ECOLOGY OF A BRAZILIAN BAUXITE MINE ABANDONED FOR FIFTY YEARS[1]

Jackeline S. Lorenzo[2], James J. Griffith, Ivo Jucksch,
Agostinho L. de Souza, Maria G. F. Reis, and Antônio B. do Vale[3]

Abstract: This study analyzed natural regeneration on bauxite-mined land to learn how mining affects plant communities and to identify appropriate woody species for site reclamation. The site chosen in Poços de Caldas, Minas Gerais State, had last been mined 50 yr ago, by hand. Such a long-standing site, abandoned but free of further ecological disturbance, is rare in the tropics and subtropics. Three site conditions were studied: heavily mined, lightly mined, and adjacent undisturbed terrain. Mined sites were found to have soils of sandy clay loam texture; undisturbed soils have clayey texture. Chemical characteristics also differ, especially aluminum (Al^{3+}), which is much lower on mined sites. Woody species show more exuberance on heavily mined sites with family Melastomataceae showing the highest index of importance value; family Compositae was highest on undisturbed sites. Considering that mining usually degrades soil, it might seem surprising that, for the three sites, the most copious vegetation occurs on the most heavily mined site. It is suspected that bauxite mining, in some cases, may improve soil chemistry by removing aluminum. The hand mining done 50 yr ago also created pits that accumulate water and sediment during rains, which may be useful to woody species.

Introduction

A bauxite mine called Campo do Saco, located in the municipality of Poços de Caldas in southern Minas Gerais State, provided a rare opportunity to study regeneration of woody species on long-standing degraded lands. This mine started production at the outset of the 1930's. Excavation by pick and shovel continued during the 1940's until the mine was finally abandoned with no attempt at reclamation. Despite this abandonment, a considerable quantity of the area's bauxite remained untouched. Under new ownership, the mining company periodically opened small excavations in the area until 1971, as part of its legal obligation to maintain the mineral concession.

Intending to reopen the mine in 1991, the company decided to do a model job by preplanning reclamation. It commissioned, among others, a phytosociological study of existing vegetation to predict environmental impacts from reopening the mine. The objective of this paper is to analyze how vegetation at Campo do Saco has changed in relation to soil characteristics modified by mining. It was done by the Department of Forest Resources, Federal University of Viçosa, in cooperation with the company that operates the mine.

Various authors have described mining's environmental impact in temperate regions. Changes in naturally established plant communities have been reported by researchers such as Johnson et al. (1982), Manner et al. (1984), and Smith et al. (1988). Palaniappan's (1974) work on Malaysian cassiterite mines is one of the few regeneration studies on abandoned sites in the tropics.

In general, these and other studies point to the following hypotheses for the Campo do Saco situation:

1. Degradation caused by mining usually includes substantial alteration of the original, native vegetation and soil structure. Mining in the Poços de Caldas region may not be so harmful as undisturbed vegetation overlying bauxite deposits in the region tends to be low and sparse.

2. Disturbed soil characteristics after mining should largely explain characteristics of plants found on excavated sites. For this study, this relationship will probably have to be understood within the context of soil conditions typical of the "cerrado" phytogeographic region, which marginally includes the Campo do Saco study area.

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[2]Jackeline S. Lorenzo, Biologist, Department of Environment, Oficina Nacional de Planificación, Santo Domingo, Dominican Republic.

[3] James J. Griffith, Professor of Forestry, Ivo Jucksch, Assistant Professor of Soils, Agostinho L. de Souza, Professor of Forestry, Maria G. F. Reis, Professor of Forestry, and Antônio B. do Vale, Professor of Forestry, Universidade Federal de Viçosa, Viçosa, MG, Brazil.

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3. If undisturbed after cessation of mining, a natural succession of plants will probably occur on the abandoned sites. However, it is not known if 50 yr at Campo do Saco has been enough time for the reestablishment of its original ecological communities. Neither is it known if a reclamation project could achieve, even in the long term, perfect biological restoration, given the degree of degradation. An analysis of naturally occurring regeneration could, however, reveal promising candidate species for the area's future reclamation.

Material and Methods

Campo do Saco is located in southern Minas Gerais State, Brazil, between 21° 15' 20" latitude south and 46° 33' 55" longitude west, in a region characterized by mild subhumid mesothermal climate with two dry months. Average annual precipitation is 1,722 mm, January being the hottest month (20.3° C average) and the rainiest (297.21 mm average); July is the coldest (13.6° C) and the driest (25.7 mm). Frosts may occur in winter.

Semideciduous forest ("floresta subcaducifólia") and grasslands ("savana gramineo-lenhosa") represent the vegetation cover of the region (Brasil 1993). On more fertile sites, forest strata may reach 20 to 30 m in height. The grasslands occur above 1,000 m and are covered by herbaceous plants; however, isolated shrubs also occur. The Campo do Saco area is a hilltop covered with native vegetation. Altitude is generally 1,300 m.

Bauxite in Poços de Caldas occurs on ridge tops and is concentrated on the northern part of the region's plateau. The mineral occurs near the surface, covered by bauxite-rich soil about 50 cm deep (Dias 1982).

To determine the area's existing phytosociology and predict impacts likely to affect vegetation when the mine reopens, three study strategies were necessary:

1. Verify the situation of flora at the Campo do Saco area where no old excavations exist and no new mining has yet occurred, as a point of reference for the possible future reclamation objective of reestablishing original plant communities.

2. Compare the plants' situation on previously mined sites with the adjacent undisturbed area, as an indication of the biological conditions that future excavations will leave behind with the reopening of the mine.

3. Investigate how mining intensity affects regeneration conditions for plants. To achieve this, it would be necessary to compare the area lightly mined (small, shallow excavations up to 95 m long and 2.0 m deep) with heavily mined areas (larger and deeper pits up to 150 m long and 3.35 m deep).

To carry out these studies, the Campo do Saco area was classified into three sites: I - unmined (control plots); II - lightly mined; and III - heavily mined terrain. Of the total area, site I occupies 2 ha; II, 2.03 ha; and III, 4.3 ha. Each site was divided into four quadrants, in which were randomly distributed various 10 - by 8 - m plots which represent approximately 2.5% of the total area of each site.

Soil samples were taken at four different points for each site, at six depths: 0 to 5 cm, 5 to 15 cm, 15 to 40 cm, 40 to 60 cm, 60 to 80 cm and 80 to 100 cm. Texture was analyzed for percentages of sand, silt, and clay. Also analyzed were pH in H_2O (1:2.5), concentrations of available phosphorus (P) and potassium (K) using a Mehlich-1 extractor, and exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), and aluminum (Al^{3+}) using the 1*N* KCl extractor to determine sum of bases (SB) and effective cation exchange capacity (CEC).

Vegetation sampling consisted of identifying and counting woody species for each plot and then measuring the height and coverage of each individual. Coverage (C_i) for each species was measured using the expression

$$C_i = \left(\frac{L_1 + L_2}{4}\right)^2 \times \pi, \tag{1}$$

in which L_1 and L_2 are the perpendicular lines of crown length and width.

Relative coverage (CR_i) was estimated by the expression

$$CR_i = \frac{C_i}{CT} \times 100, \tag{2}$$

in which C_i is the coverage provided by the "i"th species and CT is the sum of coverages for all the species in the area.

The parameter estimates for species density and frequency were obtained by using the following expressions:

$$\text{Absolute density } (DA_i) = \frac{N_i}{A}, \tag{3}$$

$$\text{Relative density } (DR_i) = \frac{DA_i}{\sum_{i=1}^{p} DA_i} \times 100, \tag{4}$$

$$\text{Absolute frequency } (FA_i) = \frac{U_i}{U_t} \times 100, \tag{5}$$

$$\text{Relative frequency } (FR_i) = \frac{FA_i}{\sum_{i=1}^{p} FA_i} \times 100, \tag{6}$$

where N_i = number of individuals sampled of the "i"th species,

A = area sampled, ha,

DA_i = absolute density of the "i"th species,

DR_i = relative density of the "i"th species,

U_i = number of sample units in which the "i"th species is present,

U_t = total number of sampling units,

FA_i = absolute frequency of the "i"th species,

FR_i = relative frequency of the "i"th species,

and p = total number of species sampled in the community.

Using these estimates, the ecological importance of each species was calculated, using the Cottam and Curtis index of value importance (IVI) as described by Matteucci and Colma (1982):

$$IVI = FR_i + DR_i + CR_i\,. \tag{7}$$

These measures should help explain the observed dynamics of ecological succession at Campo do Saco and suggest which pioneer species should be planted.

Results

Field data collection was done from September to December 1989, followed by analysis of each site's soil and vegetation.

Physical and Chemical Soil Characteristics

Analysis showed marked differences between soils on undisturbed site I and mined sites II and III, but little difference between soils on the two types of mined sites (table 1).

Table 1. Values for physical characteristics of soil at different depths in sites I (unmined), II (lightly mined), and III (heavily mined).

Area and soil depth, cm	Physical characteristic			
	Sand, %	Silt, %	Clay, %	Texture class
Site I (unmined):				
0-5	19.30	28.00	52.70	Clayey.
5-15	19.70	21.50	58.80	Clayey.
15-40	22.80	17.30	59.90	Clayey.
40-60	12.60	18.30	69.10	Very clayey.
60-80	14.80	14.20	71.00	Very clayey.
80-100	22.80	16.80	60.40	Very clayey.
Site II (lightly mined):				
0-5	60.80	15.80	23.50	Sandy clay loam.
5-15	54.80	14.50	30.80	Sandy clay loam.
15-40	39.80	13.30	46.90	Sandy clay.
40-60	56.25	8.25	35.50	Sandy clay.
60-80	52.80	11.50	35.70	Sandy clay.
80-100	63.00	10.70	26.30	Sandy clay.
Site III (heavily mined):				
0-5	52.75	24.00	23.25	Sandy clay loam.
5-15	59.50	13.50	27.00	Sandy clay loam.
15-40	44.75	15.75	39.50	Sandy clay.
40-60	50.75	10.25	39.00	Sandy clay.
60-80	59.00	11.00	30.00	Sandy clay loam.
80-100	61.00	12.00	26.75	Sandy clay loam.

Mined plots were found to generally have soils of sandy clay loam texture; undisturbed soils have clayey texture. According to Almeida (1977), drainage confined by topography contributes to creation of a clay layer (clayey soil) in ore deposits of this type. This material gets mined out along with the ore.

In terms of acidity (figure 1*A*), the undisturbed soils (site I) present more adverse conditions, with pH varying from 4.8 to 5.3, whereas mined-out soil (sites II and III) pH values range from 5.0 to 5.3 in lightly mined plots and from 4.9 to 5.6 in heavily mined plots. In the three types of sites, pH increased slightly with sample depth.

Results of the CEC analysis also indicated that the undisturbed site is more adverse (figure 1*B*). Values ranged from 0.08 to 2.63 on that site, from 0.05 to 1.75 for the lightly mined site, and from 0.02 to 1.24 for the heavily mined site. The CEC value almost always decreased as samples got deeper; the largest contrasts between the three types occurred at a depth of 5 to 15 cm.

The relation between sum of bases (SB) for the three sites also showed the same tendencies (figure 1*C*): the unmined terrain had highest values (0.03 to 1.79), followed by lightly mined terrain (0.05 to 1.52) and then by heavily mined terrain (0.02 to 1.24).

Although scarce, available P in the soil varied among the three situations (figure 1*D*): 0.85 to 11.0 for undisturbed sites, 2.45 to 16.4 for lightly mined sites, and 1.65 to 15.8 for heavily mined sites. Analysis of aluminum (Al^{3+}) revealed the greatest difference between unmined and mined sites (figure 1*E*). The undisturbed terrain contains more aluminum,

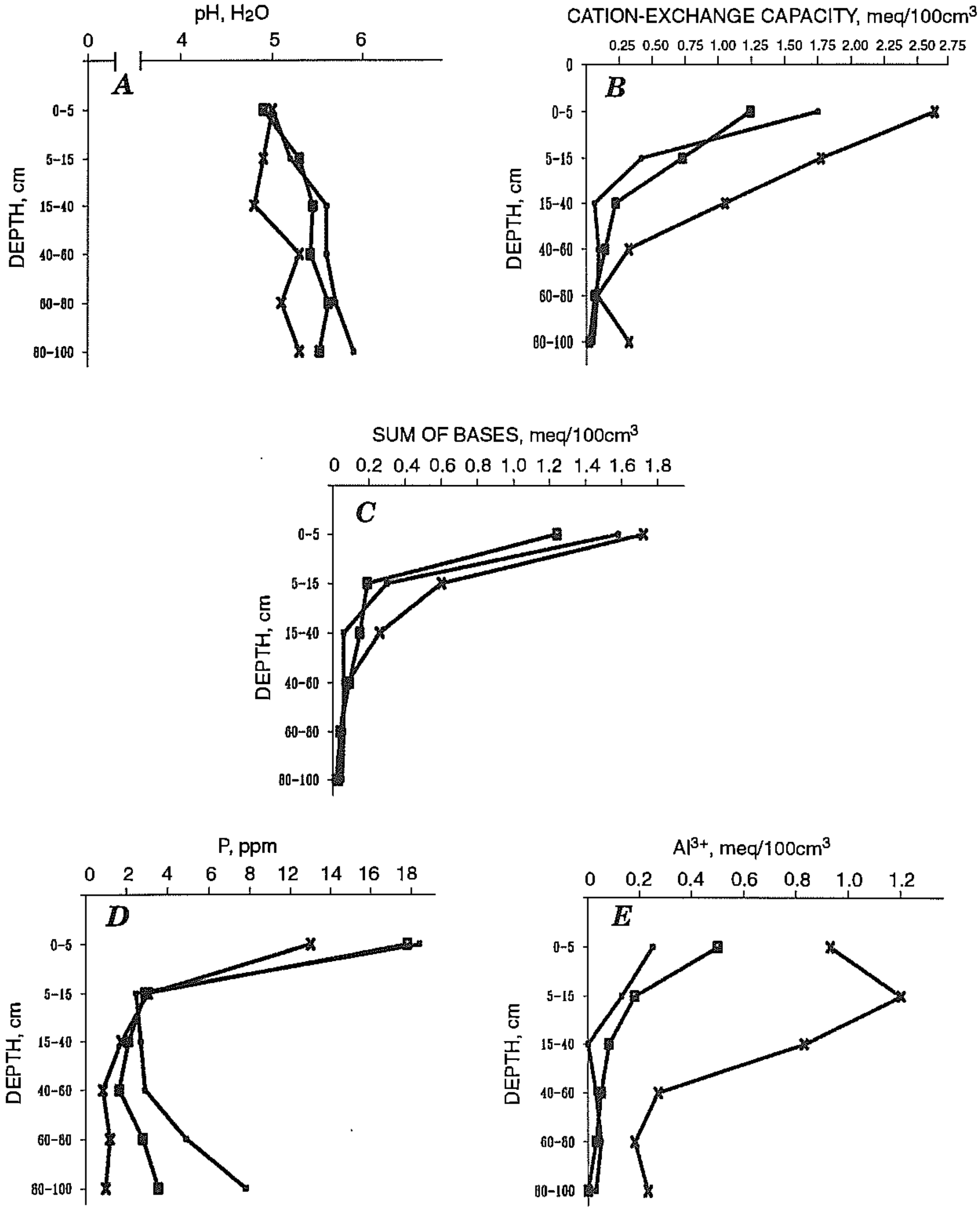

Figure 1. Variation in chemical characteristics of soil according to depth in sites I (unmined) (x), II (lightly mined) (•), and III (heavily mined) (■) .

ranging from 0.23 to 1.20 meq/100 cm^3. Aluminum concentration reached 0.25 meq/100 cm^3 in shallow excavation pits and 0.50 meq/100 cm^3 in deep pits.

Vegetation Characteristics

Table 2 summarizes data on vegetation. On site I, the undisturbed terrain, low woody species (maximum average height of 0.59 m) were found dispersed among dense grass cover. On the other hand, woody species found on site III, the most heavily mined (large excavations), revealed greater density and a maximum average height of 1.25 m. On site III, individuals were scattered among sparse, low grasses. Vegetation covering small excavations (site II) showed intermediate parameters between undisturbed and heavily mined sites. It is possible that mining's removal of grasses - strong competitors for growing space - has aided woody species.

Table 2. General data for vegetation (woody species) found on sites I (unmined), II (lightly mined), and III (heavily mined).

Site	Total surface area sampled, m^2	Maximum average height, m	Total number of individuals	Total number of species	Total coverage, m^2	Coverage by m^2	Total density, individuals/ m^2
I	1,040	0.59	31.9	30	45.37	4.36	0.31
II	480	1.00	46.1	23	77.56	16.00	.96
III	1,040	1.25	124.0	40	479.74	46.13	1.19

Figure 2 illustrates the general profile of vegetation at the Campo do Saco study area, for each type of site. *Miconia ligustroides* Naud. (Melastomataceae) reached greatest height (1.25 m) on the undisturbed site, *Eupatorium vautherianum* DC. (Compositae) showed greatest height (3.0 m) on the shallow excavation site, and *Tibouchina* aff. *moricandiana* (Melastomataceae) was the tallest (4.2 m) on the large-excavations site.

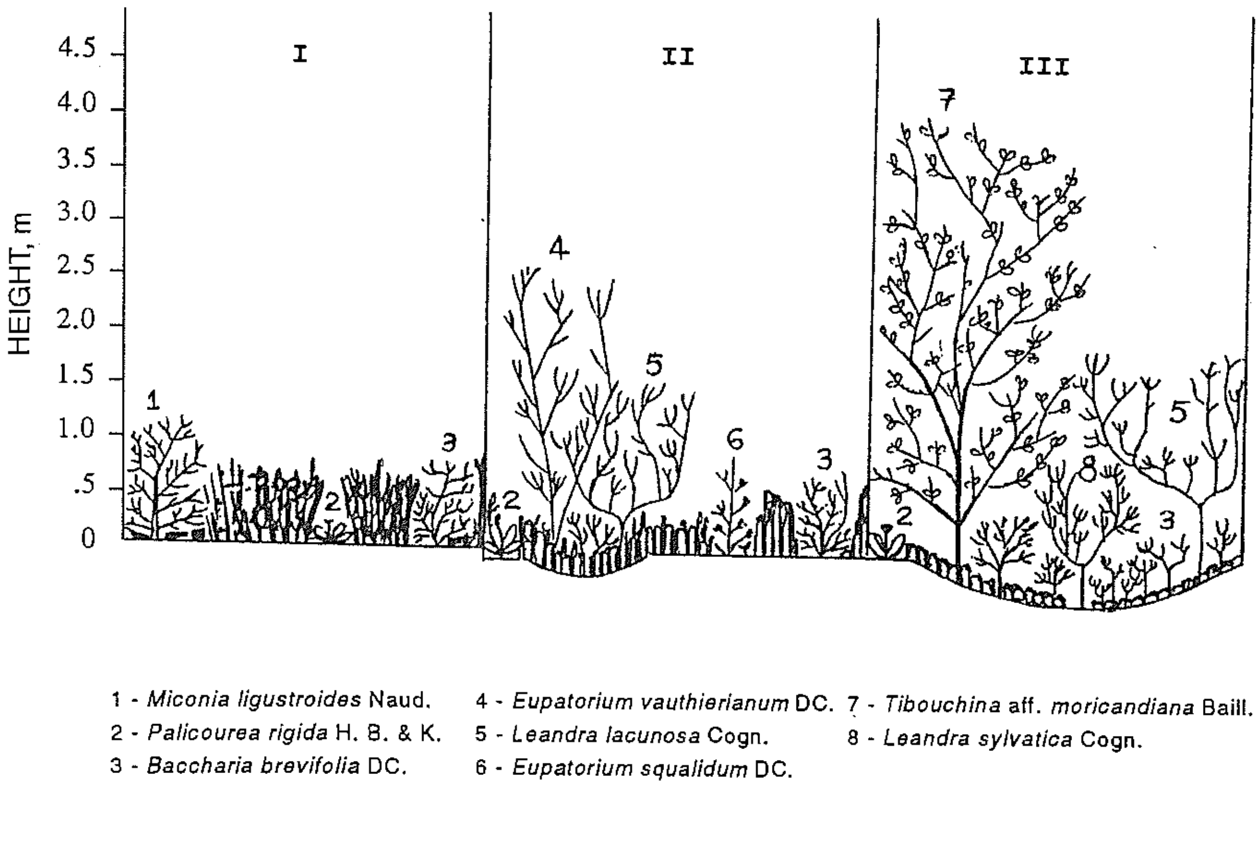

Figure 2. Profile representing vegetation found on sites I (unmined), II (lightly mined), and III (heavily mined).

Besides height, other important differences were found among woody species, principally between mined and unmined sites. Figure 3 shows the distribution, by order of index of value importance (IVI), for the botanical families found at each type of site. Differences in population parameters for the principal species common to all three types of sites were also observed (table 3).

Species with largest index of value importance were

- On unmined terrain, *Baccharis brevifolia* DC. (74.76), *Sapium marginatum* Muell. Arg. (26.57) and *Aegiphila tomentosa* Cham. (21.81).
- On lightly mined sites, *Miconia ligustroides* Naud. (67.85), *Leandra lacunosa* Cogn. (49.73), and *Eupatorium squalidum* DC. (35.00).
- On heavily mined sites, *Tibouchina stenocarpa* Cogn. (78.06), *Leandra lacunosa* Cogn. (68.54) and *Miconia ligustroides* Naud. (46.45).

The high IVI value for *Tibouchina stenocarpa* Cogn. on mined sites and its absence from the undisturbed site (figure 2) probably indicate that the occurrence of this species depends on drastic site alteration. However, it also occurs in other types of adjacent plant communities outside the study area, such as alongside stream courses.

Relatively few species are found in both mined and undisturbed sites. Those that do occur in all three sites always showed greater phytosociological values for the mined terrain. Only two woody species showed much higher values for undisturbed terrain: *Baccharis brevifolia* DC. and *Aegiphila tomentosa* Cham. It may be concluded that these two probably naturally dominate the latter stages of the original "cerrado" grassland vegetation.

Vegetation in Relation to Soil

The undisturbed site is characterized by very clayey soils of moderate acidity, moderate levels of exchangeable Al^{3+}, and P deficiency. In these soils, a plant formation has developed consisting of savanna almost free of woody species. Dense grasses reaching a height of 0.8 m dominate this community. A few woody species, scattered and with little coverage, reaching 1.25 m in height, were also found in these soils.

Excavated sites feature soils with sandy clay loam texture, moderate acidity, low levels of exchangeable Al^{3+}, and P deficiency. These levels of P, however, are greater than those found on undisturbed terrain. Grasses on the heavily mined site show levels of density, coverage, and height ranging from low to medium. On the other hand, woody species found on these large excavations showed high density, medium coverage, and a height of 4.20 m. Many more species were found on heavily mined terrain than on the undisturbed site.

Dias (1982) reported that chemical analyses of soils from the Poços de Caldas region generally show high acidity and high levels of exchangeable Al^{3+}. For the case of the Campo do Saco study area, the excavations and the 50-yr rest following abandonment have probably altered soil conditions at the mined sites, causing changes in the normal development of vegetation. In addition, excavation lowered the soil's surface closer to the water table, and the remaining pits accumulated rainwater and sediments, factors that modify vegetation's behavior.

If mining had not occurred, it would be difficult to say if original vegetation would have evolved into what we see today covering the study area because some soil characteristics, such as pH, show similar values for both mined and undisturbed sites. The presence of aluminum does not necessarily affect plant growth. However, depending on nutrient richness and H^+ ion activity (pH), it may lead to greater Al^{3+} ion activity, provoking plant toxicity. Because mining removes aluminum present in bauxite, excavating ore might improve soil conditions.

Conclusions and Recommendations

As of 1991, fifty yr after the cessation of bauxite mining, vegetation covering Campo do Saco presented three situations:

1. Nonexcavated sites were covered by normal "campo-cerrado" vegetation. If there had not been any mining, this savannalike vegetation would probably be covering the entire study area today.

2. Heavily excavated sites featured woody species, which were visually more copious than for the rest of the study area. The natural regeneration of these woody species is assumed to have largely disseminated from other nearby plant communities, including riparian forests, brushy secondary growth, and other adjacent "cerrado" formations.

3. Lightly excavated sites developed vegetation with intermediate characteristics between undisturbed and heavily mined sites.

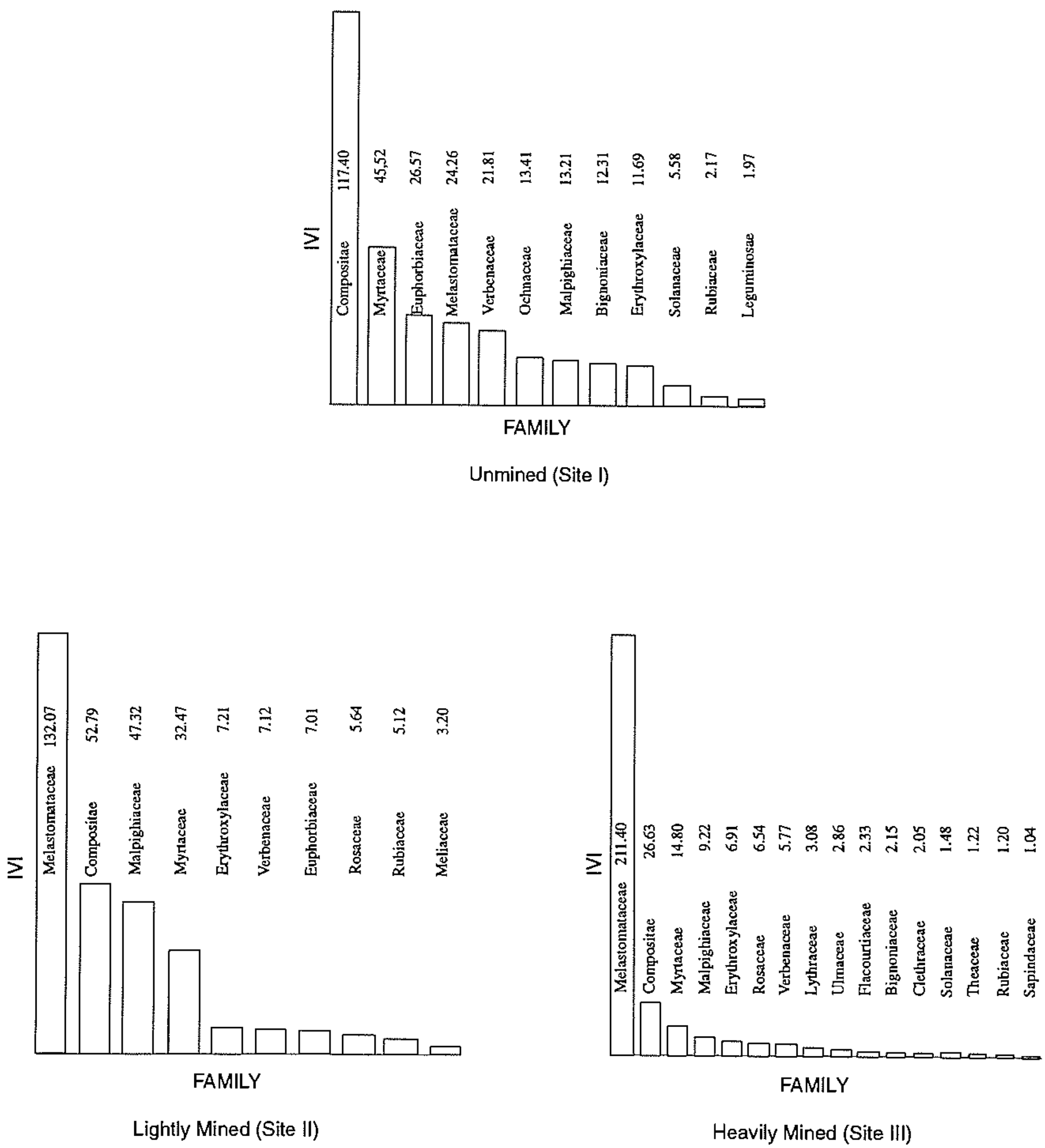

Figure 3. Distribution by order of index of value importance (IVI) of botanical families found at sites I (unmined), II (lightly mined), and III (heavily mined).

Table 3. Population characteristics of principal species found on sites I (unmined), II (lightly mined), and III (heavily mined).

Family and species	H_{max}, m			CR_i, %			FR_i, %			DR_i, %			IVI		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Bignoniaceae															
Jacaranda caroba DC.	.40	ND	.40	2.11	ND	.01	3.66	ND	.94	1.57	ND	.08	7.24	ND	1.03
Compositae															
Baccharis brevifolia DC.	.76	.80	.84	23.73	.14	2.06	13.41	1.75	4.72	37.62	.43	4.72	74.76	2.32	11.50
Kanimia oblongifolia Baker	.64	.60	ND	.80	.11	ND	3.66	1.75	ND	2.82	2.17	ND	7.28	4.03	ND
Eupatorium squalidum DC.	ND	.90	1.35	ND	4.98	.09	ND	7.02	2.83	ND	23.00	1.30	ND	35.00	4.21
Baccharis dracunculifolia DC.	.50	ND	1.40	.65	ND	.42	1.22	ND	.94	.94	ND	2.10	2.81	ND	3.46
Eupatorium vauthierianum DC.	ND	3.00	ND	ND	.96	ND	ND	1.75	ND	ND	.65	ND	ND	3.36	ND
Erythroxylaceae															
Erythroxylon suberosum A. St. Hil.	.60	2.10	2.75	1.19	1.33	2.08	2.44	1.75	3.77	.63	1.09	1.05	4.26	4.17	6.91
Euphorbiaceae															
Sapium marginatum Muell. Arg.	1.10	1.70	ND	13.64	.88	ND	8.54	5.26	ND	4.39	.87	ND	26.57	7.01	ND
Malpighiaceae															
Byrsonima intermedia A.	.64	.82	.80	7.60	4.07	1.24	3.66	8.77	6.60	2.19	2.82	1.37	13.45	15.66	9.22
Melastomataceae															
Leandra lacunosa Cogn.	.68	1.40	2.00	.84	11.66	29.00	2.44	8.77	11.32	1.88	29.30	28.22	5.16	49.73	68.54
Miconia ligustroides Naud.	1.25	1.70	1.50	4.57	46.71	18.38	1.22	8.77	12.26	.31	12.37	15.81	6.10	67.85	46.45
Tibouchina frigidula Cogn.	.57	.90	.90	3.42	3.56	.38	4.88	7.02	.94	4.70	3.91	3.23	13.00	14.49	4.54
Leandra sylvatica Cogn.	ND	ND	.70	ND	ND	.31	ND	ND	.94	ND	ND	1.21	ND	ND	2.46
Tibouchini aff. moricandiana Baill.	ND	ND	4.20	ND	ND	.62	ND	ND	3.77	ND	ND	.89	ND	ND	5.28
Tibouchina stenocarpa Cogn.	ND	ND	3.00	ND	ND	38.94	ND	ND	12.26	ND	ND	26.85	ND	ND	78.06
Myrtaceae															
Campomanesia Ruiz & Pav. sp.	.30	.59	1.65	2.01	3.34	.42	3.66	8.77	1.90	1.57	1.74	.24	7.24	13.85	2.54
Eugenia Mich. ex Linn. sp.	ND	.40	.75	ND	.18	.49	ND	1.75	2.83	ND	.22	1.13	ND	2.15	4.45
Psidium cinereum Mart. ex DC.	.92	ND	.54	1.76	ND	.02	4.88	ND	.94	1.25	ND	.08	7.89	ND	1.04
Psidium Linn. sp.	.30	ND	1.20	.24	ND	.12	1.22	ND	1.90	.31	ND	.89	1.78	ND	2.90
Campomanesia obversa Berg	.41	.25	ND	.39	.28	ND	1.22	8.77	ND	1.25	1.08	ND	2.86	1 .13	ND
Pseudocaryophyllus acuminatus (Link) Burret	.25	.20	ND	1.00	.20	ND	9.76	5.26	ND	5.64	.87	ND	16.40	6.33	ND
Rosaceae															
Bubus brasiliensis Mart.	ND	1.10	1.25	ND	.62	.23	ND	3.51	2.83	ND	1.52	1.37	ND	5.64	4.43
Rubiaceae															
Palicourea rigida H. B. & K.	.16	.33	.30	.32	.37	.01	1.22	3.51	.94	.63	1.52	.24	2.17	5.19	1.20
Solanaceae															
Solanum lycocarpum A. St. Hil.	.62	ND	.60	.35	ND	.30	3.66	ND	.94	1.57	ND	.24	5.58	ND	1.48
Verbenscese															
Aegiphila tomentosa Cham.	.76	.50	.80	8.71	1.03	.70	2.44	1.75	.94	1 .66	4.34	1.21	21.81	7.12	2.86

ND = not detected.

Bauxite mining also affected natural plant regeneration at Campo do Saco because it modified these soil characteristics:

1. Substrate texture - soils that were originally very clayey before mining gave way to sandy clay loam.

2. Available humidity - excavations lowered the soil surface closer to the water table; these pits also accumulate water and sediment when it rains.

In general, the two exploited but later abandoned sites at Campo do Saco revegetated into more copious landscapes than did the undisturbed site. Mining, however, usually does not improve landscape conditions. The effect observed at Campo do Saco is probably exceptional, reflecting increased water availability and bauxite removal.

As for reopening the mine, this study supports these recommendations:

1. Set site rehabilitation, and not restoration, as the revegetation program's goal. Edaphic conditions altered by mining seem to prohibit a return to original plant communities at Campo do Saco. It would be better to improve these conditions so that mined-out lands can be returned to productive and self-sustaining use.

2. Try cultivating *Tibouchina stenocarpa* Cogn., *Leandra lacunosa* Cogn., and other species of Melastomataceae. This study suggests that planting these pioneer species could accelerate the natural process of regeneration at Campo do Saco.

3. To disseminate best adapted species, use several different seed sources such as

- Plants that regenerate naturally in the area.
- Stands of riparian forests and other plant communities adjacent to the mine, protected during mining as reserves for this use.
- Topsoil removed during the initial phases of the mine reopening, especially from previously unmined parcels.
- Wildlife (especially birds and bats), which carry seeds to the degraded sites.

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Literature Cited

Almeida, E. B. de. 1977. Geology of the bauxite deposits of the Poços de Caldas District, State of Minas Gerais, Brazil. Stanford University, Stanford. 273 p. (Ph.D. Dissertation).

Brasil, 1993. Mapa de vegetação do Brasil. Fundação Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro.

Dias, A. C. 1982. Reabilitação de áreas mineradas de bauxita em Poços de Caldas. p. D2.1-D2.11. In I Seminário Nacional Sobre Lavra a Céu Aberto. Anais. (Instituto Brasileiro de Mineração, s. l.).

Johnson, F. L., D. J. Gibson and P. G. Risser. 1982. Revegetation of unreclaimed coal strip-mines in Oklahoma: I. Vegetation structure and soil properties. Appl. Ecology 19(2):453-463.
http://dx.doi.org/10.2307/2403479

Manner, H. I., R. R. Thaman, and D. C. Hassal. 1984. Phosphate mining induced vegetation changes on Nauru Island. Ecology 65(5):1454-1465.
http://dx.doi.org/10.2307/1939126

Matteucci, S. D. and A. Colma. 1982. Metodologia para el estudio de la vegetaci6n. Organizaci6n de Estudios Americanos, Washington, DC, Monografia 22, 168 p.

Palaniappan, V. M. 1974. Ecology of tin tailing areas: plant communities and their succession. Appl. Ecology 2(1):133-150. http://dx.doi.org/10.2307/2402011

Smith, P. W., E. J. DePuit and B. Z. Richardson. 1988. Plant community development on petroleum drill sites in Northwestern Wyoming. Range Management 41(5):372-377.
http://dx.doi.org/10.2307/3899569