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Effect of Soil Parameters on the Distribution of Soil Fauna from Roadside Trees at Three Elevations in Mauritius

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Abstract

The effect of soil parameters on the distribution of soil fauna was carried out in Mauritius during summer from November 2012 to April 2013. The objective of this study was to determine the distribution of soil fauna of roadside trees at three elevations in Mauritius. Soil fauna were collected utilizing pitfall traps made of plastic cups at three different elevations (Flic en Flac, 5 m; Rose-Hill, 221 m; and Mare aux Vacoas, 569 m). Traps were placed among *Casuarina equisetifolia* (5m), *Dictyosperma album* (221 m) and *Pinus sylvestris* (569 m) trees. A total of 18730 individuals were sampled of which 10740 individuals were sampled at 5 m, 5293 individuals at 221 m and 2697 individuals at 569 m. Significant difference was recorded between study sites and months when considering humidity, temperature, soil carbon content and soil moisture ($p<0.05$). However, no significant difference was recorded between months when considering soil pH and soil calcium ($p>0.05$) but significant difference was recorded between study sites ($p<0.05$). Principal component analysis extracted 18 out of 24 soil fauna species. Preference of soil fauna for higher levels of certain soil parameters was observed. Higher Shannon Weiner Diversity Index and Evenness were recorded at Mare aux Vacoas, while higher Margalef Index was recorded at Rose-Hill. This index was used to quantify the species richness. This study can be useful in determining soil fauna distribution and their specificity as such data has implications for biological control as well as for collection of specific insects. Moreover, this study also has implications for town planners with respect to planting roadside trees and their ensuing edaphic communities for managing insect pests. Moreover, the soil fauna species richness and community structure from roadside trees located at different elevations in Mauritius were also considered.

Keywords: soil fauna; soil parameters; bait traps; roadside trees fauna.

Introduction

Mauritius is an island located some 900 km east of Madagascar and is approximately 1865 km^2 [1]. The island's forest cover presently stands at 2% [2], however active conservation efforts have been put in practice to reverse the loss in tree cover, such as planting roadside trees in urban areas amongst others [3].

Roadside trees constitute the urban landscape where they not only add to the aesthetic aspect of the streets, but more importantly help in mitigating soil erosion, water runoff, flooding [4], stabilize highly disturbed soils after road constructions [5] and are important habitats of soil fauna which are ecosystem engineers influencing soil properties as well redistributing resources used by other organisms [6].

Different elevations offer different environments with respect to temperature and moisture, thus influencing the variation in geographical richness patterns [7-9] of soil fauna. Temperature, precipitation and humidity are influenced by wind, while soil structure is influenced by tree species and inhabiting soil fauna as well as the climate [10].

The soil fauna of Mauritius comprises some 1993 species from 22 orders with 744 endemics recorded from the main island of Mauritius [11]. The soil fauna species richness in Mauritius however, is likely to be underestimated due to the paucity of taxonomical studies. The existing literature on the native forest insects is limited with respect to their ecology and biology and is largely biased towards the Coleoptera (beetles) [12]. Out of the 167 extant beetle families that have been recorded from Mauritius, 11 families comprise single species while 13 families do not include any endemics either at the genus or species level. Published information on soil fauna orders such as the Protura, Collembola, Diplura, Plecoptera, Grylloblatlodea, Mecoptera and Rhaphidioptera is not available [11]. Recent studies of soil fauna from Mauritius have been reported [13-15]. This study reports on the distribution and abundance of soil arthropod species in terms of community structure and species richness; affected by physico-chemical parameters. The data generated would provide an account of soil arthropod species richness and community structure in Mauritius [13]. However, in this paper, more emphasis is drawn to the effect of soil parameters on the soil fauna.

Materials and Methods

Soil fauna sampling sites were at Mare aux Vacoas (569 m, 20°22'31.46'S, 57°30'18.58'E), Rose-Hill (221 m, 20°13'60S, 57°28'0E) and Flic en Flac (5 m, 20°16'47.2074'S, 57°21'59.2302'E) (Figure 1). The primary species of roadside trees at Flic en Flac was *Casuarina equisetifolia*, at Rose-Hill was *Dictyosperma album* and at Mare aux Vacoas was *Pinus sylvestris*.

Bait traps made of plastic cups were utilized to sample soil fauna. Three bait traps each containing different baits (soapy water, beef extract, and beer and banana) were placed within 200 m intervals among the roadside trees along a 2 km transect line at each elevation

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Figure 1: Location of study sites in Mauritius [18].

(in total 30 bait traps per elevation: 10 containing soapy water; 10 containing beef extract; and 10 containing beer and banana) [15].

The traps were lodged into the ground to a depth of 5 cm and were placed at their respective elevations among the roadside trees between 4 am to 10 am and fauna samples were collected after 48 hrs. Six sampling trips were conducted during the summer season from November 2012 to April 2013. Collected samples were separated into containers according to sites and pitfall trap types. In the laboratory the soil fauna were washed with distilled water to remove debris and then preserved in 70% alcohol. The soil fauna were enumerated and were identified at the Mauritius Sugarcane Research Institute (MSRI) [15].

Four soil parameters were recorded in this study namely, soil pH, soil carbon content, soil moisture, soil calcium content, and temperature and humidity. Soil samples were taken at each sampling station (10 sample stations) per study site and later analysed in the laboratory of MSIRI. Temperature and humidity records were obtained from the Mauritius Meteorological Services.

The Shannon Wiener Diversity, H [16], Shannon Evenness, J [17] and the Margalef, D [16] indices were utilized to determine the community structure of the soil fauna. A One-way ANOVA was conducted to determine significant difference of environmental parameters at each study site while a Two-way ANOVA was conducted to determine significant difference of elevation and bait trap on soil fauna abundance and biomass by utilizing SPSS ver. 22 software. A principal component analysis was conducted for soil parameters on soil fauna abundance using PC-ORD ver.6 software. A Pearson's multiple correlation was conducted between the environmental parameters and utilizing SPSS ver. 22 software.

Results

Abundance

A total of 18,422 soil arthropods were sampled from 11 orders, 11 families comprising 16 species were collected [18], and a total of 18,730 soil fauna specimens were collected comprising 18 families represented by 24 species. Rose-Hill recorded 14 families comprising 18 genera and 18 soil fauna species, and 11 roadside tree species; Mare aux Vacoas recorded 13 families comprising 18 genera and 18 soil fauna species, and 1 roadside tree species; Flic en Flac recorded 8 families comprising 14 genera and 14 soil fauna species, and 1 roadside tree species.

Carpophilus cheesmani (mean abundance=4.36 individuals) was most abundant at Flic en Flac while *Nylanderia dodo* (mean abundance=3.169 individuals) at Rose-Hill and *Anisolabis maritima* (mean abundance=0.865 individuals) at Mare aux Vacoas (Table 1).

Higher Shannon Wiener Diversity was recorded at Mare aux Vacoas (H'=2.54), while Rose-Hill (H'=1.21) recorded the lowest value (Table 2). The Shannon Evenness for Rose-Hill (J'=0.77) was higher than at Mare aux Vacoas (J'=0.53), while higher Margalef Index was recorded at Rose-Hill (D'= 2.72) and lowest at Flic en Flac (D'=1.41) (Table 2). Significant difference in diversity was recorded between months at each study site ($p<0.05$). The Shanon and evenness indices were significantly higher in Dec-12 (mean: H'=1.87; J'=0.76) but significantly lower in Feb-13 (mean: H'=0.72; J'=0.37) from the three study sites (Figures 2 and 3). Margalef's Index was higher in Jan-13 (mean D'= 1.79) than the

Mean Abundance (indiciduals)				
Species	**Flic en Flac**	**Rose-Hill**	**Mare aux Vacoas**	**Totoal**
Achatina immacualata	-	0.036	0.047	0.083
Agelenopsis aperta	-	0.064	0.128	0.192
Deroceras laeve	-	0.008	0.303	0.311
Anisolabis maritima	-	-	2.594	2.594
Gromphadorhina portentosa	0.317	0.208	-	0.525
Bradybaena simularis	-	0.022	0.097	0.119
Drosophila melanogaster	0.25	0.089	0.111	0.225
Elater abruptus	0.011	-	-	0.011
Ceciliodes acicula	-	0.114	0.039	0.153
Anoplolepis gracilipes	6.703	3.097	0.139	9.939
Camponotus maculatus	0.278	0.244	-	0.522
Nylanderia dodo	0.386	9.506	0.122	10.014
Nylanderia bourbonica	0.411	0.067	0.208	0.686
solenopsis geminata	5.56	0.158	-	5.719
Lithobius forficatus	-	0.019	-	0.019
Lithobius terrestris	-	-	0.028	0.028
Carpophilus cheesmani	13.089	0.808	2.014	15.911
Nitidula rufipes	0.325	0.061	-	0.386
Cyllodes ater	0.022	-	-	0.022
Pholcus Phalangioides	0.075	-	0.022	0.097
Porcellio scaber	0.128	0.022	0.178	0.328
Talitroides sylyaticus	-	-	1.317	1.317
Blapstinus fortis	0.783	0.175	0.147	1.106
Laeyivaulis alte	-	0.011	-	0.011
(Total-24 species	(Total=28.114)	(Total=14.711)	(Total=7.494)	(Total=50.319

Table 1: Mean abundance of Soil Fauna Sampled by Study Sites in Mauritius.

Study Site	**Shannon Wiener Diversity (H')**	**Shannon Evenness (J')**	**Margalef (D')**
Flic en Flac	1.84	0.70	1.41
Rose-Hill	1.21	0.42	2.72
Mare aux Vacoas	2.54	0.92	2.15

Table 2: Species Diversity and species richness for three study sites in Mauritius.

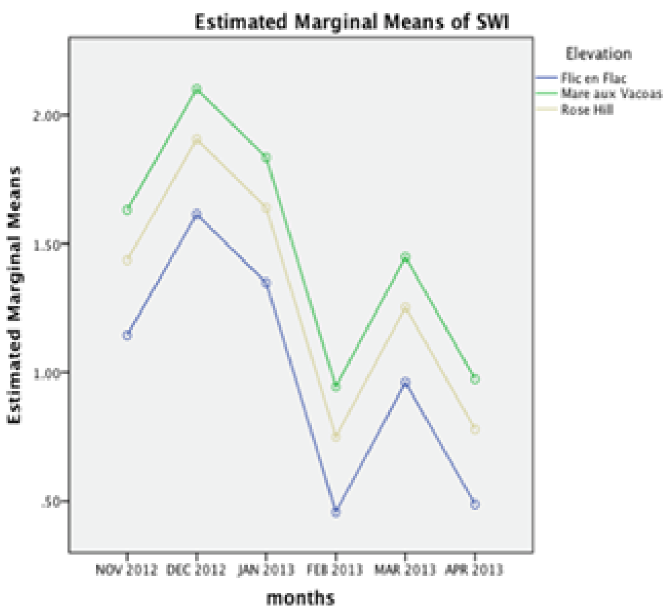


Figure 2: Monthly record of Shannon Wiener Diversity at the three study sites.

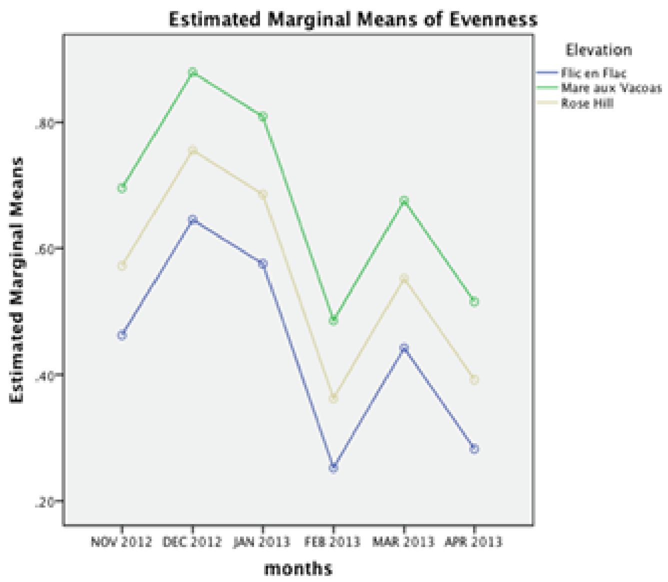


Figure 3: Monthly record of Shannon Evenness at the three study sites.

other months while Feb-13 (mean D'=0.95) recorded the lowest species richness (mean D'=0.95) (Figure 4).

Soil carbon content

Soil carbon content during the first three months (Nov-12, Jan-13 and Feb-13) was relatively low and somewhat similar, but higher from Feb-13 to Apr-13 at the three study sites (Figure 5). Higher soil carbon content was recorded at Mare aux Vacoas (mean=45.78 ± 28.64 g) followed by Flic en Flac (mean=36.27 ± 23.89 g) and lowest at Rose-Hill (mean=28.01 ± 10.32 g). Significantly higher soil carbon content was observed during the last 3 months of the sampling period (Feb-13 to Apr-13) ($p<0.05$) between the study sites.

Soil moisture

Higher soil moisture was recorded at Mare aux Vacoas while lower at Flic en Flac (Figure 6). Significant difference in soil moisture content was observed between Mare aux Vacoas and Flic en Flac ($p<0.05$). Soil moisture content at Mare aux Vacoas (mean=31.45 ± 5.14%) was higher than Rose-Hill (mean=16.67 ± 5.41%) and lowest at Flic en Flac (mean=13.05 ± 3.37%). Significant difference was recorded between Dec-12 and other months ($p<0.05$) for the three elevations.

Soil pH

The pH at Flic en Flac (mean=7.89 ± 0.11) and Rose-Hill (mean=7.53 ± 0.46) was significantly higher than at Mare aux Vacoas (mean=5.53 ± 0.32); and between Flic en Flac (mean=7.89 ± 0.11) and Rose-Hill (mean=7.53 ± 0.46) ($p<0.05$). However, no significant difference was observed between months ($p>0.05$) for the three sites (Figure 7).

Soil calcium content

The calcium content at Flic en Flac (mean=12.52 ± 0.04 g) was significantly higher than at Rose-Hill (mean=6.75 ± 0.53 g) and Mare

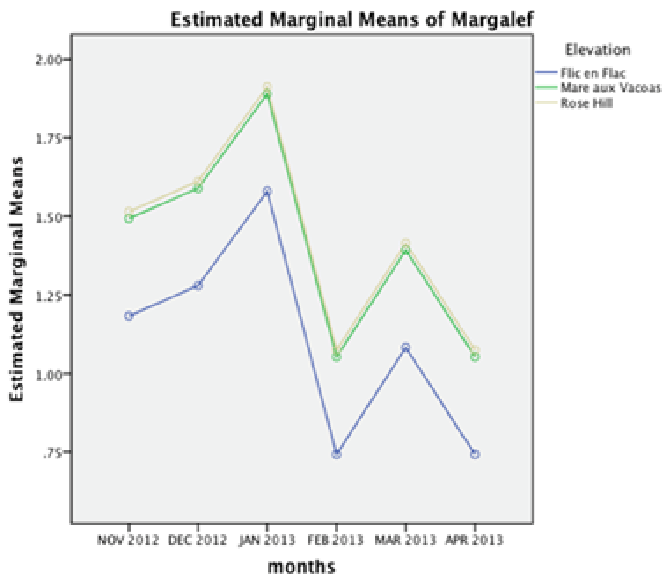


Figure 4: Monthly record of Margalef Index at the three study sites.

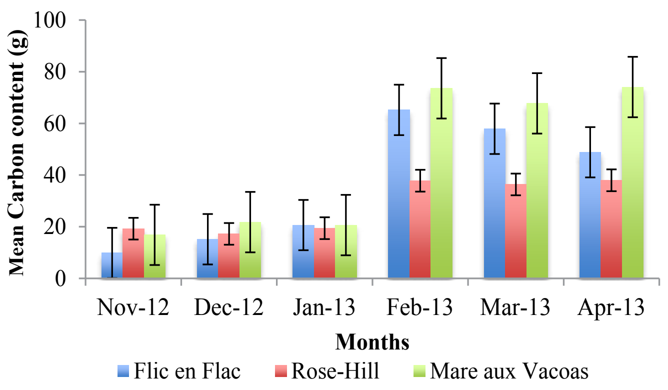


Figure 5: Mean carbon content of soil at three study sites in Mauritius.

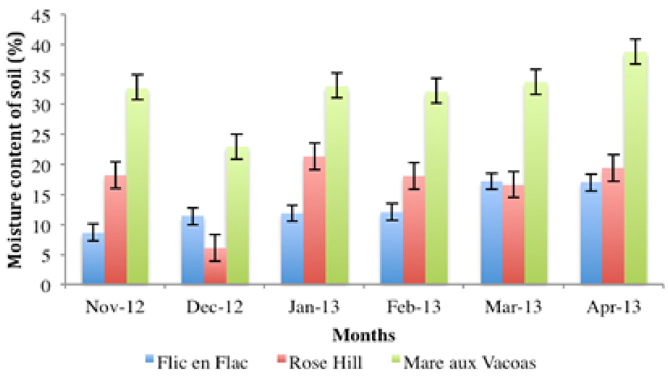


Figure 6: Soil moisture content of soil at three study sites in Mauritius.

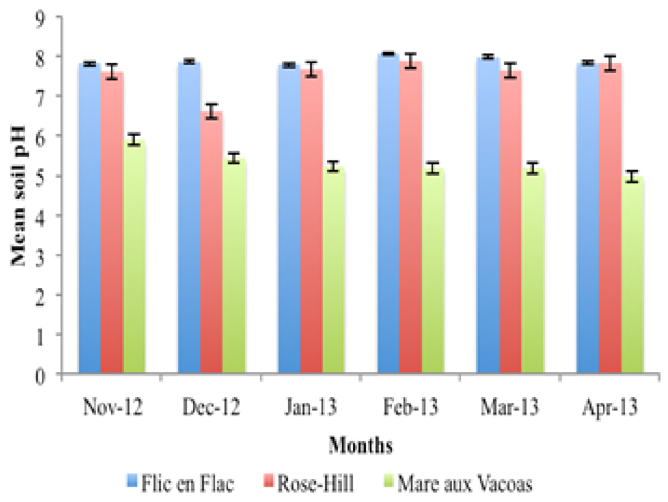


Figure 7: Soil pH at three study sites in Mauritus.

aux Vacoas (mean=9.46 ± 0.21 g) ($p<0.05$), but no significant difference was recorded between months per study site ($p>0.05$) (Figure 8).

Temperature and humidity

Significant difference in temperature between elevation and months was observed (Nov-12, Dec-12, Marc-13 with the other months) ($p<0.05$). There was significant difference in humidity between elevations and months (between Nov-12 and Jan-13, Feb-13, Mar-13, Apr-13; between Dec-12 and Feb-13, Apr-13; between Feb-13 and Jan-13, Mar-13) ($p<0.05$) (Figure 9).

The canonical response between environmental parameters and soil fauna abundance is given in Figure 10. Out of 24 species of soil fauna, only 18 species were extracted due to their higher relative abundance. *Achatina immaculata*, *Ceciliodes acicula* and *Bradyaena simularis* were abundant at Mare aux Vacoas where soil moisture content and humidity were high but pH of soil and temperature was low. *Agelenopsis aperta, Elater abruptus, Gromphadorhina portentosa, Nylanderia dodo, Nylanderia bourbonica* and *Blapstinus fortis* were abundant at Flic en Flac where pH of soil, temperature and soil calcium content were high, but soil moisture and humidity were low. *Porcellio scaber* was mostly abundant at Mare aux Vacoas where soil carbon content was higher.

Pearson correlation

Soil pH showed a strong inverse relationship with soil moisture (-0.813) ($p<0.001$) but a significant positive relationship with temperature (0.941) and soil calcium content (0.874) ($p<0.001$) (Table 3). Soil moisture showed a strong significant inverse relationship with soil calcium content (-0.801) ($p<0.001$) and temperature (-0.871) ($p<0.001$) and a significantly positive relationship with humidity (0.52) ($p<0.05$). Soil calcium content was significantly inversely related to humidity (-0.67) ($p<0.05$) and positively related to temperature (0.909) ($p<0.001$).

Discussion

The Rapoport's Rule [19] states that species richness decreases from lower to higher altitudes but peaks at mid-elevations. This is contrary

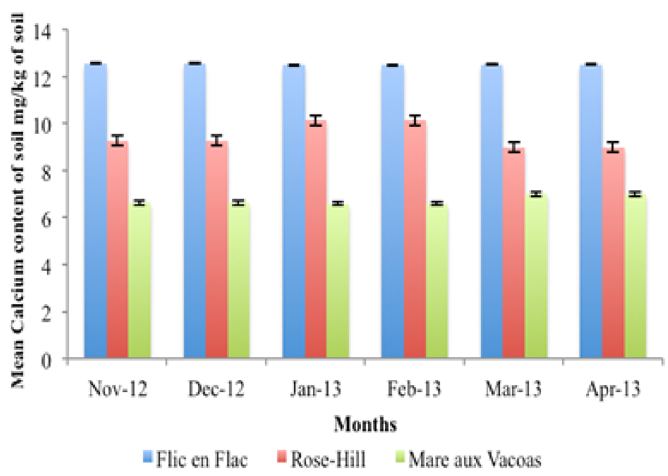


Figure 8: Calcium content of soil at three study sites in Mauritius.

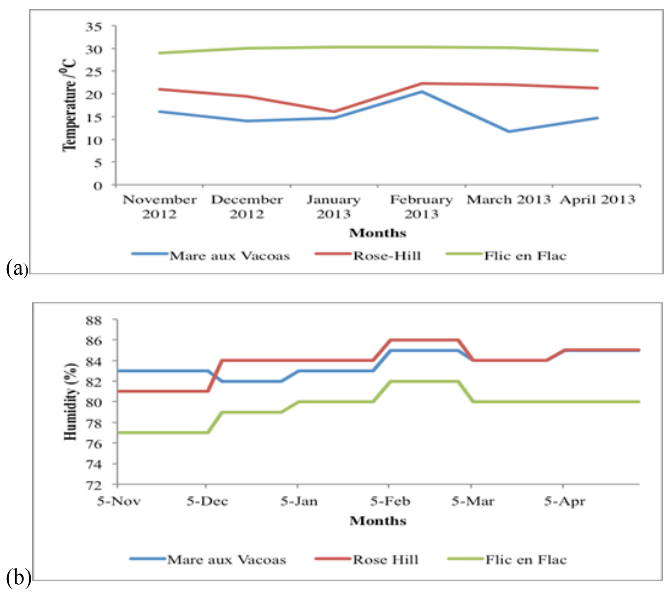
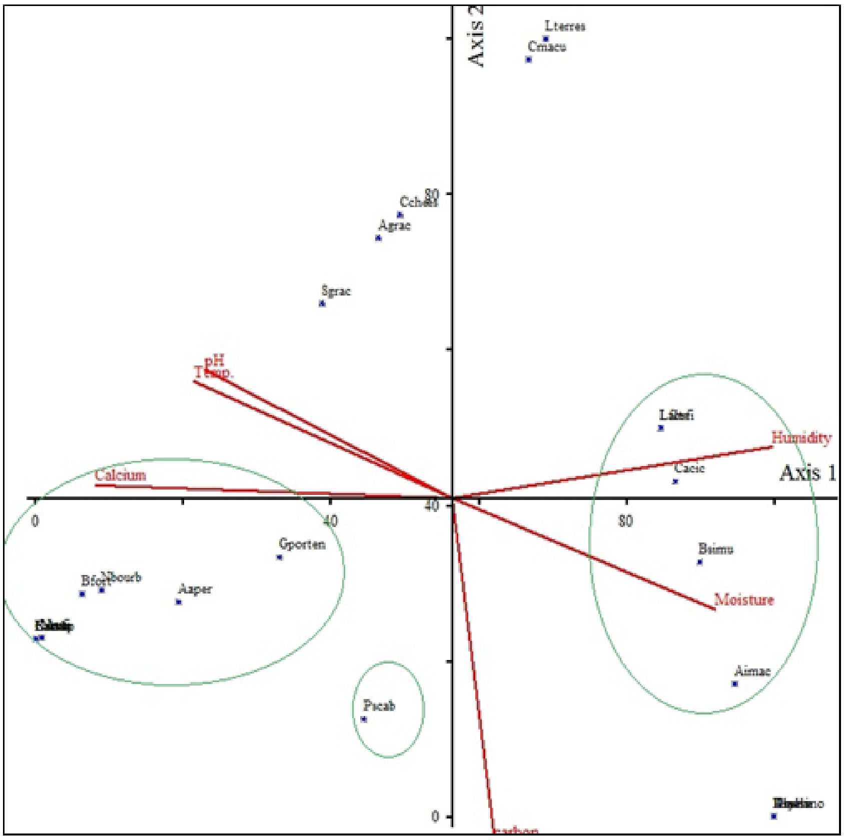


Figure 9: Temperature (a) and humidity (b) at three study sites in Mauritius.



Aaper : *Agelenopsis aperta*	Cacic: *Ceciliodes acicula*	Pscab: *Porcellio scaber*
Agrac: *Anoplolepis gracilipes*	Cchees: *Carpophilus cheesmani*	Nbourb:*Nylanderia bourbonica*
Aimac :*Achatina immaculata*	Dlaev: *Deroceras laeve*	Ndodo: *Nylanderia dodo*
Bsimu: *Bradybaena simularis*	Dmela:*Drosophila melanogaster*	Nrufi: *Nitidula rufipes*
Bfort: *Balpstinus fortis*	E.abru*: Elater abruptus* Gporten:*Gromphadorhina portentosa*	Sgrac: *Solenopsis geminata*
Cmacu:*Camponotus maculatus*		L.terre: *Lumbricus terrestris*

Figure 10: Principal component (or Canonical correspondence?) analysis ordination of soil fauna abundance with environmental parameters per study site.

to the trend in the present study which showed that soil fauna species richness increased from lower to higher elevations. The decrease in soil fauna abundance and increase in species richness towards higher elevation in this study was perhaps affected more by anthropogenic disturbance which was higher at low elevation and low at high elevation. More litter dumping was observed as a result of recreational activities at the beach at lower elevation but little to no litter was observed at the higher elevations. Soil fauna species richness was however higher at the middle elevation at Rose-Hill (D'=2.72) and this was also observed by other studies [20] between ant species richness and elevation effect. Higher species richness at mid-elevation may be explained by low climatic severity, higher resource availability and lower predation [20]; higher productivity due to higher photosynthesis rates and lower plant respiratory rates [21,22]. Lower elevations tend to receive more disturbances, thereby reducing species diversity.

The high abundance of *C. cheesmani* (Coleoptera beetle) at Flic en Flac was perhaps correlated to higher temperature and lower humidity as beetles prefer warm and dry conditions [23-25]. *Anisolabis maritima* (earwig) abundance at Mare aux Vacoas was somewhat related to low temperature, high humidity and high soil moisture. Earwigs are generally found in a variety of habitats such as under bark or dead and decaying logs, beneath bricks and stones as well as at the edge of streams, rivers and at moist places [26,27]. The sampling site at Mare aux Vacoas was located within a water catchment which consisted of tall grasses and decaying matter (logs), favourable for the earwig.

Higher ant (Formicidae) abundance at Flic en Flac and lower at Mare aux Vacoas was probably related to higher rainfall, humidity, lower temperature and higher soil moisture content despite the high carbon content at Mare aux Vacoas. The Formicidae are generally found in dry and warm environments. Despite being a tropical

		pH	Carbon	Moisture	Calcium	Humidity	Temperature
pH	Pearson Correlation	1	-.284	-.813**	.874**	-.432	.941**
	Sig. (2-tailed)		.253	.000	.000	.074	.000
	N	18	18	18	18	18	18
Carbon	Pearson Correlation	-.284	1	.449	-.156	.389	-.200
	Sig. (2-tailed)	.253		.062	.537	.111	.427
	N	18	18	18	18	18	18
Moisture	Pearson Correlation	-.813**	.449	1	-.801**	.520*	-.871**
	Sig. (2-tailed)	.000	.062		.000	.027	.000
	N	18	18	18	18	18	18
Calcium	Pearson Correlation	.874**	-.156	-.801**	1	-.670**	.909**
	Sig. (2-tailed)	.000	.537	.000		.002	.000
	N	18	18	18	18	18	18
Humidity	Pearson Correlation	-.432	.389	.520*	-.670**	1	-.418
	Sig. (2-tailed)	.074	.111	.027	.002		.085
	N	18	18	18	18	18	18
Temperature	Pearson Correlation	.941**	-.200	-.871**	.909**	-.418	1
	Sig. (2-tailed)	.000	.427	.000	.000	.085	
	N	18	18	18	18	18	18

(*) indicate relationships between environmental parameters.
(**) indicate significant relationship (inverse or direct) between environment parameters.

Table 3: Multiple Pearson's Correlation of Environmental Parameters at Three Study Sites in Mauritius.

island, the winter temperature at Mare aux Vacoas can be as low as 7.7°C [28] which ants may not be adapted to. Low temperature is an environmental barrier that soil fauna have to overcome to disperse. High rainfall impacts ants through nest flooding and nest breakage [29-32]. Ecosystem processes are profoundly influenced by precipitation as it modifies soil moisture availability [33] and that soil moisture content also varies spatially (vertically and horizontally) due to soil variability [34-37]. A decrease in precipitation and soil moisture content can reduce bacterial and fungal activities which will eventually reduce their population and disrupt carbon and nutrient cycling [38]. Alterations to microbial populations will in turn affect the decomposer food web affecting soil fauna community structure [39].

At Flic en Flac, high soil calcium content and low soil pH may have influenced the adundance of *A. aperta, N. dodo* and *N. bourbonica*. Significant correlation (0.87) between soil calcium content and soil pH (alkaline soils), and significantly higher soil calcium content ($p<0.05$) and low soil pH ($p<0.05$) was recorded at Flic en Flac. Low leaching of calcium from alkaline soils at Flic en Flac possibly explains the higher soil calcium content. Ants are known to buffer soil pH towards neutral value by depositing either acidic or basic nutrients [40]. Soils containing ant nests have higher calcium content [41], suggesting high calcium storage by ants. In contrast, Mare aux Vacoas with low ant abundance had significantly low calcium content and high pH (acidic soils) soils.

The higher diversity and evenness of soil fauna at Mare aux Vacoas (H'=2.54), was due to high species richness (D'=2.15) and low dominance (J'=0.92) of soil fauna species. The low diversity (H'=1.21) and evenness (J'=0.42) at Rose-Hill indicated high dominance of soil fauna taxa, especially by *Nylanderia dodo* and to a lesser extent *A. gracilipes*. The relatively higher Margalef Index (D'=2.72) at Rose-Hill however, was perhaps related to the higher species richness of roadside trees (11 species) and leaf litter diversity which together may provide diverse habitats for the soil fauna. Plant species richness may affect soil processes by influencing microclimate [42]. Plant diversity can also help lower soil temperature [43] and this has positive impact on soil fauna activities such as stress reduction. Increase in feeding activity [44-46] affect chemical and physical properties of soil [47] which favours increase in soil fauna abundance and biomass. The low diversity (H'=1.84) at Flic en Flac was related to low species richness (D'=1.41) and high dominance by *C. cheesmani* (Coleoptera) and to a lesser extent *S. germinata* and *A. gracilipes* (Formicidae).

The community structure differences of soil fauna between the warmer (November 2012– January 2013) and colder (January-April 2013) months at the three study sites was related to differences in humidity, temperature, soil carbon content and soil moisture. Higher diversity (H'), evenness (J') and species richness (D') of soil fauna was measured during the warmer months (high temperature, low humidity, high soil carbon content, high soil moisture) while low diversity, evenness and species richness was measured during the colder months (low temperature, high humidity, low soil carbon content, low soil moisture content). Differences in temperature, humidity and soil moisture can affect soil characteristics as well as soil fauna function [48,49] such as growth, reproduction and community interactions.

Conclusion

This study can conclude that the environmental parameters measured influenced the abundance and distribution of the soil fauna. Higher species richness at mid-elevation was a result of low climatic severity, higher resource availability and adequate habitat scope. The decrease in soil fauna abundance and increase in species richness towards increasing elevations in this study was affected by anthropogenic disturbance which was higher at low elevation and lowest at high elevation.

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