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## Original article

# Spatial and temporal distribution of litter arthropods in different vegetation covers of Porto Santo Island (Madeira Archipelago, Portugal)

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## ABSTRACT

The main objective of this study is to assess the soil diversity and temporal and spatial distribution of litter macro-arthropods, captured with pitfall traps, on different vegetation covers from Porto Santo Island (Portugal) with different soil physical and chemical characteristics. The PCA clearly separated sampling areas geographically more exposed to winds and solar radiation, from the others that were not. In this analysis, seasons seemed to have no influence on this distribution. Non-exposed areas were characterized by high soil temperatures, water and organic matter contents. Among these areas, those that were covered by *Pinus halepensis* and *Eucalyptus ficifolia* showed the highest C/N ratios in winter, which may be explained by likely inhibitory effects of phenolic compounds of the leaves of both species on the decomposition process. The highest number of organisms was recorded on the exposed areas. Variance partitioning using CCA showed that the different vegetation covers and environmental variables explained 19% and 30%, respectively, of the variance in macro-arthropods distribution. Four environmental variables (exposure, temperature, C/N ratio and exchangeable K) were positively correlated with the taxa abundance matrix. The results showed that non-exposed areas with *E. ficifolia* and *Cupressus macrocarpa* seemed to favour the establishment of a high diversity of taxa, especially in the summer, when soil conditions tend to be extreme.

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## 1. Introduction

Vegetation affects soil structure by the physical and chemical actions of their roots, improves the nutrient content of soils, through the decomposition of organic residues and absorption of nutrients that have been leached from the surface

[42]. Biologically, higher plants affect the life of almost all the organisms. Differences in the chemical composition of decomposing litter, depending on type of leaf litter, and decaying stages of litter and wood may have considerable effects on litter arthropod populations [48]. Thick organic layers also offer increased habitat space for soil fauna [24,38] and

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reduce temperature and temperature variability among seasons, protecting animals more susceptible to drought and high temperatures [3,6,8].

On the other hand, soil macro-fauna gives an important contribution to soil fertility, by promoting the stability and productivity of forest ecosystems, mainly due to their influence on soil processes such as litter decomposition and nutrient dynamics [4,12,15,18,20,22]. Lavelle and Spain [25] divide soil macro-fauna into ecosystem engineers (organisms like earthworms and termites that are capable of changing the soil environment and being directly involved in the decomposition of organic matter) and litter transformers. The role of this last guild (that also includes some mesofauna groups) is mainly indirect; besides comminution of litter, they act as regulators of the abundance and community structure of micro-organisms [1,7,14]. According to Bird et al. [4], established arthropod communities stabilize the availability of nutrients to plants and change the physical conditions of the soil, which become more suitable for root growth and plant water uptake. These conditions are important for maintaining productivity.

Several studies have showed that litter arthropods are non-randomly distributed and reported the great dependence of their abundance and diversity from the chemical, physical and ecological properties (e.g. soil water content, temperature, prey availability, and plant cover) of this compartment [20,35,48,53]. Hence, litter arthropods are a group suited to

characterize ecosystems where they inhabit and to monitor responses of forest management practices [4,32,41].

The objective of this study was to analyse patterns of spatial and seasonal distribution of litter macro-arthropods among different vegetation covers (tree plantations and herbaceous areas) of the Porto Santo Island and to identify the main environmental variables influencing that distribution.

## 2. Material and methods

### 2.1. Study site

Porto Santo is a small Portuguese island, with 43 km<sup>2</sup>, from the Madeira Archipelago, located in the Atlantic Ocean (33° 04' N and 16° 21' W), near the West African Coast (Fig. 1). Volcanic islands from the archipelago of Madeira, Azores, Canary and Cabo Verde belong to a biogeographical region known as Macaronesia. Porto Santo Island presents two elevated areas: one in the Southwest and the other in the Northeast part of the island, with a mean altitude of 85 m. Several peaks, characterized by the dominance of different arboreous species, exist on both areas, which are separated by a smooth valley. Pico do Facho in the Northeast part of the island presents the greatest altitude (517 m) (Fig. 1). The island has a semiarid climate, with an average rainfall of 384.4 mm yr<sup>-1</sup>. The mean annual

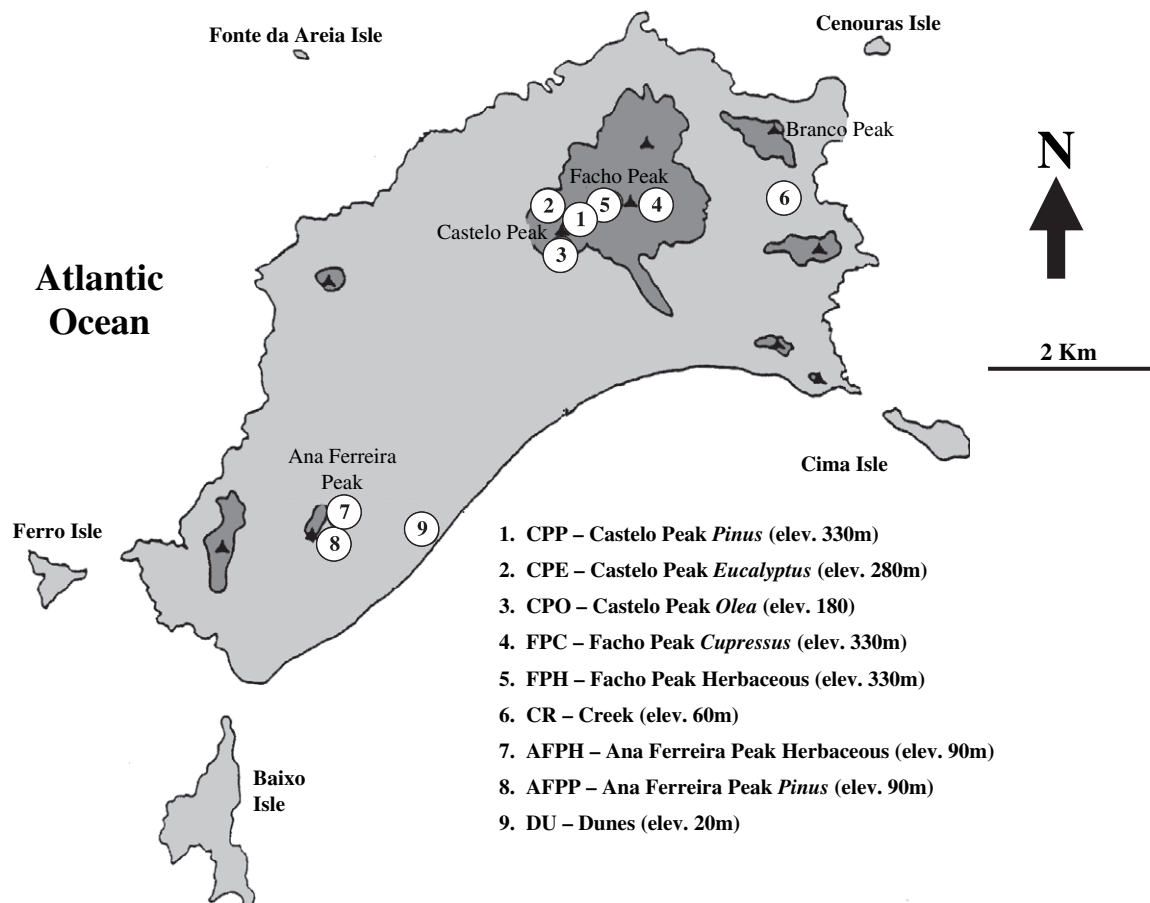


Fig. 1 – Geographical location and elevations of the sampling areas chosen in the Porto Santo Island. Dark areas represent higher elevations.

temperature being fairly uniform during the year, being the mean annual temperature around 18 °C. June and October are usually the warmer months in the year.

The island was discovered in 1418 by Portuguese navigators and in the first years of colonization its luxuriant natural vegetation was practically destroyed by fires, rabbits brought from the mainland, corn crops and by corsair's attacks [29,34]. The rabbits were considered the main destructive factor of native vegetation because they can reach high population densities, being serious pest crops [29]. Therefore, since the 15th century Porto Santo Island faces a dramatic process of soil erosion due to intense runoff of rainwater followed by a nutrient impoverishment. In order to decrease the rate of these processes, several attempts have been made to reforest different areas of the island, with some arboreous species, namely: *Cupressus macrocarpa* Hartweg, *Olea europaea* L. ssp. *maderensis* Lowe, *Pinus halepensis* Mill. and *Eucalyptus ficifolia* F. Muell. Nowadays, the island presents scattered small forest patches.

## 2.2. Samples collection

Fieldwork was conducted in February (w – winter) and July (s – summer) of 2002. Macro-arthropod sampling was done in nine areas, chosen at different locations in the island in order to include the existing vegetation cover types. These sampling areas also tried to represent the main habitats of the island, that due to their geographical location, in different slopes, were exposed or not to sun and dominant winds. The location and the code of each sampling area are described in Fig. 1. In each area five pitfall traps (8 cm in diameter) separated by 5 m were set and maintained in the field for 10 days. After this period, the content of each pitfall trap was collected and placed in 80% ethyl alcohol. Macro-arthropods were identified to the taxonomic level of order or family and the total number of individuals of each taxon, per trap, was recorded.

For the determination of soil chemical properties (pH, conductivity, water and organic matter content) 10 samples (10 cm depth) were randomly collected in each area, performing a total of 90 soil samples analysed. Samples were hand mixed on site and coarse materials, such as plant roots and stones, were removed. In the laboratory, air dried samples were sieved (2 mm) and stored in polyethylene bags at –20 °C until analysed.

## 2.3. Chemical and physical analyses

Soil pH and conductivity were measured in a soil water suspension (1:5 w/v extraction ratio) according to the method described in Ref. [9]. A WTW 330/SET-2 pH meter was used for all pH measurements. Conductivity was measured on the same suspension, which was left overnight in order to allow the bulk of the soil to settle, using an LF 330/SET conductivimeter [9]. The particle size distribution was determined by mechanical analysis following the method described in Ref. [9]. The mineral portion of the soil samples, obtained by a pre-treatment with hydrogen peroxide, to oxidize organic matter, and with a sodium hexametaphosphate solution to disperse particles, was separated in different fractions (2 mm, 1 mm, 500 µm, 250 µm, 100 µm, and 60 µm) by sieving and soils

were classified in terms of texture according to Gerrard [12]. Soil temperature was measured for all the sampling sites within approximately the same hours of the day, in the upper 10 cm of the soil surface at the shadow.

Soil water content was determined from the loss in weight after drying at 105 °C for 24 h. Organic matter content was determined by loss on ignition at 450 °C, during 8 h [40]. Organic carbon [46], total nitrogen [23], exchangeable K and Ca [39] and extractable phosphorus [47] were also analysed, however, only in three samples of each area. Soil organic carbon was determined by the wet digestion of soil with an acid dichromate solution followed by back titration of the remaining dichromate with ferrous ammonium sulphate solution and the determination of  $\text{Cr}^{3+}$  by potentiometry [46]. For total nitrogen determination, soil samples undergone a wet digestion with a mixture of sulphuric acid and selenium followed by distillation through vapour current [23]. Exchangeable K and Ca were extracted from soil samples with  $\text{CH}_3\text{COONH}_4$  (1 M, pH = 7) and determined by a flame emission spectrophotometer (Jenway PFP 7) and by an atomic absorption spectrophotometer (Perkin Elmer 3100) at 422.7 nm, respectively [39]. Phosphorus was extracted from soil samples with ammonium lactate (pH = 3.6) following the method of Egner et al. (1960 in Ref. [47]). The phosphate in the extract was then measured by the reaction with ammonium molybdate in an acid medium to form molybdophosphoric acid. This substance was then reduced to a blue coloured complex through the reaction with ascorbic acid (Murphy and Riley, 1962 in Ref. [47]). Absorbance was read at 882 nm using a spectrophotometer Thermospectronic Genesis 20.

## 2.4. Data analysis

Two-way ANOVA with seasons (winter and summer) and sampling areas as factors, followed by Tukey multiple comparison tests was used to analyse environmental variable data.

Several diversity descriptors were calculated for each sampling area at each season, namely richness (Margalef), diversity (Shannon) and evenness (Pielou) indices. Whittaker  $\beta$ -diversity was calculated for each season. These parameters were calculated according to Ref. [27]. Two-way ANOVA was also performed to test the influence of seasons and sampling sites on diversity parameters. In order to meet normality and variance homoscedasticity assumptions, environmental variables and diversity data were transformed by the equation  $x' = \log(x + 1)$  [49]. Analysis was done using SigmaStat 3.1 software.

For multivariate analysis the average number of animals per taxa, for each sampling area and for each season, and environmental variables' mean values were used to build data matrices. Prior to analysis taxa data were transformed using the equation  $x' = \log(x + 1)$ . A principal component analysis (PCA) [49], calculated using CANOCO for Windows version 4.0 [44], was used to summarize environmental variables into a few number of components that can be used to analyse relationships between the different sampling areas [33]. The following environmental variables were used: temperature, soil water content, pH, conductivity, organic matter, organic carbon, total nitrogen, C/N ratio, extractable P and

exchangeable K and Ca. Furthermore, the geographical exposure to dominant winds and sun (coded as present or absent) was also used as variable.

The relationship between soil fauna and explanatory variables was analysed through a canonical correspondence analysis (CCA). The CCA analysis is an ordination method in which the axes are linear combinations of environmental variables and the response variables (e.g. taxa) are distributed following a unimodal response to those variables [43]. Before the analysis, and in order to reduce the number of variables, the forward selection method was used to rank explanatory variables based on their role in the distribution of soil macro-fauna [45]. The Monte Carlo permutation ( $n = 499$ ) test was used to test the relation between each environmental variable and the biological data. In order to evaluate the contribution of vegetation to explain the variation in the distribution of soil litter arthropods, between the different sampling areas in the island, a partial correspondence analysis (pCCA) with vegetation patches as covariables was also performed.

### 3. Results

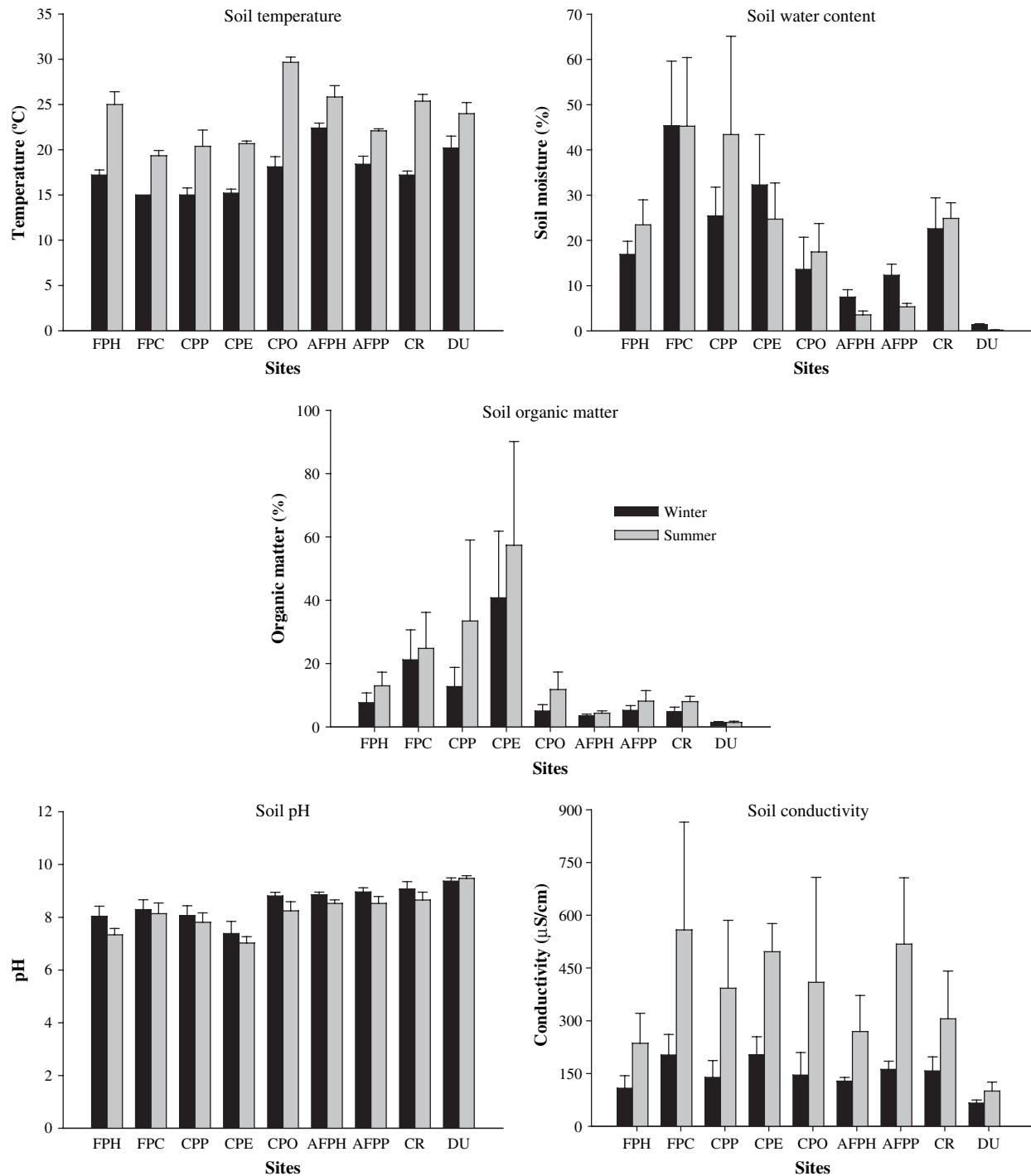
#### 3.1. Soil environmental variables

The soil type of all the sampling areas chosen in the Porto Santo Island was characterized by sandy silt loam soil except AFPH and DU which were located in a sandy loam and in a loamy sand soil, respectively.

The variation of the soil physical and chemical parameters between the two periods of the study, for each sampling area, is represented in Fig. 2. Significant interactions were found among seasons and sampling sites for soil temperature, water content, organic matter and pH (Table 1). Soil temperature varied between  $15.0 \pm 0.0$  °C (FPC) and  $20.4 \pm 4.2$  °C (AFPH) in the winter and  $19.3 \pm 0.6$  °C (FPC) and  $29.7 \pm 0.6$  °C (CPO) in the summer. Significant differences among seasons were recorded for all the sampling sites ( $p < 0.001$ ). As it was expected more exposed areas such as AFPH, AFPP, CPO, DU, CR and FPH presented significantly higher temperatures in the summer when compared with non-exposed areas such as FPC, CPP and CPE ( $p < 0.05$ ). No significant differences were found for soil water content among CR and FPH, CPE and CPP ( $p > 0.05$ ), as also between both vegetation patches of the Castelo Peak (CPP). The highest percentages for this parameter were measured at FPC ( $45.4 \pm 14.2\%$ , winter;  $45.3 \pm 15.2\%$ , summer) and CPP ( $43.4 \pm 21.8\%$ ). Soil water content varied significantly among seasons for all the sampling areas, except for FPC ( $p = 0.9$ ) and CR ( $p = 0.332$ ). The *Eucalyptus* ( $57.4 \pm 32.8\%$ ), *Pinus* ( $33.4 \pm 25.6\%$ ) and *Cupressus* ( $24.8 \pm 11.4\%$ ) patches of the Castelo and Facho peaks presented significantly higher soil organic matter contents, when compared with other sampling areas ( $p < 0.05$ ). The soil organic matter content varied significantly among seasons ( $p < 0.001$ ), except for FPC and DU. Almost all sampling areas were characterized by alkaline soils with pH values ranging between  $7.02 \pm 0.24$  (CPE, summer) and  $9.47 \pm 0.10$  (DU, summer). All the sampling areas showed significant differences among seasons, except FCP ( $p = 0.233$ ), CPP ( $p = 0.053$ ) and DU ( $p = 0.421$ ). No significant differences

were recorded for pH values among AFPH, AFPP, CPO and CR. The *Pinus* cover of the Castelo Peak (CPP) also showed pH values that did not differ significantly from those recorded in the *Pinus* (FPP) and herbaceous (FPH) cover of the Facho Peak, nearby. Sampling areas covered by *Cupressus*, *Eucalyptus* and *Pinus* patches [ $558 \pm 306.6$   $\mu\text{S}/\text{cm}$  (FPC);  $496.3 \pm 79.9$   $\mu\text{S}/\text{cm}$  (CPE); and  $518.1 \pm 188.3$   $\mu\text{S}/\text{cm}$  (AFPP)] showed significantly high conductivity values, especially in the summer, than areas with sparse vegetation such as DU, FPH and AFPH ( $p < 0.05$ ). Conductivity values recorded in the Dunes (DU) were also significantly lower than those recorded at CPO ( $p < 0.001$ ), CPP ( $p < 0.001$ ) and CR ( $p < 0.012$ ). And this sampling area also did not showed significant differences among seasons for this parameter.

Regarding soil nutrients (Fig. 3), no significant interactions were found among both factors tested by two-way ANOVA ( $p < 0.005$ ). The percentage of soil organic carbon was significantly higher ( $p < 0.001$ ) in the *Eucalyptus* cover of the Castelo Peak ( $11.64 \pm 4.16\%$ , winter;  $15.94 \pm 0.85\%$ , summer), when compared with all the other sampling areas. Additionally, only CPP and FPC presented significantly higher values for this parameter, when compared with Dunes (DU). No significant differences were recorded among seasons. Soil total nitrogen showed a similar pattern, however, the percentage of this nutrient in the soil of all the sampling areas was about 10 times lower than those recorded for organic carbon. Although remarkably high C/N ratios were recorded in the Dunes in summer ( $22.8 \pm 28.5$ ), CPP ( $14.19 \pm 1.27$ , winter;  $13.05 \pm 1.34$ , summer) and FPC ( $15.47 \pm 1.58$ , winter;  $14.22 \pm 4.51$  summer), no significant differences were recorded for this parameter among seasons and among sampling sites. As expected, extractable phosphorus, which includes mineral forms of phosphorus, an important macronutrient for plants, was particularly high in sampling areas with low organic matter contents, namely FPH ( $1106.7 \pm 644.2$   $\text{mg kg}^{-1}$ ), FPC ( $993.3 \pm 826.8$   $\text{mg kg}^{-1}$ ), CPO ( $1296.7 \pm 489.9$   $\text{mg kg}^{-1}$ ) and CR ( $1246.7 \pm 360.7$   $\text{mg kg}^{-1}$ ). However, only the last two sampling areas presented significant high values for this parameter when compared to DU, CPP and CPE sampling areas ( $p < 0.005$ ). The concentration of exchangeable potassium was significantly low in the Dunes (DU) ( $p < 0.005$ ), what is in agreement with the great mobility of this element in soils with a small adsorption capacity such as sandy soils. The highest concentrations of exchangeable potassium were recorded in the FPH ( $2.88 \pm 0.99$   $\text{cmol}^{(+)} \text{kg}^{-1}$ , winter;  $4.18 \pm 1.78$   $\text{cmol}^{(+)} \text{kg}^{-1}$ , summer) and CR ( $2.91 \pm 0.34$   $\text{cmol}^{(+)} \text{kg}^{-1}$ , winter;  $3.23 \pm 1.40$   $\text{cmol}^{(+)} \text{kg}^{-1}$ , summer). These two sampling areas had low organic matter contents, but were characterized by sandy silt loam soils which probably had a high retention capacity. In general, exchangeable calcium presented its highest levels in the sampling areas where exchangeable potassium was low, what is in agreement with its comparable high retention capacity due to its charge (++) and low hydration capacity [37]. The highest concentrations of this element were recorded in the Castelo Peak, namely CPP ( $19.36 \pm 7.78$   $\text{cmol}^{(+)} \text{kg}^{-1}$ , summer), CPE ( $19.89 \pm 3.18$   $\text{cmol}^{(+)} \text{kg}^{-1}$ , summer) and CPO ( $22.16 \pm 1.27$   $\text{cmol}^{(+)} \text{kg}^{-1}$ , winter). These sampling areas were significantly different from FPH and DU ( $p < 0.05$ ). Differences among seasons were especially recorded at CPP ( $p < 0.001$ ).



**Fig. 2 – Variation of the soil physical and chemical parameters (mean + SD), recorded in the different sampling areas at the Porto Santo Island, in the summer and winter study periods. Area codes as in Fig. 1.**

The PCA biplot of sampling areas and environmental variables separated two different groups: one including the less exposed sampling areas (CPE, CPP, and FPC), the other grouped the most exposed areas (AFPG, AFPP, FPH, CPO, CR, and DU). DUs was set apart from both groups (Fig. 4). The C/N ratio was the main discriminating factor of this sampling area which was characterized by an extremely high C/N ratio. The first component explained

46.7% of the total variance while the second component accounted for 18.2%. Organic matter, organic carbon and total nitrogen were the main contributors to the positive part of axis 1, while exposure and pH give the highest contribution to the negative part of the same axis. The positive part of axis 2 was mainly determined by the C/N ratio, while extractable P and exchangeable K were the main contributors to the negative part of the axis (Fig. 4).

**Table 1 – Summary table of the two-way analyses of variance applied to environmental variables and diversity parameters**

Endpoint	Source variation	F	d.f.	p
Temperature	Season	808.7	1	<0.001
	Sampling area	66.17	8	<0.001
	Season × sampling area	13.68	8	<0.001
	Residual		53	
Water content	Season	10.30	1	0.002
	Sampling area	254.2	8	<0.001
	Season × sampling area	12.90	8	<0.001
	Residual		179	
Organic matter	Season	45.90	1	<0.001
	Sampling area	102.4	8	<0.001
	Season × sampling area	2.495	8	0.014
	Residual		179	
pH	Season	63.20	1	<0.001
	Sampling area	107.6	8	<0.001
	Season × sampling area	3.249	8	0.002
	Residual		179	
Conductivity	Season	247.0	1	<0.001
	Sampling area	29.78	8	<0.001
	Season × sampling area	1.873	8	NS
	Residual		179	
Shannon index	Season	44.28	1	<0.001
	Sampling area	5.645	8	<0.001
	Season × sampling area	4.368	8	<0.001
	Residual		89	
Pielou equitability index	Season	54.77	1	<0.001
	Sampling area	6.977	8	<0.001
	Season × sampling area	5.272	8	<0.001
	Residual		89	
Diversity	Season	0.004	1	NS
	Sampling area	1.806	8	NS
	Season × sampling area	1.709	8	NS
	Residual		89	

NS = non-significant.

### 3.2. Soil litter macro-fauna

The total number of macro-arthropods and molluscs counted was 1910 in winter and 4511 in the summer. In the summer, the highest number of specimens was recorded in CR (1370), in the olive cover of the Castelo Peak (CPO, 866) and in the herbaceous cover of Ana Ferreira Peak (AFPH, 588) and of the Facho Peak (FPH, 568) (Fig. 5). In the winter, FPC and DU showed the highest number of specimens both with 310. Arthropods were distributed within 20 orders and 44 families (Table 2). From these, ants (Fam. Formicidae), millipedes (order Julida), aphids (Fam. Aphidae), coleopterans (Fam. Staphylinidae and Tenebrionidae), spiders (Fam. Zodariidae) and isopods (Fam. Porcellionidae) were the most abundant groups recorded in the pitfall traps.

The interaction among seasons and sampling areas for the Shannon index values was highly significant in winter (Table 1 and Fig. 5). The maximum diversity values were recorded in CPO ( $0.68 \pm 0.22$ ), AFPH ( $0.68 \pm 0.13$ ), FPH ( $0.67 \pm 0.15$ ), CPE ( $0.63 \pm 0.22$ ) and CPP ( $0.55 \pm 0.16$ ). Significant differences

among sampling areas were recorded only in the summer. In this season AFPH was, the area with the highest diversity ( $0.64 \pm 0.17$ ), differing significantly from the DU ( $p < 0.001$ ) and from the non-exposed Pinus (CPP) ( $p < 0.05$ ), *Eucalyptus* (CPE) ( $p < 0.01$ ) and *Cupressus* (FPC) ( $p < 0.01$ ) covers of the Castelo and Facho peaks. Additionally, FPC and CPE showed significantly diversity values when compared with FPH ( $p < 0.01$ ), CR ( $p < 0.01$ ) and CPO ( $p < 0.05$ ). The Pielou evenness index showed exactly the same pattern as the Shannon diversity index (Table 1 and Fig. 5). The highest number of taxa was recorded at CR (24) during summer. CPEw and AFPHs had the lowest number of taxa (11). The average value of taxa recorded in pitfalls did not show significant variation among seasons and among the different sampling areas in the island (Table 1 and Fig. 5). These results were in agreement with Whittaker  $\beta$ -diversity values calculated for the island, which were low and similar for both seasons (2.48 to winter and 2.15 to summer).

The canonical correspondence analysis (CCA) using the method of forward selection showed that temperature, C/N ratio, exchangeable K and exposure were the only variables with a significant effect on the distribution of the different taxa (Monte Carlo permutation test with  $p < 0.05$  for all these variables). The CCA performed with these variables had eigenvalues of 0.221 (axis1), 0.186 (axis 2) and 0.149 (axis 3) (Table 3 and Fig. 6). Temperature and exposure were positively correlated with axis 1 ( $r = 0.93$  and  $r = 0.58$ , respectively) while the C/N ratio was positively correlated with axis 2 ( $r = 0.78$ ). Exposure was also negatively correlated with axis 2 ( $r = -0.67$ ). In the CCA ordination diagram of taxa, soil environmental variables and sampling areas, it can be observed that a great number of taxa occurred near the origin of the axes (Table 3 and Fig. 6). These taxa can be considered as habitat generalists, while those occurring far from the origin are habitat specialists. Irrespective of the season, isopods (Fam: Porcellionidae, Endomychidae, Armadillidiidae), coleopterans (Fam: Scolytidae, Nitidulidae) and spiders (Fam: Pisauridae, Clubionidae, Oonopidae) were related with non-exposed sampling areas, namely the *E. ficifolia* and *P. halepensis* plantations of the Castelo Peak (CPE and CPP) and the *C. macrocarpa* plantation of the Facho Peak (FPC), respectively. Other families of coleopterans (Fam: Loccineidae, Byturidae), spiders (Fam: Thomosidae, Zoridae), true bugs (Fam: Cicadellidae) and thrips (Fam: Thysanoptera) were related with most exposed sampling areas (CPO, FPH, AFPP, AFPH and DU), particularly in the winter. True bugs (Fam: Piesmidae, Pentatomidae) and true crickets (Fam: Gryllidae) were related with the Dunes (DU) in the summer.

In order to analyse the influence of the different vegetation covers on the relationship among taxa data and soil environmental variables, a partial canonical correspondence analysis (pCCA) with vegetation patches as covariables was performed. Total variance explained by global and partial CCA models, calculated as the quotient between the sums of all the canonical eigenvalues and the sum of eigenvalues, is described in Table 4. The analysis of this table shows that soil environmental variables explained the greatest percentage of variation in the distribution of soil fauna among the sampling areas (30%). The vegetation patches only contributed to 19% of the explained variation while 59% remains unexplained.

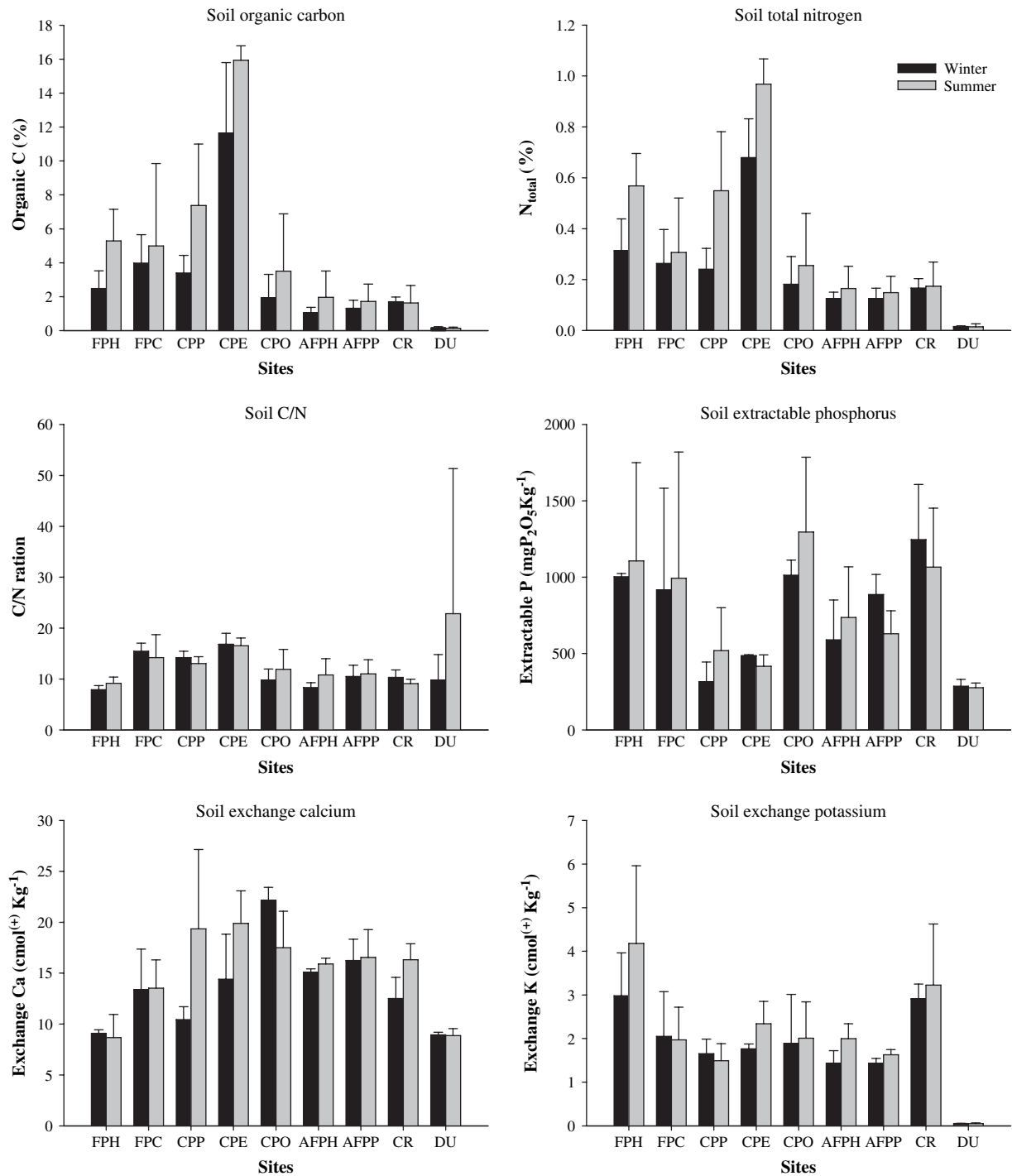
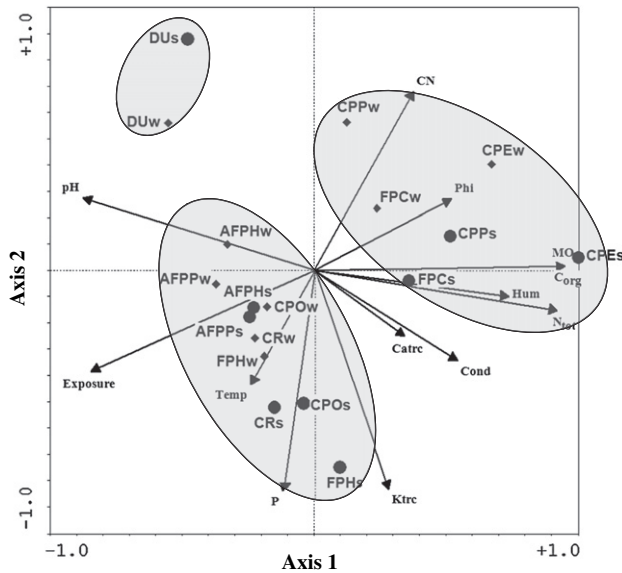


Fig. 3 – Variation of the soil nutrient concentrations and C/N ratio (mean + SD), recorded in the different sampling areas at the Porto Santo Island, in the summer and winter study periods. Area codes as in Fig. 1.

#### 4. Discussion

In our study, the biplot derived from PCA analysis showed that the geographical exposure to winds and solar radiation was relevant in determining the separation of the different sampling areas chosen in the Porto Santo Island. This dichotomy between non-exposed (CPP, CPE and FPC) and exposed areas

(AFPP, AFPH, FPH, CPO, DU, and CR) did not take into consideration the tree species planted in each area and the season. However, analysis of variance showed that environmental variables (temperature, soil water content, soil organic matter and pH) varied significantly among seasons, suggesting that the variable exposure is probably masking or overlapping the effect of seasons. The non-influence of seasonality was



**Fig. 4 – PCA biplot of sampling areas and environmental variables. Except for exposure, the other environmental variables are represented by arrows (Temp – temperature; pH; Cond – conductivity; OM – organic matter;  $C_{org}$  – organic carbon;  $N_{tot}$  – total nitrogen; C/N ratio;  $K_{exc}$  – exchangeable potassium;  $Ca_{exc}$  – exchangeable calcium; P – extractable phosphorus). Area codes as in Fig. 1 and s – summer; w – winter.**

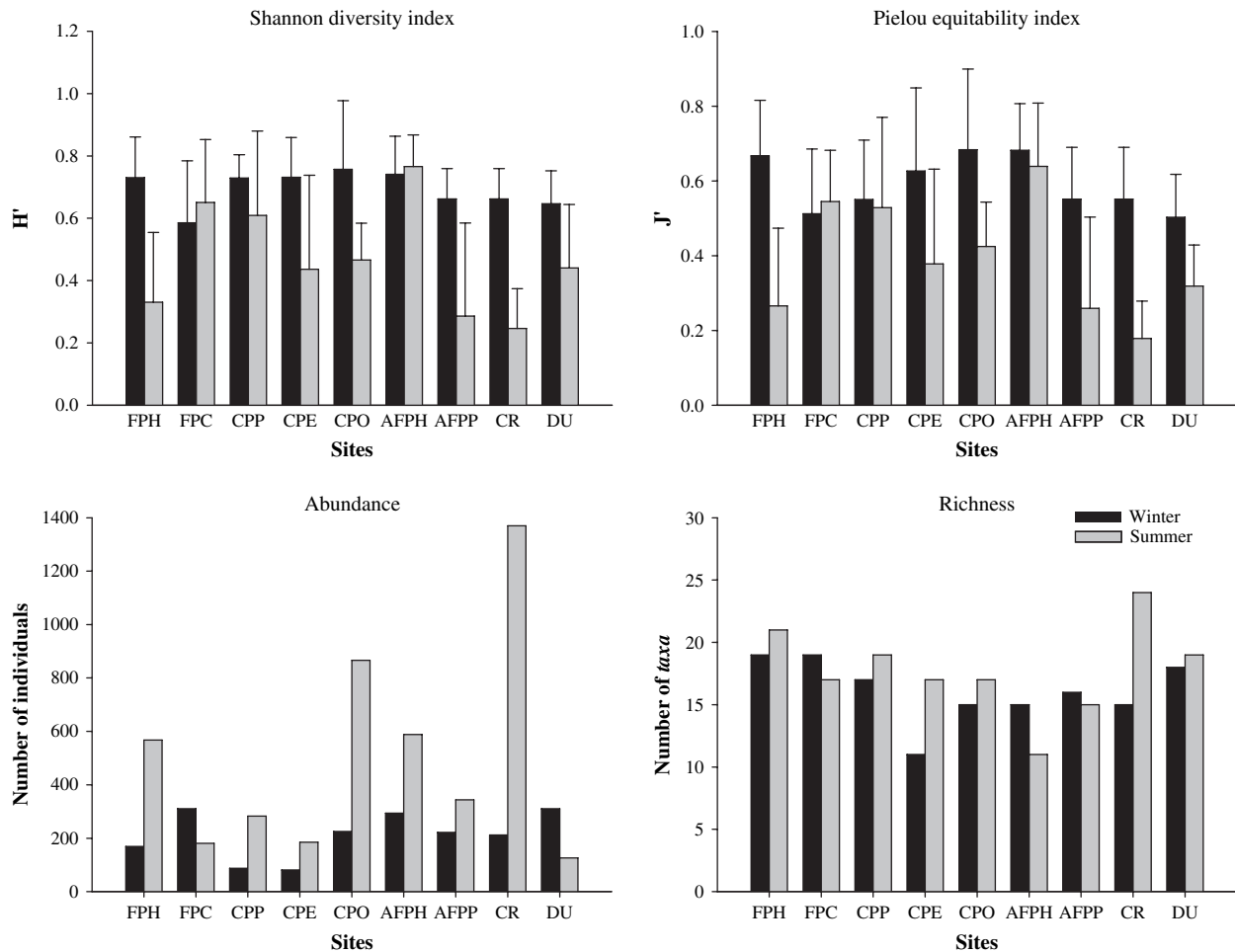
expectable since Porto Santo Island is a small island in the middle of the Atlantic Ocean where homogeneous climatic conditions, moderated by the sea, are expected all over the year [5]. However, in more exposed areas, such as edge zones of the forests, higher wind speeds usually alter physical conditions of the forest floor, but also blows away a substantial part of the litter [21]. This may explain the higher soil temperatures, the low percentage of soil water content recorded in the exposed areas of the Porto Santo Island. In fact soil water content and temperatures are close related factors since at high temperatures soils are more likely to desiccate because of faster evaporation leading to soil drought that may have adverse effects on the litter fauna [11]. In opposition, non-exposed areas are mainly characterized by lower soil temperatures and higher percentages of soil water content. High C/N ratios and high organic matter contents were also recorded in the soil of CPP, CPE and FPC. Similarly to other studies (e.g. [17]), this observation suggests that leaf litter chemistry was probably influencing decomposition processes in these areas.

In the Porto Santo Island, the highest number of macro-arthropods was recorded in the summer and in the sampling areas more exposed to winds and solar radiation (CR, CPO, AFPH and FPH). This fact may be explained by the likely evolution, in some taxon, of a resistance to desiccation as an adaptation to habitat condition. This is a process that is particularly favoured by the isolation effect of the islands and has been already recorded by other authors [2]. On these exposed areas, soil fissures (personal observation) may also offer a sheltered habitat for the protection of some taxa of

macro-arthropods. Bauer et al. [2] observed that soil crevices can maintain an atmosphere saturated with water vapour which provide conditions for litter arthropods to prevent excessive water loss.

Regarding the diversity of arthropods in the forest floor, it has been assumed that it enhances system complexity which in turn can influence ecosystem stability [4]. In the Porto Santo Island, the  $\beta$ -diversity values recorded in both seasons reflected the high similarity between community composition of the different sampling areas chosen in the island [19]. The highest Shannon index diversity values were recorded in the winter, on the herbaceous cover of two exposed areas (FPH and AFPH) and in CPO. In opposition non-exposed areas covered by *P. halepensis*, *E. ficifolia* and *C. macrocarpa* presented significantly high diversity values in the summer, when compared with exposed areas, such as FPH, CPO and CR. However, the Pielou evenness index showed the same pattern of variation, confirming that in these areas, the increment in diversity is more related with evenness than with the number of taxa. In fact, in FPC the increase in diversity in the summer occurred in parallel with a decrease in taxa number. While CPP and CPE showed the opposite trend, since a decrease in diversity corresponded to an increase in taxa number. According to Bird et al. [4] who have recorded lower diversity values in a Texas pine plantation during the summer months (between July and October), this may be explained by the migration of organisms downwards in the soil profile during the hot summer months, preventing them from being caught by the pitfall traps. In opposition, in Porto Santo Island, the smoothed environmental conditions offered by non-exposed areas, such as that covered by *Pinus* and especially by *Cupressus*, have avoided this kind of behaviour. Hence, considering tree species planted on the island, *P. halepensis* and *C. macrocarpa* Castelo Peak seem to promote soil properties in an extent that makes these areas able to support a great diversity of litter macro-arthropods. According to Maestre and Cortina [26], *P. halepensis* plantations can actually improve soil properties in a few years to decades, being this species considered a pioneer species that favours the establishment of late successional stages. However, these authors also pointed the reduction in water availability as one of the disadvantages of *P. halepensis* plantations that has to be counterbalanced with the improvements in soil fertility. Additionally, pines are frequently hosts of pine feeding insects that can become pests [10,26,36]. Although in a small number, since they spend most of their adult life on trees, bark beetles (Fam. Scolytidae) were associated with the CPP sampling area (Fig. 6), suggesting that if appropriate conditions for their development are attained, this taxon may impair the health of the *P. halepensis* plantations, from the Porto Santo Island. In spite of the sheltered habitat offered by the litter layer of the *E. ficifolia* plantation in the Castelo Peak (CPE) this area showed the lower number of taxa, in winter, what may be explained by the high levels of phenolic compounds in the leaves of trees of the genus *Eucalyptus* whose effects on fungi and on the reproduction and mortality of isopods were already reported [13,17,31,51]. On the other hand, as it can be observed on the triplot from the CCA analysis, the highest diversity of the herbaceous cover of the Ana Ferreira (AFPH) and Facho (FPH) peaks may be explained by the association of most generalist taxa with these areas.





**Fig. 5 – Variation of the diversity and equitability indexes, total abundance and species number, in the different sampling areas chosen in the Porto Santo Island, in the summer and winter study periods.**

The partitioning of variance of the canonical ordination demonstrated that the different vegetation covers had a small influence on macro-arthropods distribution among sampling areas, because they only explained 19% of the total variance of data. Environmental variables alone explained 30% however, 59% of the total variation remains unexplained, because sampling areas also differ in other biotic and abiotic parameters that were not accounted in this study. Several studies demonstrated the influence of litter chemistry and soil microbial activity (assessed by several different parameters as for example microbial biomass, enzymes activity, biologic, etc.) on the colonization of soil by arthropods [20,28,51,52]. Some of these microbial parameters were assessed in parallel with this study, in order to get more information about the ecological properties of the different plantations, in Porto Santo Island. The CCA triplot of taxa, environmental variables and sampling areas showed, once more, the influence of the geographical exposures to winds and solar radiation on the distribution of litter macro-arthropods. This variable separated exposed areas, mainly characterized by high soil temperatures and associated with more generalist taxa, from non-exposed areas characterized by high temperatures and high C/N

ratios and inhabit by more specialized taxa. The influence of soil temperature on the distribution of litter macro-arthropods was already recorded by other authors [30,50].

In conclusion, our study showed that in the Porto Santo Island, the exposure to solar radiation and winds was of primary importance in determining the soil physical and chemical conditions of the different areas and the subsequent distribution of the litter macro-arthropods. Temperature and C/N ratio were the abiotic factors with the greatest influence on the variation of taxa abundance and presence/absence among sites. The effect of seasons seems to be greater on diversity, creating a dichotomy among exposed areas, covered by herbaceous vegetation and non-exposed areas or areas covered by arboreous vegetation that offered more sheltered conditions for soil macro-arthropods, particularly in the summer. However, this observation may result from an adaptable burrowing behaviour of litter macro-arthropods to prevent exposure to higher temperatures and low soil water content conditions in the warmer periods that reduce the efficiency of pitfall traps, in exposed areas. Higher diversity values were recorded in exposed areas of the island, with a sparse herbaceous vegetation cover (AFPH and FPH), what may be

**Table 2 – Taxa recorded in Porto Santo Island and corresponding abbreviations used in the partial CCA triplot (Fig. 6)**

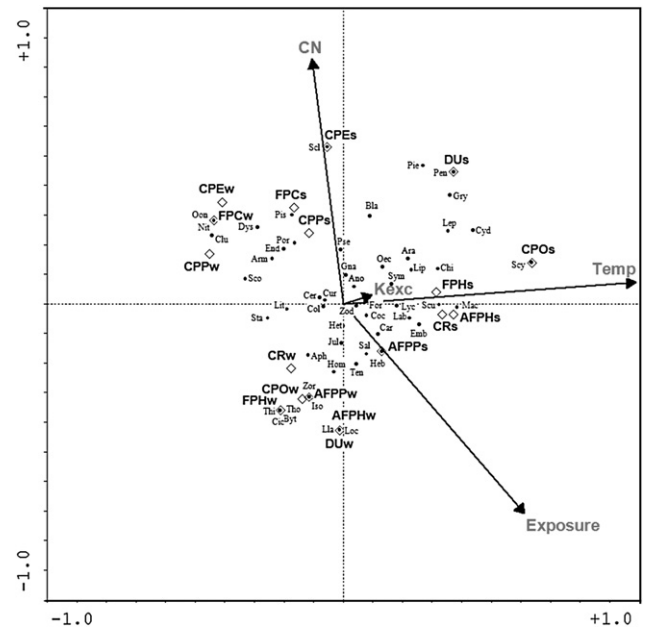
Ordem	Taxa	Abbrev.
Araneae	Araneidae	Ara
Araneae	Clubionidae	Clu
Araneae	Dysderidae	Dys
Araneae	Gnaphosidae	Gna
Araneae	Lycosidae	Lyc
Araneae	Oecobiidae	Oec
Araneae	Oonopidae	Oon
Araneae	Pisauridae	Pis
Araneae	Salticidae	Sal
Araneae	Scytodidae	Scy
Araneae	Thomisidae	Tho
Araneae	Zodariidae	Zod
Araneae	Zoridae	Zor
Blattodea		Bla
Coleoptera	Anobiidae	Ano
Coleoptera	Byturidae	Byt
Coleoptera	Carabidae	Car
Coleoptera	Cerambycidae	Cer
Coleoptera	Coccinellidae	Coc
Coleoptera	Coleoptera larvae	Col
Coleoptera	Curculionidae	Cur
Coleoptera	Endomychidae	End
Coleoptera	Loccinellidae	Loc
Coleoptera	Nitidulidae	Nit
Coleoptera	Scolytidae	Sco
Coleoptera	Staphylionidae	Sta
Coleoptera	Tenebrionidae	Ten
Dermaptera	Labiidae	Lab
Embioptera	Embioptera	Emb
Hemiptera	Aphididae	Aph
Hemiptera	Cicadellidae	Cic
Hemiptera	Cydnidae	Cyd
Hemiptera	Herbridae	Her
Hemiptera	Heteroptera larvae	Het
Hemiptera	Pentatomidae	Pen
Hemiptera	Piesmidae	Pie
Homoptera	Homoptera larvae	Hom
Hymenoptera	Formicidae	For
Isopoda	Armadillidiidae	Arm
Isopoda	Isopoda larvae	Iso
Isopoda	Porcellionidae	Por
Julida	Julida	Jul
Lepidoptera	Lepidoptera larvae	Lla
Lithobiomorpha	Lithobiidae	Lit
Orthoptera	Gryllidae	Gry
Pseudoscorpiones	Pseudoscorpiones	Pse
Psocoptera	Liposcelidae	Lip
Scolopndromorpha	Chilopoda larvae	Chi
Scolopndromorpha	Scolopndromorpha	Scl
Scutigermorpha	Scutigermorpha	Scu
Symphyla	Symphyla larvae	Sym
Thysanoptera	Thiridae	Thi
Thysanura	Lepismatidae	Lep
Thysanura	Machilidae	Mac

**Table 3 – Interset correlations of soil environmental variables with axes**

	Axis 1	Axis 2	Axis 3
Temperature	-0.535	0.058	-0.052
C/N	0.671	0.516	0.127
K <sub>exc</sub>	0.014	-0.544	-0.527
Exposure	-0.768	0.174	-0.250

explained by the presence of most generalist taxa that were recorded in the centre of the CCA triplot. Regarding plantations, *P. halepensis* and *C. macrocarpa* showed the highest diversity values, especially in the summer, indicating that both species seem to promote suitable ecological properties for litter arthropods community. Most specialist taxa were associated with *C. macrocarpa*, *E. ficifolia* as well as *P. halepensis* covers suggesting that chemical properties of the litter yield by these tree species may also have an influence on the litter macro-arthropods distribution.

A great percentage of the variability in the litter macro-arthropods distribution remains unexplained, indicating that other abiotic and biotic parameters as for example litter chemistry, soil micro-fauna abundance and distribution and soil microorganisms biomass and activity have to be assessed to provide a more precisely comprehension of the litter macro-arthropods distribution and of it's relationship with the different tree species planted in the island.



**Fig. 6 – CCA ordination diagram of taxa, sampling areas and environmental variables. Significant environmental variables ( $p < 0.05$ ) are represented by arrows (C/N ratio; Exposure; Temp – temperature; K<sub>exc</sub> – exchangeable potassium). The abbreviations of taxa names are plotted and complete names are listed in Table 2. Area codes as in Fig. 1 and s – summer; w – winter.**

**Table 4 – Summary of variance partition calculated from global CCA (environment + seasons) and partial CCA (defining vegetation as covariable)**

	Total of eigenvalues	Sum of all canonical eigenvalues	Total variability explained (%)
CCA model, species/ environmental variables	2.126	0.870	41
CCA model, species/ vegetation patches	2.126	0.639	30
Partial CCA model with vegetation patches as covariables	1.487	0.643	30
Total variance explained by: vegetation patches 30% – 11% = 19%, variance unexplained = 59%			

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