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Morphological Diversity of Coleoptera (Arthropoda: Insecta) in Agriculture and Forest Systems

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ABSTRACT: Coleopterans (Coleoptera) are major ecosystem service providers. However ecomorphological features that are comparable in a wide range of invertebrates within this group and in various environments must be found, to be able to study regions with different species, contributing to overcome difficulties of the taxonomic approach and understand the functioning of ecosystems. This research addressed the diversity of Coleoptera, using a methodology of ecomorphological traits, as well as their relation with the land use systems (LUS) and the soil properties. The following LUS were evaluated: no-tillage (NT), crop-livestock integration (CLI), pasture (PA), *Eucalyptus* stands (EST), and native forest (NF). Samples were collected using a 3 × 3 point grid (sampling points at a distance of 30 m), in winter and summer, in three municipalities on the Southern Santa Catarina Plateau, Brazil. Coleopterans were collected using the methodology recommended by the Tropical Soil Biology and Fertility Program, based on the excavation of soil monoliths, and on pitfall traps. To evaluate the biological forms (morphotypes) and ecomorphological groups, the ecomorphological index (EMI) methodology was adopted and the modified soil biological quality (SBQ) index was determined. At the same points, samples were collected to evaluate environmental variables (soil physical, chemical, and microbiological properties). Density data underwent nonparametric univariate statistical analysis and multivariate abundance to verify the distribution of coleopterans in the LUS, and the environmental variables were considered as explanatory. Regardless of the LUS, 14 morphotypes were identified, and adult coleopterans with epigean morphologic adaptations were more abundant than hemi-edaphic and edaphic coleopterans, respectively. Morphotype diversity was higher in the systems NF, EST, and PA in summer and in NT in winter. The reductions in SBQ index were not associated with a gradient of land use intensification (NF> EST> PA> CLI> NT), and the index was higher for NF and lower for EST. Principal component analysis (PCA) indicated a different distribution of invertebrates between the LUS. For the edaphic species, better adapted to life in the soil, a relation with NT and CLI was observed, due to more favorable pH values and phosphorus content. In the NF, a greater amount of morphotypes was identified, and the properties related to soil carbon dynamics contributed to explain this distribution. Separation at the morphotype level, taking adaptation level to soil life into consideration, has proved efficient to discriminate the LUS, mainly along with other explanatory environmental variables.

Keywords: ecomorphological traits, edaphic biodiversity, morphotypes, soil biological quality.

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INTRODUCTION

Coleopterans (Coleoptera), along with other faunal components, microorganisms, and plant roots, make up the soil biological system and act in chemical, physical, and biological processes (Bardgett and Van Der Putten, 2014). These invertebrates can be found in almost all environments and at various soil depths. They perform important functions in this system; some of them act in the decomposition of excreta and waste of animal and vegetal origin (Yamada et al., 2007) and soil aeration and organic matter transport (Almeida and Louzada, 2009) and others in the biological control of insect pests and weeds (Lee and Albajes, 2016). Some even contribute to increase plant growth, due to their activity of incorporating manure into the soil (Scarabaeinae) (Nichols et al., 2008).

Anthropogenic changes influence both coleopterans and the rest of the biota, directly or indirectly and at various levels and intensities, e.g., by the use of agrochemicals, intensive soil rotation, and especially changes in plant composition (Baretta et al., 2014; Lee and Albajes, 2016). As groups of soil Coleoptera affect the ecosystem functionality in many ways, these insects can respond immediately to ongoing changes in the habitat and thus indicate environmental conditions on and in the soil, as well as soil balance or disturbance levels, mainly related to management practices in agriculture and forest areas (Portilho et al., 2011; Gibb et al., 2017).

Many studies on sensitivity of the Coleoptera groups to various environmental disturbance levels have already been conducted (Pompeo et al., 2016; Renkema et al., 2016; Gibb et al., 2017; Magura, 2017). Along with these and other research published in recent years, major discoveries about these insects were made, but almost 2/3 of the species await formal description, and researchers using only taxonomic analysis often focus on the ecology of a little known species of insect families (Fountain-Jones et al., 2015). Because of these difficulties resulting from the lack of taxonomic knowledge, an approach based on traits (related with Coleoptera behavior and their relation with the environment) may be used as an alternative, with promising possibilities to deepen the understanding of the functional role of coleopterans in ecosystems as well as on the effects of habitat changes on the community (Pey et al., 2014; Fountain-Jones et al., 2015; Mickaël et al., 2015).

Many morphological traits may be evaluated and used as tools contributing to understand the functions of coleopterans in the environment, e.g., longer body length and darker coloring, related to a higher level of forest cover (Vandewalle et al., 2010). These are considered effect-and-response traits, because insect size is linked to dispersion capacity and fecundity, and coloring to protection against predators and temperature maintenance. In turn, traits such as antenna length and shape are linked to habitat preference and hunting ability (Talarico et al., 2007).

A relevant methodology to study soil microarthropods, including the Coleoptera group, was proposed by Parisi (2001). The author suggested the creation of an index based on the following concept: the higher the soil quality, the larger the number of well-adapted microarthropod groups. Thus, organisms are separated according to their ecomorphological traits and life forms, in order to evaluate their adaptation level to soil life and to overcome the limitations of taxonomic analyses (Parisi et al., 2005). The index was designed with a view to encompass all soil faunal groups (Parisi, 2001; Parisi et al., 2005; Vandewalle et al., 2010; Mohamedova and Lecheva, 2013), but other studies have already adapted and used this methodology to study a specific group of edaphic invertebrates, e.g., springtails (Machado, 2015; Oliveira Filho et al., 2016; Silva et al., 2016), with promising results.

Coleopterans can be separated into three different adaptation levels to soil life. The edaphic group maintains a lifelong direct contact with the soil, the hemi-edaphic group has intermediate life forms, and the epigean group lives on the soil surface, closer to plant litter (Parisi et al., 2005). Many studies in Brazil have evaluated the responses of Coleoptera groups to environmental changes (Rodrigues et al., 2013; De Farias et al., 2015; França et al., 2016). However, none of the above provided an ecomorphological characterization of coleopterans using the methodology adapted from Parisi et al. (2005) and/or analyzed the influence of the soil physical, chemical, and microbiological properties on the distribution, especially involving different land use systems (LUS), issues addressed in this research.

The following hypothesis have been made: i) land use and management systems may interfere with the density and abundance of Coleoptera individuals and the structural diversity of biological forms (morphotypes); ii) environmental variables (soil chemical, physical, and microbiological properties) may help explain the diversity of Coleoptera morphotypes; iii) land use types influence the ecomorphological groups, the occurrence of traits linked to life forms and soil biological quality (SBQ). Therefore, this study tested these hypothesis using a new methodology of ecomorphological Coleoptera traits in forest and agriculture systems on the Southern Santa Catarina Plateau, Brazil (native forest, *Eucalyptus* stands, pasture, crop-livestock integration, and no-tillage cultivation) and determine in which of these use types the SBQ is the highest.

MATERIALS AND METHODS

Study sites

This study was conducted in the municipalities of Lages, Campo Belo do Sul, and Otacílio Costa, Santa Catarina, Brazil, located on the Southern Santa Catarina Plateau, a region characterized, according to Köppen's climate classification system, as subtropical humid, with an oceanic climate (Cfb), with no dry season, with well-distributed rainfall and average temperature in the warmest month below 22 °C, with mild summers (Alvares et al., 2013). The annual rainfall ranges from 1,600 to 1,900 mm, with severe and frequent frosts.

Due to the complexity of geological formation and climatic action, there is a diversity of soil types in this region; however, most of them are characterized by medium depth, with low to medium natural fertility (Santos et al., 2006). The soils studied in Lages and Campo Belo do Sul were classified as *Nitossolo Bruno* (Humic Kandiudox) and those in Otacílio Costa as *Cambissolo Húmico* (Humic Dystrudept) (Rosa et al., 2015).

The land use systems (LUS) studied, representative for each location, covering the three analyzed municipalities, were ordered according to a gradient of anthropic intervention, namely: native forest (NF), *Eucalyptus* stands (EST), perennial pasture (PA), crop-livestock integration (CLI), and no-tillage (NT). The municipalities were selected according to their geographic properties, soil types, and management history and they are considered true replicates of the studied systems. Information on LUS properties and history is displayed in table 1, and further information was provided by Bartz et al. (2014a) and Rosa et al. (2015).

Sampling and ecomorphological characterization of Coleoptera

Samples were collected in a winter (June and July 2011) and a summer season (December 2011 and January 2012). Samples were collected using a 3 × 3 point grid, with sampling points at a distance of 30 m from each other and surrounded by a 20-m border, covering 1 ha for each LUS (Rosa et al., 2015; Oliveira Filho et al., 2016). A total of 270 points were sampled, consisting of nine points in five land use systems in three municipalities, in the two study periods.

For the evaluation of edaphic coleopterans, two sampling methods were used, one based on tropical soil biology and fertility (TSBF) (Anderson and Ingram, 1993), which is quantitative and consists of collecting soil monoliths (0.25 × 0.25 m wide and 0.20 m deep), using a sampler made of galvanized iron plates. The other method was that of pitfall traps, consisting of 500 mL cylindrical containers (diameter 8 cm), containing 200 mL of 0.5 % detergent solution (v/v), inserted in the soil so that their perforated lid

Table 1. Land use characteristics and history of native forest (NF), *Eucalyptus* stands (EST), perennial pasture (PA), crop-livestock integration (CLI), and no-tillage (NT) areas on the Southern Santa Catarina Plateau. Adapted from Bartz et al. (2014a) and Rosa et al. (2015)

System	Size	Coordinates	Altitude	Age	Vegetation and management history
	ha		m	year	
			Lages		
NF	100	S 27° 47.963’ W 50° 35.743’	895	-	Secondary Atlantic Forest, with well-established vegetation; entrance of cattle and people.
EST	29	S 27° 47.752’ W 50° 36.069’	852	7	*Eucalyptus benthamii* Maiden and Cambage; formerly native grassland; entrance of cattle.
PA	100	S 27° 47.873’ W 50° 36.000’	858	15	Montane grassland, native vegetation; stocking rate from 0.4 to 1.5 cattle per ha.
CLI	10	S 27° 47.544’ W 50° 35.802’	873	10	No-tillage and crop rotation; soybean (*Glycine max* L.), maize (*Zea mays* L.), ryegrass (*Lolium multiflorum* L.), oats (*Avena strigosa* Schreb), and pasture. With fertilization, liming and applications of herbicides, insecticides and fungicides.
NT	7	S 27° 47.123’ W 50° 35.972’	883	7	No-tillage; soybean, maize, ryegrass, and oats. Fertilization, liming, and use of agrochemicals.
			Campo Belo do Sul		
NF	5	S 27° 52.943’ W 50° 39.338’	1.016	-	Secondary Atlantic Forest, with well-established vegetation; entrance of cattle and people.
EST	1.2	S 27° 53.363’ W 50° 39.056’	989	20	*Eucalyptus dunnii* Maiden; formerly native grassland; entrance of cattle.
PA	30	S 27° 52.130’ W 50° 39.175’	1.004	12	Montane grassland, native vegetation; with controlled burning every two years.
CLI	25	S 27° 52.131’ W 50° 39.980’	947	25	No-tillage and crop rotation; soybean, maize, wheat (*Triticum aestivum* L.), oats or pasture. With fertilization, liming, and use of agrochemicals.
NT	55	S 27° 52.365’ W 50° 40.366’	923	11	No-tillage and crop rotation; soybean, maize, wheat, and fallow. Fertilization, liming, and use of agrochemicals.
			Otacílio Costa		
NF	3	S 27° 35.674’ W 49° 50.927’	919	-	Secondary Atlantic Forest, with well-established vegetation; entrance of cattle and people.
EST	2.4	S 27° 33.446’ W 49° 56.879’	855	21	*Eucalyptus* sp.; planted after previous pine stands.
PA	10	S 27° 37.151’ W 49° 51.461’	900	-	Montane grassland, native vegetation; with controlled burning every year.
CLI	22	S 27° 37.110’ W 49° 51.418’	902	11	No-tillage and crop rotation; soybean, maize, ryegrass, wheat, or pasture. With fertilization, liming, and use of agrochemicals.
NT	80	S 27° 29.063’ W 49° 54.215’	879	10	No-tillage; soybean, maize, and fallow. Fertilization, liming, and use of agrochemicals.

was even with soil surface, maintained in the field for three days (Baretta et al., 2014). Samples collected by both methods were screened and all organisms of the Coleoptera order were separated and preserved in 80 % alcohol.

Morphotype identification and counting were performed by means of a magnifying glass (stereoscopic microscope at 40 × magnification) coupled with a camera. In this study, morphotyping consisted of an analysis of ecomorphological traits. The ecomorphological index (EMI) value was evaluated (Parisi, 2001; Parisi et al., 2005; Vandewalle et al., 2010), a methodology to separate organisms according to their degree of soil adaptation, observing specific traits. To this end, the morphotypes were evaluated first, i.e., four traits of each coleopteran were recorded, namely: body length longer or shorter than 2 mm, thin or stiff integument, reduced or absent membranous wings, and reduced/absent or normal insect eyes (Table 2). These traits are related to ecosystem functions and adaptations to edaphic life depend particularly on them, i.e. if a coleopteran is highly adapted to live in the soil, it will probably be small and have lower dispersion, without big eyes or long membranous wings (used for flying). A morphotype was assigned to each different combination of characteristics (Table 3), with a final EMI value corresponding to the sum of the four assessed characteristics ranging from 1 to 20. After identifying the morphotypes and defining the total EMI values, the morphotypes were classified into three ecomorphological groups: edaphic (inhabiting the soil, low dispersion power, and well-adapted to soil), whose morphotypes show values ranging from 15 to 20 (Ed); hemi-edaphic (intermediate), with value of 10 (H); and epigean (inhabiting the surface - plant litter, least adapted to soil, with high dispersion power), with values ranging from 1 to 5 (Ep). Thus, it may be inferred that a high EMI value corresponds to mostly edaphic and a low value to mostly epigean organisms.

Soil sampling for evaluating chemical, physical, and microbiological properties

For soil chemical and microbiological analysis, 15 subsamples were collected around each point of the sampling grid in the 0.00-0.20 m layer, to constitute a representative composite sample. Undisturbed soil samples for physical analyses were removed with steel cylinders (5 cm high, 5 cm diameter).

Table 2. Trait and score used to calculate the EMI value (ecomorphological index) for the discrimination of various Coleoptera morphotypes

Trait(1)	Codification	Partial EMI value
Size (length)	Shorter than 2 mm Longer than 2 mm	5 0
Integument	Thin Stiff/hard	5 0
Membranous wings	Reduced or absent Long	5 0
Eyes	Reduced or absent Large - greater than ¼ of the head	5 0

(1) Adapted from Parisi et al. (2005).

Table 3. Classification pattern of the categories of morphological Coleoptera traits

Partial value of the ecomorphological index (EMI)				Final EMI	Ecomorphological group	Morphotype
Size	Integument	Membranous wings	Eyes			
0	0	0	0	1*	Epigean	Ep5
0	0	0	5	5	Epigean	Ep4
0	0	5	0	5	Epigean	Ep3
0	5	0	0	5	Epigean	Ep2
5	0	0	0	5	Epigean	Ep1
0	5	0	5	10	Hemi-edaphic	H6
0	5	5	0	10	Hemi-edaphic	H5
0	0	5	5	10	Hemi-edaphic	H4
5	0	0	5	10	Hemi-edaphic	H3
5	0	5	0	10	Hemi-edaphic	H2
5	5	0	0	10	Hemi-edaphic	H1
0	5	5	5	15	Edaphic	Ed5
5	0	5	5	15	Edaphic	Ed4
5	5	0	5	15	Edaphic	Ed3
5	5	5	0	15	Edaphic	Ed2
5	5	5	5	20	Edaphic	Ed1

*Clearly epigean life form (no traits of edaphic adaptation).

The chemical properties (pH in water, Ca^{2+}, Mg^{2+}, Al^{3+}, P, K, organic matter (OM), and potential acidity (H+Al)) were evaluated by the methodology proposed by Tedesco et al. (1995). Soil volumetric water content (Vwc) was determined in the laboratory by oven-drying at 105 °C for 24 h (Claessen, 1997). Soil bulk density (BD) and total porosity (TP) were evaluated for physical analyses with undisturbed samples, according to a manual proposed by Claessen (1997) (Table 4).

The analysis of properties linked to soil carbon dynamics, microbial biomass carbon (MicC) was determined by the fumigation-extraction method (Vance et al., 1987). Total organic carbon (TOC) and particulate organic carbon (POC) (Cambardella and Elliot, 1992) were determined by dry combustion by a Vario EL cube CHNS elemental analyzer. From the

Table 4. Soil chemical, physical, and microbiological properties in the 0.00-0.20 m layer, in native forest (NF), *Eucalyptus* stands (EST), perennial pasture (PA), crop-livestock integration (CLI), and no-tillage (NT) systems on the Southern Santa Catarina Plateau

Soil property	**Land use systems**				
	NF	**EST**	**PA**	**CLI**	**NT**
			Winter		
pH(H_2O)	4.4	4.6	4.7	5.3	5.6
P (mg dm^{-3})	4.3	3.9	3.6	8.7	5.8
K (mg dm^{-3})	112	84	190	135	128
Ca^{2+} (cmol$_c$ dm^{-3})	5.2	2.0	2.1	7.2	7.5
Mg^{2+} (cmol$_c$ dm^{-3})	1.7	1.8	1.4	3.8	3.8
OM (dag kg^{-1})	6.2	4.4	5.3	4.7	4.5
Al^{3+} (cmol$_c$ dm^{-3})	3.9	2.8	3.0	0.5	0.1
H+Al (cmol$_c$ dm^{-3})	20.8	17.0	17.5	6.2	4.9
Vwc (%) (v/v)	58	42	51	40	40
BD (g cm^{-3})	0.89	0.98	0.95	1.01	1.01
TP (m^3 m^{-3})	0.65	0.65	0.66	0.65	0.65
MicC (µg C g^{-1})	577	394	544	284	280
Mic*q* (%)	1.06	1.15	1.34	0.80	0.80
TOC (g kg^{-1})	57	35	41	37	36
POC (g kg^{-1})	4.55	3.12	3.51	2.42	1.71
			Summer		
pH(H_2O)	4.4	4.6	4.7	5.3	5.6
P (mg dm^{-3})	4.3	3.9	3.6	8.7	5.8
K (mg dm^{-3})	112	84	190	135	128
Ca^{2+} (cmol$_c$ dm^{-3})	5.2	2.0	2.1	7.2	7.5
Mg^{2+} (cmol$_c$ dm^{-3})	1.7	1.8	1.4	3.8	3.8
OM (dag kg^{-1})	6.2	4.4	5.3	4.7	4.5
Al^{3+} (cmol$_c$ dm^{-3})	3.9	2.8	3.0	0.5	0.1
H+Al (cmol$_c$ dm^{-3})	20.8	17.0	17.5	6.2	4.9
Vwc (%) (v/v)	55	36	41	32	35
BD (g cm^{-3})	0.89	0.98	0.95	1.01	1.01
TP (m^3 m^{-3})	0.65	0.65	0.66	0.65	0.65
MicC (µg C g^{-1})	382	244	424	185	199
Mic*q* (%)	0.57	0.60	0.88	0.49	0.52
TOC (g kg^{-1})	69	43	49	40	39
POC (g kg^{-1})	4.55	3.12	3.51	2.42	1.71

Average repetitions (n = 27). pH in water at a ratio of 1:2.5 v/v; K and P extracted by Mehlich-1 solution; OM determined by Walkley-Black method; Al^{3+}, Ca^{2+}, and Mg^{2+} were extracted by 1 mol L^{-1} KCl; H+Al: potential acidity extracted with calcium acetate 0.5 mol L^{-1}; Vwc: soil volumetric water content; BD: soil bulk density determined by volumetric ring method; TP: total porosity determined by the relation between BD and particle density - volumetric flask method; MicC: microbial biomass carbon (fumigation-extraction method); Mic*q*: microbial quotient (Relation between MicC and TOC); TOC (total organic carbon) and POC (particulate organic carbon) (Dry combustion by the elementar equipment - Vario EL Cube).

MicC and TOC results, the microbial quotient (Mic*q*) expressed as MicC percentage in relation to TOC was calculated (Anderson, 1994) (Table 4).

Data analysis

The analyses were performed at the LUS level, using the value for three municipalities (true replicates) (n = 3 × 9 points = 27) in the two seasons (winter and summer) analyzed separately. Evaluations of diversity and distribution of the Coleoptera morphotypes were carried out using the methods of sampling soil invertebrates together, i.e., total abundance of individuals at each point, since the two Coleoptera sampling methods used show limitations with regard to the representative capacity of all ecomorphological groups. Pitfall traps captured mobile coleopterans on soil surface and varied in size, covering the meso (100 µm - 2 mm) and macrofauna (>2 mm) (Swift et al., 1979). Soil monoliths, taken by the TSBF method, are used to collect the macrofauna and to collect the least mobile individuals, living deep in the soil. Considering these conditions, the traps cannot sample individuals with limited dispersion nor those that do not have an epigean habit, while by the second method the tiniest individuals may be overlooked during manual sorting, representing fundamental restrictions for distinguishing structural morphotypes. On the other hand, sampling by soil monoliths makes it possible to collect coleopterans in the larval phase. Therefore, the evaluation by both methods, has a complementary effect and reduces sampling limitations.

Density, abundance, and diversity of Coleoptera morphotypes

The abundance of Coleoptera individuals sampled by soil monoliths was converted into density of individuals per square meter (ind per m^2). These density values, as well as abundance of trap-sampled coleopterans (ind per trap) were compared between the LUS by non-parametric Kruskal-Wallis analysis at 5 % significance, using the statistical software *SPSS*, version 20 (SPSS IBM, 2011).

To check the similarity of morphotype abundances in each LUS and assess their diversity, the Pielou equability (J) and Shannon-Wiener diversity (H’) indices were calculated for the abundance data of Coleoptera morphotypes. These indices were calculated using R statistical software, with the VEGAN package (R Core Team, 2011).

Multivariate statistical analysis

Abundance values were subjected to detrended correspondence analysis (DCA), in order to determine the gradient length generated by the data matrix. As this length was <3, with linear response, we decided to perform principal component analysis (PCA) for each studied season (winter and summer), since season effects were detected ($p \leq 0.05$). Morphotype abundance was used as a response variable and soil chemical, physical, and microbiological properties as explanatory environmental variables in PCA. The collinear and significant explanatory variables were identified by redundancy analysis (RDA), removing the variables with collinearity and maintaining the significant ones ($p \leq 0.05$). Only the last variables selected by RDA were later used in PCA as passive explanatory environmental variables for changes observed in ecomorphological groups of Coleoptera. All multivariate statistical analyses were conducted using statistical software CANOCO, version 4.5 (ter Braak and Smilauer, 2002).

Soil biological quality and dominance of life form traits

From the EMI, the SBQ values were calculated according to Parisi (2001). In an attempt to take all soil fauna groups into consideration, Parisi et al. (2005) also generated EMI values for various edaphic organisms. In the case of organisms such as coleopterans, which may have more than one EMI value, the index value is determined by the highest EMI, i.e., the most adapted organisms determine the final index value for the group. In this study, an adaptation was used to calculate the SBQ index, based specifically on the Coleoptera group, where the EMI value was used, multiplied by abundance of coleopterans of this morphotype and adding the sum of this multiplication to all morphotypes of the LUS. In this way, a more comprehensive idea is obtained in terms of a scale of environmental adaptation and this information may be associated with various LUS, in a gradient of land use intensification.

In addition to the SBQ, the mT (mean value of the community trait) was calculated. The latter can be calculated for each morphotype trait as the average of these values in the community, weighted by the relative abundance of morphotypes for each value. This metric is often understood as the definition of the dominant functional attribute in a community or the proportion of a certain functional group (Vandewalle et al., 2010). Therefore, mT was calculated as an average value for a given morphotype divided by the abundance of organisms, weighed by the specific EMI value linked to the life form, considering actual participation in relation to the total number of coleopterans.

RESULTS

Coleoptera community structure

A total of 776 individuals were found by the trapping method and 665 individuals in the soil monoliths, totaling (traps + monoliths) 1,441 adult coleopterans. In the larval phase of Coleoptera, 764 individuals were sampled, 750 of which by the TSBF and 14 by the trap method.

The average densities of coleopterans in the winter and summer were 91.4 and 76.6 ind per m^2, respectively. Pairwise comparisons showed highest densities of Coleoptera in the winter in NF, CLI, and PA soil, and the lowest in EST and NT soil, when compared to NF (Figure 1a). In turn, the density in summer was low only in EST compared to NF (Figure 1b). Abundance values (ind per traps) were quite low in winter, not differing between the LUS. In the summer, the highest abundance occurred in NF (Figure 1b).

Adult coleopterans were distributed in 13 morphotypes, plus 1 morphotype related to the larval phase (Table 5), to which a significant participation of the group of hemi-edaphic organisms was attributed, according to the ecomorphological analysis adapted from Parisi et al. (2005). Among adults, the morphotypes Ep5, Ep2, H6, and Ed2 stood out as

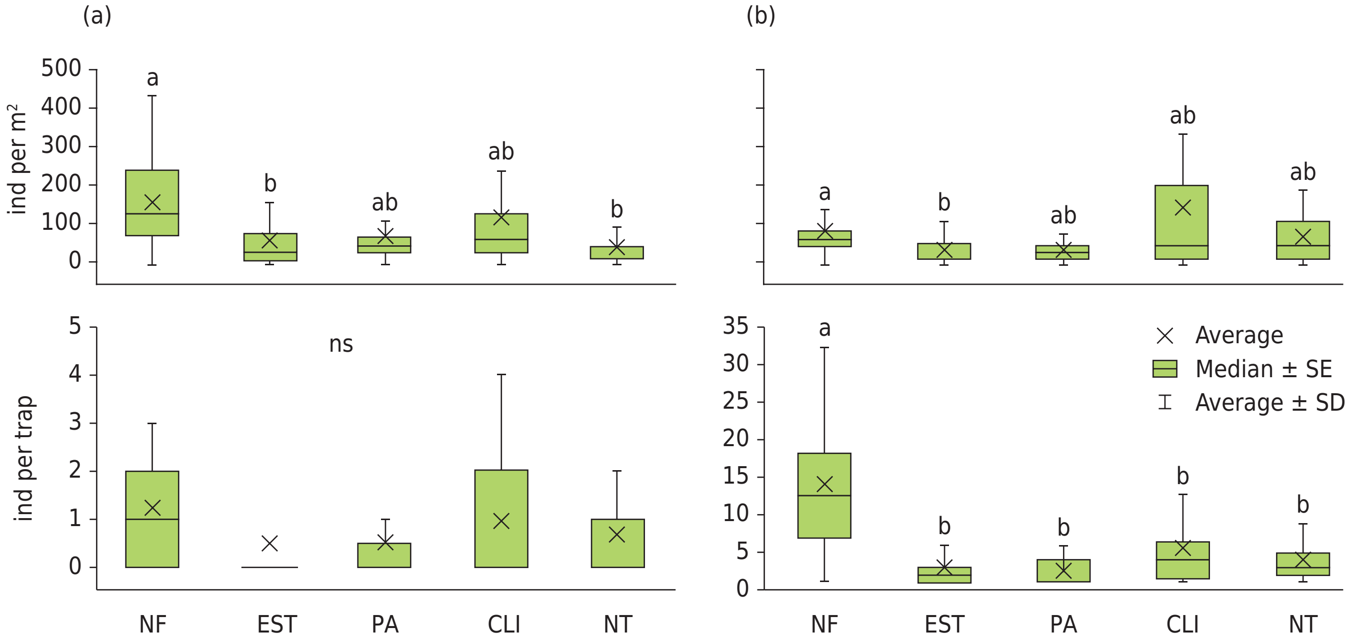

Figure 1. Coleoptera density (ind per m^2) and abundance (ind per trap) in native forest (NF), *Eucalyptus* stands (EST), perennial pasture (PA), crop-livestock integration (CLI), and no-tillage (NT) in winter (a) and summer (b) on the Southern Santa Catarina Plateau. Mean values followed by the same letter are similar by the Kruskal-Wallis test (p<0.05; n = 135); ns: non-significant difference.

Table 5. Abundance, richness, and Shannon-Wiener diversity (H') and Pielou equability indices (J) of Coleoptera morphotypes in native forest (NF), *Eucalyptus* stands (EST), perennial pasture (PA), crop-livestock integration (CLI), and no-tillage (NT) systems on the Southern Santa Catarina Plateau

Morphotypes	NF	EST	PA	CLI	NT	Total(1)	NF	EST	PA	CLI	NT	Total
	Winter						Summer					
Ed1	-	-	-	-	1	1	1	-	2	-	1	4
Ed2	2	1	-	2	7	12	84	5	11	3	12	115
Ed5	4	-	5	3	6	18	3	1	3	3	11	21
H1	7	1	5	2	6	21	8	9	4	3	13	37
H2	2	4	1	2	1	10	3	2	1	1	1	8
H4	4	-	2	1	-	7	3	-	1	1	-	5
H5	5	2	-	1	2	10	10	2	-	-	-	12
H6	24	-	22	23	2	71	11	3	9	40	1	64
H-larvae	160	65	66	121	27	439	69	34	27	154	41	325
Ep1	4	-	-	-	-	4	5	1	1	-	-	7
Ep2	24	11	7	15	7	64	133	16	19	16	43	227
Ep3	2	-	-	3	-	5	1	3	4	4	1	13
Ep4	29	6	7	4	2	48	10	4	7	-	-	21
Ep5	39	28	17	59	31	174	169	38	20	152	83	462
Abundance	306	118	132	236	92		510	118	109	377	207	
Richness	13	8	9	12	11		14	12	13	10	10	
Shannon-Wiener index	1.65	1.31	1.57	1.44	1.82		1.75	1.84	2.12	1.3	1.61	
Pielou index	0.62	0.49	0.59	0.54	0.69		0.66	0.7	0.8	0.49	0.61	

(1) Total of individuals by morphotype. Ed: edaphic; H: hemi-edaphic; Ep: epigean.

the most frequent in each ecomorphological group (epigean, hemi-edaphic, and edaphic). In turn, the least representative were the morphotypes Ep4, H1, Ed5, H5, Ep3, H2, H4, Ep1, and Ed1. The most abundant coleopterans were the epigean, where the morphotypes Ep2 and Ep5 were the most abundant in winter and summer (Table 5).

Regarding the results of Coleoptera diversity (Table 5) the values of H' and J indices was highest in NT in winter and PA in summer. In the three systems, NF, EST, and PA increased H' and J in summer, this pattern was not observed for CLI and NT, which showed reduction in these indices within the same period when compared to winter.

Principal component analysis

For Coleoptera morphotypes, sampled both in winter (Figure 2a) and in summer (Figure 2b), PCA showed a separation between the LUS, by relating the main components (PC) 1 and 2.

Observing the PCA results for winter (Figure 2a), data variability explained by PC1 was 27.2 % and 17.6 % by PC2. There was a distinction between the LUS, where Coleoptera morphotypes were more distributed in the FN and CLI systems, separating the others, PA, NT, and EST on the other side of the axis. In winter, edaphic morphotypes Ed2 and Ed5 obtained greater interaction with the CLI system, a relation that may be explained by better soil chemical properties, such as P and pH. In turn, most of the hemi-edaphic species, including larvae, were more abundant in NF due to higher values of TP, Vwc, OM, POC, and Al properties.

In summer (Figure 2b), the PCA results show that data variation was 24.1 % in PC1 and 19.4 % in PC2. Again, NF stands out with most Coleoptera morphotypes. The variables OM, Vwc, and TOC contributed most to explain this distribution. In turn, in the other systems, some morphotypes were arranged farther away from each other, a factor that may be explained by the participation of the variable Hi (hydrogen) positioned between NF and NT, along with the edaphic and hemi-edaphic groups. There was also a higher abundance of the morphotypes H4, Ep3, and Ed1 in association, in parts of the PA area, perhaps due to the higher MicC and TP values.

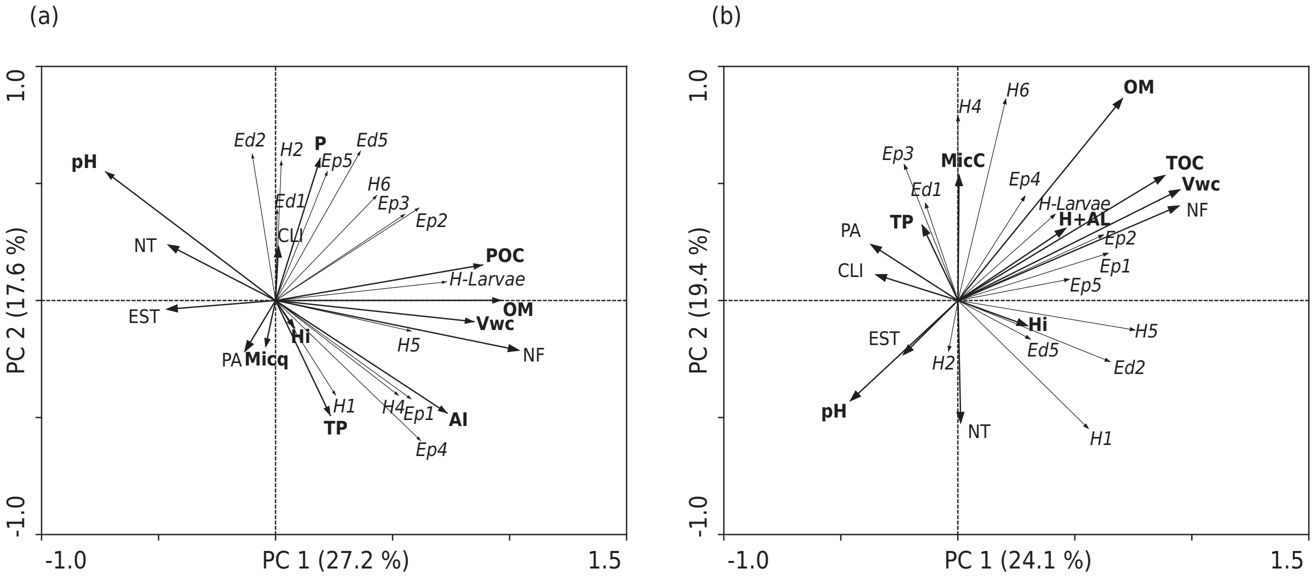

Figure 2. Principal component analysis of Coleoptera morphotypes (italic letters) distinguishing land use systems in winter (a), summer (b), and environmental variables (bold), used as explanatory variables, on the Southern Santa Catarina Plateau. NF: native forest; EST: *Eucalyptus* stands; PA: perennial pasture; CLI: crop-livestock integration; NT: no-tillage; Ed: edaphic; H: hemi-edaphic; Ep: epigean; H+Al: potential acidity; OM: organic matter; TOC: total organic carbon; POC: particulate organic carbon; MicC: microbial biomass carbon; Micq: microbial quotient; Vwc: soil volumetric water content; TP: total porosity; P: phosphorus; Hi: hydrogen; Al: aluminum.

Table 6. Soil biological quality and mean value of the community trait (mT) for ecomorphological groups of Coleoptera in native forest (NF), *Eucalyptus* stands (EST), perennial pasture (PA), crop-livestock integration (CLI), and no-tillage (NT) systems on the Southern Santa Catarina Plateau

Season	LUS	SBQ				Number of morphotypes				mT
		Ed	H	Ep	Total	Ed	H	Ep	Total	
Winter	NF	90	2,020	334	2,444	2	6	5	13	7.99 ± 1.40
	EST	15	720	113	848	1	4	3	8	7.19 ± 1.87
	PA	75	960	87	1,122	1	5	3	9	8.50 ± 1.60
	CLI	75	1,500	169	1,744	2	6	4	12	7.39 ± 1.44
	NT	215	380	76	671	3	5	3	11	7.29 ± 0.82
Summer	NF	1,325	1,040	914	3,279	3	6	5	14	6.43 ± 0.73
	EST	90	500	158	748	2	5	5	12	6.34 ± 0.78
	PA	250	420	175	845	3	5	5	13	7.75 ± 0.70
	CLI	90	1,990	252	2,332	2	5	3	10	6.18 ± 1.25
	NT	365	560	303	1,228	3	4	3	10	5.93 ± 0.62

LUS: land use systems; SBQ: soil biological quality; Ed: edaphic; H: hemi-edaphic; Ep: epigean; and mT: mean value of the community trait.

Soil biological quality and mean value of the community trait

The SBQ results calculated by means of the EMI value for the larval phase (Table 6), demonstrate that reduced total values of the index do not follow a land use intensity gradient (NF > EST > PA > CLI > NT), as it has been reported for soil macrofauna (Rosa et al., 2015). The SBQ gradients was highest in NF for winter and summer where: NF > CLI > PA > EST > NT and NF > CLI > NT > PA > EST, respectively (Table 6).

The analysis of mT values provides a different perspective on the SBQ index, for considering the total number of organisms of each system, i.e. the relative morphotype abundance (Vandewalle et al., 2010). The winter mT values ranged from 7.19 in EST to 8.5 in PA; in turn, in summer the values showed greater variation, from 5.93 in NT to 7.75 in PA (Table 6).

DISCUSSION

Coleoptera community structure

Low density of coleopterans in EST is probably related to a lower diversity of plants in these areas, since *Eucalyptus* is an exotic species, usually grown in monoculture (Figure 1). Therefore, the EST areas have less diverse, lower-quality forest litter, providing fewer resources for soil coleopterans. These conditions, in addition to other edaphic properties and ecological relations, may provide a less attractive environment to some coleopterans than sites with native vegetation and/or greater resource availability for invertebrate survival, a fact confirmed by the low density of individuals (ind per m^2) at these sites. On the other hand, greater abundance of individuals trapped in NF (Figure 1b), reinforces the idea that an environment with higher diversity and lower land use intensity favors the occurrence of coleopterans.

In summer sampling, the LUS with no or reduced management obtained the highest H' and promoted the highest diversity in morphotypes of structural groups with different soil habits (Table 5). The same pattern was described by Machado (2015), for the H' index of ecomorphological groups of springtails, collected in traps in the same LUS on the Southern Santa Catarina Plateau. All studied LUS had some kind of soil cover, however, their specific management and edaphoclimatic conditions can induce differences between Coleoptera morphotypes, as observed in this study in both seasons.

Principal component analysis

The highest pH (Figure 2a) was related to liming in NT and CLI, a practice required by crops in these systems to decrease active soil acidity. Also, a higher Al^{3+} content was evident where no liming was applied, as in the NF areas. In the CLI systems, the higher P content may be explained by fertilization, and this increase, as well as pH, favored some morphotypes, mainly the edaphic (Ed1, Ed2, and Ed5). Perhaps, this group is benefited by on-site management, mainly in relation to chemical properties (Table 4).

Systems providing a higher level of OM in the soil, mainly by plant residue, as that observed for NF (Table 4 and Figure 2), can increase TOC and POC contents and contribute to the sustainability of ecosystems (Loss et al., 2011). These factors may have influenced the presence of epigean and hemi-edaphic morphotypes, such as H-Larvae and Ep2, since OM increases depend on organic waste deposition on and maintenance in the soil (Rosa et al., 2015). In NF, plant material is continuously applied, with an enriched quality and quantity, due to the higher diversity of native vegetation and animal species. Management systems with reduced or no-tillage and maintenance of the vegetation cover tend to preserve the soil structure, especially in terms of edaphic diversity and physical properties, such as porosity (Bartz et al., 2014b). The material constituting plant litter and SOM is related to the activity and abundance of edaphic fauna, contributing to maintain these organisms in the systems (Baretta et al., 2011).

The lower diversity and density of Coleoptera larvae in native araucaria forest than in managed areas was related to edaphoclimatic conditions and moisture, apart from the plant material, which can influence this variation strongly (Merlim et al., 2006), corroborating the results of this study for H-larvae (Figure 2).

Soil microbiota, as well as the edaphic meso and macrofauna, is favored by vegetation cover, which provides a greater accumulation of OM and a greater source of nutrients for the microbial community growth. Thus, higher MicC values are expected in forest or native soil, when compared to other LUS (Alves et al., 2011) (Figure 2b). However, aside from vegetation cover and organic waste, increased microbial biomass may be related to the presence of some coleopteran morphotypes. According to Kuzyakov and Blagodatskaya (2015), there is an increased microbial biomass and microorganism activity in the pores formed by root growth and faunal soil excavation and where the feces of these animals are found, which contribute to introduce labile and recalcitrant organic compounds in the system. In this context, the presence of some ecomorphological groups with edaphic adaptations was observed, such as Ed1, H4, and H6, maybe linked to the variables TP and MicC, as they move deep into the soil, deposit their feces in the pores and some, e.g., hemi-edaphic coleopterans, can transport organic material from the soil surface to deeper layers, stimulating the microbial action. In addition, microorganisms, as well as the edaphic Coleoptera fauna, perform essential functions in nutrient cycling and OM decomposition in soil. The interaction between these various organisms can have beneficial or harmful effects on the cultivation systems, because they are influenced by management and chemical and physical soil properties (Kladivko, 2001).

On the other hand, significant trophic relationships occur below the surface, which affect population dynamics and ecosystem processes (Bardgett and Van Der Putten, 2014). These relationships may influence the presence of some Coleoptera groups at locations with more MicC (Figure 2b).

Soil biological quality and mean value of the community trait

Both in winter and summer, NF performed better than the other management systems in terms of soil biological quality and mean value of the community trait, followed by CLI (Table 6). There are no evident factors that explain the higher SBQ in CLI than in PA systems, where vegetation is native and the land use less intense. It was assumed that more favorable microclimatic conditions influenced this result, or that controlled fire was used in PA as a management form (Table 1), or because the soil chemical properties were more favorable to organisms in CLI (Table 4), resulting from liming, maintenance of the vegetation cover, and OM input, which favored the persistence of ecomorphological groups, mainly the hemi-edaphic insects. In general, the highest soil quality was attributed to areas with native vegetation, but in a study conducted in Europe by Mohamedova and Lecheva (2013), with several fauna groups, a higher SBQ value was also found in cultivated areas. This suggests that in certain cases these systems may be appropriate for microarthropod communities, with adaptations to soil life, especially the hemi-edaphic group in this study. The CLI system, on certain occasions, may show greater abundance of soil fauna, when compared to perennial systems such as EST and PA, as already observed for edaphic fauna in other regions in Santa Catarina, Brazil (Bartz et al., 2014b).

For larvae of holometabolic insects, as of the Coleoptera order, the EMI value is equal to 10, i.e. they are considered intermediate (H-larvae), because their score is proportional to the degree of edaphic specialization (Parisi et al., 2005; Mohamedova and Lecheva, 2013). The larvae generally provided a considerable increase in SBQ for the hemi-edaphic group (H), along with other morphotypes of this ecomorphological category and improved the EST system condition, because according to the index, the soil biological quality of the NT areas was lower in winter. On the other hand, in summer the lowest value was observed in EST soils (Table 6).

In most systems, mT for Coleoptera morphotypes was very similar, except for NT, suggesting that most coleopterans were distributed in few morphotypes with lower EMI scores, i.e. traits of lower edaphic adaptation (Table 6). For NF, it was noticed that even when this system had highest SBQ values, mT was not the highest, unlike in PA. This indicates that even when the forest has higher morphotype richness, fewer individuals have edaphic traits in relation to the total number of individuals in this system than in PA. The great similarity of mT values may have resulted from the significant larvae participation in the LUS.

CONCLUSIONS

The richness and abundance of Coleoptera morphotypes was highest in NF, proving to be the most stable of the studied LUS. Overall, epigean coleopterans were more abundant than hemi-edaphic and edaphic ones.

In the systems with no or reduced management (NF, EST, and PA), the highest diversity of Coleoptera morphotypes occurred in summer. In winter, there was increase of diversity in cultivated systems (NT and CLI). In short, Coleoptera morphotypes are influenced by soil chemical, physical, and microbiological properties, especially by P, pH, OM, TOC, POC, Vwc, TP, and MicC.

The soil biological quality, based on the ecomorphological value, varied between the studied seasons. However, did not follow relation with land use intensification, following the order: NF> CLI> NT> PA> EST in winter and NF> CLI> PA> EST> NT in summer.

The analysis of the ecomorphological traits to assess Coleoptera morphotypes and form groups according to their characteristics of edaphic adaptation were efficient to distinguish the land use types.

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