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Preliminary Estimate of Earthworm Abundance and Species Richness in *Spathodea campanulata* Beauv. Forests in Northern Puerto Rico

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ABSTRACT.—The alien tree species *Spathodea campanulata* forms monodominant stands in abandoned agricultural lands in Puerto Rico. In July 2005, we excavated three replicate randomly located soil pits (25 by 25 by 30 cm) in each of six stands of *Spathodea*. Three of the stands were located in the moist alluvial geoclimatic zone and three were in the moist karst geoclimatic zone, all in the north coast of Puerto Rico. We examined all the soil by hand, sampled, and counted all the earthworms, determined their fresh weight, and identified them to species. Earthworms were absent from all nine pits in the karst forest. Earthworm density in the alluvial forest averaged 84/m^2 or 279/m^3, representing an earthworm fresh weight of 47 g/m^2 or 157 g/m^3. Four species of earthworms were present in our sampling: *Onychochaeta borincana*, *Pontoscolex spiralis*, *P. cynthiae*, and *P. corethrurus*. Of these, *P. corethrurus* is an alien, and the other three are native species. *Pontoscolex spiralis* usually lives in wet conditions, while *O. borincana* and *P. corethrurus* are indicators of disturbed conditions. The density and biomass of earthworms in the alluvial forest are comparable to density and biomass in other Puerto Rican forests. The absence of earthworms in the same kinds of stands in karst forests may imply either a clumped distribution of earthworms in those forests or else the animals were located deeper in the soil profile.

KEYWORDS.—alien species, earthworms, alluvial forests, karst forests, *Spathodea campanulata*, Puerto Rico, land cover change

INTRODUCTION

Earthworms have had over 200 years of scientific attention (Satchell 1983) but still their taxonomy, biogeography, and ecology are poorly understood, particularly in the Neotropics (Fragoso et al. 1995). With the expansion of human activity and the invasion of alien earthworm species, earthworm distribution and their ecological significance have changed their subsequent interactions with native species or their functioning in ecosystems that previously had no earthworms (Baskin 2005). The effects of earthworms on ecosystems are usually considered positive because of their role in aerating and enriching soils (Coleman et al. 2004; Baskin 2005). However, alien earthworm invasions are known to cause changes in plant species composition in the understory of temperate forests (Baskin 2005). Moreover, the abundance, functions, and interactions between native and alien earthworms is not clear in tropical forests. Ecologists need to study a broad range of disturbed and undisturbed ecosystem types to fully understand the interaction between human activities, earthworm ecology, and ecosystem function.

Puerto Rico is particularly well suited for earthworm ecological research for two main reasons. First, its oligochaete fauna is among the most studied in the Neotropics, although it is still considered "moderately inventoried" (Borges 1996; Rodríguez et al.

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in press). The island has 29 earthworm species, 38 percent of which are alien species (Rodríguez et al. in press). Second, its landscapes have been heavily disturbed by human activity, including deforestation, long periods of agricultural use, and in places, some 60 years of vegetation growth following abandonment of agricultural lands (Lugo and Helmer 2004). This history of human activity created a natural disturbance matrix in which to study the effects of land use change on earthworm diversity and abundance.

The history of land use in Puerto Rico has led to the establishment of alien species both in its vegetation (Lugo and Helmer 2004) and earthworm fauna (Fragoso et al. 1995). Our earthworm study was conducted on a forest type that is new to Puerto Rico (*sensu* Lugo and Helmer 2004), a forest dominated by *Spathodea campanulata* (african tulip or meaito), a common but invasive alien tree species in Puerto Rico (Lugo and Brandeis 2005). As part of a larger program on the ecology of this emerging ecosystem, we surveyed its earthworm populations to see how its species composition and abundance (density and biomass) compared with those reported for mature undisturbed and disturbed secondary forests in Puerto Rico and in other temperate and tropical ecosystems. Based on previous studies in Puerto Rico (González et al. 1996; Zou and González 1997), we anticipated high densities of earthworm populations dominated by alien species.

METHODS AND MATERIALS

Study sites

We selected six study sites on the north coast of Puerto Rico (Fig. 1). Sites had to meet the following criteria: the stands had to be monodominant of *Spathodea*, they had to be of similar age, and they had to be close to each other on similar geoclimatic zones. We elected to study three stands on each of two contrasting geoclimatic zones (Lugo 2005): subtropical moist karst, and subtropical moist alluvial. From now on we will identify the forest types as karst and alluvial, corresponding to the respective geoclimatic zones. These sites are at low elevation (Table 1) with an annual rainfall of 1443 mm and a mean annual temperature of 25°C (NOAA 2002). Rainfall in July (the month of the study) is typically 93 mm or 6.4% of the annual total.

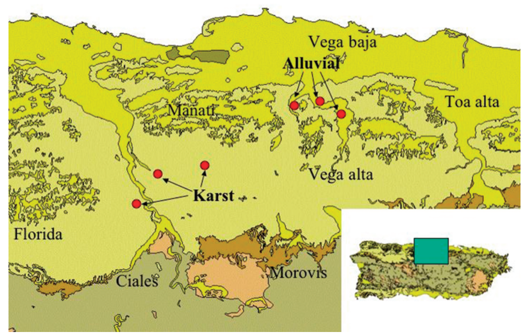

FIG. 1. Location of the study sites in northern Puerto Rico. The base map is from Krushensky, R. D. 2001. Geological map of Puerto Rico. USGS Open File Report 98-34 CD-ROM, San Juan, PR.

The study sites (Fig.1; Table 1) were the following: Pugnado, Juan Nieves, and Ollas y Calderas (karst sites) and Paso del Indio, Cibuco I, and Cibuco II (alluvial sites). All sites are in the subtropical moist life zone (*sensu* Holdridge 1967). The karst soils were rocky with a high organic carbon concentration in the surface layer, while the alluvial soils were flat and homogeneous with lower organic carbon concentration (Table 1). Through interviews with residents we estimated that the stands were 25 to 40 years old. The alluvial sites were established on abandoned sugar cane fields and karst sites included forests occupying abandoned subsistence agricultural fields. Vegetation structure is summarized in Table 2.

Sampling

In July 2005, we excavated three randomly located soil pits (25 by 25 by 30 cm) in each of six stands of *Spathodea*. These pits were located at random distances along a randomly located 100 m transect through the forest stand. Excavated soil was placed on a plastic tarp so that we could examine all the soil by hand while searching for earthworms. All earthworms within each

Fig. 1 live 4/C

TABLE 1. Stand elevation above mean sea level, soil bulk density and carbon concentration, and soil types in *Spathodea campanulata* stands sampled for earthworms. Standard error of the mean is in parenthesis followed by the number of samples. Soil series are approximate.

	Bulk density (g/cm^3)		Organic carbon (%)		
Site and elevation (m)	0-15 cm	>15-30 cm	0-15 cm	>15-30	Soil series
			Karst		
Pugnado (170)	0.43 (0.02, 4)	0.51 (0.10, 3)	7.3 (1.14, 4)	5.0 (2.7, 2)	San Sebastián gravelly clay, mollisol
Juan Nieves (30)	0.39 (0.02, 4)	0.29 (0.03, 4)	2.9 (0.1, 5)	1.8 (0.3, 4)	San Germán gravelly loam, entisol
Ollas y Calderas (140)	0.52 (0.05, 5)	0.54 (0.02, 5)	6.6 (1.6, 5)	4.5 (1.0, 6)	San Sebastián gravelly clay, mollisol
Mean	0.45 (0.02, 13)	0.45 (0.04, 12)	5.5 (0.8, 14)	3.7 (0.7, 12)	
			Alluvial		
Paso del Indio (10)	0.53 (0.02, 5)	0.53 (0.04, 5)	3.6 (0.3, 5)	2.4 (0.2, 6)	Toa silty clay, mollisol
Cibuco I (10)	0.57 (0.02, 5)	0.57 (0.05, 5)	2.7 (0.2, 5)	2.3 (0.2, 6)	Coloso silty clay, inceptisol
Cibuco II (10)	0.44 (0.03, 5)	0.62 (0.03, 5)	2.9 (0.2, 5)	2.0 (0.1, 6)	Toa silty clay, mollisol
Mean	0.51 (0.02, 16)	0.58 (0.02, 16)	3.1 (0.2, 15)	2.2 (0.1, 18)	

TABLE 2. Stand structure (tree density, basal area, and tree height), number of tree species and importance value of *Spathodea campanulata* forest canopies (trees ≥10 cm dbh) and number of species, and importance value of *S. campanulata* in the understory of karst and alluvial study sites. Importance value is based on relative density and relative basal area of tree species.

						Spathodea importance value (%)	
Site	Tree density (trees/ha)	Basal area (m^2/ha)	Tree height (m)	Canopy species (number)	Understory species (number)	Canopy	Understory
			Karst				
Pugnado	859	71	15	9	24	78	6.6
Juan Nieves	612	33	13	6	30	87	2.1
Ollas y Calderas	790	55	13	6	26	74	6.3
			Alluvial				
Paso del Indio	1825	82	13	3	14	92	14.8
Cibuco I	1071	77	11	4	8	90	18.4
Cibuco II	1090	105	12	3	19	91	7.5

of the eighteen 18,750-cm^3 soil monoliths were collected and counted in the field and immediately stored in plastic zip-lock bags with 5 ml of ten percent formaldehyde; earthworms were preserved stretched to facilitate identification in the laboratory. After preservation, they were transported to the laboratory where we determined their fresh weight and identified them to species. Earthworm density and biomass results were expressed by unit area and unit volume of soil. Site values were averaged and we used student t test ($\alpha = 0.05$) to establish any significant difference among the means.

RESULTS

Although we observed evidence of earthworm presence in the karst sites, we found no earthworms in our soil pits (Table 3). In the three alluvial sites, we found earthworms in every pit. Earthworm density was significantly higher at Paso del Indio than Cibuco I or Cibuco II. The three sites had similar earthworm biomass (Table 3).

TABLE 3. Number of species, density, and fresh weight biomass of earthworms in *Spathodea campanulata* forests in Puerto Rico. Standard error is given in parenthesis. N is three for individual sites and nine for all alluvial forests. The area sampled per site was 0.1875 m^2 and 0.05625 m^3.

Site	Species (number)	Earthworm density		Biomass	
		(per m^2)	(per m^3)	(g/m^2)	(g/m^3)
		Karst			
Pugnado	0	0	0	0	0
Juan Nieves	0	0	0	0	0
Ollas y Calderas	0	0	0	0	0
		Alluvial			
Paso del Indio	1	128 (18)	426 (62)	64 (14)	214 (46)
Cibuco I	3	69 (14)	231 (47)	44 (19)	147 (63)
Cibuco II	2	53 (37)	178 (128)	33 (12)	110 (41)
Mean		84 (17)	278 (57)	47 (9)	157 (30)

We found four species of earthworms in the alluvial forests (Table 4). All belong to the Glossoscolecidae family and one is alien to Puerto Rico (*Pontoscolex corethrurus* Gates 1954). Paso del Indio had only one species, while Cibuco I had three of the four species. Only *Onychochaeta borincana* Borges 1994 was found at all three alluvial sites. For two of the species (*Onychochaeta borincana* and *Pontoscolex spiralis* Borges and Moreno 1990) we found adults as well as immature individuals.

DISCUSSION

The earthworm densities that we found in alluvial forests (Table 3) are within the range reported for tropical forests in general (125 earthworms/m^2, Coleman et al. 2004), and forests in Puerto Rico (120 earthworms/m^2; Alfaro and Borges 1996; Borges and Alfaro 1997; Zou and González 1997; González and Zou 1999; Sánchez de León et al. 2003) and mature forests in Puerto Rico (75 earthworms/m^2; González et al. 1996; Borges and Alfaro 1997; Zou and González 1997; González and Zou 1999; González and Seastedt 2001; Sánchez de León et al. 2003). Values are smaller than those observed in secondary forests (272 earthworms/m^2; Alfaro and Borges 1996; González et al. 1996; Zou and González 1997; Sánchez de León et al. 2003), but all these data are variable and the number of studies is insufficient to reach definitive conclusions (Rodríguez et al. in press).

In terms of biomass, the values we found are in the upper range of data reported for tropical secondary forests. For example, Coleman et al. (2004) report a range of <10 to 50 g/m^2 for earthworm biomass in tropical forests. Schulze (1967) found higher earthworm biomass in secondary tropical forests (90 g/m^2) than mature tropical wet forests (75 g/m^2). In Puerto Rico, mature subtropical wet forests have a range of earthworm biomass of 3 to 386 g/m^2, but the high value is for 1 m-deep pit (Moore and Burns 1970; Odum et al. 1970). For depths similar to ours, Borges and Alfaro (1997), Zou and González (1997), and González and Zou (1999) found earthworm

TABLE 4. Earthworm species and their abundance in *Spathodea campanulata* alluvial forests in Puerto Rico. Numbers correspond to individuals identified per 625 cm^2 soil pit. Empty cells mean the species was not found.

Species	Paso del Indio	Cibuco I	Cibuco II
Onychochaeta borincana (Borges 1994)	3, 3, 3	1, 3, 1	1, 1, 0
Pontoscolex cynthiae (Borges and Moreno 1990)		1, 0, 0	
*Pontoscolex corethrurus** (Gates 1954)		2, 0, 0	
Pontoscolex spiralis (Borges and Moreno 1990)			7, 0, 0

*alien species.

biomass of 16 to 78 g/m^2 in mature subtropical wet forests. The highest earthworm biomass values for Puerto Rico are for pastures and secondary forests in subtropical moist conditions (105 to 175 g/m^2, Zou and González 1997). Notably, the abundance and biomass of earthworms in the alluvial *Spathodea* forest were more similar to those of mature forests than to secondary forests or pastures reported by Zou and González (1997).

The significantly higher densities of earthworms and lower species richness in Paso del Indio compared to the two Cibuco sites could be attributed to differences in microsite conditions; at the time of sampling, soil at Paso del Indio appeared to be wetter than at Cibuco I and II, and it is possible that earthworms were more congregated at shallower depths.

We could not find reports of density or biomass expressed per cubic meter of soil. However, we present such data to underscore depth as an important factor in the distribution of earthworms (Reinecke 1983). Endogeic (soil-feeding) earthworms exploit the soil volume more than soil area, although epigeic (leaf litter-feeding) earthworms depend on litter inputs, which occur on an area basis.

The absence of earthworms in the karst forests could be an artifact of our random sampling and the depth of our soil pits (30 cm). It is possible that in karst forests characterized by the rocky terrain and rapid infiltration, earthworms occur deeper in the soil profile or else under rocks or other clumped distribution. We observed earthworm casts associated with the base of trees in both forest types, suggesting a clumped distribution of organisms or presence only at certain times of the year. More sampling is needed in this forest type to resolve this issue.

We expected that alien earthworms would dominate the alluvial forests because of the effects of human activity on these sites. They had been deforested and cultivated for centuries and following abandonment, only the alien tree *Spathodea* colonized the sites. Succession (in terms of tree species richness) has advanced very slowly after the colonization by *Spathodea*, which still accounts for about 90 percent of the canopy species Importance Value (Table 1). Yet, our results show that native earthworms dominate these forests while the alien species was found at only one site (Table 3). However, both the native and alien species that we found are associated with disturbed conditions (Fragoso et al. 1995; Alfaro and Borges 1996). Other native species inhabit natural sites (Fragoso et al. 1995) or areas such as abandoned pastures and croplands (González et al. 1996; Zou and González 1997; Sánchez de León et al. 2003). Furthermore, *P. spiralis* is associated with wet places, such as the alluvial soils that we sampled.

In summary, our study suggests that the alien alluvial forests of *Spathodea campanulata* contain what appear to be functioning earthworm communities. These *S. campanulata* forests are dominated by native earthworm species that exhibit high population densities and high biomass. We found an alien earthworm species, but it did not appear to dominate the earthworm populations in these alluvial forests. We recommend more sampling to elucidate the dynamics of these populations, establish their functioning in these forests and to describe the spatial and temporal distribution of the earthworms in the karst forests of the region.

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