Response of dung beetles diversity to remediated soils ecosystems in the Ecuadorian Amazon

Wilmer E Pozo-Rivera [1], **Carlos Quiloango-Chimarro** [1, 2], **Xavier Paredes** [1], **Mario Landivar** [1], **Carlos Chiriboga** [1], **Daniel Hidalgo** [3], **Karina Garcia** [3], **Jaime Villacis** [Corresp. 1]

[1] Departamento de Ciencias de la Vida y de la Agricultura, Universidad de las Fuerzas Armadas (ESPE), Sangolquí, Pichincha, Ecuador

[2] Department of Biosystems Engineering, Universidade de São Paulo-USP, Piracicaba, Sao Paulo, Brasil

[3] Centro de Investigación de Tecnologías Ambientales del Proyecto Amazonía Viva, Empresa Pública PETROECUADOR, La Joya de los Sachas, Orellana, Ecuador

Corresponding Author: Jaime Villacis
Email address: jevillacis@espe.edu.ec

Dung beetles are considered to be habitat quality bioindicators. However, studies regarding the Scarabaeinae diversity in remediated ecosystems previously affected by hydrocarbon activity are null. We evaluated the diversity of dung beetles present in remediated soils previously contaminated with hydrocarbons and heavy metals (Agricultural soils and Sensitive ecosystems) and in non-contaminated soils (Natural forest and Palm plantations) in the Ecuadorian Amazon. Four sampling sites within each type of soil were established. At each site, six pitfall traps were installed and eleven samples were carried out monthly over one year. Each month, the traps remained active for 24 hours during a period of five consecutive days, resulting in a total sampling effort of 880 monitoring days with 330 trap-days per site. A total of 7,506 individuals belonging to 13 genera and 37 species of Scarabaeinae were captured. Mean values of abundance, richness, and diversity differed between ecosystems within each month. The non-contaminated soils ecosystems presented a higher abundance, richness, and diversity of beetles than the remediated soils ecosystems. Natural forest and Palm plantations presented higher abundance, richness, and diversity than Sensitive ecosystems and Agricultural soils, respectively. It can be concluded that dung beetle diversity in soils non-degraded (Natural forest and Palm plantations) do not only depend on the characteristics of the ecosystems, but also on the month of sampling.

Response of Dung Beetles Diversity to Remediated Soils Ecosystems in the Ecuadorian Amazon

Wilmer E. Pozo-Rivera[1], Carlos Quiloango-Chimarro[1,2], Xavier Paredes-Chiquiza[1], Mario Landívar[1], Carlos Chiriboga-Novillo[1], Daniel Hidalgo-Lasso[3], Karina García[3], Jaime Villacís*[1]

[1] Departamento de Ciencias de la Vida y de la Agricultura, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Pichincha, Ecuador
[2] Department of Biosystems Engineering, Universidade de São Paulo-USP, Piracicaba, São Paulo, Brazil
[3] Centro de Investigación de Tecnologías Ambientales del Proyecto Amazonía Viva, Empresa Pública PETROECUADOR, La Joya de los Sachas, Orellana, Ecuador

Corresponding Author:
Jaime Villacís *[1]
Av. Rumiñahui s/n, Sangolquí, Pichincha, Zip code 171-5-231-B, Ecuador
Email address: jevillacis@espe.edu.ec

Abstract

Biodiversity in remediated soil ecosystems previously affected by hydrocarbon activities is poorly understood. Therefore, bioindicators such as dung beetles could be a valuable tool to elucidate the benefits of remediation processes. We evaluated the diversity of dung beetles on remediated soil ecosystems (Agricultural soils and Sensitive ecosystems) and on non-contaminated soils (Natural forests and Palm plantations) in Sucumbíos and Orellana provinces, Ecuadorian Amazon. The study was conducted at four sampling sites per ecosystem type (a total of 16 sites). At each sampling site, six pitfall traps were installed and monitored monthly for a 120-hour period during one year. We collected 37 species and 7,506 individuals of dung beetles. We observed significant differences in mean species abundance, richness and diversity between non-contaminated soil ecosystems and remediated soil ecosystems, with Natural forests presenting the highest values, and Agricultural soils the lowest values. Regarding sampling month, we also found significant differences among ecosystems. It is remarkable that between the Agricultural soils (remediated soil ecosystems) and Palm plantations (non-contaminated soils) we found the highest species similarity (34.2%). Variation in dung beetle diversity among ecosystems may aid in decision making to improve remediation processes at sites affected by hydrocarbon activities.

Subjects Biodiversity, Ecology, Entomology

Keywords Scarabaeinae, tropical rain forest, degradation, ecological restoration

Introduction

The extraction of hydrocarbon resources has led to the fragmentation of tropical forests around the world (Abrahams, Griffin & Matthews, 2015; Bogaert et al., 2011; Thomas, Brittingham & Stoleson, 2014). In addition, oil extraction processes often cause accidental spills, which result in contamination of soil and water sources, affecting the environment and hence all life forms (Sajna et al., 2015; Souza, Vessoni-Penna & De Souza Oliveira, 2014). In Ecuador, the Amazon Forest is the most affected site by hydrocarbon activities (Villacís, 2016; Villacís et al., 2016a; Villacís et al., 2016b), where crude oil spills of around 650,000 barrels have negatively impacted the diversity of flora and fauna (Yánez & Bárcenas, 2012; Ministerio del Ambiente, 2016). Due to this situation, the Ecuadorian government has remediated 1,200,098 m^3 of contaminated soil (PETROAMAZONAS EP, 2018). The remediation process includes the collection and washing of solid waste; the suction and transport of fluids; the cleaning of contaminated soil; and the revegetation of intervened areas (García-Villacís, 2021). After remediation, each site is catalogued as either Agricultural soil or Sensitive ecosystem in accordance with specific permissible levels of hydrocarbons, cadmium, nickel, and lead established in environmental regulations (Ministerio de Energía y Minas, 2010).

García-Villacís et al. (2021) analyzing the benefits of the remediation process in Ecuador included ecosystem variables such as acidification, terrestrial-, and freshwater-eutrophication, and freshwater ecotoxicity. However, organisms that serve as bioindicators of ecosystem alterations were not included. Changes in the abundance, diversity, and composition of these organisms can elucidate the effects of environmental disturbance (Kremen, 1992; Grand et al., 2017). Among the most commonly used bioindicators are dung beetles (Coleoptera, Scarabaeinae), which are distributed across a wide range of geographical locations (Lumaret & Lobo, 1996; Herzog et al., 2013), have high levels of diversity (Espinoza & Noriega, 2018), and are sensitive to microclimatic changes caused by deforestation and forest fragmentation (Campos & Hernández, 2015; Davis & Sutton, 1998; Davis et al., 2001). Dung beetle communities are commonly decreasing under environmental changes that also affect overall ecosystem health (Otavo, Parrado-Rosselli & Noriega, 2013), since these organisms fulfill important ecological functions such as secondary seed dispersal, decomposition of organic matter, and nutrient cycling (Rangel-Acosta & Martínez-Hernández, 2017; Fernandes et al., 2019).

Several studies have been conducted to assess the diversity of dung beetles in degraded ecosystems (Andresen, 2005; Feer & Hingrat, 2005; Nichols et al., 2007; Sánchez-de-Jesús et al., 2016). Therefore, dung beetle diversity could be a useful tool to better understand the impact of remediation activities on sites previously affected by hydrocarbon activities. It was hypothesized that sites with soil degradation (Sensitive ecosystems and Agricultural soils) decrease dung beetle diversity when compared to non-contaminated soils (Natural forests and Palm plantations). To address this hypothesis, changes in abundance, richness, and diversity of dung beetle communities were evaluated in two types of remediated ecosystems.

Materials & Methods

Ethics statement

This study was authorized under research permit 016-2018-IC-DPAO/AVS and authorization for the mobilization of specimens 005-2019-MOV-FAU-DPAO/AVS, both issued by the Ministerio del Ambiente del Ecuador.

Study area

The study was performed in the Sucumbíos (0° 5′S, 76° 53′W) and Orellana (0° 56′S, 75° 40′W) provinces in the Ecuadorian Amazon. The land use of the localities is distributed in 70% for natural forest, 22% for crops and pastures, and 8% for urban and industrialized areas (Ministerio de Agricultura y Ganadería, 2015). The predominant climate is Humid Tropical Rainforest according to the Holdridge climate classification (Holdridge, 1967), with a mean annual temperature of mean 24.5 º C and heavy rainfall throughout the year (4132 mm). Mean of climate variables during the study period are showed in table 1.

Selection of collection sites

Sampling sites were established after the completion of the remediation process (~1 year) in ecosystems previously affected by hydrocarbon activities (Sensitive ecosystems and Agricultural soils). The designation as sensitive ecosystems or agricultural soils is based mainly on contaminant levels in accordance with environmental regulations (lower in Sensitive ecosystems) but also on the landscape characteristics of each site (Table 2). In addition, two types of non-contaminated soil ecosystems used as controls (Natural forests and Palm plantations) were also included. Before the beginning of the study, a composite soil sample (5 per sampling site) was collected in order to determine the total petroleum hydrocarbon and polycyclic aromatic hydrocarbon concentrations (Table 2) using GC2 014 gas chromatographs (Shimadzu Scientific Instruments, Inc, Columbia, MD, USA). In addition, the concentration of cadmium (Cd), nickel (Ni), and lead (Pb) in soils (Table 2) was determined by using atomic absorption spectrometry (AA-6800; Shimadzu Scientific Instruments, Inc, Columbia, MD, USA) as indicated by the EPA SW-846 method (Le Blanc & Majors, 2001). The analyses were performed at the Soil Laboratory of the Universidad de las Fuerzas Armadas, Ecuador.

Sampling design

Sixteen sample sites (four per each ecosystem type) were established. In each sample site, six pitfall traps baited with pig dung were placed 10 m apart. Pitfall traps consisted of plastic containers of 0.8 L (15 cm depth × 10 cm diameter) buried up to their rims in the soil and containing a solution 50:50 of water with alcohol. The traps remained active at the sites for 120 h per month during one year (February 2018 to January 2019). The amount of dung per trap was ~50 g and was replaced every 24-36 h. In April, 2019 the traps were not evaluated due to conflict with the landowners, who prevented the entrance to the sampling sites in La Joya de los Sachas locality.

Dung beetles were preserved in 70% ethanol, and some specimens were pinned and identified to species using dichotomous keys (Chamorro et al., 2018; Vaz-De-Mello et al., 2011) and comparing with voucher specimens from Museo de Historia Natural "Gustavo Orcés", (Escuela Politécnica Nacional, Quito, Ecuador). Vouchers were deposited in the Museum of Zoological Researches (Universidad de las Fuerzas Armadas, Sangolquí, Ecuador).

Data analysis

All analyses were performed using the software INFOSTAT (Di Rienzo et al., 2008) in interface with R (R Core Team, 2013). To detect the effectiveness of the inventories, species accumulation curves were created using the Clench method (Moreno & Halffter, 2000; Soberon & Llorente, 1991). In addition, the richness observed in each type of ecosystem was evaluated using the non-parametric estimator Chao 1 (Colwell & Elsensohn, 2014).

The monthly data were grouped to estimate the total species abundance, richness and Shannon diversity index of each plot (Magurran, 1998). Pooled data were used to compare the four types of ecosystems due to the homogeneity among the four sampling sites per ecosystem type.

Abundance, richness, and diversity were analyzed by using repeated measures (by month). Differences between ecosystems were analyzed using analysis of variance with mixed models for a complete randomized design with six replications. In addition, we performed orthogonal contrast for treatments. The first contrast evaluated differences in abundance, richness, and diversity between remediated soil ecosystems and non-contaminated soil ecosystems. The second contrast evaluated the differences between Agricultural soils and Palm plantations, and the third contrast evaluated the differences between Sensitive ecosystems and Natural forests. Furthermore, we tested for differences between ecosystems, months and interactions by using a DGC post hoc test ($P < 0.05$). The normality of the data was verified using the Shapiro-Wilks test, and the homoscedasticity was modeled using independent variances.

The Sørensen index was used to compare the similarity of dung beetle species composition between each type of ecosystem evaluated. Finally, a dendrogram was prepared using this information (Beals, 1984).

Results

We collected 7,506 individual beetles of the Scarabaeinae subfamily, belonging to 13 genera and 37 species (Table 3). Specific abundance varied greatly, ranging from one to 1,502 individuals (an average of 202.86 individuals ± 52.81 SE per species). *Canthon aequinoctialis* (20% of total abundance), *Ontherus sulcator* (13%), *Dichotomius ohausi* (10%), and *Deltochilum howdeni* (9%), accounted for 52% of all individuals collected. Fifty-one percent of the species were classified as rare, with a relative frequency of less than ten percent. Twenty-two percent of the total species collected were found in all four evaluated ecosystems, while 12 others were exclusive to one of them: 11 in the natural forest and one in the Sensitive Ecosystem. *Canthidium aurifex*, *Eurysternus atrosericus*, *Ontherus sulcatur*, *Onthophagus osculatii*, and *O. nyctopus* are new provincial records, whereas *O. hircus* is a new record for Ecuador (Table 3).

As the sampling time increased, the accumulated richness of the dung beetle decreased from the seventh month in the Natural forests, whereas in the Sensitive ecosystems, Agricultural soils and Palm plantations, the curves did not stabilize (Fig. 2). The non-parametric estimator of richness (Chao 1) showed that the efficiency of the inventories reached 99.20 % in natural forest, 97.63 % in sensitive ecosystems, 94.34 % in agricultural soils, and 87.35 % in palm plantations.

The average values of abundance, richness, and the Shannon index differed between ecosystems within each month (Table 4).

The orthogonal contrast showed that non-contaminated soil ecosystems contained higher abundance, richness and diversity of beetles in comparison to remediated soil ecosystems ($F_{1, 132} = 313.51$, $P < 0.0001$). Natural forest presented higher abundance, richness and diversity than Sensitive ecosystems ($F_{1, 132} = 313.51$, $P < 0.0001$) and Palm plantations presented higher abundance, richness and diversity than Agricultural soils ($F_{1, 132} = 51.60$, $P < 0.0001$; Fig. 3). The highest monthly average values for abundance (January and November), richness (January, February, September, October and November) and Shannon's index (September and November) were recorded in the Natural forests (Fig. 4).

Cluster analysis showed that Agricultural ecosystems and Palm plantations presented a species similarity of 32.4%, and both were similar to the Sensitive ecosystems at 26.8%. The Natural forests were similar to other ecosystems only at 8.53% (Fig. 5).

Discussion

Our study provides the first quantitative data on dung beetle communities in ecosystems affected by hydrocarbon activities in the Ecuadorian Amazon. For all evaluated ecosystems, the richness of dung beetle communities was greater than 87%, which suggests that minimum changes in species inventories could exist if sampling effort is increased (Feinsinger, 2001).

The species presented in this study represent 17% of the 220 species of dung beetles registered in Ecuador (Chamorro et al., 2018) and more than 50% of previously registered species in the Orellana and Sucumbíos provinces. Five species are new for these provinces, whereas *Ontophagus hircus* was recorded for the first time in Ecuador. This demonstrates that beetle diversity must be studied to understand soil disturbance in tropical forests (Beiroz et al., 2017).

Dung beetle diversity

The community structure in the non-contaminated soil ecosystems trends toward high abundance, richness, and diversity when compared to remediated soil ecosystems. The results are similar to those reported by Da Silva, Vaz-de-Mello & Di Mare (2013) and Batilani-Filho & Hernandez (2017), who also found higher values of abundance, richness, and diversity of dung beetles in remnant Atlantic forests (Southern Brazil) and lower values in soils affected by agriculture and deforestation. This could be because natural forests are the habitat of birds and mammals, which provide food resources for dung beetles (Campos & Hernández, 2015; Niero & Hernández, 2017).

Dung beetles are very sensitive to habitat disturbance (Audino, Louzada & Comita, 2014; Campos & Hernández, 2015; Da Silva, Vaz-de-Mello & Di Mare, 2013). Changes in dung beetle community structure have been reported under low vegetation cover (Nichols et al., 2007) as a result of intense solar radiation on the soil surface, which accelerates the decomposition rate of food sources (Méndez et al., 2019). Moreover, chemical perturbations affect dung beetle communities in several ways such as changes in composition, diversity and population. (Hutton & Giller, 2003; Correa et al., 2022). Therefore, the presence of hydrocarbons and heavy metals in Agricultural soils and Sensitive ecosystems as well as landscape modifications at oil exploitation sites could influence abundance, richness, and diversity of dung beetle assemblages.

Similarly, cluster analyses showed an acute division between the Natural forests and other ecosystems evaluated. This could be because natural forest fragments within human modified landscapes constitute wildlife refuges (Blaum et al., 2009). This trend of decreased dung beetle diversity between the Natural forest and the other ecosystem types follows a general decreasing gradient of diversity and an increase in anthropomorphic disturbances due to contamination and land use (Aninta et al., 2019; McCain, 2005; Stevens & Gavilanez, 2015). For example, Scarabaeinae diversity in Palm plantations was similar to that found in Agricultural soils. This is consistent with previous studies of Fitzherbert et al. (2008) and Harada et al. (2020), which reported that agrochemicals could favor the degradation of soil and nutrients and hence diminish dung beetle diversity.

Temporal variation of dung beetle diversity

The diversity of dung beetles is determined by regional rainfall patterns (Novais et al., 2016). Our results indicated that the diversity of dung beetles in the Natural forests was higher during the month with lower levels of precipitation (October 238 mm month^{-1}) which is consistent with the study of Ibarra-Polesel, Damborsky & Porcel (2015), who studied dung beetles in subtropical ecosystems. However, previous studies demonstrate that higher beetle diversity is linked to the months with elevated values of precipitation (Escobar et al., 2008; Nunes et al., 2016; Rangel-Acosta & Martínez-Hernández, 2017).

Higher dung beetle diversity during the months with lowest levels of rainfall in the evaluated ecosystems may be due to the interference of factors other than rainfall. For example, alteration of microclimates and microhabitats (Medina, Escobar & Kattan, 2002; Noriega & Realpe, 2018; Sánchez-Hernández et al., 2022), changes in trophic structure (Novais et al., 2016), as well as altitudinal gradient effects (Noriega & Realpe, 2018). These factors could affect mainly the mobility, displacement, and genetic flow of organisms between ecosystems (Harvey, Gonzalez & Somarriba, 2006). For example, the Natural forests in the provinces where the study was conducted are under a higher degree of environmental disturbance (deforestation, forest fragmentation, oil spills, population growth, etc.) (Rivera-Parra et al. 2020) and, in general, the entire Amazon basin is under massive degradation due to deforestation (Marin et al. 2022).

Implications for the conservation

The diversity of dung beetles provides a useful tool for assessing the temporary status of remediated sites previously affected by hydrocarbon activities. Although differences in beetle diversity were found between remediated ecosystems, similar recommendations for conservation measures can be made for both Agricultural soils and Sensitive ecosystems. Therefore, Agricultural soils and Sensitive ecosystems should not only be based on the levels of hydrocarbons and heavy metals but also on the diversity of bioindicators.

The presence of dung beetles in the remediation ecosystems provides a guideline for implementing strategies to conserve the existing diversity. However, the conservation of biodiversity in remediated ecosystems depends not only on remediation activities, but also on other anthropogenic activities in the Amazonian tropical forests.

Overall, dung beetle diversity could be used for conservation planning and management of hydrocarbon- and heavy metal-contaminated ecosystems. In addition, our study provides a baseline for future research that may include other environmental variables and activities that modify dung beetle diversity.

Conclusions

Our study shows that in sites where hydrocarbons and heavy metals were present, the abundance, richness and diversity of dung beetles were lower compared to non-contaminated sites. In addition, dung beetle diversity changed throughout the year and was significantly higher in months with low precipitation.

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Figure 1

Location of collection sites in the Sucumbíos and Orellana provinces

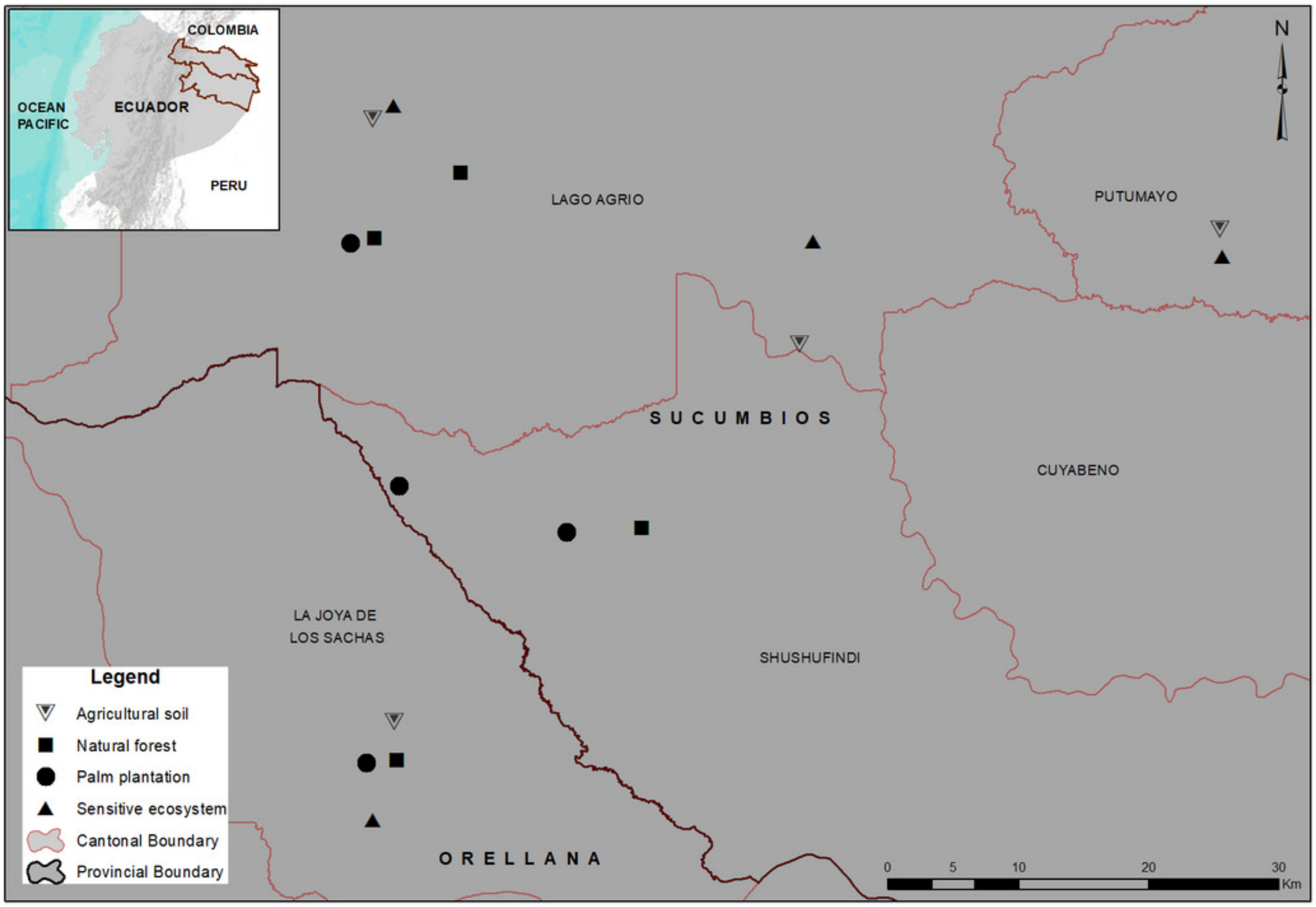

Figure 2

Species accumulation curves of Scarabaeinae communities recorded in remediated soil ecosystems and non-contaminated soil ecosystems in Ecuadorian Amazon

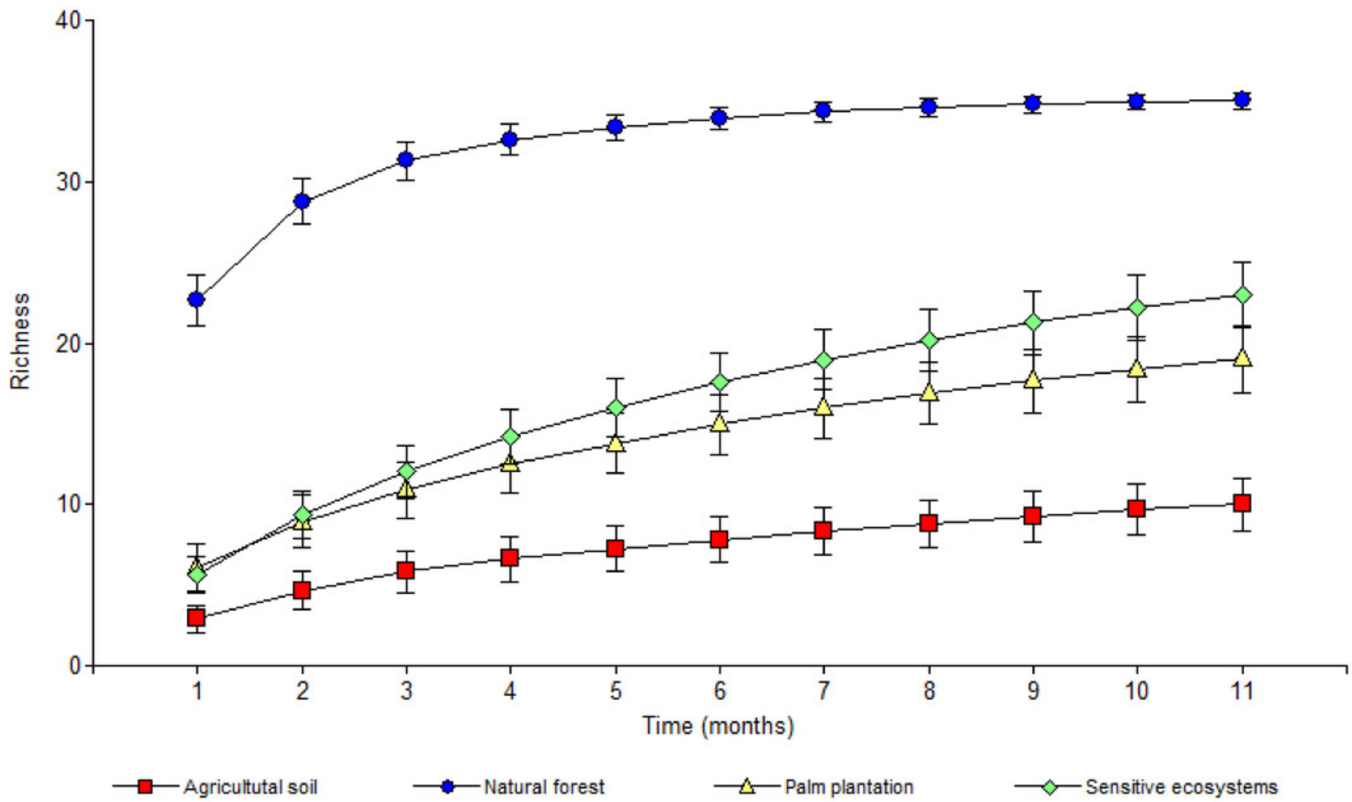

Figure 3

Abundance, richness, and diversity of beetles that were collected in remediated soil ecosystems and non-contaminated soil ecosystems in the Ecuadorian Amazonia

Bars represent means ± standard error (n = 44)

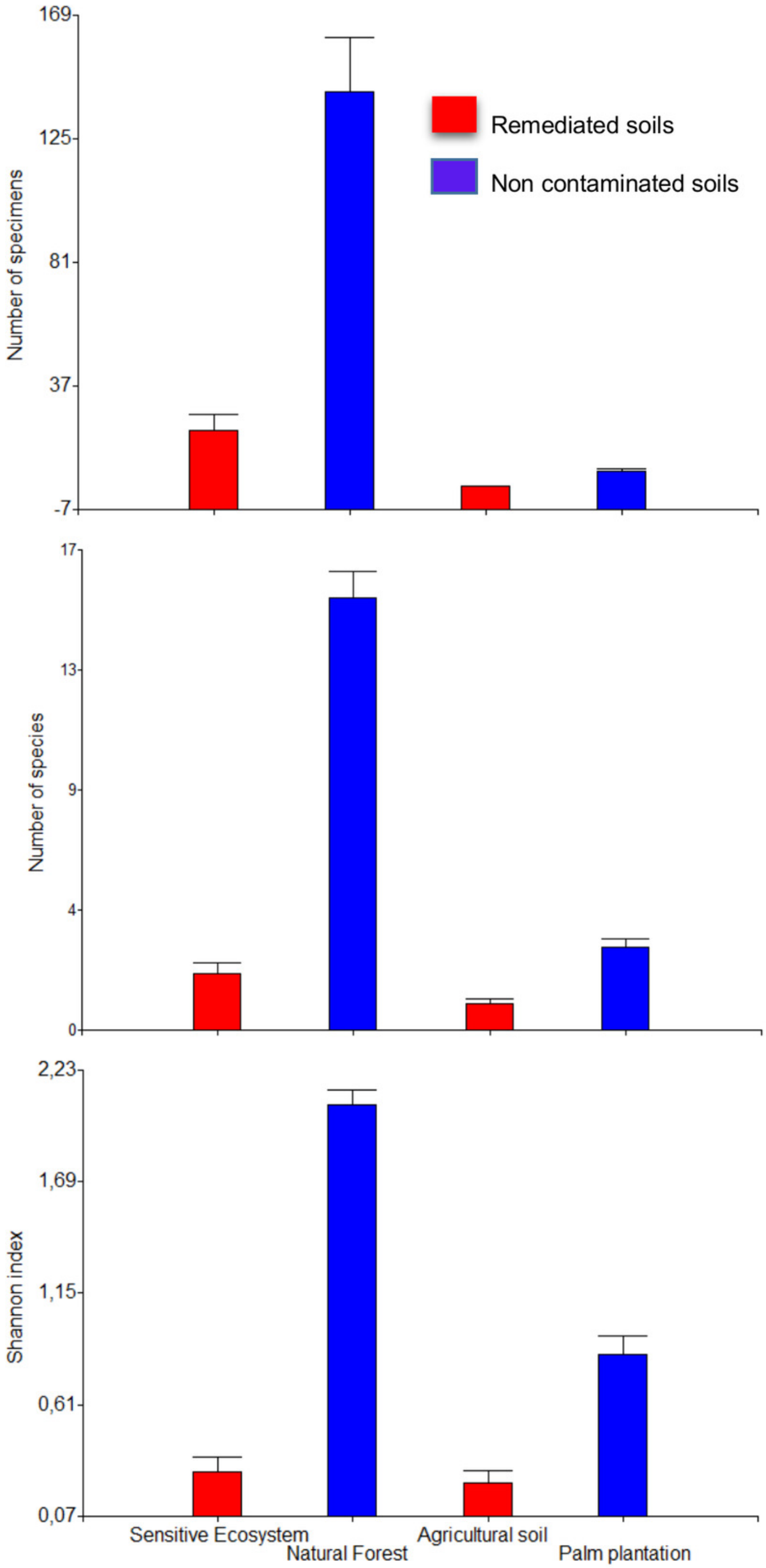
169
125
81
37
-7
Number of specimens
Remediated soils
Non contaminated soils
17
13
9
4
0
Number of species
2,23
1,69
1,15
0,61
0,07
Shannon index
Sensitive Ecosystem
Natural Forest
Agricultural soil
Palm plantation

Figure 4

Abundance (top), richness (middle), and diversity (bottom) of beetles that were collected monthly on remediated soil ecosystems and non-contaminated soil ecosystems in the in the Ecuadorian Amazon

Values are means ± standard error (n = 4). Different letters in each point indicate significant differences (DGC, $P < 0.05$)

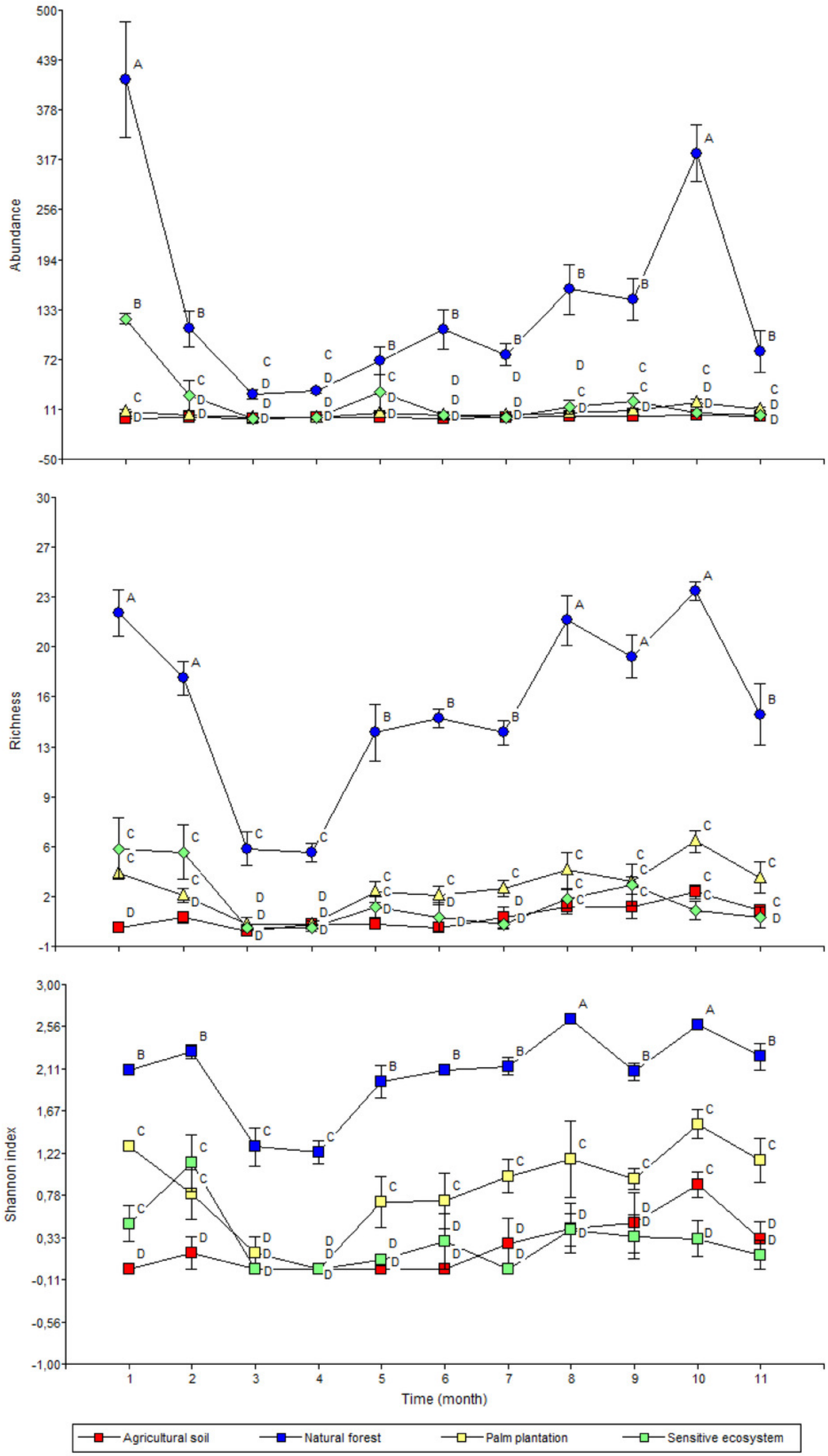
Abundance
Richness
Shannon index
Time (month)
Agricultural soil
Natural forest
Palm plantation
Sensitive ecosystem

Figure 5

Species similarity clusters based on the Bray-Curtis distance of the Sorensen similarity percentage in remediated soil ecosystems and non-contaminated soil ecosystems in the Ecuadorian Amazon

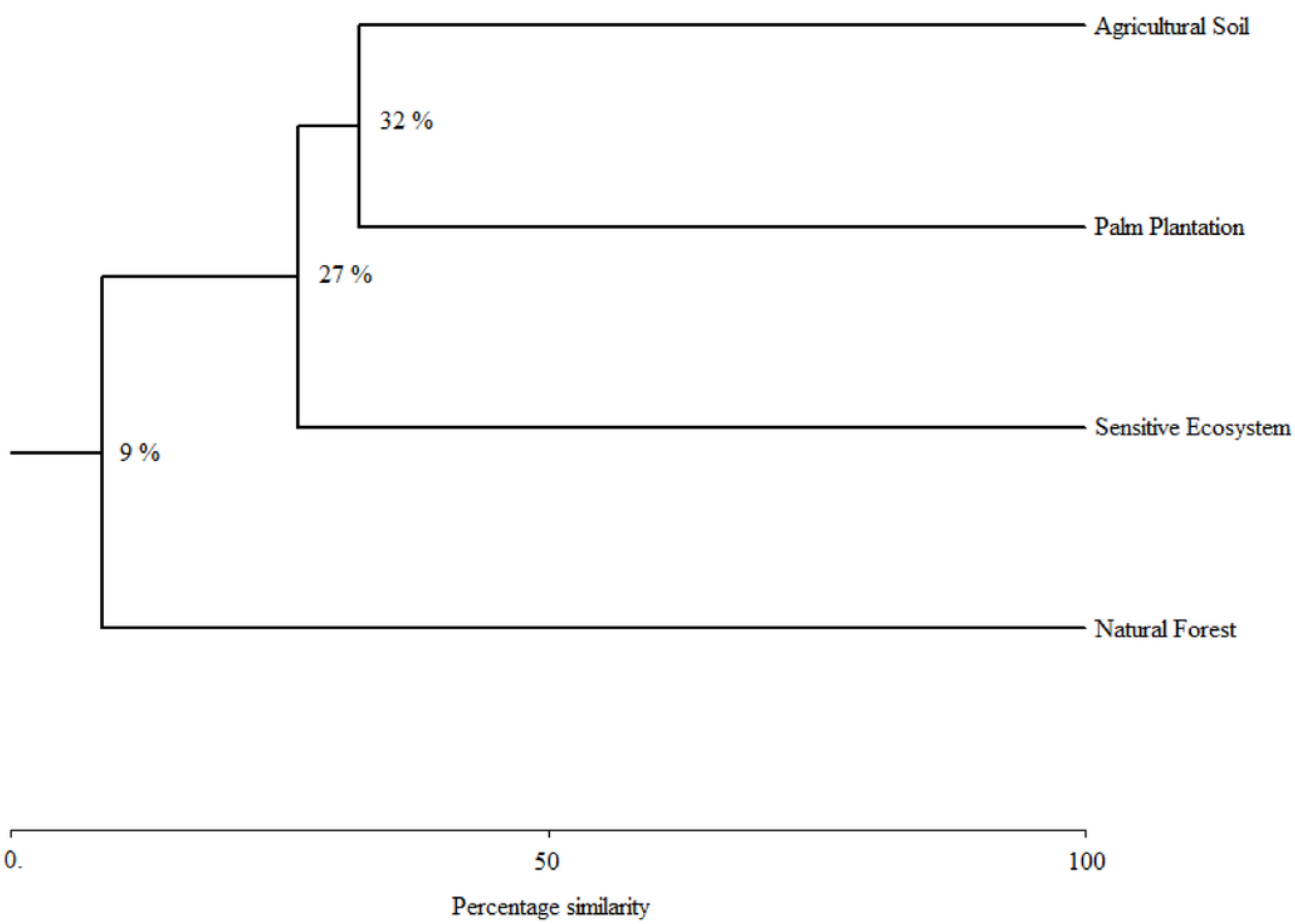

Table 1 (on next page)

Mean values of climatic variables in the ecosystems evaluated

Order	Month/Year	Rainfall mm	Temperature °C	Humidity %
1	February/2018 [r]	368.81	24.36	90.86
2	March/2018 [r]	429.65	24.2	92.14
3	May/2018 [r]	372.02	24.2	93
4	June/2018 [r]	381.61	23.5	91.43
5	July/2018 [d]	322.25	23.96	90
6	August/2018 [d]	293.75	24.08	89
7	September/2018 [d]	248.15	24.48	88.17
8	October/2018 [d]	238.49	24.93	89.14
9	November/2018 [d]	298.9	24.92	88.5
10	December/2018 [r]	350.52	24.46	89
11	January/2019 [r]	376.31	24.76	89.5

[r]= High rainfall, [d]= Low rainfall

Table 2(on next page)

Soil characteristics of the remediated soil ecosystems and non-contaminated soil ecosystems in the Ecuadorian Amazon

Variable	Remediated soil ecosystems		Non-contaminated soil ecosystems	
	Sensitive ecosystems	**Agricultural soils**	**Natural forest**	**Palm plantations**
	Application of air and water to the soils with compressors and high-pressure pumps to release crude oil (Petroamazonas EP, 2018)			
Remediation Activities	Yes	Yes	No	No
Plot size (ha)	1	1	1	1
Total hydrocarbons (mg kg^{-1})	< 1 0000	< 2 500	No	No
Polycyclic Aromatic Hydrocarbons (mg kg^{-1})	< 1	< 2	No	No
Cadmium (mg kg^{-1})	< 1	< 2	No	No
Nickel (mg kg^{-1})	< 40	< 50	No	No
Lead (mg kg^{-1})	< 80	< 100	No	No
Agrochemical Use	No	No	No	Yes (herbicides and fungicides)
Tree cover presence	Yes	No	Yes	No
Number of present strata	2	0	4	2
Most abundant tree species	*Otoba parvifolia, Guarea* sp., *Pouroma* sp.	No	*Ceiba pentandra*, *Otoba parvifolia*, *Pouteria aubrevillei, Inga* sp., *Nectandra guadaripo*. *Cordia alliodora.*	*Elaeis guianensis*
Mean number of trees DAP > 10 cm per ha	3.6	-	21.47	143
DAP mean ± SE (cm)	44.13±1.69	-	45.72±1.61	35.45±4.54
Mean total height ± SE (m)	14.54±0.65	-	16.23±0.25	18.45±2.21

Table 3 (on next page)

Dung beetle species collected in remediated soil ecosystems and non-contaminated soil ecosystems in the Ecuadorian Amazon

No.	Species	Record type	Agricultural soils	Natural forest Total	Sensitive ecosystems Total	Palm plantations	Assemblage
1	*Canthon aequinoctialis* Harold, 1868	RE		**1 490**	12		**1 502**
2	*Ontherus sulcatur* Fabricius, 1775	NR-P	**18**	135	**747**	**90**	990
3	*Dichotomius ohausi* Luederwaldt, 1923	RE	7	639	17	72	735
4	*Deltochilum howdeni* Martínez, 1955	NR-P		671	13	1	685
5	*Onthophagus haematopus* Harold, 1887	RE		493	7		500
6	*Eurysternus plebejus* Harold, 1880	RE	6	386	4	30	426
7	*Onthophagus osculatii* Guérin-Méneville, 1855	NR-P		395	7		402
8	*Coprophaneus telamon* Erichson, 1847	RE	11	307	22	33	373
9	*Onthophagus xanthomerus* Bates, 1887	RE		246	22	5	273
10	*Dichotomius* sp. 1	NA		232		1	233
11	*Dichotomius mamillatus* Felsche,1901	RE		186	2	1	189
12	*Deltochilum amazonicum* Kolbe, 1905	RE		175		3	178
13	*Eurysternus atrosericus* Génier, 2009	NR-P	1	134	5	5	145
14	*Eurysternus squamosus* Génier, 2009	RE		107			107
15	*Canthon luteicoliis* Erichson, 1847	RE		92	1	1	94
16	*Eurysternus caribaeus* Herbst, 1789	RE	4	76		13	93
17	*Eurysternus wittmerorum* Martínez, 1988	RE	1	61	7	10	79
18	*Canthidium* cf. *rufinum* Harold, 1867	RE		76			76
19	*Onthophagus hircus* Billberg, 1815	**NR-E**	10		40	6	56
20	*Onthophagus nyctopus* Bates, 1887	NR-P		52	2		54
21	*Dichotomius podalirius* Felsche, 1901	RE		49			49
22	*Uroxys* sp. 1	NA		48			48
23	*Eurysternus foedus* Guérin-Méneville, 1844	RE	3	30	1	6	40
24	*Phaneus chalcomelas* Perty, 1830	RE		28	3	1	32
25	*Scyballocanthon macullatus* Schmidt, 1920	RE		31	1		32
26	*Oxysternon silenus* d'Olsouefieff, 1924	RE	1	4	1	16	22
27	*Eurysternus hamaticollis* Balthasar, 1939	RE		19	1	1	21
28	*Onthophagus onore* Zunino & Halffter, 1997	RE		15			15
29	*Canthidium* sp. 1	NA		10	3	1	14
30	Canthidium aurifex Bates, 1887	NR-P		9	3		12
31	*Oxysternon conspicillatum* Weber, 1801	RE		8			8
32	*Deltochilum carinatum* Westwood, 1837	RE		7			7
33	*Onthophagus marginicollis* Harold, 1880	RE			6		6
34	*Scyballocanthon furvus* Schmidt, 1920	NA		4			4
35	*Canthidium onitoides* Perty, 1830	RE		3			3
36	*Malagoniella astyanax* Halffter, Pereira & Martínez, 1960	RE		2			2
37	*Canthon angustatus* Harold, 1867	RE		1			1
	Abundance		62	6 221	927	296	7 506

Richness	10	35	23	19	37

Data in bold indicate species with greatest specific abundance by ecosystem type in the study. RE = registered in the provinces studied, NR-P = newly registered in the provinces studied, NA = not evaluated, NRE = newly registered in Ecuador

Table 4(on next page)

Analysis of variance for the abundance, richness, and diversity of beetles that were collected monthly in remediated soil ecosystems and non-contaminated soil ecosystems in the Ecuadorian Amazon

Ecosystems were considered fixed factor and months random factor

Source	df	Abundance		Richness		Shannon	
		F	P	F	P	F	P
Ecosystems types	(3)	302.09	< 0.0001	462.21	< 0.0001	314.65	< 0.0001
Remediated soils ecosystems vs. Control ecosystems	1	374.32	< 0.0001	483.13	< 0.0001	313.51	< 0.0001
Agricultural soils vs. Palm plantations	1	991.54	< 0.0001	59.97	< 0.0001	51.60	< 0.0001
Sensitive ecosystems vs. Natural forest	1	289.20	< 0.0001	502.33	< 0.0001	427.16	< 0.0001
Months	10	26.09	< 0.0001	18.63	< 0.0001	9.56	< 0.0001
Ecosystems × Months	30	8.07	< 0.0001	2.41	0.0003	1.90	0.0073

df = degrees of freedom; F = result of F-Fisher value; P = result of probability.