CSR analysis of plant functional types in highly diverse tropical grasslands of harsh environments.

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Abstract

The classification of plant species according to the CSR ecological strategy scheme has been proposed as a common language that allows comparison among species, communities and floras. Although several studies on European continent have demonstrated a consistent association between CSR strategies and key ecosystem processes, studies of this type are still lacking in other ecoregions worldwide. For the first time the CSR strategy scheme is applied in a tropical plant community. In a Brazilian mountain grassland ecosystem characterized by both high biodiversity and environmental stress, we sampled various functional traits of 48 herbaceous species in stony and sandy grasslands, and evaluated the relationship between CSR strategies and functional traits with several environmental parameters. The extremely infertile soils in the two studied habitats may have acted as a major environmental filter leading to a clear predominance of the stress-tolerant strategy in both communities. However, fine-scale environmental differences between the two communities resulted in the filtering of distinct functional trait values. The sites with coarser soil texture, lower percentage of plant cover and (paradoxically) higher mineral nutrient concentrations favored plants with narrower leaves, higher stress tolerance, lower competitiveness, and higher sclerophylly (i.e., lower specific leaf area and higher leaf dry matter content). The comparison between the functional character of stony and sandy communities evidenced the influence of soil texture and water availability in the environmental filtering. This study highlighted the validity of the CSR classification outside the temperate region where it was originally developed and corroborated.

Introduction

The classification of plant species into functional types reflects the need for a common language to establish comparisons between different types of flora, regions and scales (Weiher et al. 1999). A long series of studies led to the identification of a set of traits that are often closely correlated to key functional properties of plants (e.g., relative growth rate, leaf-decomposition rate, leaf life span and reproductive investment), facilitating the quantification of these traits in a large number of species (Cornelissen et al. 2003). According to the ecological strategy scheme known as CSR (C: competitive, S: stress-tolerant, R: ruderal; Grime 1977, 2001; Grime and Pierce 2012), sets of functional traits define plant survival strategies, representing trade-offs between the ability to compete with neighbors (strategy C), tolerate stresses (strategy S), or survive partial destruction of biomass (strategy R). According to this scheme, plants can exhibit different proportions of the characteristics associated with each of the three primary strategies: plants with greater stature due to investment in growth and the rapid uptake of resources (C); plants with reduced stature and high longevity due to investment in durable and well-defended structures (S); and small-sized plants with short longevity and a high reproductive investment (R). The method of CSR classification proposed by Hodgson et al. (1999) uses seven easily measured traits to calculate the relative importance of these three primary strategies in herbaceous (i.e., non-woody) species. This method has been used in several studies and applied to more than 1,000 species from diverse environments in Europe (e.g., Caccianiga et al. 2006; Pierce et al. 2007; Massant et al. 2009; Cerabolini et al. 2010*a*, *b*; Navas et al. 2010), in general revealing a strong connection with key ecosystem processes. The application of this classification in other types of vegetation worldwide has the potential to improve the understanding of the underlying hypotheses of the CSR theory in addition to benefitting the

communities studied by providing useful information for the development of conservation, management and restoration programs targeting these plant communities.

Rupestrian grasslands are a unique vegetation complex that occurs mainly at the peaks and crests of mountains that make up the Espinhaço mountain range in southeastern and northeastern Brazil. This vegetation complex has a great conservation value due to its enormous plant and animal biodiversity composed of a large number of endemic species (Negreiros et al. 2009; Echternacht et al. 2011; Carvalho et al. 2012). In general, the physiognomy of rupestrian grasslands is characterized by the dominance of graminoids and forbs interspersed with some small evergreen sclerophyllous shrubs (Giulietti et al. 1997). The vegetation associated with rupestrian grasslands is under high environmental stress because of its highly infertile soils, which are of quartzite and sandstone origin and have high levels of aluminum (Benites et al. 2007, Messias et al. 2014) and due to a pronounced seasonal drought, intense light exposure and strong and constant winds (Negreiros et al. 2009, Carvalho et al. 2012). Despite its apparent physiognomic homogeneity, this vegetation complex can be best defined as a mosaic of environments conditioned mainly by the particle-size composition of the substrate (Carvalho et al. 2012; Le Stradic 2012), which varies from soils with finer textures, such as in peat bogs and the crevices of rocky outcrops, to soils where sand and gravel predominate (sandy and stony grasslands, respectively). The plant communities of the sandy and stony grasslands of the Serra do Cipó were recently characterized in more detail regarding their composition and environmental parameters (Le Stradic 2012). Although these two grassland types occur side by side, stony grasslands contain sparser vegetation cover than sandy grasslands, with a larger proportion of bare rocky substrate, but with relatively greater nutrient levels than sandy grasslands. In this context, the present study applies, for the first time, the CSR classification of

plant strategies in a tropical plant community. To the best of our knowledge, there have been no reports of the application of the CSR classification (*sensu* Hodgson et al. 1999) in the Southern Hemisphere or in the tropical region, although some studies use a general approach employing concepts that underlie the CSR theory (e.g., Mcg King and Wilson 2006; Saporetti-Junior et al. 2012).

In this study, we aimed to evaluate the relative importance of C, S and R strategies in two distinct habitats typical of rupestrian grasslands by classifying a representative sample of herbaceous species and evaluating the proportion of these strategies (among the 19 possible categories) in these two highly stressed communities. Since chronically unproductive environments favor species with traits typical of stress resistance syndrome (Chapin et al. 1993; Grime et al. 1997; Aerts and Chapin 2000), we expected that in both stony and sandy grasslands there would be a higher proportion of the strategies near the stress tolerance corner of the triangle (i.e., S, S-SC, S/SR and S/CSR). On the other hand, since stony and sandy grasslands have consistently distinct micro environmental features (e.g., amount of plant cover, proportion of fine soil and degree of soil fertility), we expect that these differences will filter distinct functional strategies and features in each habitat (i.e., there would be a significant connection between habitat structure and functional identity of these two herbaceous communities).

Materials and methods

Study area and species sampled

This study was carried out in the Reserva Natural Vellozia (19°17'46"S, 43°35'28"W, altitude of approximately 1,200 m asl) and surrounding areas located in the Morro da Pedreira Environmental Protection Area, Serra do Cipó, southern portion of the Espinhaço mountain

range, Minas Gerais, Brazil. The climate of the region is mesothermal (Cwb in the Köppen classification) and markedly seasonal, with two well-defined seasons: one rainy and hot (between November and April) and the other dry and cold (between May and October). The region has an annual precipitation of 1,370 mm and a mean annual temperature of 21.2°C (Madeira and Fernandes 1999).

Based on topography and apparent soil texture, we designated and studied two main types of rupestrian grasslands. We selected five sites on slopes with stony substrate and five sites on flat areas with sandy substrate. Sites were located between 1,100 m and 1,300 m asl. The phytosociological data obtained by Le Stradic (2012) were used in this study, which consisted in the measurement of 15 plots (1×1 m) in each area, totaling 75 plots per habitat. There was a minimum distance of 800 m between the areas of the same habitat. The abundance of each species within the plots was measured as a number of sub-plots (20×20 cm) where a species occurred, ranging from 0 to 25 sub-plots per m^2. A total of 48 herbaceous (non-woody) species were selected for the measurements of functional traits. The selection was made to include the species with the greatest abundance in each habitat, although rarer species were also sampled to obtain a greater representativity of the functional description of the two communities studied. The species sampled (42 in each habitat) corresponded to 83.67% and 79.86% of the total herbaceous species abundance in the stony and sandy grasslands, respectively. The remaining abundance not sampled corresponded to 64 and 70 rarer herbaceous species in the stony and sandy grasslands, respectively (Le Stradic 2012). Among the 36 species that occurred in both habitats, 21 species of greater abundance were collected separately in each habitat. The 15 remaining species were collected in the habitats where they occurred with greater abundance (see Online Resource 1 and 2 for details).

Functional traits and CSR classification

Functional traits of recognized importance in ecosystem processes (Grime et al. 1997; Weiher et al. 1999; Díaz et al. 2004) and widely used in studies of functional ecology (e.g., Cerabolini et al. 2010*a*; Batalha et al. 2011) were sampled. All measurements followed the standardized protocols extensively described by Cornelissen et al. (2003). From December to February (2010-2012), at the peak of the rainy season (i.e., the period considered most favorable for plant growth in rupestrian grasslands, Silveira et al. 2012), ten reproductively mature, healthy-looking individuals (i.e., ramets for clonal plants) of each species were randomly sampled from the surrounding locations of the sites where the phytosociological measurements were taken. Sampled individuals were distant at least ten meters from each other, to avoid the risk of measurement on the same genet.

The relative importance of the C, S and R strategies was calculated using seven traits. Four traits were sampled *in situ*: the canopy height (from the soil surface to the crown top), lateral spread (six categories related to the architecture and clonality of the plant; see Hodgson et al. 1999), flowering period (normal duration of flowering period) and month of the flowering start (obtained over two years of observation; Le Stradic 2012). To determine the three leaf traits necessary for the calculations of the CSR strategies (specific leaf area, leaf dry matter content and leaf dry weight), whole ramets were collected in the field (e.g., bulbs or tussocks), preferably with a portion of the root system to avoid the desiccation of the leaf material. The period of strongest sunlight (10:00-15:00) was avoided during sampling. The ramets collected were immediately saturated with water using a spray bottle, packed in moist paper bags, sealed in plastic bags and stored in a thermal box until they were transported to the laboratory. The plant

material collected was kept in a refrigerator at 4°C for a minimum of 12 h to achieve complete turgidity. Measurements were taken from two leaves (including the petiole) per individual up to 48 h after field collection. Only fully expanded and hardened young leaves without signs of pathogens, herbivory, or malformation were sampled, following Cornelissen et al. (2003). The leaf area was obtained with the use of a desktop scanner and the Leaf Area Measurement software (A.P. Askew 2003, The University of Sheffield, UK). Curved leaves were cut into fragments and positioned so that they were in complete contact with the surface of the scanner. The leaf fresh weight was obtained from the turgid leaves previously dried with soft paper towel and the leaf dry weight was determined with an analytic scale (with a precision of 0.01 mg) after 96 h of drying in an oven at 60°C. In addition to the traits used in the calculation of the CSR strategies, the leaf toughness and width were determined. The leaf toughness was measured using a digital penetrometer (Chatillon® model DFE-010, Largo, Florida, USA) coupled to a cone-shaped tip (model SPK-FMG-009A), according to Silva and Batalha (2011). The values of leaf toughness were standardized using leaf thickness (obtained with the use of a digital micrometer, Mitutoyo® series 293, with a precision of 0.0001 mm). The leaf width was obtained using a digital caliper (Mitutoyo® 500-144B, with a precision of 0.01 mm), measuring the leaf blade width in the position equidistant between the base and the apex of the leaf. The level of endemism was determined based on geographic distribution data for the species (Le Stradic 2012).

The classification of the species into categories of CSR strategies (among the 19 possible types) was carried out using a spreadsheet provided by Hodgson et al. (1999). The percentage of importance of each CSR strategy was calculated using the method of Hodgson et al. (1999), with the coordinates of the axes C, S and R adapted for ternary plots (after Caccianiga et al. 2006)

using the Excel spreadsheet provided by Pierce et al. (2007). The trait flowering start was used only in the calculations of non-graminoid species corresponding to ten species: nine dicots and one Orchidaceae (see Online Resource 1). Because this study was performed in the Southern Hemisphere, a correction of six months was made to the values of the month of flowering start to calculate the strategies (see Weiher et al. 1999). For a detailed discussion of the validity of applying the CSR classification in the present study, please see Online Resource 3. In order to assess the relative importance of the C, S and R strategies in the stony and sandy grasslands, the sampled species were represented in a triangular space containing all the possible strategies (with each coordinate varying from 0 to 100%, following Caccianiga et al. 2006). The representation of the categories of the CSR strategies using colors was performed by converting the C, S and R coordinates into red, green and blue, respectively, following Pierce et al. (2007).

Relationship between the functional and environmental traits

To test the expectation that the functional traits of species are associated to the characteristics of the habitat, an RLQ (R-mode linked to Q-mode) analysis using simultaneously three matrices (floristic, functional and environmental) was performed. The RLQ analysis was developed to study environmental filters in ecological communities by assessing the combination of functional traits of maximum covariance with a given combination of environmental parameters (Dolédec et al. 1996). In the floristic matrix (L), the rows correspond to the areas (5 replicates $\times$ 2 habitats) and the columns correspond to the 48 species, with each cell containing the absolute abundance value of the species in the area. In the functional matrix (Q), the rows corresponded to the species and the columns corresponded to the functional traits. Mean values were used for the species that were sampled in the both habitats (see Online Resource 1). In the

environmental matrix (R), the rows corresponded to the areas and the columns corresponded to the environmental parameters. The data utilized in the environmental matrix were obtained from the study of Le Stradic (2012). The soil pH, percentage of organic carbon, aluminum saturation, sum of bases ($K + Ca^{2+} + Mg^{2+}$), phosphorus and nitrogen contents were determined according to Silva et al. (1999) from three replicates per area in the dry and rainy seasons. The percentages of fine soil (fraction of soil with particles smaller than 2 mm) and fine sand were determined according to EMBRAPA (1999) from three replicates per area. The percentage of plant cover, litter cover and woody species cover were estimated in each plot of 1×1 m used in the phytosociological survey (n = 15 replicates per area). For all the environmental parameters, the mean values of each area were considered for the analyses. To meet normality assumptions, the following traits were log-transformed: canopy height, flowering period, specific leaf area, leaf dry weight, leaf toughness, leaf width, sum of bases, organic carbon, nitrogen and phosphorus contents. The ordinal variables (lateral spread, flowering start and endemism) were ranked and henceforth treated as quantitative variables. To conduct the RLQ analysis, a correspondence analysis was used for the floristic matrix, while a principal component analysis (PCA) was used for the functional and environmental matrices. In the functional PCA, the species were weighted by their overall relative abundance over both habitats, while in the environmental PCA, the areas were weighted by the relative number of plants observed (Dolédec et al. 1996; Dray and Dufour 2007; Pavoine et al. 2011). Both analyses were carried out in the R (R Development Core Team 2012) software with the "ade4" package (Chessel et al. 2004; Dray and Dufour 2007) and some functions provided by Pavoine et al. (2011).

Results

In both communities, there was a clear predominance of the stress-tolerant strategy, with the majority of species showing a proportion of S above 50% (Fig. 1a,b). The species with the greatest abundance in the stony grassland was *Mesosetum exaratum*, which exhibited an extremely stress-tolerant strategy (C:S:R = 18.8:81.2:0.0%), followed by *Tatianyx arnacites* (25.9:74.1:0.0), which also exhibited a high ratio of stress tolerance (Fig. 1a). The species with the greatest abundance in the sandy grassland was *Paspalum erianthum* (23.7:76.3:0.0), with a high ratio of stress tolerance (Fig. 1b), followed by *T. arnacites* and *Homolepis longispicula* (48.1:51.9:0.0), a species with a similar ratio of C and S. Considering the 19 possible categories of strategies in the CSR space (Fig. 2a), the predominance of strategies close to the stress-tolerant corner of the triangle stands out (Fig. 2b-e). Although there was a strong resemblance between the two habitats regarding the number of species in each CSR categories (Fig. 2d-e), the comparison based on abundance highlighted the more stress-tolerant character of the stony grassland community (Fig. 2b,c).

The overall association between the species traits and the habitat structure was significant (p = 0.010) according to the test based on the total co-inertia of the RLQ analysis (Monte-Carlo with 100,000 permutations). Axis 1 of the RLQ analysis accounted for 90.1% of the total variation. The positive side of this axis corresponded to the areas with a greater proportion of fine soil (particle size < 2 mm) with greater aluminum saturation, greater plant cover, less acidic pH, greater proportion of fine sand, lower levels of nutrients and organic carbon and less coverage by woody species (Fig. 3a). The species with greater importance in these areas shared similar traits, showing wider geographic distributions, less stress tolerance, greater competitiveness, greater stature and leaves that were larger and wider with less toughness and

sclerophylly (i.e., with greater specific leaf area and lower leaf dry matter content; Fig. 3b). In contrast, the negative side of this axis represented areas with predominantly stony soils (particle size > 2 mm) with greater levels of nutrients and organic carbon and greater acidity, although with less aluminum saturation, less plant cover and greater woody species cover (Fig. 3a). The species with greater importance in this area generally exhibited a more restricted geographic distribution, greater stress tolerance, lower competitiveness, smaller stature and leaves that were smaller and narrower with greater toughness and sclerophylly (i.e., lower specific leaf area and higher leaf dry matter content; Fig. 3b). The environmental parameter of litter cover and the functional traits flowering start, flowering period, ruderalism and lateral spread showed low correlation with the main axis of the RLQ (Fig. 3).

Discussion

The present study evaluated *in situ* functional characteristics of two herbaceous communities in a neotropical mountain vegetation complex under heavy environmental stress, showing the role of environmental filters in the determination of plant functional diversity in these habitats. Predominantly ruderal species were not found in either of the habitats and the few species with a greater level of competitiveness had a low relative abundance. The extremely infertile soils in the two studied habitats (Benites et al. 2007; Negreiros et al. 2009; Messias et al. 2014) may have acted as a major environmental filter leading to a clear predominance of the stress-tolerant strategy in both communities. This result confirmed the expectation that chronically unproductive environments favor species with traits typical of stress resistance syndrome (Chapin et al. 1993; Grime et al. 1997; Aerts and Chapin 2000).

On the other hand, fine-scale environmental differences between the two communities resulted in the filtering of distinct functional trait values. In this sense, the RLQ analysis indicated a strong and significant association between habitat structure and functional character of the herbaceous communities. The sites with higher proportion of coarse textured soil, lower percentage of plant cover and with relatively higher amounts of mineral nutrients favored plants with narrower leaves, higher stress tolerance, lower competitiveness and higher sclerophylly (i.e., lower specific leaf area and higher leaf dry matter content), and in a less extent, plants with smaller and tougher leaves with narrower geographic distribution. The comparison between the functional character of stony and sandy communities highlighted the influence of soil texture and water availability in the environmental filtering. The coarser texture of the stony grassland soil is associated with both lower water-retention capacity compared to the sandy grassland (Saporetti-Junior et al. 2012) and lesser availability of physical space for roots (given that in stony soils the amount of fine soil is on average only 40%; Le Stradic 2012). Contrary to the expectations, the areas with relatively greater nutrient availability exhibited a greater proportion of species with higher stress tolerance and sclerophylly. Strong differences between the two grassland types regarding to soil texture properties (which is closely linked with water-retention capacity and fine soil availability) may have overshadowed the influence of minor soil fertility differences between the stony and sandy grasslands. The apparently contradictory association between high stress-tolerance with higher soil fertility indicates that in ecological studies of natural vegetation, the parameters used to characterize the habitat structure should be selected based on the widest scope possible, never considering solely the nutritional status.

The strong association of stress tolerance and competitiveness with the environmental gradient in the surveyed areas highlights the validity of the CSR classification proposed by

Hodgson et al. (1999) and adapted by Caccianiga et al. (2006) in studies of ecological filters, even in a wider biogeographical and ecological context. The opposition between stress tolerance and competitiveness reflected both leaf economics and size spectra, previously recognized as the two main axes of plant specialization worldwide, considering the established phase of plant life cycles (Wright et al. 2004; Díaz et al. 2004; Cerabolini et al. 2010*a*; Pierce et al. 2012). In contrast, ruderalism and the two factors related to the regenerative phase of the lifecycle of plants (the flowering start and flowering period) had a generally low association with the environmental gradient. This pattern could indicate a minor role of disturbances in structuring these habitats because these two factors are commonly related to the disturbance regime (Lavorel and Garnier 2002).

Although the present study confirms the validity and applicability of the method of classifying herbaceous species proposed by Hodgson et al. (1999) for a neotropical mountain vegetation (see Online Resource 3), we agree with Cerabolini et al. (2010*a*) that there is still room to improve the calibration of the equations used in this classification. For example, 58% of the species evaluated by Cerabolini et al. (2010*a*) had 0.0% stress tolerance and 37% of species in the present study had 0.0% ruderalism, which makes it clear that a recalibration based on wider geographic and ecological samples has the potential to increase the precision and applicability of this tool for functional studies worldwide.

Implicit in the analyses developed to demonstrate environmental filters in ecological communities is the attribution of relative weights to species according to their abundance (Dolédec et al. 1996; Dray and Legendre 2008). This weighting scheme reflects the idea that dominant species should have a greater influence on ecosystem processes (Grime 1998; Díaz et al. 2007; Mokany et al. 2008; Lavorel et al. 2011). Keeping sight of the fact that there is

currently a long list of easily-measured traits that are highly correlated to key physiological traits, ecological processes and ecosystem services (Weiher et al. 1999; Cornelissen et al. 2003; Díaz et al. 2004, 2007), we argue that other herbaceous vegetation types of high priority for conservation should be sampled to identify their dominant species with respect to these functional traits, such as those used in the present study. In this way, valuable information will be made available with relatively little effort, which may be incorporated into conservation and management programs given the relevance of this information to understanding the resilience and resistance of these vegetation complexes to the impacts of climate and land-use change (Suding et al. 2008; Frenette-Dussault et al. 2013). In this sense, the geographic distribution of species was related to the environmental and functional spectra. Sites with higher proportion of coarse textured soil hosted preferentially species with narrower geographic distribution. This result highlights the conservation value of studies of this nature, given that reduced population size is frequently cited as one of the main causes of extinction of plant species in Brazilian rupestrian grasslands (cf., Martinelli & Moraes 2013).

This study highlighted the validity of the CSR classification outside the temperate region where it was originally developed and corroborated, and provided evidence that the CSR classification is sufficiently sensitive to detect differences in plant strategies even when comparing communities apparently subjected to similar environmental conditions and sharing a majority of species.

Acknowledgements

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Electronic Supplementary Material

Online Resource 1 Functional traits of 48 herbaceous species sampled in the stony and sandy grasslands of the Serra do Cipó, MG, Brazil

Online Resource 2 Influence of exclusive and rare species in the detection of environmental filtering

Online Resource 3 Validation of the CSR classification for a tropical grassland vegetation

Figure Captions

Fig. 1 Species sampled in two herbaceous communities of rupestrian grassland in Serra do Cipó, MG, Brazil. (a) and (b): CSR classification showing the relative importance of the C (competitiveness), S (stress-tolerant) and R (ruderalism) axes in species of stony and sandy grasslands, respectively. The species were represented in grayscale according to their respective abundances. Numbering indicated in the circles corresponds to the following species: 1 *Calea coronopifolia*; 2 *Richterago polymorpha*; 3 *Ri. arenaria*; 4 *Evolvulus lithospermoides*; 5 *Agalinis brachyphylla*; 6 *Eriope arenaria*; 7 *Gomphrena incana*; 8 *Polygala glochidata*; 9 *Siphanthera arenaria*; 10 *Homolepis longispicula*; 11 *Tatianyx arnacites*; 12 *Mesosetum exaratum*; 13 *M. loliiforme*; 14 *Axonopus* sp.; 15 *Echinolaena inflexa*; 16 *Paspalum erianthum*; 17 *Pas. pectinatum*; 18 *Panicum cyanescens*; 19 *Schizachyrium tenerum*; 20 *Trachypogon spicatus*; 21 *Aulonemia effusa*; 22 *Xyris melanopoda*; 23 *X. minarum*; 24 *X. nubigena*; 25 *X. obtusiuscula*; 26 *X. pilosa*; 27 *Paepalanthus geniculatus*; 28 *Pae. nigrescens*; 29 *Leiothrix crassifolia*; 30 *Syngonanthus cipoensis*; 31 *Rhynchospora riedeliana*; 32 *Rh. ciliolata*; 33 *Rh. terminalis*; 34 *Rh. tenuis*; 35 *Bulbostylis eleocharoides*; 36 *B. emmerichiae*; 37 *B. lombardii*; 38 *B. paradoxa*; 39 *Lagenocarpus tenuifolius*; 40 *L. alboniger*; 41 *L. velutinus*; 42 *Cephalostemon riedelianus*; 43 *Cyrtopodium parviflorum*; 44 *Vellozia caruncularis*; 45 *V. resinosa*; 46 *V. variabilis*; 47 *V. epidendroides*; 48 *Barbacenia blackii*

Fig. 2 Categories of the CSR strategies and their representativity in two herbaceous communities of rupestrian grassland in Serra do Cipó, MG, Brazil. (a): denominations, coordinates and color representation of the 19 categories of the CSR strategies. The colors of each category derive

from the conversion of the ratio of C, S and R to red, green and blue, respectively, following Pierce et al. (2007); (b) and (c): representativity of the CSR categories in stony and sandy grasslands, respectively, according to the sum of plant abundance. (d) and (e): representativity of the CSR categories in stony and sandy grasslands, respectively, according to the number of species. In Figs b-e, the circle size in each category corresponds to the legend between the triangles

Fig. 3 Relationships between environmental and functional traits of the vegetation in stony and sandy grasslands in Serra do Cipó, MG, Brazil. (a): Pearson's correlation (weighted by the relative abundance of plants in each area) between environmental parameters and the coordinates of the areas along axis 1 of the RLQ analysis. (b): Pearson's correlation (weighted by the relative abundance of each species) between functional traits and the coordinates of the species along axis 1 of the RLQ analysis. For the ordinal traits (lateral spread, flowering start and endemism) Spearman's rank correlation is reported
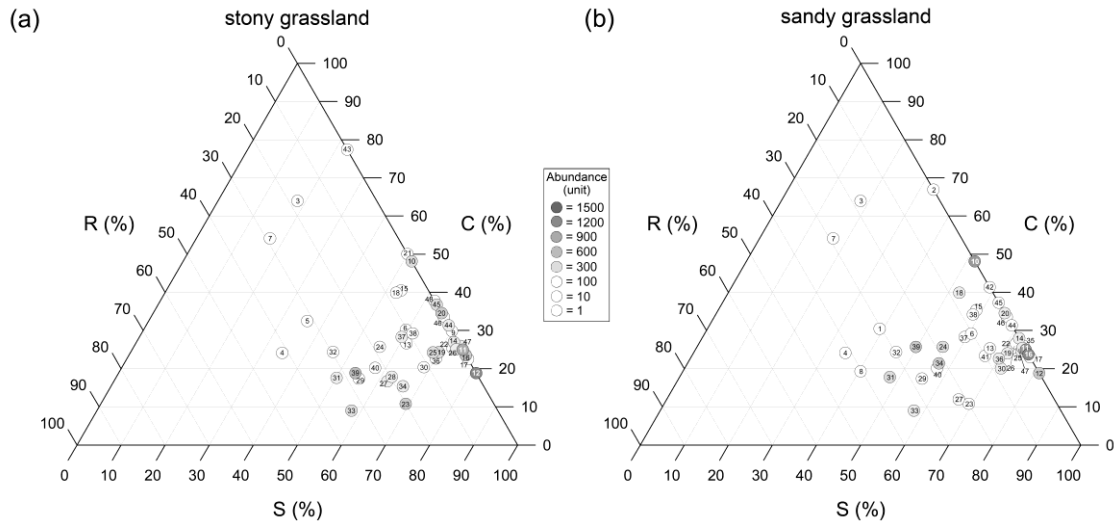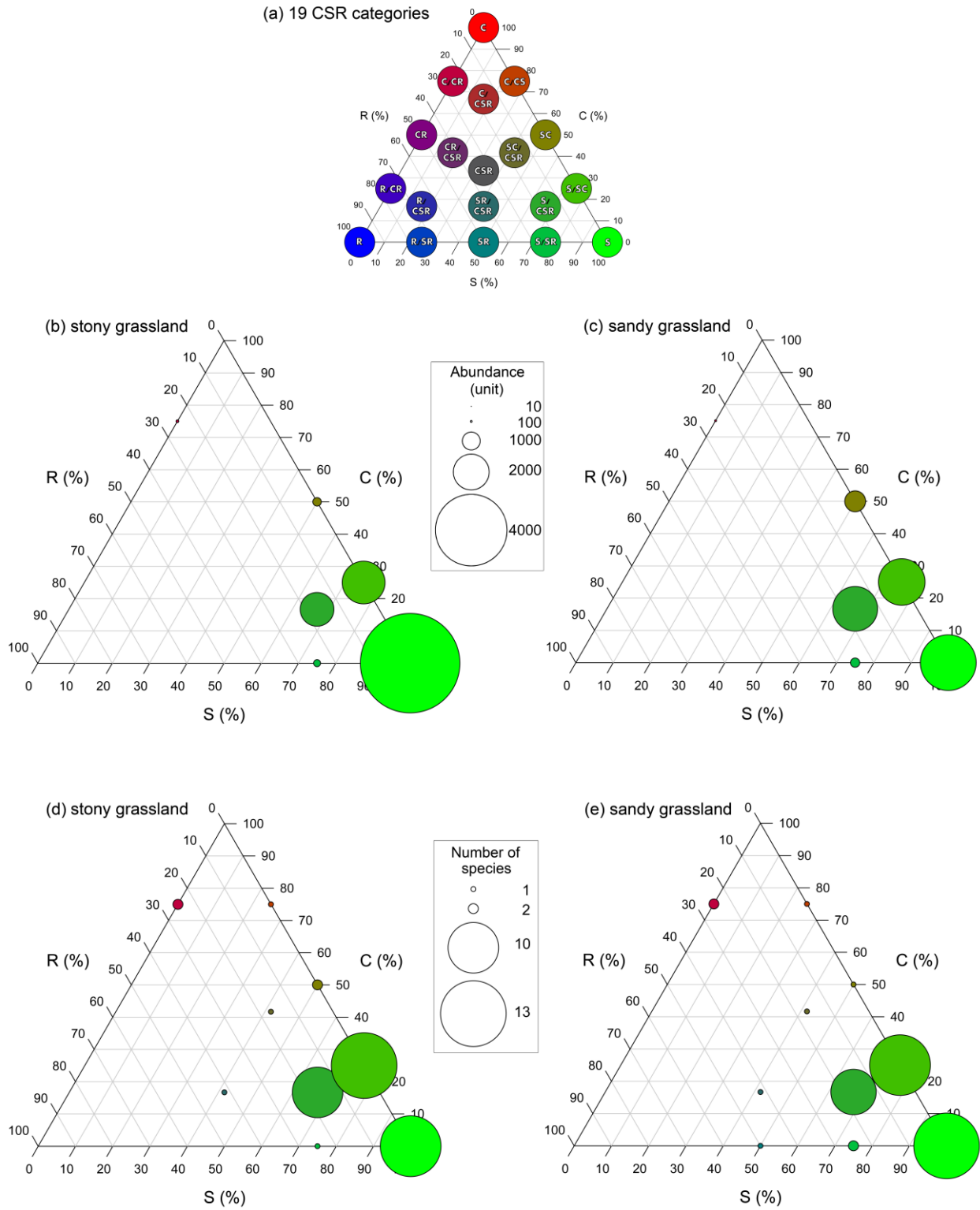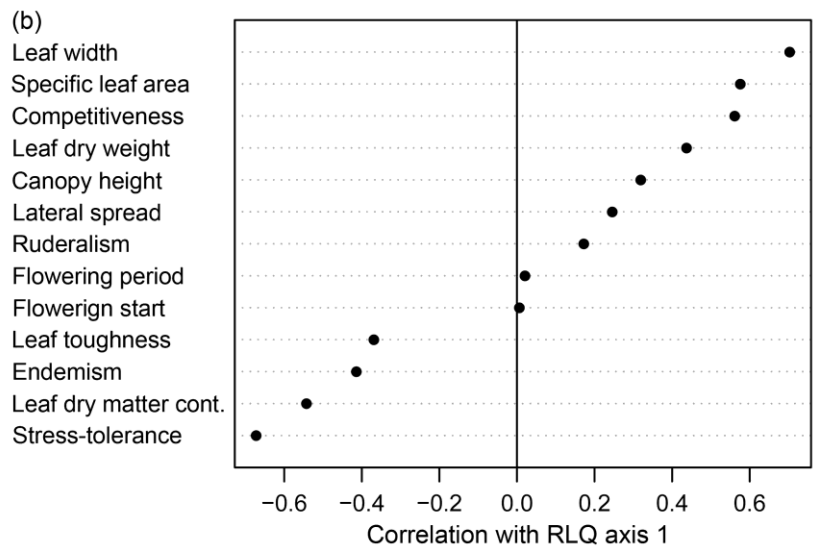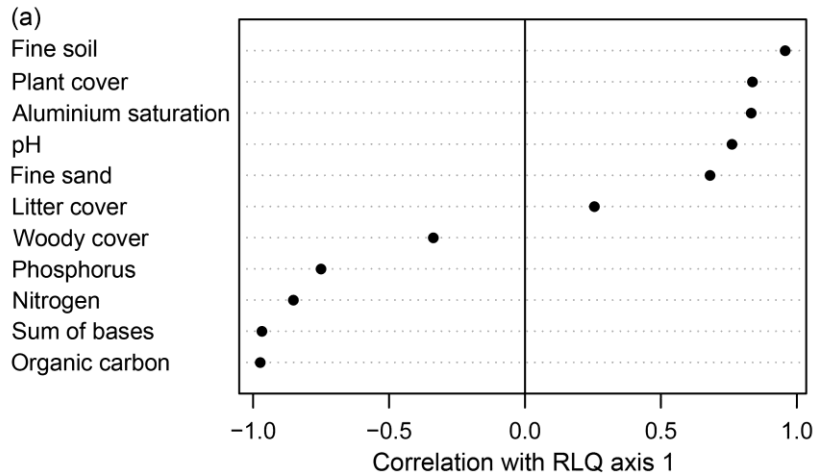
Figure 1

Figure 2

(a)

(b)

Figure 3