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Ecological classification of Brazilian earthworms: a first attempt using morphological data

Daniel Piacentini de Andrade[1]; George Gardner Brown[2] & Mac Aaron Callaham Jr[3]

[1] Majoring in Biology/ CNPq Scholarship, Faculdade Integrada Espírita, Campus Bezerra de Menezes, Rua Tobias de Macedo Júnior, nº 246 Santo Inácio – Curitiba – Paraná CEP 82.010-340 danielpda0@hotmail.com; [2] Agronomist, Embrapa Florestas Researcher, Estrada da Ribeira, km 111 Cx. Postal: 31, Colombo – Paraná – BR, CEP 83411-000, browng@cnpf.embrapa.br; [3] Biologist, USDA Forest Service Researcher, 1400 Independence Ave., SW, Washington, D.C. 20250-0003, mac.callaham@gmail.com

Pôster

INTRODUCTION

About 300 species of earthworms are known in Brazil, but little is known of their biology and ecology. Earthworms can be ecologically classified according to their morphology, behavior and feeding habits, and Bouché's (1977) classification system is the most widely used. This classification separates the worms into three main categories, depending on 15 anatomical and behavioral characteristics: epigeic, anecic and endogeic. The epigeic earthworms are small, pigmented, live in the litter and consume fresh organic matter, and rarely ingest mineral soil. The anecic species tend to have larger individual size and live in soil, which they consume mixed with fresh organic matter, collected on the soil surface. The endogeic species have variable size, consume soil organic matter and inhabit the mineral soil horizons, rarely rising to the soil surface. Lavelle (1981) further subdivided the endogeic earthworms into three sub-groups (polyhumic, mesohumic and oligohumic), depending on the quality of organic matter they ingest. Most of the Brazilian species have yet to be classified into ecological categories, mainly due to lack of data.

MATERIAL AND METHODS

We chose seven morphological parameters from the original taxonomic descriptions for 41 earthworm species currently known from Brazil to test if the available data could be used to classify them into ecological categories. The traits used included: length, diameter, pigmentation, muscular development of the gizzard and surrounding segments, calciferous glands (development and number) and typhlosole (Table 1). These characters were chosen because they were considered potentially related to the behavior, nutrition and depth of soil inhabited by these earthworms. Data were extracted from the original or other taxonomic descriptions in the literature. To standardize the diameter and length used in the Table 1, only the greater measures mentioned in the descriptions were used, then the ratio length/diameter was calculated, and this ratio was used in statistical modeling instead of both data separately. For pigmentation, the criteria used were the intensity and location (dorsal, ventral or complete). In the development of typhlosole, two variables were considered: the length of the intestine occupied by typhlosole, and the form and degree of folding of the typhlosole. The last character used was the development of the gizzard musculature and the muscular development of the forward segments, which was basically classified as absent, weak, moderate and strong. For each of these characters we devised a categorization with values ranging from 0-3 to indicate the degree of development of the character. The characters used, and the categorization scheme are shown in Table 1. Forty-one earthworm species found in Brazil were evaluated (18 exotic, 23 native), of which 18 (Table 2) had previously been assigned an ecological category. We included these species in order to establish whether the morphological parameters would serve to correctly separate them according to their known classifications.

We used two different statistical approaches to analyze the earthworm morphological data. The first was a Principal Components Analysis using the software Canoco®, and the second was a Clustering analysis using the software SAS®.

We conducted five separate PCA analyses: 1) using all of the categorical data for only the species with known ecological strategies; 2) using all the categorical data for unknown species including two species with known ecological strategies as "references"; 3) using limited datasets (i.e. without calciferous gland data) for species with known ecological categories; 4) using the limited dataset for unknown species with references as in #2 above; and 5) using all available data for all 41 species.

Additionally, we conducted a series of cluster analyses using several combinations of data (raw data, categorical data, and a combination of raw and categorical), which were designed to generate different numbers of clusters (3, 5, or 7) to simulate the different number of ecological categories expected in the species we evaluated.

RESULTS AND DISCUSSION

PCA Analyses

Results from the principal components analysis using all of the available data for the earthworm species with known ecological strategies indicated good separation of two main groups. The factors that were most important in this ordination were pigmentation and muscular development. The resulting two groups can be interpreted as representing endogeic species in one group, with the other group consisting of species that spend at least some time at or near the soil surface including both epigeic and epi-endogeic types (Fig. 1a). The PCA using all available data for the species with unknown ecological strategies resulted in considerably less spread, with pigmentation and muscular development still being important factors influencing the spread of species in the ordination, but size and typhlosolar development having equal or greater influence on the ordination. The two “reference” species, *Eisenia andrei*, and *Pontoscolex corethrurus* were loosely grouped with species having similar pigmentation, for example, but these were not completely satisfactory, as some pigmented species were located on the opposite side of the ordination from *E. andrei* (Fig. 1b). It is possible that the lack of spread among the set of species in the second ordination is due to the fact that they are more closely related, taxonomically and geographically, than those in the first analysis.

Principal components analyses that utilized limited datasets (not including calciferous gland parameters) resulted in ordinations with very good separation of endogeic and epigeic/epiendogeic species, and reinforced the importance of pigmentation and muscular development as discriminating characters (Fig. 2a). However, results of the PCA using the limited dataset for earthworms with unknown ecological strategies were essentially identical to the analysis using the entire dataset with only minor changes in position for individual species in the ordination plot (Fig. 2b, 3).

Cluster analysis

It is difficult to draw conclusions from the results of the various different analyses using clustering techniques. In general, it appears that the clustering analysis was sensitive enough to group the species along taxonomic lines, but that the utility of this technique for discriminating ecological or behavioral differences may be limited. For example, clustering the entire dataset (41 species) into five groups resulted in all of the megascolecid species being assigned to a single group, and all the species of the genus *Dichogaster* assigned to another group (with some other species). Furthermore, there was only a single instance of congeneric species being assigned to different groups, with *Glossoscolex giganteus australis* being separated from the other *Glossoscolex* spp. (Table 2). Cluster analysis of species with known ecological strategies showed the sensitivity of the technique to unusual characteristics (Table 3), with two groups containing only single species (*Glossoscolex giganteus australis*, unusually large; *Dichogaster annae*, the only heavily pigmented *Dichogaster* in our analysis).

Although we observed separation of the species studied using both analytical tools, and the groups sometimes coincided with the five known ecological categories, neither of the statistical approaches perfectly indicated the ecological and behavioral attributes of the subset of species for which the information was known. This suggests that the information contained in taxonomic descriptions is probably insufficient to determine precisely the categories of species for which there is no behavioral information, and we suggest that future taxonomic descriptions might be modified to contain as much ecological information for described species as possible.

CONCLUSION

The results of our analysis are not perfect, but they demonstrate that ecological classification may be a promising field, which can be improved if performed with more exact parameters. Including more ecological data in species descriptions, when possible, would greatly facilitate the process.

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Table 1. Selected characters used in the ecological category analysis. Categorical values were assigned for each character based on the criteria in the table.

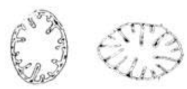
Category assigned	Size (Lenght / Diameter)	Pigmentation	Typhlosole development		Calciferous gland development / number		Muscular development
0	20 or less	Absent	Absent		Absent		n/a
1	20-32	Anterior or anterio-dorsal only	Simple, length < 1/2 diameter of gut.		Simple, few lamellae, large lumen, low surface area to volume ratio (S:V)		Weak
2	33-48	Dorsal for full body length, or complete but light in color	Simple, single blade, > ½ diameter of gut, or multiple low blades		Lamellar, Reniform, intermediate S:V		Moderate
3	49 or more	Completely pigmented along and around the body	Complex, T – shaped, folded, or otherwise occupying much of the gut lumen		Panicled tubular, intertwined tubular, high S:V		Strong

Table 2: Selected species of known and unknown ecological categories divided into exotic and native groups.

Exotic		Native	
Eukerria saltensis	**Endogeic**	*Alexidrilus lourdesae*	
Ocnerodrilus occidentalis	**Polyhumic endogeic**	*Andiorrhinus bucki*	
Eudrilus eugeniae	**Epigeic**	*Chibui bari*	
Hyperiodrilus africanus	**Epigeic endogeic**	*Diachaeta kannerae*	
Aporrectodea rosea	**Endogeic**	*Enantiodrilus borelli*	
Bimastos parvus		*Fimoscolex sporadochaetus*	
Eisenia andrei	**Epigeic**	*Glossodrilus parecis*	
Murchieona minuscula		***Glossoscolex paulistus***	**Endogeic anecic**
Octolasion cyaneum		*Glossoscolex matogrossensis*	
Amynthas corticis	**Epigeic endogeic**	*Pontoscolex cuasi*	
Amynthas gracilis	**Epigeic endogeic**	*Rhinodrilus hoeflingae*	
Metaphire schmardae	**Endogeic**	*Rhinodrilus motucu*	
Polypheretima elongata	**Mesohumic endogeic**	***Urobenus brasiliensis***	**Epigeic endogeic**
Dichogaster affinis	**Polyhumic endogeic**	***Belladrilus pocaju***	**Endogeic**
Dichogaster annae	**Epigeic**	*Haplodrilus tagua*	
Dichogaster bolaui	**Endogeic**	*Lourdesia paraibaensis*	
Dichogaster gracilis		*Eukerria emete*	

Microscolex phosphoreus	*Dichogaster ibaia*	
	Neogaster angeloi	
	Wegeneriona belenensis	
	Andiorrhinus meansi	
	Glossoscolex giganteus australis	**Endogeic anecic**
	Pontoscolex corethrurus	**Mesohumic endogeic**

Table 3: Results of the cluster analyses including with all species, and only with known ecological groups species.

Cluster number	All species	Species with known ecological classes
1	*Murchieona minuscula* *Octolasion cyaneum*	*Glossoscolex giganteus australis*
2	*Amynthas corticis, Amynthas gracilis* *Metaphire schmardae, Microscolex phosphoreus* *Polypheretima elongate*	*Dichogaster annae,*
3	*Fimoscolex sporadochaetus, Hyperiodrilus africanus* *Glossodrilus parecis, Haplodrilus tagua* *Glossoscolex giganteus australis*	*Amynthas corticis, Amynthas gracilis* *Glossoscolex paulistus, Eisenia andrei* *Metaphire schmardae*
4	*Andiorrhinus meansi, Andiorrhinus bucki* *Dichogaster annae, Dichogaster bolaui* *Dichogaster gracilis, Dichogaster ibaia* *Diachaeta kannerae, Eudrilus eugeniae* *Pontoscolex corethrurus, Pontoscolex cuasi* *Aporrectodea rosea, Chibui bari* *Dichogaster affinis, Rhinodrilus hoeflingae* *Rhinodrilus motucu, Urobenus brasiliensis*	*Pontoscolex corethrurus, Aporrectodea rosea,* *Dichogaster affinis, Urobenus brasiliensis* *Hyperiodrilus africanus, Dichogaster bolaui* *Eudrilus eugeniae*
5	*Alexidrilus lourdesae, Bimastos parvus* *Eisenia andrei, Belladrilus pocaju* *Enantiodrilus borelli, Eukerria emete* *Eukerria saltensis, Glossoscolex matogrossensis* *Lourdesia paraibaensis, Ocnerodrilus occidentalis* *Glossoscolex paulistus, Neogaster angeloi* *Wegeneriona belenensis*	*Eukerria saltensis, Ocnerodrilus occidentalis* *Polypheretima elongata, Belladrilus pocaju*

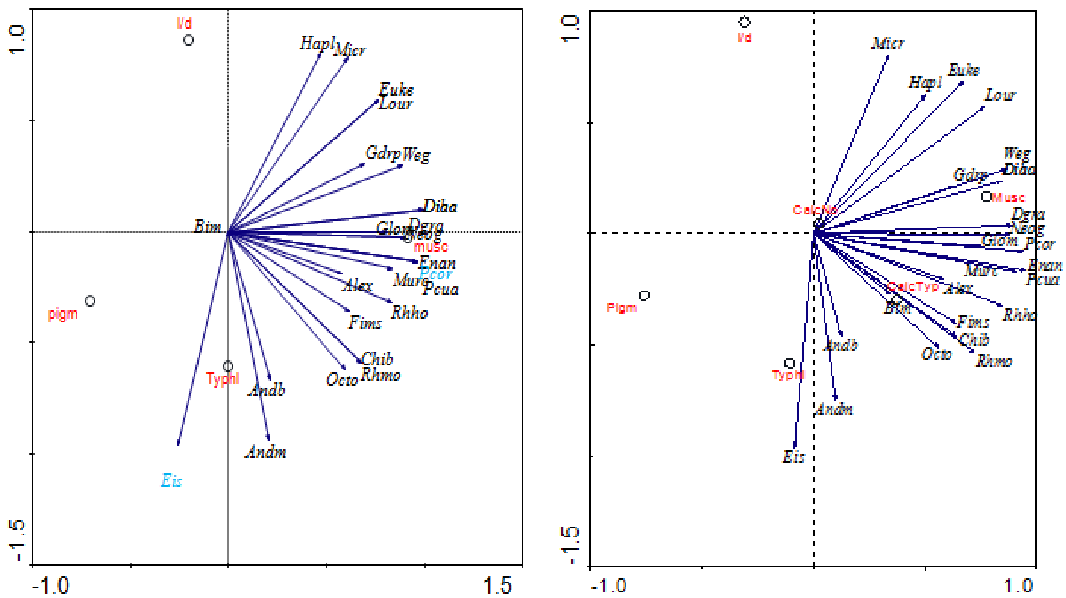


Figure 1a: Analysis of all of the categorical data only for the species with known ecological strategies; **1b:** Analysis of all the categorical data for unknown species including two species with known ecological strategies as “references”; l/d = length / diameter; Pigm = Pigmentation; Typhl = Typhlosole; Musc = Muscular development in gizzard and surrounding area; CalcNo = Number of calciferous glands; CalcTy = Type of calciferous glands.

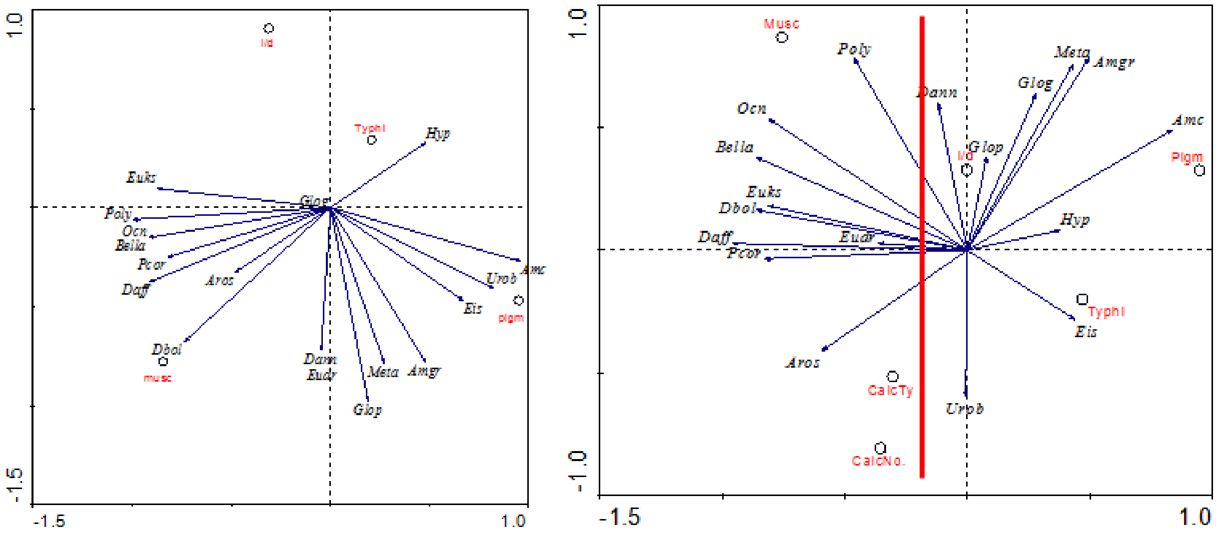


Figure 2a: Analysis using limited datasets (i.e. without calciferous gland data) for species with known ecological categories; **2b:** Analysis using the limited dataset for unknown species with “references”.

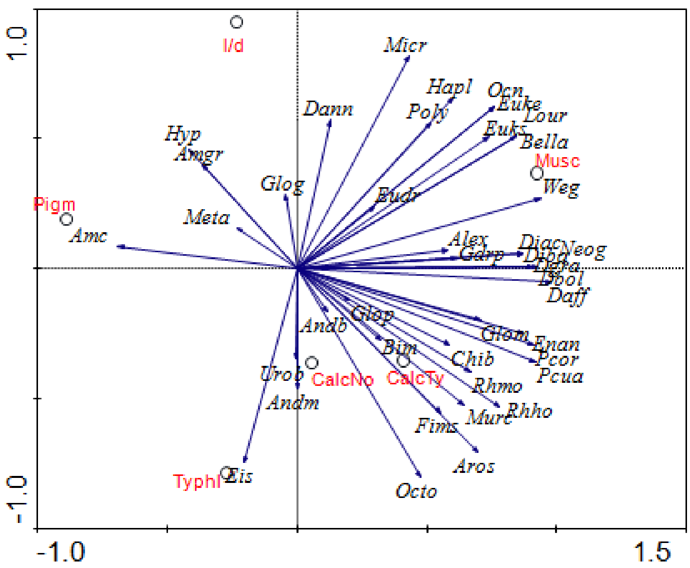


Figure 3: Analysis using all available data for all 41 species