeable acidity (H+Al) and available P, and the negative relationships of these parameters with fine sand and pH. These parameters were closely related to the X-axis that accounted for 47% of total variance. Axis 2 explained 25% of total variance and was highly correlated with native earthworm populations (*Glossoscolex* and *Fimoscolex* sp.), and associated with higher soil pH, K, Mg and clay contents. Environmental (soil) parameters explained 46% of the total variability.

The Principal Component Analysis using data from the second sampling date (Fig. 2), confirms the positive relationships between soil P and coarse sand and *P. corethrurus* and total

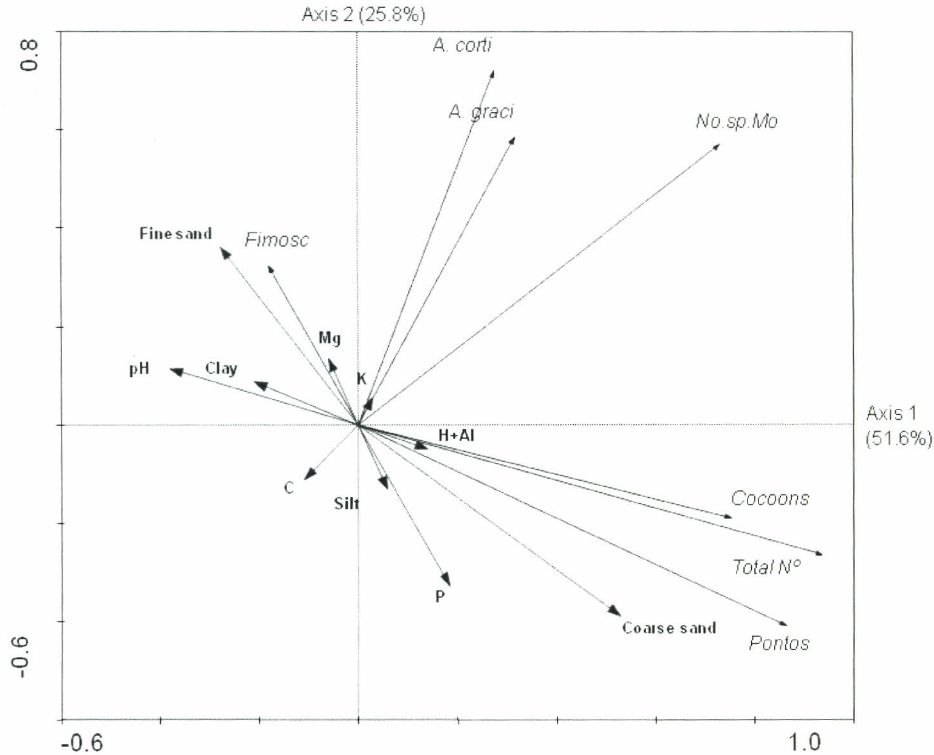

Fig. 2. Principal component analysis (PCA) showing Axes 1 and 2 (and % explained variance), using data on earthworm species abundance in Jan. 2012 (second sampling) and soil chemical and physical parameters as explanatory environmental variables. *Pontos* = *P. corethrurus*; *No.sp. Mo* = number species monolith^{-1}; *Fimosc* = *Fimoscolex* n. sp.; *A. graci* = *A. gracilis*; *A. corti* = *A. corticis*; *Total N* = Total abundance.

earthworm abundance and the negative relationship of these parameters with fine sand and pH. Total variance explained by the analysis was 93.7% in four axes, of which 77.4% was explained by the first two axes (51.6% axis 1 and 25.8% on axis 2, respectively). Axis 2 was related to native earthworms (*Fimoscolex* n. sp.), but also to both *Amynthas* spp. Native worm abundance was positively related to higher fine sand, clay and soil pH contents. Environmental (soil) parameters explained 53% of total variance.

Discussion and Conclusions

The initial hypothesis that *P. corethrurus* would be dominant in *Eucalyptus* plantations was confirmed for EM and ED, but not for EB, where native species of *Fimoscolex* and *Glossoscolex* predominated, although in low numbers and biomass. These new species were also found in *Pinus* and *Araucaria* plantations and native forests nearby (LIMA 2011). Interestingly, different earthworm communities occurred in EB and ED despite the absence of

Table 5. Sites where earthworm populations have been studied in different *Eucalyptus* plantations throughout the world (from various sources). [1]Values in parentheses refer to the estimated proportion of each species encountered. Density in No. indiv. m^{-2}. Biomass in g m^{-2}.

Location/ Country	*Eucalyptus* plantation	Density	Biomass	Earthworm species found[1]	References
Bargagh, India	*Eucalyptus* sp.	108-459	nd	*Lenogaster* sp. (92%), *Lampito mauritii*	DASH & SENAPATI (1991)
Dezful, Iran	*E. camaldulensis* *E. microtheca*	15 57	1.3 10.4	nd	SAYAD et al. (2012)
Eshowe, South Africa	*E. grandis*	~570	~820	*P. corethrurus* (38%), *Amynthas rodericencis* (52%), *A. minimus*, *Dichogaster saliens*	DLAMINI & HAYNES (2004)
Pointe Noire, Congo	*Eucalyptus* sp.	30	nd	*P. corethrurus*	MBOUKOU-KIMBATSA et al. (2007)
	Eucalyptus spp.	0-58	0-10.5	nd	MBOUKOU-KIMBATSA et al. (1998)
Loudima, Congo	*Eucalyptus* sp.	293	74.5	nd	MBOUKOU-KIMBATSA et al. (1998)
Marondera, Zimbabwe	*E. grandis*	7	0.4	nd	DANGERFIELD (1990)
Hakalau, Hawaii	*E. saligna*	91 1	nd nd	*P. corethrurus* *A. gracilis*	ZOU (1993)
	E. saligna (75%) + *Paraserianthes falcataria* (25%)	276 5	nd nd	*P. corethrurus* *A. gracilis*	
	E. grandis *E. urophylla*	12-398 154	4.2-136 53	*P. corethrurus* *P. corethrurus*	ZOU & BASHKIN (1998)
Kamae'e, Hawaii	*E. saligna*	~68-95 2-14	~40-50 0.5-13	*P. corethrurus* *A. gracilis*	LI et al. (2010)
Huimanguillo Mexico	*E. grandis*	166	36.8	*P. corethrurus*	URIBE et al. (2012)
Toa Baja, Puerto Rico	*E. robusta*	0-196	4.7	*P. corethrurus*	WARREN & ZOU (2002)
Joanicó, Uruguay	*Eucalyptus sp.*	0-733	nd	*Aporrectodea caliginosa*, *A. rosea*, *E. fetida*	GROSSO et al. (2006)
Santa Maria, Brazil	*Eucalyptus* sp.	16	nd	*Allolobophora* sp.	SOARES & COSTA (2001)
São Mateus do Sul, Brazil	*Eucalyptus* sp.	0-2	nd	nd	SAUTTER et al. (1994), DIONISIO et al. (1994)
Rolândia, Brazil	*Eucalyptus* sp.	12	0.7	nd	BROWN et al. (2003)

significant differences between soil physical and chemical parameters of the soils in these plantations. The main soil type is different in EB (latossol) and ED/EM (cambissol), but it is possible that some other soil/environmental factor may be responsible for the different worm communities of these plantations. For instance soil compaction, pH, P, C, Mg and N contents are important for the presence and growth of this species (LAVELLE et al. 1987, MARICHAL et al. 2010, 2011, 2012), but some of these factors were not measured in the present study. It is known that *P. corethrurus* has a general preference for soils with higher organic matter (particularly N) and silt contents and pH (MARICHAL et al. 2010). However, significant relationships were only found between soil textural characteristics, P, Al and pH and the abundance of *P. corethrurus*. Furthermore, contrary to MARICHAL et al. (2010), relationships with pH were negative, although the variation in pH values in the present study was very low, and the correlation coefficients were also low.

P. corethrurus is a parthenogenetic invasive species widely distributed throughout tropical regions of Latin America (BROWN & FRAGOSO 2007) and worldwide (GATES 1973). More than 150 years ago, when it was described from specimens collected in southern Brazil, MÜLLER (1857) had already reported this species as one of the commonest earthworms in the region, particularly in areas disturbed by humans. In Brazil, it is one of the best known species (BROWN & JAMES 2007), and although native to the Guyanan Plateau region (RIGHI 1984), should be considered an exotic species in S and SE Brazil (BROWN et al. 2006). The species is adapted to disturbed soils and withstands a wide range in factors such as temperature, precipitation pH, organic matter, N, P and CEC, among others (LAVELLE et al. 1987, KNAPPER & PORTO 1979, MARICHAL et al. 2010). The present study confirms previous observations of the dominance of *P. corethrurus* in forest plantations (*Araucaria* and *Pinus*), which is probably related to the former agricultural land use and management of these areas at Embrapa Forestry (DA SILVA 2010, LIMA 2011). It is likely that this is also responsible for the widespread occurrence and frequent dominance of *P. corethrurus* and other exotic earthworm species in *Eucalyptus* plantations throughout the world (Table 5). *P. corethrurus* was reported from eight of the eleven plantations where species were identified. Its abundance reached 398 individuals m^{-2} and 136 g. m^{-2} in Hawaii (ZOU & BASHKIN 1998), values similar to those found in EDI and EDII plantations in the present study.

The present study is the first known paper quantifying and identifying earthworm populations in *E. dunnii, E. benthamii* and mixed *Eucalyptus* plantations, and is the only one that identified the worms collected to species level in Brazil. Abundance in ED and EM plantations was comparable to those reported in other *Eucalyptus* spp. plantations abroad (Table 5), but abundance in EB was more comparable to values reported for other Brazilian sites (i.e., <16 indiv. m^{-2}), and drier areas of the world (Iran, Zimbabwe). Reasons for the large variation in abundance in *Eucalyptus* plantations worldwide are not known, but are likely to be due to either soil limitations or land use history, as observed in the present study.

The presence of other exotic species such as *M. schmardae*, *A. gracilis*, *A. corticis, A. rodericencis, A. minimus* and various lumbricids in *Eucalyptus* plantations also confirm the anthropogenic disturbance at the present study site and in other sites of the world (Table 5). These species have been reported from a variety of disturbed sites throughout Brazil and Latin America (BROWN & FRAGOSO 2007), and can be considered indicators of disturbance. Still, the high worm abundance and biomass reached in some of the plantations worldwide, and particularly EDI and EDII in the present case, is evidence of their importance for soil bioturbation and effects on physical, chemical and biological soil properties. *P. corethrurus* is known to affect plant growth in a generally positive manner (BROWN et al. 1999), although very little is known of the effects of this species on perennial plants such as tree seedlings.

Amynthas spp. worms are also known to positively affect plant growth, including tree seedlings (KOBIYAMA et al. 1994, PEIXOTO & MAROCHI 1996, BROWN et al. 1999), but nothing is known of their impacts on *Eucalyptus* sp. growth. These topics certainly merit further investigation.

Exotic *Eucalyptus* plantations at Embrapa Forestry and worldwide tend to have mainly exotic earthworm species, composed in many cases of *P. corethrurus*. In a few exceptional cases, e.g. *E. benthamii* plantation on a Latossol in the present study, native species can predominate. The high density and biomass of exotic earthworms is likely due to the disturbance history of these plantations, many times established over former agricultural areas. Future studies should focus on better establishing the relationships between *P. corethrurus* prevalence and various soil factors, as well as the impacts of high abundance of this species on soil properties and tree growth.

Acknowledgements. We wish to thank Paulino Graff, Irineu Oliniski and Wilson Maschio for help with field work. The study received support of the UFPR Graduate School (Soil Science Dept.), Embrapa and CNPq through a fellowship to G. G. Brown.

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Addresses for correspondence: Wagner Maschio and Fabiane Vezzani, Universidade Federal do Paraná, Departamento de Solos, Av. dos Funcionários 1540, Juvevê, Curitiba – PR, Brasil, CEP: 80035-050. – George Gardner Brown, Embrapa Florestas, Estrada da Ribeira Km. 111, C.P. 319, Guaraituba, Colombo-PR, 83411-000. – Contact e-mail: george.brown@embrapa.br.