

A First Survey of the Earthworms of Bosque del Pueblo, Puerto Rico

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ABSTRACT.—The oligochaeta fauna of Bosque del Pueblo, located in the central mountain region of Puerto Rico, was surveyed for the first time. Organisms were hand-sorted from forty two samples from three typical plant associations (coffee, fern, and spike-moss) of the forest. Using a 0.25 m quadrant, samples were taken from four successive soil depths of 10 cm. Various soil analyses (texture, pH, moisture, and organic matter content) were performed to obtain information on the distribution of these organisms. No correlation was found between these and total abundance, total biomass or specific species of earthworms. Only two earthworm species were found, both new records for this part of the island: the exotic *Pontoscolex corethrurus* (Müller, 1856) and the native *Onychochaeta borincana* Borges, 1994. Species diversity was low but typical of a region that has been extensively disturbed and with little time for regeneration of the native earthworm fauna.

KEYWORDS.—*Pontoscolex*, *Onychochaeta*, disturbance, tropical, earthworms

INTRODUCTION

The Bosque del Pueblo, or Pueblo Forest, comprises some 530 hectares located in the municipality of Adjuntas in the western part of the central mountain range of Puerto Rico, a region classified as a Wet Subtropical Forest by Ewel and Whitmore (1973). This region has been submitted to intense human activities, especially for agriculture. Since it was established as a reserve in 1996, many aspects of this forest have not been studied. One of the goals of its managers is to survey its flora and fauna to elaborate an effective management plan for the area.

Terrestrial oligochaetes constitute an interesting group to study because the diversity, abundance and distribution of these organisms provide valuable information about the forest such as to the extent it has been affected by human activity. Fragoso et al. (1995) mention that the elimination of native vegetation affects the earthworm communities because some native species are unable to adapt to the new conditions

and thus could become locally extinct. Furthermore, even though Puerto Rico has the most complete survey of terrestrial oligochaetes in the West Indies, there are several areas of the island, like Adjuntas and the central mountainous region, where collections have been scarce (Borges 2004). The main goal of this study is to provide a base line characterization of the terrestrial oligochaetes of Bosque del Pueblo by sampling in the three typical associations of the forest: fern *Dicranopteris flexusosa*, coffee *Coffea arabica*, and spike-moss *Selaginella* spp. This survey will provide information on the oligochaeta fauna of the forest and of its possible recuperation from the anthropogenic activities in the region. Since the terrestrial oligochaetes of the area have never been surveyed the study will simultaneously augment the knowledge on the earthworms of Puerto Rico.

MATERIALS AND METHODS

Two collection trips were performed in October 1997 during the rainy season. Forty two random samples (uneven design) were taken in three typical associations or stands of the forest: *Dicranoteris flexusosa* (13), *Coffea arabica* (17), and *Selaginella* spp. (12), which border a trail that leads from the en-

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trance of the forest down to the Pellejas River. Organisms were hand sorted from four consecutive, 10 cm deep soil layers, in a 0.25 m² quadrant and soil samples were collected at each depth for soil analyses. Earthworms were preserved in a 10% solution of commercial formaldehyde. Their biomass and density were calculated. Soil pH, moisture (Brady 1974), texture (Bouyoucos 1951), and organic matter content (Allison 1965) were determined from the soil sample collected at each depth.

Two-way analysis of variance (ANOVA) tests with replication were applied to weekly soil property measures to test for differences between temporal, spatial, and/or interaction effects. A one-way ANOVA was performed to test differences between dates at each association for the soil properties.

RESULTS

The temporal and spatial patterns of the soil properties were characterized by a significant interaction between sample dates and stations ($p < 0.001$) (Table 1). Even though one-way ANOVA demonstrated that silt content was the only soil property that did show significant differences among sampling dates and among stations (associations), the following general trends can be observed. In the three associations, organic matter content (OM) was higher in the top 10 cm of soil and diminished with depth. Also, the three associations exhib-

ited a similar pattern of soil moisture; the upper soil level had slighter lower values. All pH values fell within the general tolerance limits of oligochaetes. Overall, coffee had a greater abundance of clay and higher pH (6.7-6.8), fern stand had over 60% of sand and had the greatest amount of OM and mid levels of pH (5.8-6.8), while the spike-moss stand had approximately 50% of sand and significantly lower ($P < 0.05$) OM and pH (5.3-5.9). Soil moisture was higher on the second sampling date for all sites ($P < 0.05$). No positive correlation was found between any of the soil properties and the total abundance or total biomass of earthworms.

Two glossoscolecid species were collected: the exotic *Pontoscolex corethrurus* (Müller, 1856) and the native *Onychochaeta borincana* Borges, 1994. No positive correlation was found between any soil property and the total abundance or total biomass of earthworms. *Pontoscolex corethrurus* was collected in all associations while *O. borincana* was only found in the *Selaginella* association (Table 2). The abundance of *P. corethrurus* was greater during the second sampling date with a one to threefold increase at all stations for the first two soil layers (Table 2).

In all associations worms were found mostly in the first 10 cm of soil (Table 2). The highest biomass values were always found in this top soil layer, with a significant decrease towards the deepest layers (Table 3). Average earthworm density and

TABLE 1. Mean values of soil properties at the three associations: OM: organic matter content, C org: organic carbon, SM: soil moisture content. n = 168

Association	Depth cm	pH	clay %	sand %	silt %	OM %	C org %	SM %
Coffee	0-10	6.8	44.3	27.6	28.1	4.7	2.7	27.4
	10-20	6.7	47.7	25.5	27.5	3.5	2.0	23.5
	20-30	6.8	52.3	25.4	29.9	2.7	1.6	24.1
	30-40	6.8	50.5	25.3	24.1	2.5	1.5	22.1
Fern	0-10	5.8	19.2	63.5	17.2	7.0	4.1	34.0
	10-20	6.8	19.1	66.3	14.5	6.3	3.7	30.4
	20-30		18.9	65.9	15.7	6.6	3.8	31.8
	30-40	6.1	21.2	64.6	14.2	5.7	3.3	31.8
<i>Selaginella</i>	0-10	5.33	21.9	51.3	26.8	2.9	1.7	30.3
	10-20	5.9	21.1	56.4	22.5	2.1	1.2	26.7
	20-30		23.9	53.2	22.9	1.6	1.0	26.8
	30-40		19.0	59.9	21.1	1.7	1.0	28.3

TABLE 2. Total number of earthworms at each association, sampling time and depth

Association	Species	Time	0-10 cm	10-20 cm	20-30 cm	30-40 cm	
Coffee	<i>P. corethrurus</i>	1	6	4	3	0	
		2	29	12	4	0	
	<i>O. borincana</i>	1	0	0	0	0	
		2	0	0	0	0	
	Fern	<i>P. corethrurus</i>	1	1	1	0	0
			2	36	0	0	1
<i>O. borincana</i>		1	0	0	0	0	
		2	0	0	0	0	
Selaginella	<i>O. borincana</i>	1	0	0	0	0	
		2	12	3	0	0	
		1	1	0	0	0	
		2	3	0	0	0	

TABLE 3. Total earthworm biomass (g/m²) at the three associations, sampling time and soil depth

Association	Time	0-10 cm	10-20 cm	20-30 cm	30-40 cm
Coffee	1	0.48	0.4	0.19	0
	2	0.72	0.34	0.15	0
Fern	1	0.09	0.07	0	0
	2	1.46	0.02	0	0.03
Selaginella	1	0.49	0	0	0
	2	0.54	0.08	0	0

biomass values were closer for the fern and coffee associations (3.66 ind/m², 2.8 g/m² and 2.81 ind/m², 1.67 g/m², respectively). The *Selaginella* association had the lowest density and biomass of all (1.56 ind/m², 1.11 g/m²).

DISCUSSION

Although the two sets of samples were performed just a week apart, soil properties differ according to date. It rained just before the second sampling and though this would undoubtedly affect some of the soil properties measured, it hardly explains all the differences. Nonetheless, earthworms were more abundant in all associations, especially in fern, in the second sample (Table 2). An increase in soil moisture may increase the number, biomass and activity of earthworms (Edwards and Bohlen 1996).

The two earthworm species collected in the Bosque del Pueblo, which constitute a new record for this part of Puerto Rico, are typically found in disturbed regions of the island. The exotic *P. corethrurus* was the

dominant species in all associations. This species was also reported for the pasture and young secondary forest (abandoned pasture for 25-40 years) in Cayey (Sánchez-de León et al. 2003). *Pontoscolex corethrurus* and *O. borincana* have been collected in the Cartagena Lagoon Reserve, an extremely disturbed region in the western part of the island (Alfaro and Borges 1996) and even from Nipe soils in Maricao which are considered inhospitable for terrestrial oligochaetes (Hubers et al. 2003). The appearance of these species in Bosque del Pueblo was predictable because human activities have extensively affected the region. Part of the historical use of the forest was the cultivation of coffee. Moreover, a portion of the forest underwent geological studies that included the removal of vegetation, the construction of tunnels and the use of explosives, among other things.

The species richness of this forest is lower than that reported from Cartagena (where four species were collected) and Maricao (with three spp.) and is similar to that of the active pasture (2 spp.) and the

young secondary forest (1 sp.) in Cayey. In fact, *P. corethrurus* was the only species found in the abandoned pasture of Cayey (Sánchez-de León et al. 2003) and the only species found in the deserted (since 1960s) coffee plantation of Bosque del Pueblo in the present study. However, although the number of samples performed in Bosque del Pueblo is numerous, these comparisons are not evenhanded considering that the oligochaeta fauna at Cartagena and Maricao were studied for a year and at Cayey for five months. Nevertheless, the average earthworm density (8.51 ind/m²) and biomass (3.55 g/m²) of Bosque del Pueblo is one of the lowest of the earthworm communities studied in Puerto Rico (Lugo et al. 2006) and in Cuba (Rodríguez et al. in press).

Soil OM, or soil organic carbon (OC), is an important factor in determining the abundance and distribution of terrestrial oligochaetes (Hendrix et al. 1992). As expected then, the highest density of worms in this forest was found in the upper soil profiles where OM values were highest and diminished with depth as OM also decreased. This pattern is especially observed in the coffee association. However, sand may counter OM effects. For instance, in the fern association, we found an absence of worms from the 10-40 cm soil levels even though the OM values (3.03-12.78%) are higher than those obtained in the coffee association. The soils of this association are sandy; this suggests that water retention may affect the abundance of earthworms. Likewise, in Cartagena (Alfaro and Borges 1996), *P. corethrurus* was more abundant (12 ind/m⁻²) in the first 10 cm of the Amelia Maguayo series where soils are sandy (68-75% sand) but also had high OM (5.75-9.32%) and moisture (10.4-33.2). This species was not found in the deeper profiles of the Amelia soils where the texture varied from 54-91% sand. In the present study, only one worm was collected from the second depth of the soil profile of the *Selaginella* association and none were found in the 20-40 cm levels. The low OM in combination with the sandy texture of soils of the fern and *Selaginella* stands may explain

the low numbers of oligochaetes at these sites in Adjuntas.

Onychochaeta borincana was found exclusively in the *Selaginella* association (on average, 54.3% sand, 26.48% moisture, and 2.12% OM). Its density is drastically lower than the one reported for this species in Cartagena (up to 126 ind/m⁻²) by Alfaro and Borges (1996). In Cartagena, however, this species predominated in soils with higher clay content (38-42%) and OM (above 5%). Nonetheless, in Nipe soils of Maricao the only five specimens (0.58 ind/m⁻²) of *O. borincana* found in the yearlong study were collected in sandy soils (34.5-51.0% sand, 25-36.5% clay) but with higher soil OM (3.94-7.29%) and moisture (22.54-28.55%) content. It seems that as with *P. corethrurus*, the low OM together with the sandy texture of these soils may explain the low density of *O. borincana*. In addition, the *Selaginella* association borders the Pellejas River and riparian systems are typically species-poor communities.

Of the 18 native species of Puerto Rico (Borges 2004) only one was found in this disturbed forest, *O. borincana*. According to Fragoso et al. (1995) the native species that are able to survive in disturbed ecosystems are generally eurytopic, have a wide distribution and a preference for pastures. Although it has not been reported from pastures, this species is amply distributed in Puerto Rico and has been collected in various ecological Life Zones (Dry, Lower Montane, and Moist Subtropical Forests), at elevations ranging from 30 to 1097 m, and in diverse soil types (Borges 1994). On the other hand, it is interesting that in Bosque del Pueblo *O. borincana* was collected where *P. corethrurus* was less abundant. A similar pattern was detected in the Nipe soils of MSF (Hubers et al. 2003). In Cartagena, *O. borincana* was more abundant (126 ind/m⁻²) than *P. corethrurus* (up to 12 ind/m⁻²) and the highest density of *P. corethrurus* was collected where the density of *O. borincana* was only 6 ind/m⁻² (Alfaro and Borges 1996). Competition between these species may be inferred but further investigation is needed before establishing this possibility.

Although the survey of the oligo-

chaeto fauna of Bosque del Pueblo is far from being complete, the findings reported here shed information on the ecology of these organisms which follow some of the patterns listed by Fragoso et al. (1995) for Mexico and discussed by Borges (2004) for the earthworms of Puerto Rico. They state that earthworm communities are composed of native and exotic species (the number of native species being higher in natural ecosystems and exotic species prevail in disturbed ones) and that the survival of natives in disturbed ecosystems depends on the time a site has been disturbed and on the intensity of the destructive practices.

The exotic *P. corethrurus* was the most common in Bosque del Pueblo while the native *O. borincana* was present in a much lower density. Zou and González (1997) examined the earthworms along a successional sequence of plant communities in abandoned pastures and found the native *Estherella gatesi* Borges and Moreno, 1989 only in associations abandoned for 15-40 or more than 40 years. Sánchez-de León et al. (2003) found the natives *Borgesesia sedecimsetae* (Borges and Moreno, 1991), *Estherella* sp., *O. borincana*, *Neotrigaster rufa* (Gates, 1962) and *Trigaster longissimus* Borges and Moreno, 1991 in pastures abandoned for more than 77 years. Evidently, the recuperation of native species has not occurred in Bosque del Pueblo maybe because not enough time has elapsed since the intense anthropogenic activities in the region.

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