Article

Succession and vegetation-soil relationship in quarries of southeastern Mexico

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Abstract:

Open pit mining is a common activity in the Yucatan peninsula for the extraction of limestone. This mining is known under the generic name of quarries, and regionally as *sascaberas (sascab*=white soil in Mayan language). These areas are characterized by the total removal of the natural vegetation cover and soil in order to have access to the calcareous material. The present study shows the composition and structure of the vegetation in five quarries after approximately ten years of abandonment, and the conserved vegetation near to each one of the quarries in southeastern Quintana Roo. Using a canonical correspondence analysis (CCA), the distribution of the species was determined in relation to the edaphic variables: soil depth, percentage of organic matter (OM), cationic exchange capacity (CEC), pH and texture. 26 families, 46 genera and 50 species were recorded in the quarries and 25 families, 45 genera and 47 species were recorded in the conserved areas. The dominant species in the quarries belong to the families Poaceae, Fabaceae, Rubiaceae and Anacardiaceae. The quarries with higher values of OM (1.63%), CEC (24.05 Cmol/kg), depth (11 cm) and sand percentage (31.33%) include the following species like *Lysiloma latisiliquum*, *Metopium brownei* and *Bursera simaruba* which are commonly found in secondary forests. On the other hand, quarries with lower values of OM (0.39%), CEC (16.58 Cmol/kg) and depth (5.02), and higher percentage of silt (42.44%) were dominated by herbaceous species belonging to the Poaceae family and by *Borreria verticillata*, which are typical in disturbed areas of southeastern Mexico. In all cases, the pH was slightly alkaline due to the content of calcium carbonate (CaCO3), characteristic of the soils of the region. The edaphic variables are significantly correlated with the development and distribution of vegetation, and with the structure of the communities.

Keywords: Post-mining regeneration; succession; tropical dry forest; Post-mining recovery.

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1. Introduction

Open pit mining for the extraction of mineral resources in forests is one of the most intense anthropogenic activities. The forest cover is strongly affected. Soil horizons and structures are

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modified with associated soil fauna decrease and finally with devastating consequences for ecosystem processes [1,2]. Other consequences of open pit mining with negative implications is the bioavailability of heavy metals, lack of moisture, soil compaction, absence of organic matter, loss of biodiversity, landscape modification, sedimentation and erosion, among others [3].

Additionally, the loss of forest cover is one of the main drivers of climate change, because it considerably alters the planet's energy balance and modifies the biogeochemical cycles [4]. Based on the IPCC report [5], it is essential to recover the largest number of degraded areas that reactivate ecosystem processes and services and contribute to reducing global warming.

It is important to mention that it is not intended to return degraded sites to their original state. However, it is necessary to know the state of vegetation in similar non-degraded areas or with a lower level of degradation, in order to establish criteria that allow us to understand the success of recovery [6].

One of the common strategies for the recovery of degraded areas is through processes of primary and secondary regeneration of the ecosystem ([2,7,8]. Some studies have evaluated rehabilitation strategies after extraction to establish the role of the surrounding native vegetation ([9–12]. It has been observed that vegetation structure tends to be similar after many years of abandonment [13,14]. However, particularly in the tropics, species composition does not always follow a predictable pattern [15–17].

As a result of a disturbance, either natural or anthropic, a deforested area will recover naturally from the processes of secondary succession, defined as the directional change in composition and species richness, as well as in the structure of vegetation through of time [18,19]. The main factors that influence the successional route and the regeneration time are the intensity and frequency of the disturbance. Therefore, sites with minor intensity and frequency disturbances are more likely to recover their floristic composition, diversity and structure in shorter time periods [20]. Similarly, it has been observed that the vegetation matrix influences the capacity for regeneration, due to the possibility of metacommunities to contribute to the dispersion of species and the maintenance of ecosystem functioning[21–26]. However, there is limited evidence from studies that have evaluated the relative contribution of functional groups such as trees, herbaceous plants and lianas on the succession of open pit mines.

One of the main attributes that would help to understand the successional routes from the first stages of regeneration is the growth form. Growth forms respond to different strategies of distribution of resources and contribute differentially in the mechanisms of succession [27]. A large number of studies have been developed on growth forms that thrive and are later replaced during secondary succession, due to activities such as farming [19,20,28,29]. It has been determined that the first stages of succession are mainly dominated by grasses, shrubs and vines, which are gradually replaced by pioneer trees of short and long time periods, followed by shade-tolerant trees [15,30,31]. However, there are few studies that have evaluated the relative contribution of the functional group life form in the development of secondary succession after extraction of material in open quarries.

Similarly, there are few studies that evaluate the speed of natural regeneration, as well as the patterns of dominance, richness and composition of species from the succession [32]. The traditional model of secondary succession establishes that communities that have suffered a disturbance of high intensity and frequency present three stages of successional development: 1) initial state (without vegetation); 2) pioneering state (with individual plants) and 3) transitional state (showing a "random mosaic") [32].

At present, the areas bound to some type of mining extraction represent 1% of the earth surface [33,34]. The state of Quintana Roo in southeastern Mexico is one of the regions with the highest growth in infrastructure and road construction for the last two decades, which has generated an increase in mining areas known as quarries [35]. In the Yucatan Peninsula, open-pit mining exploits materials derived from limestone, locally known as sascaberas (sascab = white earth in Maya language, [36]). This activity has caused a strong impact on plant communities and soil properties, thereby changing the natural conditions of the landscape. Of the 44,556 km2 of Quintana Roo [37,38],

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7.94 km2 are officially occupied by active or abandoned quarries [39–41]. However, the real estimated area used for open mining areas is much higher.

Studies have been carried out in order to restore these areas using knowledge of their floristic richness [42,43]. A recovery strategy for some quarries in the Yucatan Peninsula has been the implementation of agroforestry systems (SA), through the multi-stratification association of fruit trees with trees of timber use, with positive results in the regeneration of quarries [44]. The studies carried out in the quarries of the Yucatan Peninsula have focused more on the restoration and not on the evaluation of the process of secondary succession.

Therefore, it is a priority to analyze the diversity and structure of the plant communities, which have established in the quarries during the successional process, and to understand the importance of the adjacent conservation areas. Additionally, the information obtained can be used for the implementation of conservation programs in areas highly vulnerable to this type of disturbance. Under this view, the objective of this study is to determine the floristic composition, diversity and structure of the vegetation in three functional groups in abandoned quarries, as well as the importance of the adjacent areas as facilitators for succession and their relationship with soil variables.

2. Materials and Methods

Study area

The study was carried out near Xul-Ha, municipality of Othon P. Blanco, in the southeastern part of the state of Quintana Roo (figure 1). The predominant vegetation is medium statured forest [45,46]. However, it is common to find areas in different states of secondary succession known as acahuales, caused by different types of natural and anthropogenic disturbances [47]. According to the Köeppen climatic classification, modified by García [48], the climate is warm subhumid (Aw '' (X ')) with summer rain and a dry season between January and April. The average annual precipitation fluctuates between 1100 and 1200 mm [49], and the average annual temperature recorded in the last decade is 26.5 ° C [50]. The type of soil is rich in calcium carbonates (CaCO3), and the most common is rendzic Leptosol, followed by Vertisols, Luvisols and Gleysols, which are distributed in patches in the study area [51].

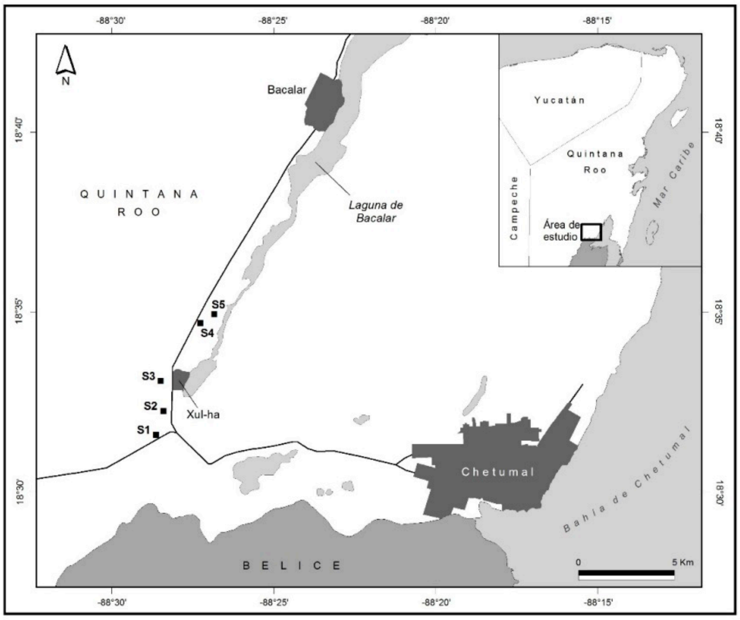

Figure 1: Location of the study area and of the sampled quarries

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Sampling design

Five open pit mines were selected for the purpose of our study. Two selection criteria were established: i) at least ten years of abandonment and ii) that they were embedded in a matrix of vegetation or forest remnants, after here considered as conserved areas, and at a distance of no more than 100 m (table 1). The time of abandonment of the pits was determined based on interviews with the owners and authorities of the region. . The distance between the pits varied between 0.78 - 1.55 km. The conserved areas were selected based on the structure of the vegetation, with a relatively closed canopy and a height of 10 m or more.

Table 1: Stand information of the five studied quarries. The approximate time of abandonment is presented in years. L = Leptosol; R = Rendzina.

Quarry	Age(Years)	Coordinates	Soil	Soil depth
S1	10	18° 31′ 30.5″ N -88° 28′ 29.5″ W	L, R	7 cm
S2	10	18° 32′ 10.1″ N -88° 28′ 16.3″ W	L, R	5 cm
S3	10	18° 33′ 01.1″ N -88° 28′ 21.9″ W	L, R	8 cm
S4	10	18° 34′ 39.6″ N -88° 27′ 12.8″ W	L, R	11 cm
S5	10	18° 34′ 55.0″ N -88° 26′ 48.1″ W	L, R	10 cm

Vegetation sampling

In each quarry, 12 randomly distributed quadrants 10 x 10 m (100 m2) were sampled. Additionally, three control plots of 10 x 10 (100 m2) were established in surrounding conserved areas. In each plot, species were identified and of all individuals diameter at breast height (DBH) ≥ 1 cm and a height ≥ 1 m was recorded. For the herb layer, four subplots of 1 x 1 m (1 m2) were randomly established within each plot of 100 m2. In all plots species, abundance, height and diameter at breast height (DAP) were recorded

Soil sampling

Soil data were taken from a composite sampling along the transect. In each of the samples the following components were determined: Total nitrogen (Nt, Micro Kjeldahl method), Phosphorus (Olsen method), Potassium (K, AS-12 with ammonium acetate), pH (water 2: 1), organic matter (MO, Walkley and Black method), cation exchange capacity (CIC, ammonium acetate pH 7.0), texture (Boucoucos method).

Data analysis

To compare the taxonomic diversity of the treatments, a rarefaction analysis (interpolation) and extrapolation (prediction) of the Hill numbers were performed, based on sample size and coverage,

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which represents a unified criterion to contrast the diversity of multiple assemblages [52]. The analysis was carried out based on the order q (richness of species) and richness estimators were determined with the iNEXT software package R. The relative importance value index was calculated in each of the plots, and for the functional groups IVI = relative density + relative area basal + relative frequency. Where: relative density = (number of individuals of species/total number of individuals)*100; relative basal area = (basal area of a species/basal area of all species)*100; relative frequency = (frequency of a species/144 frequency of all species)*100[53].

The variation in the composition of species was analyzed through an analysis of correspondence: The abundance was established with a transformation of Hellinger, which minimizes the weight of rare species. In addition, a canonical correspondence analysis was carried out to determine the relative influence of soil nutrients on the composition of species. The analysis was carried out with the CANOCO 4.56 package [54]. Additionally, statistically significant differences in the composition of woody species between the different treatments with a dissimilarity analysis (ANOSIM) in PRIMER-E 6.1.12 [55] were calculated. Finally, regression analyzes were carried out between the diversity of species found in each treatment and the soil variables. The diversity of species usually presents a Poisson distribution, and a generalized linear model (GLM) was used.

3. Results

Floristic composition

We recorded 8372 individuals, belonging to 37 families, 71 genera and 77 species. The species can be distributed in three functional groups according to their biological form: trees, herbaceous plants and lianas (Table 2). The family with the highest species richness was Poaceae with 10 species, followed by Fabaceae with eight species, Euphorbiaceae with five species, Rubiaceae and Sapotaceae with four species, Anacardiaceae, Apocynaceae and Asteraceae with three species. All of them contributed 30.8% of all botanical families. The remaining 69.2% was distributed among 28 families, seven with two species and 21 with one species. Within the functional group trees, the most important families were Fabaceae with eight species, Sapotaceae with four and Anacardiaceae with three, followed by Arecaceae, Euphorbiaceae, Moraceae, Polygonaceae and Sapindaceae with two species. The rest of the families (15) were represented by a single species. In the herb layer, the most important families were Poaceae with ten species, Asteraceae and Euphorbiaceae with three species, and Cyperaceae and Rubiaceae with two. The twelve remaining species were represented by a single species. Finally, the functional group of the lianas was represented by five families, Convolvulaceae with 2 species and Apocynaceae, Bignoniaceae, Passifloraceae, Rubiaceae with one species (Table 2).

The quarry with most species was S5 with 45 species, followed by S3 with 37 species, S2 and S1 had 36 and 35 species and S4 had the lowest species richness with 34. With respect to functional groups, trees represented 51.28% of the total species sampled with 40 species, followed by herbs and lianas that represented 41 and 7.69% with 32 and 6 six species, respectively. The highest abundance was recorded in the S2 quarry (2505 individuals), followed by S5 (1722 individuals), S4 (1378 individuals) and S3 and S1 (874 and 870 individuals, respectively). Herbs were the most abundant functional group with 7045 individuals, representing 84.14% of the total abundance. The quarries with the highest proportion of herb abundance were S2 and S5, representing 57.53% of the total (2513 and 1540 individuals, respectively). The trees represented 13.80% of the total abundance of the community, being more abundant in the quarries S5 and S4 (378 and 359 individuals, respectively). Finally, the lianas were the least abundant with 171 individuals distributed as follows: S5 (52), S3 (51), S2 (27), S4 (22) and S1 (19). (Table 2). A higher species richness was observed in the quarries (50) than in the conserved sites (47). The difference is statistically significant, as the intervals do not overlap. The species richness of the tree functional group was higher in the conserved sites (34) than in the quarry treatments (19). On the other hand, the functional group of the herbaceous plants

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presented a greater richness of species in the quarries than in the conserved areas. Lianas did not show significant differences between treatments (Table 2).

Table 2. List of species sampled in all quarries and conserved areas, indicating their growth form (GF, T = tree, H = herb, F = fern, E = epiphyte, S = shrub, P = palm; L = liana). S = sascabera / quarry; C = preserved.

Family	Specie	BF	S1	S2	S3	S4	S5	C
Anacardiaceae	*Astronium graveolens* Jacq.	T			*			*
	Metopium brownei (Jacq.) Urb.	T	*	*	*	*	*	*
	Spondias mombin L.	T				*		*
Anemiaceae	*Anemia adiantifolia* (L.) Sw.	F			*	*	*	
Annonaceae	*Malmea depressa* (Baill.) R.E. Fr.	T	*		*			*
Apocynaceae	*Echites tuxtlensis* Standl.	L				*		*
	Echites yucatanensis Millsp. ex. Standl.	L				*		*
	Thevetia peruviana (Pers.) K. Schum.	T	*	*	*	*	*	*
Araliaceae	*Dendropanax arboreus* (L.) Decne. y Planch.	S		*				*
Arecaceae	*Acoelorraphe wrightii* (Griseb. y H. Wendl.) H. Wendl. ex Becc.	P			*			*
	Sabal mexicana Mart.	P				*	*	*
Asteraceae	*Calea jamaicensis* (L.) L.	S	*			*	*	
	Melanthera sp. Rohr	H					*	
	Viguiera dentata (Cav.). Spreng.	H	*	*	*	*	*	*
Bignoniaceae	*Arrabidaea sp.*DC.	L	*				*	
	Cydista potosina (K. Schum. y Loes.) Loes.	H	*	*	*		*	*
Bromeliaceae	*Bromelia sp.* L.	E					*	
Burseraceae	*Bursera simaruba* (L.) Sarg.	T			*			*
Cannabaceae	*Trema micrantha* (L.) Blume	S					*	
Celastraceae	*Hippocratea volubilis* L.	T					*	
Convolvulaceae	*Ipomoea batatas* (Choisy) Griseb.	Hr			*			
	Ipomoea sp L.	Hr	*		*			
Cyperaceae	*Fimbristylis sp.* Vahl	H		*				
	Scleria sp. P.J. Bergius	H					*	
Ebenaceae	*Diospyros salicifolia* Humb. y Bonpl. ex. Willd.	T	*		*	*	*	*
Euphorbiaceae	*Cnidoscolus multilobus* (Pax) I.M. Johnst.	T	*		*			*
	Croton sp. L.	T	*	*			*	*
	Euphorbia dioica Kunth	H		*			*	
	Euphorbia sp. L.	H		*				
	Jatropha gaumeri Greenm.	T		*		*	*	*
Fabaceae	*Acacia collinsi* Saff.	T	*	*			*	*
	Bauhinia divaricata Lam.	T	*	*		*	*	*
	Caesalpinia gaumeri Greenm.	T			*	*	*	
	Lonchocarpus xuul Lundell	T		*	*		*	*
	Lysiloma latisiliquum (L.) Benth.	T	*	*		*	*	*
	Mimosa bahamensis Benth.	T	*				*	

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Family	Specie	BF	S1	S2	S3	S4	S5	C
	Piscidia piscipula (L.) Sarg.	T		*		*	*	*
	Senna sp. Mill.	T	*		*		*	*
Lamiaceae	*Ocimum micranthum* Willd.	H		*				
	Vitex gaumeri Greenm.	T	*	*	*	*	*	*
Lygodiaceae	*Lygodium venustum* Sw.	F			*		*	
Malpighiaceae	*Byrsonima crassifolia* (L.) Kunth	T	*	*	*	*	*	*
Malvaceae	*Waltheria indica* L.	H	*	*		*	*	
Moraceae	*Brosimum alicastum* Sw.	T			*			*
	Ficus pertusa L. f.	T					*	
Muntingiaceae	*Muntingia calabura* L.	T					*	
Myrtaceae	*Eugenia capuli* (Schltdl. y Cham.) Hook. y Arn.	S			*			*
Orchidiaceae	*Bletia purpurea* (Lam.) DC.	H			*			
Passifloraceae	*Passiflora sp.* L.	L		*		*	*	*
Piperaceae	*Piper auritum* Kunth	T	*					*
	Piper neesianum C. DC.	T			*			*
Poaceae	*Bothriochloa pertusa* (L.) A. Camus	H		*				
	Chloris inflata Link	H	*	*	*	*	*	
	Cynodon dactylon (L.) Pers	H		*				
	Dichanthium aristatum (Pior.) C.E. Hubb.	H		*		*		
	Digitaria ciliaris (Retz.) Koeler	H	*	*				
	Eragrostis ciliaris (L.) R. Br.	H		*				
	Eragrostis secundiflora J. Presl	H		*				
	Ichnanthus lanceolatus Scribn. y J.G. Sm.	H	*	*	*	*	*	*
	Paspalum blodgettii Champ.	H	*	*	*	*	*	
	Paspalum sp. L.	H	*	*	*		*	
Polygonaceae	*Coccoloba cozumelensis*Hemsl.	T, S	*	*	*	*	*	*
	Gymnopodium floribundum Rolfe	T	*		*	*		*
Rubiaceae	*Alseis yucatanensis* Standl.	T			*			*
	Borreria verticillata (L.) G. Mey.	H	*	*	*	*	*	
	Bouvardia ternifolia (Cav.) Schltdlt.	H	*			*		*
	*Morinda yucatanensis*Greenm.	Hr			*	*	*	*
Sapindaceae	*Cupania dentata* DC.	T		*	*		*	*
	Talisia floresii Standl.	T	*					*
Sapotaceae	*Chrysophyllum mexicanum* Brandegee ex Standl.	T		*	*	*	*	*
	Manilkara zapota (L.) P. Royen	T				*		*
	Pouteria campechiana (Kunth) Baehni	T	*	*	*	*	*	*
	Pouteria reticulata (Engl.) Eyma	T	*	*		*	*	*
Simaroubaceae	*Simarouba glauca* DC.	T	*		*	*	*	*
Urticaceae	*Cecropia peltata* L.	T			*	*		*
Verbenaceae	*Stachytarpheta frantzii* Pol.	H	*					

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Family	Specie	BF	S1	S2	S3	S4	S5	C
Zamiaceae	*Zamia prasina* W. Bull	H	*				*	*

Vegetation structure

The herb layer in the quarries was represented mainly by species of the family Rubiaceae and Poaceae with the highest IVI values. *Borreria verticillata* was the dominant species in the quarries S1, S2, S3 and S5, and *E. ciliaris* at S4 (table 3). The herb layer of conserved areas, was dominated by the species *Cydista potosina* at sites S1, S2, S3 and S5. *Viguiera dentata* and *Bouvardia ternifolia* were the most dominant species of site S4. [A17]

The canopy layer of the quarries is dominated by *Metopium brownei* in quarry S1, *A. collinsii* in S2, *Caesalpinia gaumeri* in S3, *Coccoloba cozumelensis* with *Lysiloma latisiliquum* in S5, and *L. latisiliquum* in S4 (table 3). The canopy layer of the conserved areas showed a wider distribution in the dominance of species, among which are *L. latisiliquum, Vitex gaumeri, Alseis yucatanensis, Bursera simaruba, Pouteria campechiana, Diospyros salicifolia*, among others (table 3).

Table 3. Importance Value Index (IVI) in quarries and conserved areas.

	Quarry					Conserved area				
Herb layer	**S1**	**S2**	**S3**	**S4**	**S5**	**C1**	**C2**	**C3**	**C4**	**C5**
Cydista potosina	-	-	-	-	-	146	180	216	-	110
Borreria verticillata	108	118	117	41	143	-	-	-	-	-
Ichnanthus lanceolatus	-	-	-	-	-	58	75	45	75	79
Eragrostis secundiflora	-	47	42	109	-	-	-	-	-	-
Paspalum blodgettii	35	39	-	44	47	-	-	-	-	-
Paspalum sp	47	17	72	-	-	-	-	-	-	-
Arrabidaea sp.	-	-	-	-	-	62	-	-	-	42
Viguiera dentata	-	-	-	-	-	-	-	-	79	-
Morinda yucatanensis	-	-	22	-	13	-	-	-	-	43
Bouvardia ternifolia	-	-	-	-	-	-	-	-	76	-
Chloris inflata	-	-	-	24	50	-	-	-	-	-
Digitaria ciliaris	49	-	-	-	-	-	-	-	-	-
Passiflora sp.	-	-	-	-	-	-	22	-	22	-
Cnidoscolus multilobus	-	-	-	-	-	-	-	39	-	-
Dendropanax arboreus	-	-	-	-	-	-	22	-	-	-
Zamia prasina	-	-	-	-	-	21	-	-	-	-
Tree layer	**S1**	**S2**	**S3**	**S4**	**S5**	**C1**	**C2**	**C3**	**C4**	**C5**
Lysiloma latisiliquum	-	-	-	143	122	61	101	-	83	-
Metopium brownei	193	-	64	64	23	-	-	-	38	-
Acacia collinsi	-	300	-	-	-	-	-	-	-	-
Caesalpinia gaumeri	-	-	189	-	-	-	-	-	-	-
Vitex gaumeri	-	-	-	25	-	-	44	52	-	58
Coccoloba cozumelensis	-	-	23	-	59	-	-	-	-	47
Bursera simaruba	34	-	-	-	-	40	17	-	23	-
Byrsonima crassifolia	39	-	24	18	-	-	-	-	-	-

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Pouteria reticulata	-	-	-	-	-	34	-	-	24	-
Alseis yucatanensis	-	-	-	-	-	-	-	48	-	-
Croton reflexifoluis	-	-	-	-	-	-	19	-	-	28
Mimosa bahamensis	34	-	-	-	11	-	-	-	-	-
Pouteria campechiana	-	-	-	-	-	-	-	45	-	-
Diospyros salicifolia	-	-	-	-	-	41	-	-	-	-
Jatropha gaumeri	-	-	-	-	-	-	-	-	-	25
Piper neesiariuum	-	-	-	-	-	-	-	21	-	-

The density was higher (F = 6.0492, p = 0.002) in the quarries (31.7 ind./ m² ± 7.5) than in the conserved zone (5.5 ind./ m² ± 2.5, figure 2a). The quarry S2 presented the highest value of density (54.16 ind. /m² ± 9.3) the quarries S1 and S3 obtained the lowest values (18.9 and 16.9 ind./ m² respectively). The conserved site with the highest density was S4 with (14.2 ind. /m² ± 8.9) and the lowest density was S3 (2.3 ind./ m² ± 0.8).

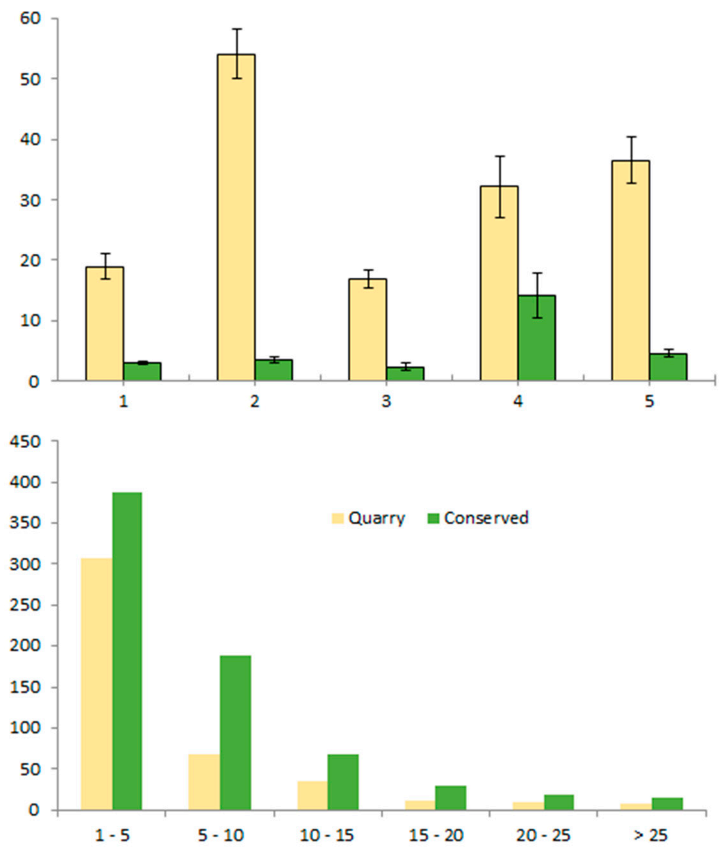

Figure 2: a) Average density of individuals in each quarry and conserved area. b) Distribution in diametric classes of quarries (n = 438) and conserved areas (n = 706)

The structure of diametric classes in the quarries and in the conserved sites showed an inverted j pattern, in which the largest number of individuals was concentrated in the youngest categories

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(figure 2b). Of the 438 individuals measured in the quarries, 74.6% are in the first diametric class (1 - 5 cm), and decreases considerably in the second class (5-10 cm), concentrating only 12.8% of the individuals; the other four categories, group 12.5%. Similar to the quarries, in the conserved areas the individuals are concentrated in the smaller classes, grouping 83.5% of the individuals in the first two classes; while 16.5% was distributed in the four largest classes.

The canonical correspondence analysis (ACC) explained 60% of the total variance, with eigenvalue of 0.89 for the first axis and 0.61 for the second axis, representing 35.5% and 24.5% of the total variance, respectively. The first axis is determined by the increase in the concentration of organic matter (OM), CEC, and percentage of sand. The second axis is determined by increase in silt and pH (figure 3). In figure 3, the plots sampled in the quarries and conserved areas are presented. Most plots of conserved areas (C1, C2, C3, C5) are grouped in the lower left; except for the conserved zone 4 (C4) located in the upper left, which was characterized by showing the highest content of MO, nitrogen (N), phosphorus (P) and potassium (K). Regarding the plots of the quarries most of the plots (S1, S2, S3, S5) are grouped in the central part of the graph; except S4, which presented better soil conditions given its distribution on axis 2. In general, it was observed that the quarries presented a soil with a slightly alkaline pH, unlike the conserved areas that have a neutral pH, and a higher percentage of silt.

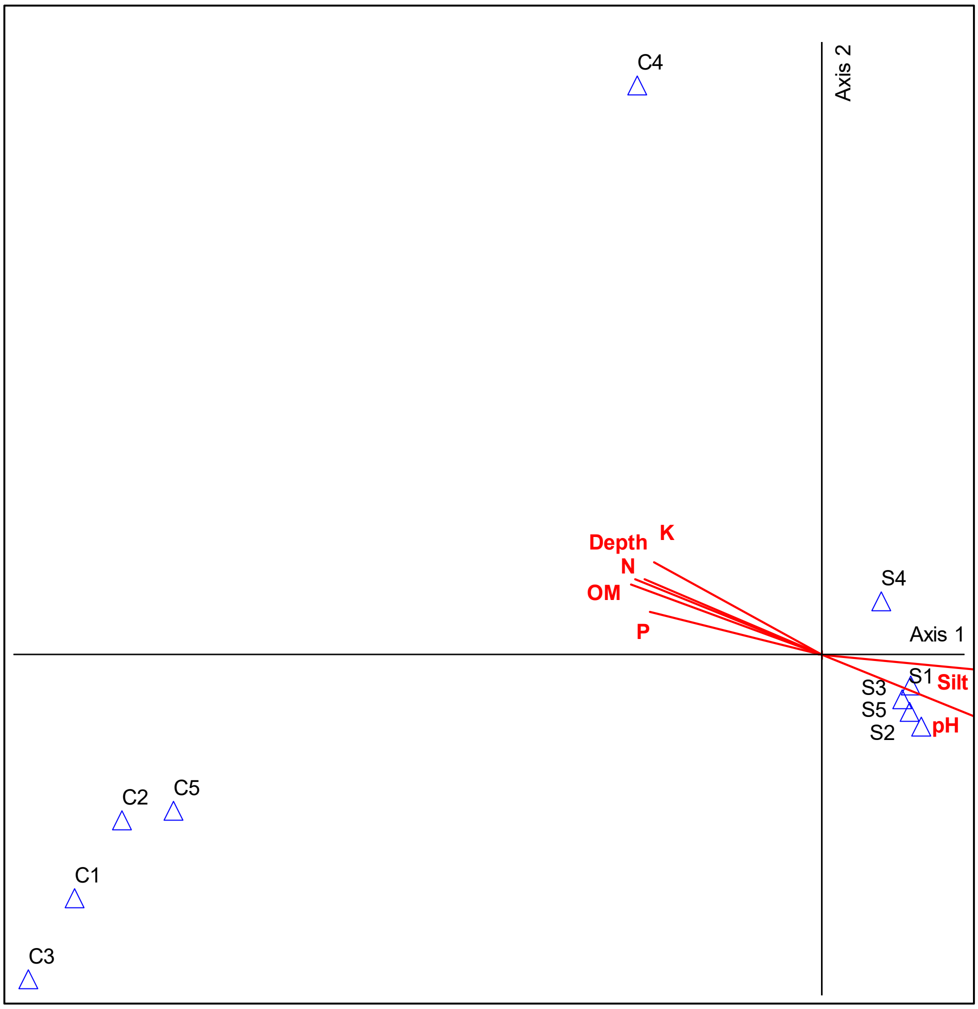

Figura 3: CCA of plots and soil variables. C conserved area plots, S quarry plots.

4. Discussion

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Pits (sascaberas) and conserved areas presented a similar number of species (50 and 47, respectively), but a different composition. In the herbaceous stratum of the quarries, the species belonging to the family Poaceae, Asteraceae and Rubiaceae, were those that presented greater density. Poaceae, Rubiaceae and Fabaceae, presented the highest values of IVI in the quarries, which are characterized by presenting species capable of establishing themselves in open sites and in areas of early regeneration, due to their strategies of anemochory [56]. Those families have been reported in the early stages of succession of the region [57], and are being common in areas that have suffered some disturbance, due to their high tolerance to open conditions [58].

Dominant tree species of the quarries are *L. latisiliquum, M. brownei, Byrsonima crassifolia*, among others. These species are characteristic of the secondary forests of the region [47,57]. Those species can develop both in shallow soils, typical of quarries, and deep soils with good drainage [59]. In contrast, the conserved areas showed a dominance of species such as *L. latisiliquum, V. gaumeri, C. cozumelensis, M. brownei, P. piscipula, Piper auritum, P. neesianum, Croton reflexifoluis, Spondias mombin, P. campechiana*, which have been identified as species with relatively high dominance values, and are present in different successional states of dry tropical forests ([60,61]).

The growth form showed clear differences between the quarries and the conserved areas. The growth form of trees showed the greatest species richness in the conserved sites, contrary to herbaceous species that clearly dominated the quarry areas. This clearly agrees with that reported in previous studies in tropical forests [13,16,30]. However, shrub growth form was only represented by one species in the quarries, which is probably due to the effect of the surrounding metacommunities, where this functional group has no presence. Finally, the functional group of lianas did not show significant differences between the conserved plots and the quarries (4 and 5, respectively). However, the abundance was higher in the conserved areas. This may be related to the availability of larger trees in the conserved areas, which offer more availability of structural support [30,62] contrary to the vegetation structure of the degraded sites.

The high number of individuals in smaller diameter classes, present in the quarries, indicate the juveniles individuals in a successional state of less than 15 years [63], as 95% of the total individuals do not exceed 15 cm of DAP (figure 2b). The species that presented the highest number of individuals in the five diametric classes were *L. latisiliquum* and *M. brownei*, which are found mainly in quarries S4 and S5, supporting the evidence of the presence of a more advanced successional state compared to the other quarries . In addition, the presence of these deciduous species probably helps the accumulation of MO and therefore, to an improvement of the edaphic conditions.

Based on the results of the CCA, species groups present in the conserved areas and the species present in the quarries can be identified (figure 3). The quarry species are characterized by a high growth rate, which is characteristic of species of early successional stages, which decrease as the process of succession progresses and are replaced by species of late succession (Uhl 1987). The species present in the conserved areas are grouped on the right side of the graph, where the depth of the soil is greater than in the quarries, favoring the accumulation of organic matter. Some of the species present in these areas, such as *B. simaruba* and *Byrsonima crassifolia* are deciduous, which promotes the constant accumulation of organic matter. Likewise, the species that are colonizing part of the sascaberas such as *L. latisiliquum, M. brownei, B. simaruba* and other, are located between the group of species from the quarries and those of the conserved areas, which shows that these species are capable of developing both in shallow soils and in deeper soils [59].

In the ordination graph (figure 3), the sample plots of quarry S4 are distributed towards the right side of the graph, where the values of soil properties approximate those of the conserved areas. The conditions of the substrate clearly affect the distribution and abundance of the species [60]. In addition to this, soil moisture plays an important role in the composition and structure of the vegetation, which is generally influenced by the amount of MO [64], because it acts as a protective layer, avoiding with the evaporation of water.

The variation of silt and sand in the quarries and conserved areas, indicates that, at higher levels of silt, the successional process develops slowly. This is probably due to the fact that soils with high percentages of silt have a lower drainage than sandy soils [65]. This may lead to partially flooding, during the dry season, and favors formation of superficial crusts that prevent the emergence of tree seedlings [66]. The low amount of nutrients, together with the high evaporation caused by the lack of a protective cover of OM in the quarries, creates a stressful environment for the plants, producing a slow development of the vegetation.

This work shows the high tolerance to stress conditions of certain species such as *Paspalum* sp., *Eragrostis secundiflora, Chloris inflata, Borreria verticillata, Calea jamaicensis, Metopium brownei, Caesalpinia gaumeri* and *Lysiloma latisiliquum*, being the most dominant in the pits. It shows the slow recovery of vegetation, which is mainly due to the total loss of soil. Soils are considered relevant for seed banks, seedlings, stems and favor successional development [24,67–70]. The effect of total soil removal, the consequent edaphic conditions that occur in the quarries, such as a slightly alkaline pH, lower percentage of OM, lower CIC, higher percentage of silt and lower percentage of sand, are ecologically significant, as they present a clear correlation with the distribution of the species, and with the characteristics of the structure of the vegetation.

5. Conclusions

One of the main consequences of open pit mining in the Yucatan Peninsula is the total loss of soil, modifying edaphic conditions and, therefore, making it difficult to recolonize the species of the dry tropical forest. Despite this, there are some species adapted to stress conditions, mainly herbaceous taxa as *Borreria verticillata* and *Eragrostis secundiflora*. These species can develop in soils with a high percentage of silt, and with a slightly alkaline pH, unlike the typical species of dry forests, which grow on soils with an acidic pH and a high percentage of sand.

In the quarries more dominance of herbaceous species was found compared to the conserved areas. However, there are some arboreal species that have a wide range of tolerance to different edaphic conditions, such as *Lysiloma latisiliquum* and *Metopium brownei*, both can be found in quarries and dry tropical forests.

Although the diversity values obtained in the quarries and the conserved areas are not statistically significant, when comparing the community structure, a higher complexity can be observed in the conserved areas, where it is possible to find species of different strata. These differences in the development and distribution of the species, as well as in the structure of the plant communities of the quarries and the conserved areas are strongly correlated with the edaphic conditions.

Under this view, it is important to carry out studies focused on the successional development in the quarries of the Yucatan Peninsula, in order to have a better understanding of the response of the species to this type of disturbances. With the increase of this type of information, it will be possible to apply adequate management plans, restoration and conservation of these areas, and to detect those species that are highly vulnerable to this type of disturbances.

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Conceptualization, Mirna Valdez-Hernández and Gerald Alexander Islebe; Formal analysis, Mirna Valdez-Hernández, Rossana Gil-Medina, Jorge Omar López-Martínez and Gerald Alexander Islebe; Methodology, Rossana Gil-Medina; Writing – original draft, Mirna Valdez-Hernández, Rossana Gil-Medina, Jorge Omar López-Martínez and Gerald Alexander Islebe; Writing – review & editing, Nuria Torrescano-Valle and Nancy Cabanillas-Terán.

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