Scientific Paper

# Evaluation of the macrofauna as indicator of the health status in seven land use systems, in Cuba

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## Abstract

The effect of seven land use systems on the soil macrofauna was studied, and fauna indicators were suggested to evaluate the impact of land use and the health status of the soil medium. Sampling was conducted in the rainy season, between 2009 and 2013, according to the TSBF standard methodology, and six soil monoliths were studied per land use replica. The macrofauna composition, richness and abundance were determined to the taxonomy level of family. A non-parametric variance analysis was made, to detect possible differences in the abundance among land use systems. As fauna indicators, the following were proposed: detritivores/non-detritivores and earthworms/ants. Such relations showed the superiority of detritivore individuals and earthworms with values close to or higher than 1, especially in forests, where there was higher soil cover and protection. In land use systems with higher disturbance degree values close to zero were obtained. A high abundance of detrivores or earthworms and a lower quantity of non-detritivore individuals or ants can represent systems with little or no disturbance and favorable fertility status. An inverse result shows more intense soil disturbance and degradation conditions. The earthworms/ants indicator is of higher practical usefulness, because the groups involved are easily identified and do not need specialized knowledge.

**Keywords:** soil degradation, soil fertility, biological indicator

## Introduction

The soil macrofauna groups easily detectable soil macroinvertebrates (higher than 2 mm of diameter) and performs different ecosystem processes and services, which allow to maintain soil quality and fertility. Among the functional groups of the macrofauna which ensure the productive capacity of the soil are detritivores, herbivores, omnivores and predators. The interactions among these groups are determined by the available resources in the ecosystem, as well as by the intensity of their management (Zerbino *et al*., 2008; Cabrera-Dávila *et al*., 2011; Marichal *et al*., 2014).

The loss of a group with key function, as in the case of detritivores –which are responsible for organic matter decomposition–, leads in the long term to the decrease of soil productivity. The macrofauna can be used as biological indicator of the impact of land use and the quality of the soil environment, due to the ecological role it plays and its relation to the soil physical and chemical properties; also to its variation in a short period of time, because of the cover changes and vegetation transformation (Rousseau *et al*., 2013; Gómez Pamies *et al*., 2016; Pauli *et al*., 2016).

Particularly in the humid tropic, several studies have been conducted in order to use macrofauna as indicator of the soil functioning. Some studies initially characterized the soil communities from their taxonomic richness, diversity, density, biomass and functional composition, and thus they evaluated land use intensity ( Feijoo *et al*., 2007; Rossi *et al*., 2010; Silva *et al*., 2015; Martínez *et al*., 2016; Mesa-Pérez *et al*., 2016; Souza *et al*., 2016). Others have proposed indexes or formulations that show only the macrofauna abundance and diversity, or relate these variables with soil physical and chemical properties; in this sense, Barros *et al*. (2002), Lavelle *et al*. (2003), Velásquez *et al*. (2007) y Ruiz *et al*. (2011) reported the earthworms/termites density index, the multifunctional indicator of soil quality (GISQ) and the biological index of soil quality (IBQS).

In Cuba, the first studies about the soil fauna had the objective of determining its abundance and diversity. Afterwards, the characterization of the macrofauna was used to interpret the effect of semi-natural and disturbed ecosystems on these communities. In one of the most recent papers about this topic the biological and functional

particularities of the macrofauna to be used as bioindicator were reviewed, as well as the results of the above-mentioned studies. In this paper the possible usefulness of the detritivore fauna, especially of earthworms, was also explained, and ants were reported as indicators of soil disturbance (Cabrera-Dávila, 2012).

The current research stands out because it compiles all the results obtained in a gradient of land use, including recently studied land use systems, from semi-natural and agroforestry ecosystems with little disturbance to highly disturbed agricultural systems, some of them with organic fertilization alone. The objective of this study was to evaluate the effect of seven land use systems on the soil macrofauna, and from it suggest, for the first time for Cuba, macrofauna indicators to diagnose the impact of land use and the soil health status.

## Materials and Methods

### Land use systems

Seven land use systems with different conservation/disturbance levels were analyzed: primary forests (Fp), secondary forests (Fs), agroforestry systems (As), pasturelands (P), sugarcane plantations (S), food crops (Fc) and urban agroecosystems (Ua), which were located in the western region of Cuba. The soil in all the land use systems corresponded to the genetic type Ferralitic Red (FRR), except in the primary forests where it was adjusted to Fersialitic Yellowish (Frs Y), according to the soil classification of Cuba (Hernández-Jiménez *et al*., 2015). The other characteristics of the systems are shown in table 1.

### Collection in the field and analysis of the soil macrofauna

The study was conducted during 2009 and 2013, only in the rainy season, because it is in this season when there is higher activity and abundance of macroinvertebrates in the soil due to the benefit of rainfall. The collection of macrofauna was adapted to the standard methodology described by the Program of Tropical Soil Biology and Fertility or TSBF (Anderson and Ingram, 1993). Between two and three replicas of the land use systems were studied, and in each replica six monoliths of 25 x 25 30 cm separated between 20 and 50 m were extracted, where the visible fauna was manually collected *in situ*. Taking into consideration the quantity of replicas per land use system a total of 12 monoliths was analyzed in Fp, As and Ua, and 18 monoliths in Fs, P, S and Fc.

The macrofauna was identified to the taxonomic level of family (Brusca and Brusca, 2003), and the ecological characterization of these communities was also made at that level. For separating the functional groups the criterion proposed by Zerbino *et al*. (2008) was followed.

The macrofauna richness and the dominance of its different groups were included in the range/abundance curves, which were constructed from $Log_{10}$ of the number of individuals or relative abundance (pi) of the families found in each land use system (Magurran, 1989). The analysis of the macrofauna richness contemplated the number of observed and estimated families, the latter determined through the non-parametric richness estimator Bootstrap, according to the program EstimateS 8.2.0.

### Macrofauna indicators to evaluate the soil health status

The relations between the abundance or number of individuals from different taxonomic or functional groups of the macrofauna, such as: detritivore/non-detritivore organisms and earthworm/ants, were calculated. The analysis was carried out through the division of the abundance of the numerator groups by the denominator groups in these relations, and the analysis of their performance and of the generated value allows to evaluate the impact of land use intensity and the health status of the edaphic medium, on any soil type of soil and ecosystem, in the rainy as well as the dry season.

**Statistical analysis**. A non-parametric one way variance analysis (ANOSIM) was used based on permutations, to evaluate the hypothesis Ho of no statistically significant differences among land use systems regarding the abundance of each functional group and of the total macrofauna. Each ANOSIM was performed with a Euclidean distance matrix and using 9999 permutations. As statistical software PAST version 3.11 was used (Hammer, 2017).

## Results

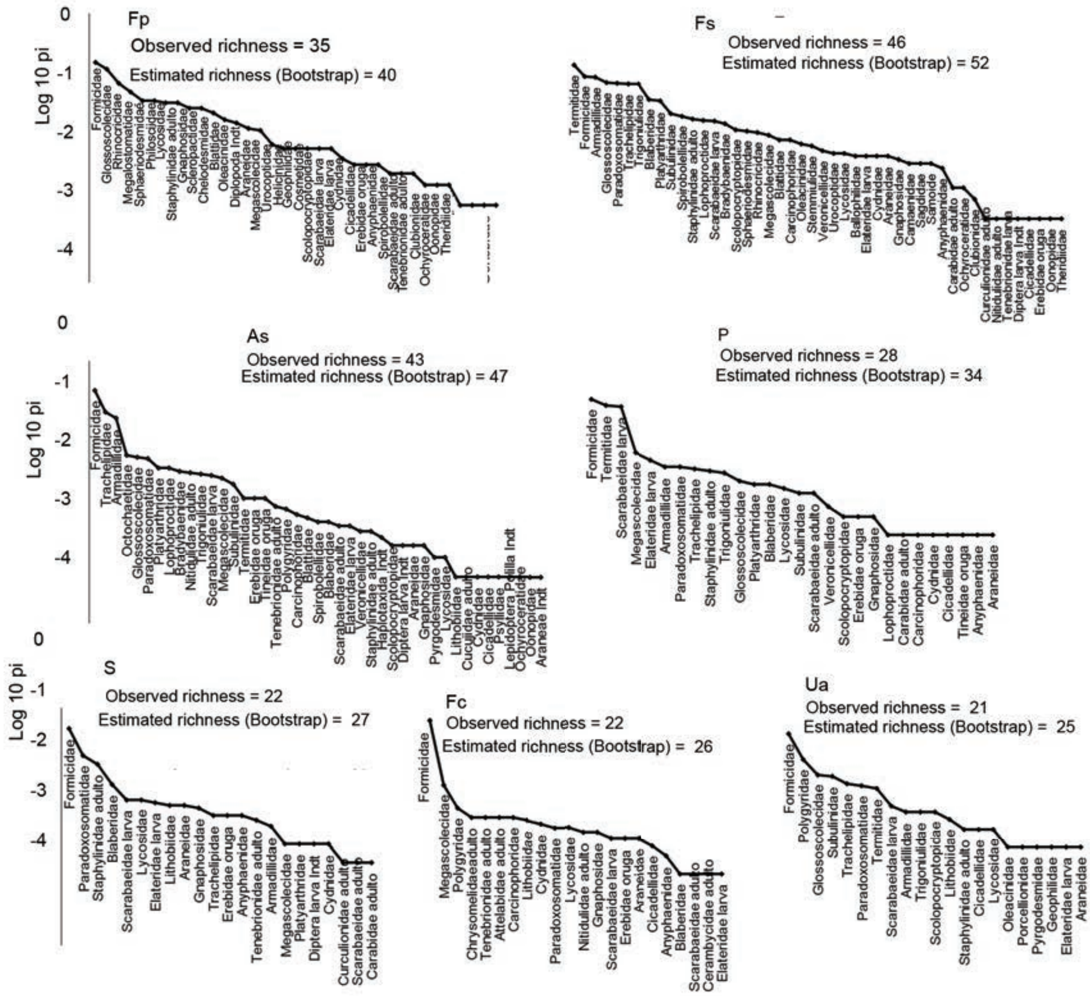
**Macrofauna richness and dominance**. In the range/abundance curves for the richness observed and estimated by Bootstrap, a higher richness of macrofauna families was found in the systems that provide higher cover for the soil, such as: primary forests (Fp),

Table 1. Description of the land use systems

| Land use system | Symbology or acronym | Replicas per system | Location | Characteristics |
|---|---|---|---|---|
| Primary forests | Fp | 2 | Biosphere reserve Sierra del Rosario, Artemisa | Vegetation of tropical evergreen medium forest, approximate height of 450 masl. In natural conservation status. |
| Secondary forests | Fs | 3 | Red plain, Mayabeque | Secondary vegetation of semideciduous forest. In natural regeneration and semi-conservation status. |
| Agroforestry systems | As | 2 | Artemisa and Mayabeque | Silvopastoral systems of leucaena, with more than 15 years of establishment and under grazing conditions. In a moderate status of anthropic intervention. |
| Pasturelands | P | 3 | Red Plain, Artemisa and Mayabeque | Naturalized systems of Guinea grass and star grass, with more than 20 years of exploitation and under grazing. In a moderate status of anthropic intervention. |
| Sugarcane plantations | S | 3 | Red Plain, Artemisa and Mayabeque | With more than 20 years of exploitation and chemical fertilization. In an intense status of anthropic intervention. |
| Food crops | Fc | 3 | Red Plain, Artemisa and Mayabeque | Main crop of potato, with more than 10 years of exploitations, use of machinery and chemical fertilization. In an intense status of anthropic intervention. |
| Urban agroecosystems | Ua | 2 | Boyeros municipality, Havana | Intensive vegetable gardens, with chard crop and rotation of other crops, with organic fertilization. In an intense anthropic intervention status. |

secondary forests (Fs) and Agroforestry systems (As); compared with those that have higher disturbing effect on the soil, in this case: pasturelands (P), sugarcane plantations (S), food crops (Fc) and urban agroecosystems (Ua). These curves also showed that the dominant family of the macrofauna was Formicidae (ants) in most of the land use systems. Nevertheless, in the systems Fp, Fs, As and P such group prevailed with similar abundance along with detritivore families, for example: Termitidae (termites), Glossoscolecidae (earthworms), Armadillidae and Trachelipidae (cochinillas); while in the systems S, Fc and Ua their predominance was more marked (fig. 1)

**Abundance of the macrofauna and its functional groups**. The statistical analysis of the average abundance of the total macrofauna showed differences among the land use systems. A significant effect was also found among the systems for the abundance of all the functional groups, although it is valid to state that there was higher dissimilarity for detritivores and predators and lower for the herbivores and omnivores (table 2).




Fp: primary forests, Fs: secondary forests, As: Agroforestry systems, P: pasturelands, S: Sugarcane plantations, Fc: food crops, Ua: Urban agroecosystems, Indt: undetermined family.

Figure 1. Range/abundance curves of the soil macrofauna, with the family richness observed and estimated through Bootstrap.

Table 2. Abundance of the soil macrofauna (mean ± SE) in the different land use systems.

| Land use system | Total macrofauna | Detritivores | Herbivores | Omnivores | Predators |
|---|---|---|---|---|---|
| Fp | 359 ± 102,3$^{b}$ | 213 ± 64,2$^{b}$ | 8 ± 3,0$^{b}$ | 67 ± 27,1$^{c}$ | 71 ± 8,0$^{a}$ |
| Fs | 523,6 ± 140,4$^{b}$ | 414 ± 137,2$^{ab}$ | 14,3 ± 2,9$^{b}$ | 49,3 ± 23,1$^{c}$ | 46 ± 10,7$^{ab}$ |
| As | 978 ± 99,6$^{a}$ | 574,5 ± 115,9$^{a}$ | 39,5 ± 22,5$^{a}$ | 351 ± 16,4$^{a}$ | 13 ± 10,0$^{c}$ |
| P | 216,3 ± 88,2$^{c}$ | 86,3 ± 30,5$^{c}$ | 51 ± 18,5$^{a}$ | 64,6 ± 52,9$^{c}$ | 14,3 ± 3,2$^{c}$ |
| S | 133 ± 34,3$^{c}$ | 34,3 ± 31,8$^{c}$ | 7 ± 3,2$^{b}$ | 59 ± 44,0$^{c}$ | 32,6 ± 7,3$^{b}$ |
| Fc | 176,3 ± 10,7$^{c}$ | 25 ± 3,2$^{c}$ | 12,6 ± 5,5$^{b}$ | 130 ± 4,0$^{b}$ | 8,6 ± 0,3$^{c}$ |
| Au | 106,5 ± 44,6$^{c}$ | 53,5 ± 38,6$^{c}$ | 3,5 ± 0,5$^{c}$ | 42 ± 3,0$^{c}$ | 7,5 ± 2,5$^{c}$ |
| ANOSIM (R) | 0,27*** | 0,35*** | 0,15*** | 0,16*** | 0,23*** |

Means with different letters significantly differ ($p < 0,05$) by the Bonferroni correction test.
Values of the statistical *R* of ANOSIM and its significance level at $p < 0,0001$).

The macrofauna abundance was higher in As, followed by Fs and Fp. The lowest values were found in the other four land use systems studied. The high macrofauna abundance in As was determined by the high values derived from the number of detritivore and omnivore individuals. The latter were represented entirely by ants in all the land use systems. Equally in Fs and Fp there was higher representativeness of detritivores in the first place, followed by omnivores and predators with close abundance between them. In the case of P, detritivores, herbivores and omnivores stood out almost in equal magnitude. In the other land use systems mainly omnivores prevailed, although in Ua detritivores predominated with very little difference (table 2).

**Macrofauna indicators**. The application of the relations between the detritivore and non-detritivore macrofauna (herbivores + omnivores + predators), and particularly between the detritivore group of earthworms and the omnivore group of ants, showed a high abundance of detritivore individuals and of earthworms; as well as values of the indicators close to or higher than 1 in the ecosystems with tree influence and higher protection on the soil, especially in Fp and Fs, with regards to the other systems of herbaceous and cultivated vegetation which had different disturbance levels, such as P, S, Fc and Ua (fig. 2A and 2B). Only for the indicator earthworms/ants in the land use system As, which showed tree cover like forests but were subject to moderate anthropic intervention due to the practice of silvopastoral systems, a more stressed difference was observed between ants and earthworms, with dominance of the former, which was shown in a value of the relation below 1 and close to 0 (fig. 2B).

## Discussion

The highest values of richness and total abundance of the macrofauna, as well as the predominance of detritivore groups in the forests and in the agroforestry systems, responded to the higher diversity of resources provided by these ecosystems, for example: shadeand protection for the soil, high soil humidity, low temperatures, contribution of litter and detritus, whose elements contribute to the subsistence of the soil fauna. Mainly in the secondary forests of natural regeneration, where the characteristics of the primary or original vegetation are being recovered, the colonization of the exotic and native fauna occurs (Pashanasi, 2001); which maybe explains the higher quantity of macrofauna associated to these forests with regards to the one found in the most preserved forests or those defined as primary ones. The other land use systems did not favor the development of the macrofauna communities, due to the grazing and trampling by the animals and to the intense tillage (through machinery and chemical fertilization), which is translated into higher edaphic degradation and loss of the biological quality of the soil. Only urban agroecosystems, in spite of being under constant tillage, were different from the above-mentioned characteristics, because in them organic fertilization, crop associations and other agroecological management were practiced. The macrofauna in this type of system was mainly represented by detritivore organisms, which were favored by the above-referred practices.

Worldwide there are similar data to the ones obtained in this work, such as those reported by: Negrete-Yankelevich *et al.* (2007), for primary and secondary forests in the Mexican cloudy mountains; Rossi *et al.* (2010), for agroecosystems in

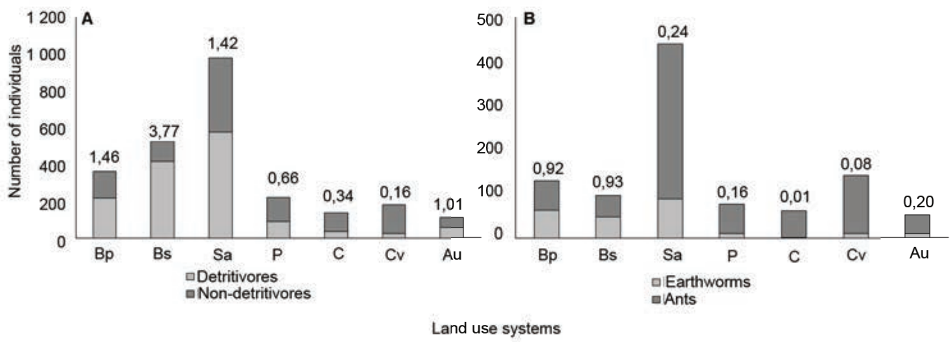



Figure 2. Number of individuals of detritivores/non-detritivores (A) and of earthworm/ants (B), as indicators of the macrofauna. (The values over the bars, in each land use system, are the result of the division between the numerators and denominators of the relations).

French Guyana; Bao-Ming *et al.* (2012), for urban spaces in China; Velásquez *et al.* (2012) and Moura *et al.* (2015), for pasturelands of the Brazilian Amazonia which were integrated by different species, among them *Leucaena leucocephala*; Vasconcellos *et al.* (2013), for semideciduous forests of Brazil with different ages; Rosseau *et al.* (2013), who studied different crops, agroforestry systems and secondary forests of Central America; Durán-Batista and Suárez-Salazar (2013) and Suárez-Salazar *et al.* (2015), who evaluated the effect of different agroforestry arrangements in the Colombian Amazonia; Siqueira *et al.* (2016), who compared sugarcane monocrop with different types of natural vegetation in the Pernambuco state in Brazil; and Chávez-Suárez *et al.* (2016), who started studies in livestock production mountain ecosystems in the eastern part of Cuba. In general, these authors found variation in the macrofauna communities, such as the disappearance and substitution of its native composition and the drastic decrease of its taxonomic richness and abundance, due to the influence of the loss of tree cover and of the conversion of natural ecosystems to plantations and cropping systems.

Regarding the proposed macrofauna indicators, it is stated that when there is high and even higher abundance of detritivore organisms or of earthworms, and a lower representation of non-detritivore individuals or specifically of ants, the systems could have little or no alteration in the edaphic environment and a possible favorable fertility status, as shown in this study mainly in the forests. In that sense, the systems with these characteristics will show values close to 1 or higher, as a result of the division between the numerator and the denominator of the relations. However, an inverse result, with predominance of non-detritivore organisms and ants, could indicate systems or practices with negative impact on the physical, chemical and biological properties of the soil and, thus, on its quality, which occurred in the pasturelands and the other intensive and unfavorably managed agricultural systems. In these cases the values of the relations were found below 1 and close to 0.

The abundance and representation indicators would be the two variants of higher contrast, for which the above-described results could not always be obtained. The indicators are proposed as a useful and fast tool to infer about a possible health status of the soil, make its primary evaluation and continue monitoring its quality. Their proposal is originated from the results of this work and, in general, the ones reached in the country and also in the world; which show the damage caused on the detritivore fauna and the earthworms, essentially generated by the decrease or lack of plant cover and litter contribution, the deep tillage in the soil and the use of chemical products, as well as by the unsuitable conditions of humidity, temperature and organic matter content in the edaphic medium. Instead, other groups, such as ants, are maintained, withstand and proliferate in the presence of these and other disturbance situations.

Zerbino *et al.* (2008) and Pinzón *et al.* (2015) obtained higher abundance of the functional group detritivores in systems of the humid tropic where conservation agriculture methods were used and in other more preserved ecosystems, and of the predator group where the soil use was more intensive. Other authors found affectations in the richness, density and biomass of earthworms in systems with higher management intensity (Feijoo *et al*., 2007; Botina *et al*., 2012; Bartz *et al*., 2013).

In the case of ants, there are different reports that support their possible use as soil disturbance indicator or which define them as indicators of the habitat quality (Chanatásig-Vaca *et al*., 2011; Crepaldi *et al*., 2014). The results of this study, as mentioned above, exemplify the prevalence and resistance of ants in degraded systems, especially of invasive species such as *Wasmannia auropunctata* (electric ant), *Nylanderia fulva* and *Solenopsis geminata* (fire ant).

Velásquez (2004) cited the fire ant among the species that suggested disturbances in ecosystems of Colombia and Nicaragua, while Chanatásig-Vaca *et al.* (2011) recommended this insect to be used in environmental monitoring. These last authors obtained a high density of ants in monocrop in Mexico, especially of *S. geminata*, which is explained by its tolerance to open environments with lower resource availability, exposed to the sun and with conventional management of application o agrochemicals and mechanical tillage.

A similar relation to that of earthworms/ants was previously taken into consideration to evaluate the alteration degree in the ecosystems, but with the use of termites instead of ants (Barros et al., 2002; Lavelle et al., 2003). Nevertheless, this relation had little application because both taxa –earthworms and termites– suffer variations from the fragmentation, isolation and degradation of habitats (Cabrera-Dávila, 2012).

On the other hand, the use of ants could be limited due to the social conduct of these insects, whose colonies are formed by thousands of individuals. However, in specialized literature it is stated that ants can be evaluated similarly to other macrofauna groups which do not have gregarious behavior, if the field collection protocol is sufficiently robust, with the adequate replicas of different land use systems and equal effort sampling in each one of them. These use replicas are defined as strata in a stratified design, which is appropriate to study the bioindicator value of the macrofauna (Huising *et al*., 2011).

The importance of the integrated study of the physical, chemical and biological properties to explain the soils status is acknowledged, although it is necessary to state that using biological indicators instead of physical and chemical measurements is advantageous because they are the first to show the changes implied by the medium disturbances; besides, they require few resources and lower cost. In that sense, the proposal of the macrofauna indicators is made, to help monitoring the evolution of soil quality, in a fast and practical way, through groups which can be easily recognized and determined, by the professional and technical staff as well as by the farmers in any soil type and crop system. Particularly, the determination of the earthworms/ants relation requires less specialized knowledge, because the involved taxa are more easily and directly identified, mainly among technicians and farmers.

## Conclusions

The taxonomic richness as well as the abundance of the soil macrofauna decreased in the face of a sustained disturbance of the edaphic medium, caused by a high degree of anthropization and higher intensity in the soil use and management. The disturbance and use intensity mainly influenced the detritivore macrofauna. The value of the macrofauna to diagnose the soil health status was shown and for that purpose fauna indicators were suggested, which consist in the relations between the abundance of different easily evaluated macrofauna groups (detritivores/non-detritivores and earthworms/ants). Likewise, the application of these indicators in different soil types and land use systems in Cuba is recommended. The generalization will contribute to their testing and validation.

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