

1 Article

2 Succession and vegetation-soil relationship in quarries of 3 southeastern Mexico

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15 Abstract:

16 Open pit mining is a common activity in the Yucatan peninsula for the extraction of limestone. This
17 mining is known under the generic name of quarries, and regionally as *sascaber*s (*sascab*=white soil
18 in Mayan language). These areas are characterized by the total removal of the natural vegetation
19 cover and soil in order to have access to the calcareous material. The present study shows the
20 composition and structure of the vegetation in five quarries after approximately ten years of
21 abandonment, and the conserved vegetation near to each one of the quarries in southeastern
22 Quintana Roo. Using a canonical correspondence analysis (CCA), the distribution of the species
23 was determined in relation to the edaphic variables: soil depth, percentage of organic matter (OM),
24 cationic exchange capacity (CEC), pH and texture. 26 families, 46 genera and 50 species were
25 recorded in the quarries and 25 families, 45 genera and 47 species were recorded in the conserved
26 areas. The dominant species in the quarries belong to the families Poaceae, Fabaceae, Rubiaceae
27 and Anacardiaceae. The quarries with higher values of OM (1.63%), CEC (24.05 Cmol/kg), depth
28 (11 cm) and sand percentage (31.33%) include the following species like *Lysiloma latisiliquum*,
29 *Metopium brownei* and *Bursera simaruba* which are commonly found in secondary forests. On the
30 other hand, quarries with lower values of OM (0.39%), CEC (16.58 Cmol/kg) and depth (5.02), and
31 higher percentage of silt (42.44%) were dominated by herbaceous species belonging to the Poaceae
32 family and by *Borreria verticillata*, which are typical in disturbed areas of southeastern Mexico. In all
33 cases, the pH was slightly alkaline due to the content of calcium carbonate (CaCO₃), characteristic
34 of the soils of the region. The edaphic variables are significantly correlated with the development
35 and distribution of vegetation, and with the structure of the communities.

36

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

38

39 1. Introduction

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

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

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

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

54 One of the common strategies for the recovery of degraded areas is through processes of
55 primary and secondary regeneration of the ecosystem ([2,7,8]. Some studies have evaluated
56 rehabilitation strategies after extraction to establish the role of the surrounding native vegetation
57 ([9-12]. It has been observed that vegetation structure tends to be similar after many years of
58 abandonment [13,14]. However, particularly in the tropics, species composition does not always
59 follow a predictable pattern [15-17].

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

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

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

86 At present, the areas bound to some type of mining extraction represent 1% of the earth surface
87 [33,34]. The state of Quintana Roo in southeastern Mexico is one of the regions with the highest
88 growth in infrastructure and road construction for the last two decades, which has generated an
89 increase in mining areas known as quarries [35]. In the Yucatan Peninsula, open-pit mining exploits
90 materials derived from limestone, locally known as sascaberas (sascab = white earth in Maya
91 language, [36]). This activity has caused a strong impact on plant communities and soil properties,
92 thereby changing the natural conditions of the landscape. Of the 44,556 km² of Quintana Roo [37,38],

93 7.94 km² are officially occupied by active or abandoned quarries [39–41]. However, the real
 94 estimated area used for open mining areas is much higher.

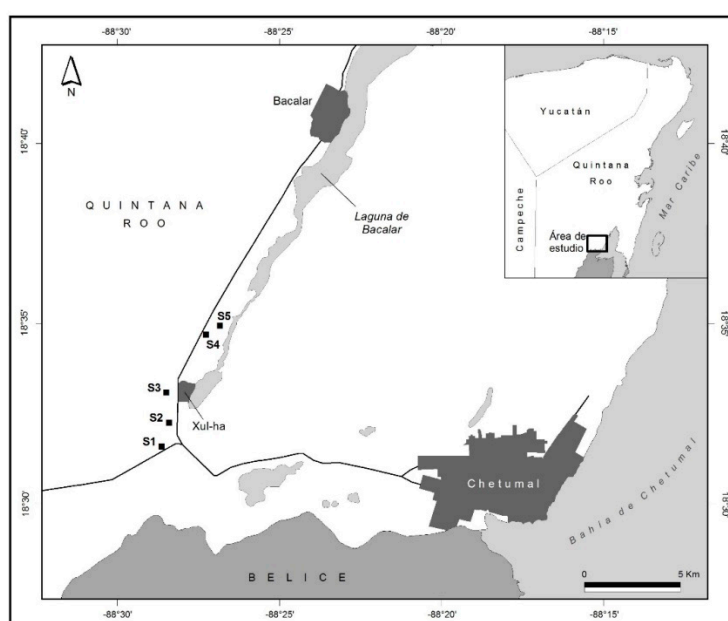
95 Studies have been carried out in order to restore these areas using knowledge of their floristic
 96 richness [42,43]. A recovery strategy for some quarries in the Yucatan Peninsula has been the
 97 implementation of agroforestry systems (SA), through the multi-stratification association of fruit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

101 Therefore, it is a priority to analyze the diversity and structure of the plant communities, which
 102 have established in the quarries during the successional process, and to understand the importance
 103 of the adjacent conservation areas. Additionally, the information obtained can be used for the
 104 implementation of conservation programs in areas highly vulnerable to this type of disturbance.
 105 Under this view, the objective of this study is to determine the floristic composition, diversity and
 106 structure of the vegetation in three functional groups in abandoned quarries, as well as the
 107 importance of the adjacent areas as facilitators for succession and their relationship with soil
 108 variables.
 109

110 2. Materials and Methods

111 *Study area*

112 The study was carried out near Xul-Ha, municipality of Othon P. Blanco, in the southeastern
 113 part of the state of Quintana Roo (figure 1). The predominant vegetation is medium statured forest
 114 [45,46]. However, it is common to find areas in different states of secondary succession known as
 115 acahuales, caused by different types of natural and anthropogenic disturbances [47]. According to
 116 the Köeppen climatic classification, modified by García [48], the climate is warm subhumid (Aw " (X
 117 ") with summer rain and a dry season between January and April. The average annual precipitation
 118 fluctuates between 1100 and 1200 mm [49], and the average annual temperature recorded in the last
 119 decade is 26.5 °C [50]. The type of soil is rich in calcium carbonates (CaCO₃), and the most common
 120 is rendzic Leptosol, followed by Vertisols, Luvisols and Gleysols, which are distributed in patches in
 121 the study area [51].
 122



123

124

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

125 *Sampling design*

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

133

134 **Table 1:** Stand information of the five studied quarries. The approximate time of abandonment is
 135 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

136

137 *Vegetation sampling*

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

144

145 *Soil sampling*

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

151

152 *Data analysis*

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

155 which represents a unified criterion to contrast the diversity of multiple assemblages [52]. The
156 analysis was carried out based on the order q (richness of species) and richness estimators were
157 determined with the iNEXT software package R. The relative importance value index was calculated
158 in each of the plots, and for the functional groups $IVI = \text{relative density} + \text{relative area basal} + \text{relative}$
159 frequency . Where: $\text{relative density} = (\text{number of individuals of species} / \text{total number of}$
160 $\text{individuals}) * 100$; $\text{relative basal area} = (\text{basal area of a species} / \text{basal area of all species}) * 100$; relative
161 $\text{frequency} = (\text{frequency of a species} / \text{frequency of all species}) * 100$ [53].

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

172

173 3. Results

174 *Floristic composition*

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

189 The quarry with most species was S5 with 45 species, followed by S3 with 37 species, S2 and S1
190 had 36 and 35 species and S4 had the lowest species richness with 34. With respect to functional
191 groups, trees represented 51.28% of the total species sampled with 40 species, followed by herbs and
192 lianas that represented 41 and 7.69% with 32 and 6 six species, respectively. The highest abundance
193 was recorded in the S2 quarry (2505 individuals), followed by S5 (1722 individuals), S4 (1378
194 individuals) and S3 and S1 (874 and 870 individuals, respectively). Herbs were the most abundant
195 functional group with 7045 individuals, representing 84.14% of the total abundance. The quarries
196 with the highest proportion of herb abundance were S2 and S5, representing 57.53% of the total
197 (2513 and 1540 individuals, respectively). The trees represented 13.80% of the total abundance of the
198 community, being more abundant in the quarries S5 and S4 (378 and 359 individuals, respectively).
199 Finally, the lianas were the least abundant with 171 individuals distributed as follows: S5 (52), S3
200 (51), S2 (27), S4 (22) and S1 (19). (Table 2). A higher species richness was observed in the quarries (50)
201 than in the conserved sites (47). The difference is statistically significant, as the intervals do not
202 overlap. The species richness of the tree functional group was higher in the conserved sites (34) than
203 in the quarry treatments (19). On the other hand, the functional group of the herbaceous plants

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

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

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

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

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

209 *Vegetation structure*

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

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

220

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

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

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

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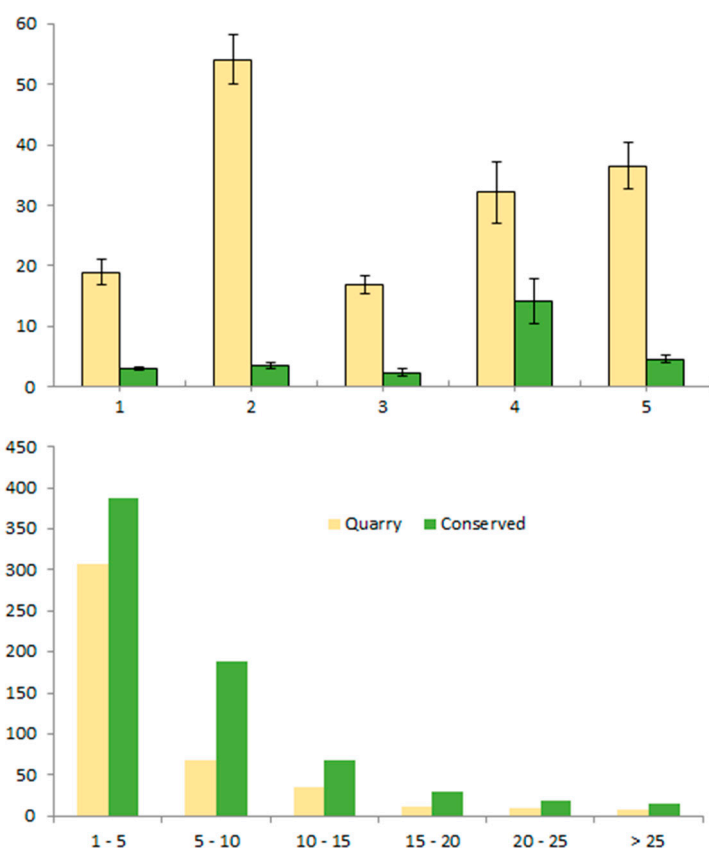
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227

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

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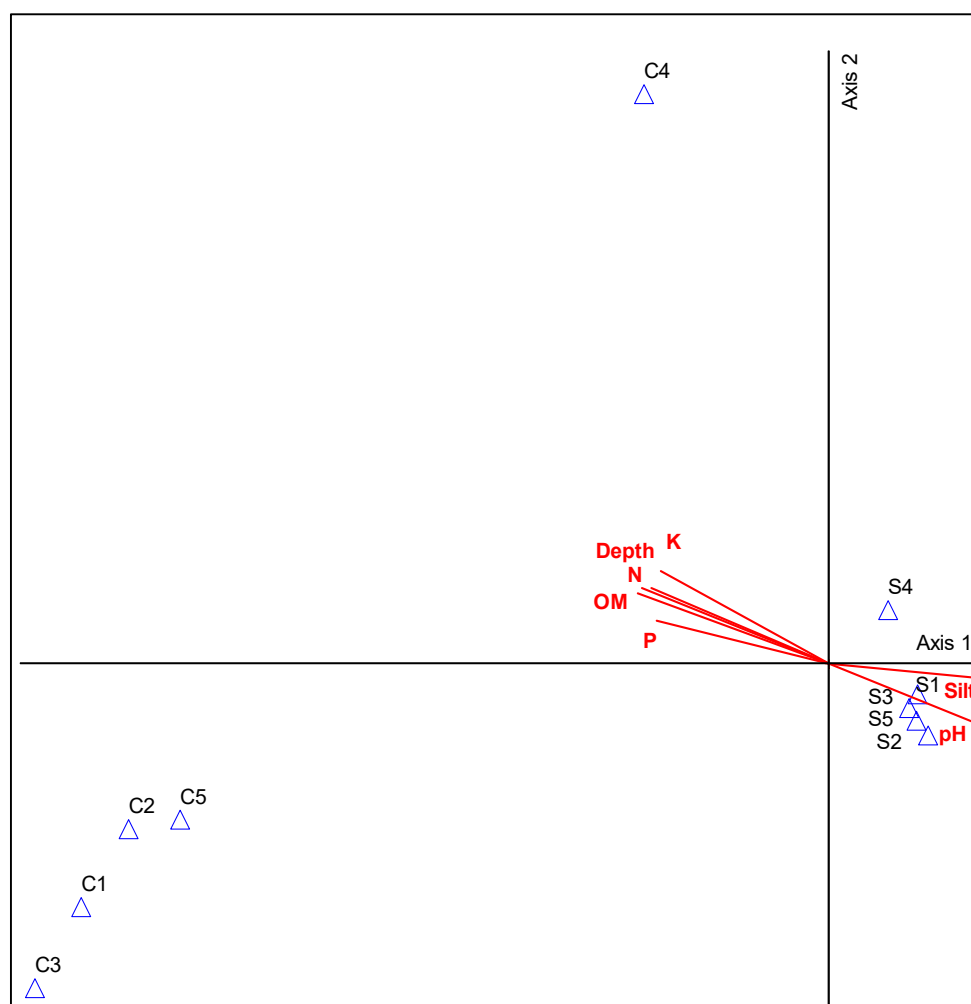
235

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

236 (figure 2b). Of the 438 individuals measured in the quarries, 74.6% are in the first diametric class (1 -
 237 5 cm), and decreases considerably in the second class (5-10 cm), concentrating only 12.8% of the
 238 individuals; the other four categories, group 12.5%. Similar to the quarries, in the conserved areas
 239 the individuals are concentrated in the smaller classes, grouping 83.5% of the individuals in the first
 240 two classes; while 16.5% was distributed in the four largest classes.

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



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254

255

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

256

4. Discussion

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

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

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

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

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

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

306 The variation of silt and sand in the quarries and conserved areas, indicates that, at higher
307 levels of silt, the successional process develops slowly. This is probably due to the fact that soils with
308 high percentages of silt have a lower drainage than sandy soils [65]. This may lead to partially

309 flooding, during the dry season, and favors formation of superficial crusts that prevent the
310 emergence of tree seedlings [66]. The low amount of nutrients, together with the high evaporation
311 caused by the lack of a protective cover of OM in the quarries, creates a stressful environment for the
312 plants, producing a slow development of the vegetation.

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

322 5. Conclusions

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

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

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

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

344
345

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347 Conceptualization, Mirna Valdez-Hernández and Gerald Alexander Islebe; Formal analysis, Mirna
348 Valdez-Hernández, Rossana Gil-Medina, Jorge Omar López-Martínez and Gerald Alexander Islebe;
349 Methodology, Rossana Gil-Medina; Writing – original draft, Mirna Valdez-Hernández, Rossana Gil-Medina,
350 Jorge Omar López-Martínez and Gerald Alexander Islebe; Writing – review & editing, Nuria Torrescano-Valle
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352

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358
359

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