Rehabilitation of Abandoned Quarry Sites in Trinidad, W.I.

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ABSTRACT

Two sand and gravel quarry sites, one a surface and the other a deep excavation, and a hillside limestone quarry were studied in northern Trinidad with the purpose of recommending rehabilitation measures using native plant species. In addition, two control sites were examined, a rehabilitated hillside quarry, and an abandoned site where natural regeneration of plants has taken place. Based on the existing abiotic and biotic conditions at the three study sites the following rehabilitation options are considered: regeneration of natural forest cover, agroforestry, recreational or commercial development, and landfill. The environmental impact of these rehabilitation options is examined.

INTRODUCTION

A great deal has been written about the revegetation of quarried landscapes outside the tropics where extensive work has been done in Europe, in particular the U.K. (Humphries 1976, Johnson and Bradshaw 1979, Coppin and Bradshaw 1982) and Germany (Knabe 1964, Petsch 1975), in North America, especially the U.S. (Hodder 1973, Marx 1975) and in Australia (Tacey 1979). In Trinidad, where a considerable number of reports have been written about the quarry industry (Salisbury 1992), very little has been published about the rehabilitation of quarried land (Heesterman 1982, Greenwood 1983, Ramdial 1983, Huber and Kisto 1986). A recent study commissioned by the Government of Trinidad and Tobago (Jackson 1993) and the efforts of the Field Naturalists' Club's Botany Group (Quesnel *et al.* 1996) have helped to rectify this shortcoming. At The University of the West Indies, St. Augustine, hardly any research has been directed towards rehabilitation. What has been done seems to be confined to the Engineering Faculty, especially the Department of Land Surveying (Ramroop 1987, Scott 1987)

The following study is an attempt to evaluate the current state of abandoned quarry sites in Trinidad with respect to their ecology and vegetation and to make recommendations for their rehabilitation. Three specific categories are considered, a complex sand and gravel quarry where mainly surface mining has taken place, a deep sand and gravel site where water-filled depressions now occur and a hillside limestone quarry. These typify approximately 75 quarries presently found in Trinidad, 35 of which are closed or abandoned. It is hoped that this study will add to the needed body of knowledge, especially in the tropical environment, that will be required on a wider scale to deal with this aspect of landscape deterioration. Trinidad is a country that prides itself on being self-sufficient in aggregate production and an exporter of aggregate material to other countries in the Caribbean region. There is no shortage of knowledge about

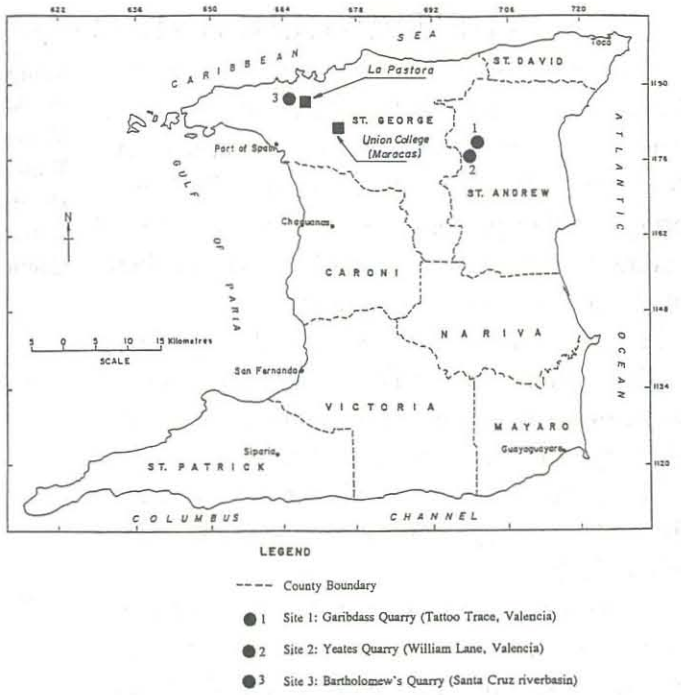

Figure 1. Location of test quarry sites, Trinidad, W.I. (Adapted from Jackson 1993).

excavation techniques but information is lacking with respect to rehabilitation. The goal of this study is to correct the inbalance to some extent.

BACKGROUND

Sites and Location

The three test sites chosen for detailed study are located in north Trinidad (Fig. 1). Two of these, Garibdass quarry complex and Yeates deep quarry, both sand and gravel, are situated inside the Valencia Wildlife Sanctuary and former Forest Reserve. The Sanctuary has an area of 2,736 ha. and is under public ownership (IUCN 1982). The other site, Bartholomew's hillside limestone quarry, is located near the upper end of the Santa Cruz Valley at the base of one of the flanks of the Northern Range. It too is on state land that has had a varied history of environmental disturbance. In addition, two control sites also were examined, the Union College quarry in the Maracas Valley where some rehabilitation work has been undertaken and La Pastora quarry in the Santa Cruz Valley where natural regeneration has occurred since the site was abandoned (Fig. 1).

Topography

The topography at the Valencia Wildlife Sanctuary is flat to gently undulating with elevations ranging from 7.5 to 15 m above sea-level. Drainage is eastward towards the Atlantic Ocean with Garibdass quarry situated between the Turure and La Seiva Rivers while Yeates quarry is located near the Quare River which flows out of Hollis Reservoir. Within the quarry sites a variety of topographic features are found which include ridges (dry areas - high), gravel heaps, flats (dry areas - low) and depressions (wet areas). Some of the depressions at Yeates are water-filled to a depth of 5 m (Jackson 1993). At the base of Bartholomew's hillside quarry elevation is approximately 105 m above sea-level and drainage is southward via the Santa Cruz River. The general topography of this area is mountainous while at the quarry site topographic features include vertical rock faces, terraces, slopes and sediment outflow at the base.

Soils

Alluvial deposits of sand and gravel over clay predominate at the Valencia Wildlife Reserve. Soil pH is generally acidic with low nutrient status (Doubleday and Jones 1977) and little or no organic matter. Internal drainage is free where sands and gravels form thick surface deposits without cementation but impeded drainage prevails where silty clays are found in the profile. The presence of limestone at Bartholomew's hillside quarry contributes to nutrient enrichment at the site and less acid conditions. Above the limestone quarry, under forest cover, a thin loamy soil with free drainage has developed over bedrock.

Climate

The climate in Trinidad is tropical, i.e., warm and wet, with distinct seasons based on the amount of rainfall. Normally, the wet season occurs from June to December with the wettest months being June, July, August and November. There is a mini dry spell in September/October known as the Petit Careme. The dry season usually lasts from January to May with the driest month being March (Marshall 1934). The amount of rainfall within the Valencia Wildlife Sanctuary ranges between 250 and 300 cm per annum while in the upper region of the Santa Cruz Valley annual rainfall is 175 cm or less. Temperatures also fluctuate according to season with the hottest month being September and the coolest month, February. Daily temperatures at low elevation non-coastal areas generally reach a high of 32° Celsius and drop by about five degrees at night. In the mountains temperatures can be about 10 degrees cooler.

Original Vegetation

When the Valencia Wildlife Sanctuary also functioned as a forest reserve, the natural vegetation was classified as Evergreen Seasonal belonging to the association *Carapa-Eschweilera* (Crappo-Gautecare) with a strong *Mora* component (Marshall 1934, Beard 1946). The presence of *Attalea maripa* (Cocorite Palm) and the absence of *Sabal mauritiiformis*(Carat Palm) in parts of this association was indicative of poor soil conditions (Marshall 1934). Other characteristic trees included *Aniba panurensis* (Laurier Canelle), *Sterculia caribaea* (Mahoe), *Pachira insignis* (Wild Chataigne), *Pentaclethra macroloba* (Bois Mulatre), *Diospyros irensis* (Bois Charbon) and *Licania biglandulosa* (Wild Debasse), the last occur-

ing in the understory (Beard 1946).

The natural forest cover in the upper regions of the Santa Cruz Valley was classified as Semi-deciduous, Foot-hills Type by Marshall (1934) with typical trees being *Cordia alliodora* (Cypre), *Tabebuia serratifolia* (Yellow Poui), *Sideroxylon quadriloculare* (Acoma), *Protium guianense* (Incense), *Astronium obliquum* (Yoke), *Terminalia obovata* (White Olivier), *Guazuma ulmifolia* (Bois d'Orme) and *Machaerium robinifolium* (Saltfish Wood). It is more difficult to fit this area into Beard's (1946) classification, the closest approximation being his Semi-evergreen Seasonal *Ficus* (Figuier) Faciation belonging to the *Trichilia-Brosimum* (Acurel-Moussara) Association which he describes as being found in mountainous limestone areas with very steep slopes.

Surrounding (current) Vegetation

Some of the relic trees from the original forest that are still growing around the Garibdass quarry complex include *Tabebuia stenocalyx* (Wild Calabash), *Terminalia amazonia* (White Olivier), *Mora excelsa* (Mora), *Pentaclethra macroloba* (Bois Mulatre), *Carapa guianensis* (Crappo), *Virola surinamensis* (Cajuca), *Byrsonima coriaceae* (Serrette), *Parinari campestris* (Bois Bande) and the palms *Euterpe precatoria* (Manac), *Oenocarpus bataua* (Palma Real) and *Manicaria saccifera* (Timite). No evidence of fire was observed in the survey area.

Fire, however, has badly damaged the forest on the west side of the study area at Yeates. This devastation probably took place during the prolonged dry season of 1987. Post-fire species observed along the forest margin include:

Cordia curassavica (Black Sage)
Clibadium surinamense (Composite)
Scleria secans (Razor Grass)
Vismia guianensis (Kiskidee)
Vismia laxiflora (Kiskidee)
Miconia myriantha (Melastome)
Cecropia peltata (Bois Canon)
Ficus amazonia
Ficus broadwayi (Beefwood)
Ficus maxima
Ficus nymphaeifolia
Blechnum serrulatum (Fern)
Nephrolepis rivularis (Fern)
Renealmia alpina

Despite the fire, a number of species that were characteristic of the original forest still remain. Those observed along the margin are:

Didymopanax morototoni (Jereton)
Tabebuia stenocalyx (Wild Calabash)
Protium guianense (Incense)
Terminalia amazonia (White Olivier)
Maprounea guianensis (Petite Feuille)
Calophyllum lucidum (Galba)
Symphonia globulifera (Yellow Mangue)
Eschweilera subglandulosa (Guatecare)
Calliandra guildingii (Niaure)
Pithecellobium jupunba (Puni)
Carapa guianensis (Crappo)
Virola surinamensis (Cajuca)
Euterpe precatoria (Manac Palm)
Manicaria saccifera (Timite)
Attalea maripa (Cocorite)
Coccoloba latifolia (Cuchape)
Parinari campestris (Bois Bande)

The forest above Bartholomew's quarry also had evidence of fire. Deciduous trees that reflect the Semi-evergreen aspect of this plant community include *Spondias mombin* (Hog Plum), *Tabebuia rufescens* (Black Poui), *Ceiba pentandra* (Silk Cotton), *Bursera simoruba* (Naked Indian), *Machaerium robinifolium* (Saltfish Wood) and *Guazuma ulmifolia* (Bois d'Orme).

Observed native trees at Bartholomew's that were a component of the original forest include:

Spondias mombin (Hog Plum)
Ceiba pentandra (Silk Cotton)
Protium insigne (Gommier)
**Croton gossypiifolius* (Bois Sang)
* *Brownea latifolia* (Cooperhoop)
* *Machaerium robinifolium* (Saltfish Wood)
Lonchocarpus punctatus (Savonette)
Andira inermis (Angelin)
Swartzia pinnata (Bois Pois)
Guarea glabra (Carimbo)
**Brosimum alicastrum* (Moussara)
**Cecropia peltata* (Bois Canon)

Attalea maripa (Cocorite)
Guazuma ulmifolia (Bois d'Orme)

* denotes common occurrence

Trees that are remnants of the former plantation or estate at the hillside site include *Carica papaya* (Pawpaw), *Dipteryx odorata* (Tonka Bean), *Artocarpus altilis* (Breadfruit), *Myristica fragrans* (Nutmeg) and *Theobroma cacao* (Cocoa).

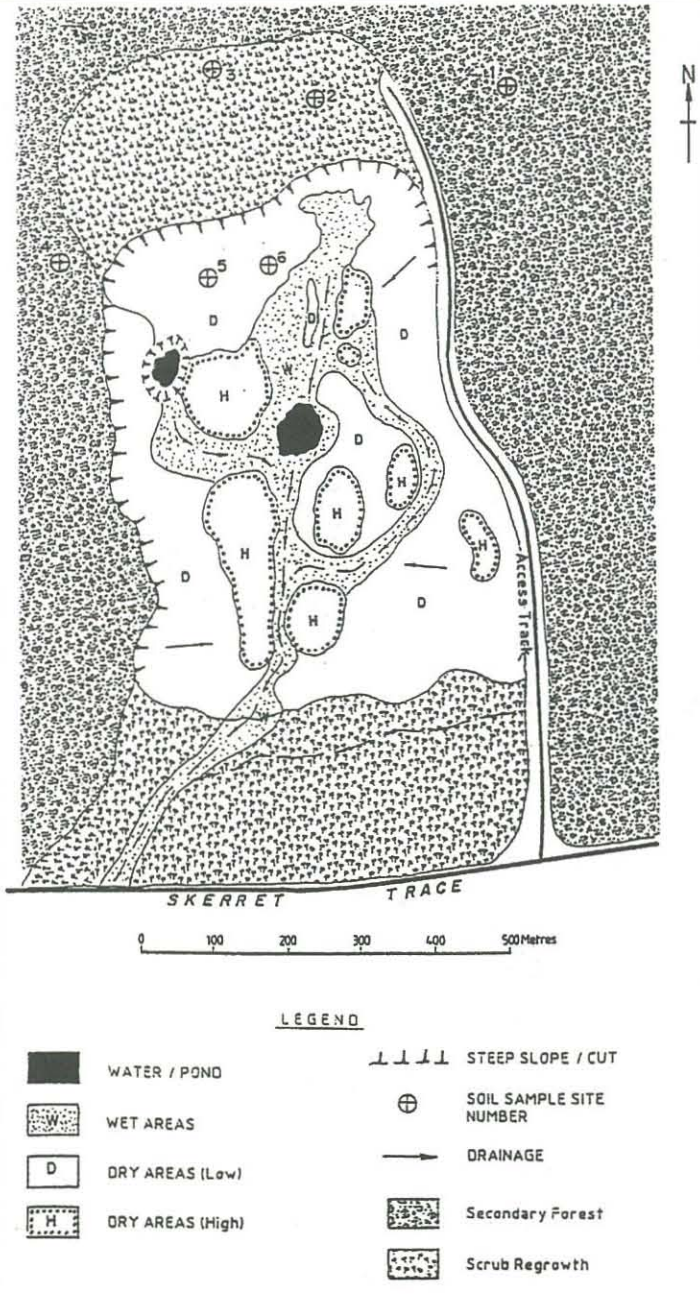

Figure 2. Surface features at Garibdass quarry, Trinidad, W.I. (Adapted from Jackson 1993).

METHODS

The vegetational survey was conducted in November 1992. At all sites, both test and control, the vegetation was classified into categories according to habit (growth form). The following categories were used: shrub or tree (ST), vine or epiphyte (VE) and herbaceous (H). The reference used for the correct spelling of botanical names is the checklist (unpublished) for the Flora of Trinidad and Tobago available at the National Herbarium. The citation for the botanical names used in this paper can be found in the published Flora of Trinidad and Tobago (Williams, R.O. *et al.* 1928-).

At each study site six soil samples, to a depth of 20cm, were taken that reflect the various topographical features. One of the six samples at each site came from under forest cover. The analysis of the samples was carried out at the U.W.I., Soil Science Department, St. Augustine.

OBSERVATIONS

A. VEGETATION

Garibdass and Yeates

As the topographic features at Garibdass quarry complex (Fig. 2) and Yeates deep quarry (Fig. 3) are very similar and with the two sites in close proximity and within the same vegetation type, i.e., Crappo-Guatecare Association, direct comparisons can be made. If we relate the habit types at these two sites to topographic features the patterns shown in Table 1 emerge.

Table 1. Habit types versus topographic features at Garibdass and Yates quarries, Trinidad, W.I.

		Habit* (No. of species)		
Area	**Topography**	**ST**	**VE**	**H**
Garibdass	ridges	**38**	12	21
Yeates	ridges	**30**	13	24
Garibdass	dry ground	9	5	**18**
Yeates	dry ground	21	6	**30**
Garibdass	depressions	4	2	**20**
Yeates	depressions	6	1	**25**

* ST = shrub or tree; VE = vine or epiphyte; H = herbaceous

Table 2. Families and species versus topographic features at Garibdass and Yates quarries, Trinidad, W.I.

Area	Topography	Families	Species
Garibdass	ridges	40	71
Yeates	ridges	33	67
Garibdass	dry ground	23	32
Yeates	dry ground	24	57
Garibdass	depressions	16	26
Yeates	depressions	16	32

It can be seen from the table that shrubs and trees (ST) are the predominant feature on ridges at the two quarry sites while herbaceous vegetation (H) is the dominant growth form on dry ground and in depressions. If we look at family and species numbers at the two sites, it is evident that ridges are species-rich and dry ground and depressions are species-poor as shown in Table 2.

At the two sites, ridges are topographic features of least disturbance in the quarried area and represent land where sand and gravel deposits were thin over clay. Therefore, they were ignored by the quarry operators. The most important families here are the Compositae (Composites), Gramineae (Grasses), Guttiferae, especially *Vismia* (Kiskidee), Melastomataceae (Melastomes) and Rubiaceae, especially *Isertia* (Wild Ixora). Although the Cyperaceae

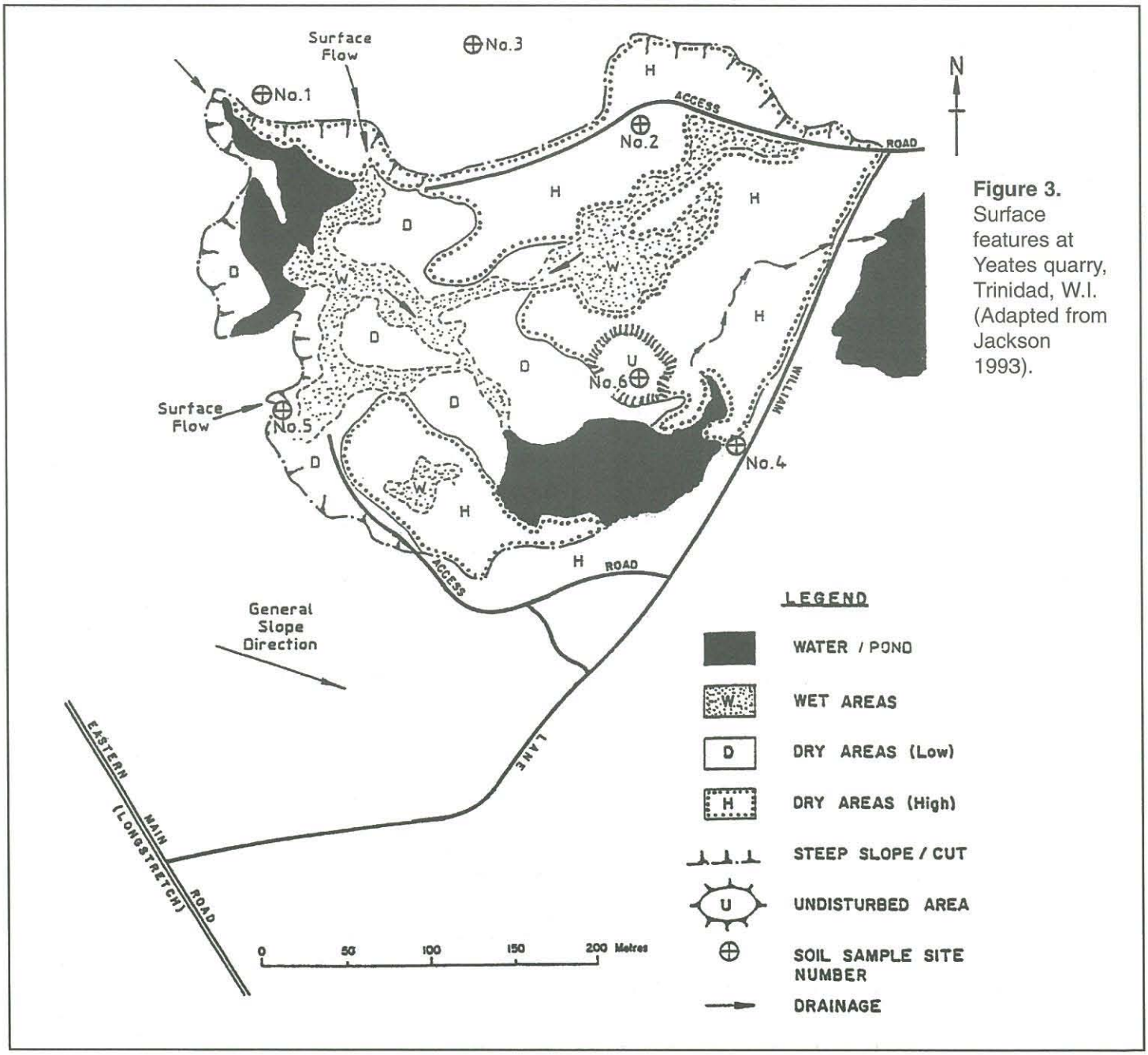

Figure 3. Surface features at Yeates quarry, Trinidad, W.I. (Adapted from Jackson 1993).

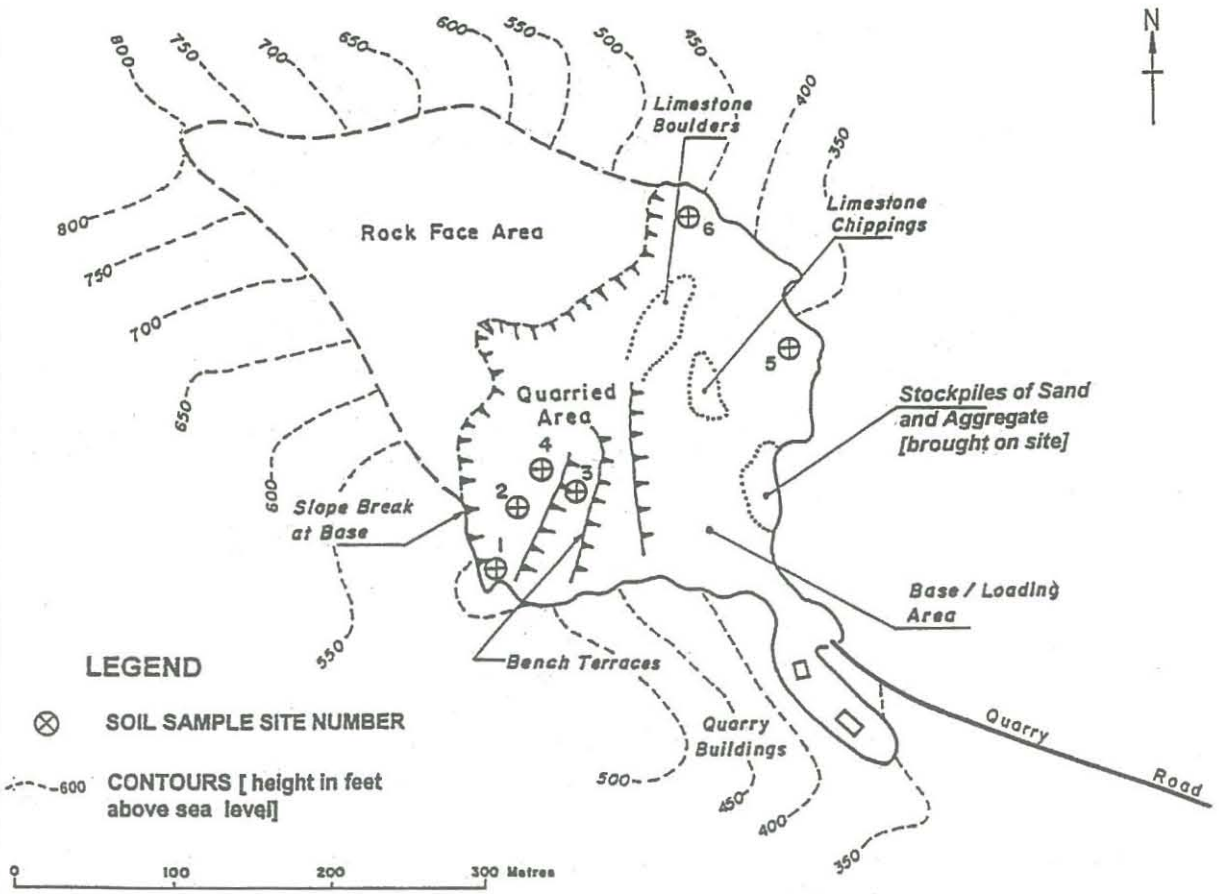

Figure 4. Surface features at Bartholomew's quarry, Trinidad, W.I. (Adapted from Jackson 1993).

Table 3. Soil analysis of samples collected from Garibdass, Yeates and Bartholomew's quarries, Trinidad, W.I.

Sample Location	Sample Lab Number	pH Units 1:2.5 Soil Water Soil Rx.	Cation Exchange Capacity cmol/kg	Exchangeable Cations				Extractable			Available P (Trong)	Organic Carbon	Total Organic Matter	Total Nitrogen
				Ca	Mg	K	Na	Al	Fe	Na				
				cmol/kg				mg/kg			mg/kg	%	%	%
GARIBDASS														
Secondary forest	1	4.8	2.83	0.03	0.04	0.03	0.03	0.00	0.10	0.00	14	0.66	1.13	0.003
Depression	2	4.5	4.54	0.02	0.14	0.05	0.03	0.00	0.00	0.00	14	0.58	1.00	0.002
Ridge	3	4.5	3.69	0.05	0.08	0.03	0.07	0.00	0.00	0.00	19	1.06	1.82	0.005
Ridge	4	5.1	1.70	0.05	0.07	0.04	0.05	1.90	0.60	0.02	19	1.34	2.30	0.005
Ridge	5	4.9	3.40	0.02	0.03	0.03	0.10	0.00	0.00	0.00	16	0.61	1.05	0.003
Depression	6	5.1	2.83	0.03	0.04	0.05	0.07	0.40	0.30	0.30	24	0.13	0.23	0.002
YEATES														
Ridge (high ground)	1	4.5	3.40	0.01	0.05	0.04	0.06	0.00	0.00	0.00	16	0.48	0.83	0.002
Ridge (high ground)	2	4.5	4.54	0.01	0.04	0.04	0.05	0.00	0.30	0.00	19	1.06	1.82	0.003
Forest (western margin)	3	4.5	1.97	0.16	0.06	0.04	0.26	0.00	0.00	0.10	10	0.41	0.71	0.002
Depression	4	5.4	1.97	0.03	0.03	0.03	0.03	0.00	0.00	0.20	10	0.13	0.23	0.000
Dry ground (gravel heap)	5	5.0	4.26	0.02	0.05	0.04	0.05	0.00	0.00	0.10	10	0.66	1.14	0.000
Ridge (isolated)	6	4.6	3.40	0.01	0.03	0.04	0.04	0.00	0.00	0.00	19	0.23	0.39	0.000
BARTHOLOMEW'S														
Forest (old bench trail)	1	4.5	3.12	2.10	0.13	0.03	0.10	0.00	0.00	0.00	trace	0.53	0.91	0.025
Quarry terrace	2	6.9	1.11	2.20	0.09	0.03	0.33	0.00	0.00	0.60	4	0.21	0.36	0.004
Quarry slope	3	8.0	0.54	2.36	0.08	0.03	0.14	0.00	0.00	0.00	14	0.58	1.00	0.004
Quarry terrace	4	8.2	2.54	1.00	0.09	0.03	0.13	0.00	0.00	0.00	7	0.58	1.00	0.010
Sediment outflow	5	8.2	0.54	2.00	0.09	0.03	0.09	0.00	0.00	0.40	4	0.53	0.91	0.002
Rubble slope	6	5.4	2.26	0.11	0.06	0.04	0.03	0.00	0.00	0.10	14	0.96	1.67	0.004

(Sedge) family has a large number of species on ridges they are all rare. When the vegetation on ridges at the two sites is compared, we find that 55% of the species from this topographic feature at Garibdass also are found on the ridges at Yeates while 58% of the species on ridges at Yeates also occur on ridges at Garibdass. Similarity values of greater than 50% are considered to be high.

Dry ground, i.e., gravel heaps and flats, at the two Valencia sites, as compared to ridges and depressions, is intermediate in terms of elevation and numbers of families and species. On dry ground the most important families are the Gramineae, especially *Andropogon*, and the Melastomataceae. Comparing the vegetation on dry ground from the two study sites, 63% of the species at Garibdass also are found at Yeates whereas only 35% of the plants at Yeates occur at Garibdass. This greater species diversity on dry ground at Yeates may reflect better environmental conditions with respect to soil moisture and seed source, or a lack of uniformity in the sampling.

When considering depressions at the two quarry sites, wet conditions prevail with periodic flooding and, in the case of Yeates, permanent surface water. The depressions are dominated by herbaceous vegetation, in dense mats at Yeates, but are species-poor when compared with the other topographic types. The most important family is the Cyperaceae (Sedges) with *Cyperus haspan*, *Eleocharis* and *Rhynchospora* being prominent species and genera. Where flowing water occurs, *Tonina fluviatilis* (Eriocaulaceae) grows vigorously and seems to be a good indicator of unpolluted water. Around one of the large ponds at Yeates, *Leersia hexandra* (Cascadoux Grass) forms dense swards at the water's edge. Other wet indicator species at the two sites include *Utricularia juncea* (Bladderwort) and *Xyris caroliniana* (Xyridaceae). Fifty percent of the species found in depressions at Garibdass also occur at Yeates while only 41% of the depression plants at Yeates are growing at Garibdass. This difference is attributable to the wetter conditions at the deep quarry site.

Bartholomew's and the Control Sites

With a different location, topography and parent material, Bartholomew's hillside quarry (Fig. 4) becomes more difficult to compare with the sites at Valencia. For this reason two additional hillside quarries were chosen as controls so more meaningful comparisons could be made. One of the control sites is located on the west side of Maracas Valley behind the Caribbean Union College and is identified in this study as the Union College quarry. The elevation at the base of this quarry is 90m above sea-level. It has been abandoned for some time and rehabilitation work by the Forestry Division began there in 1986. The other control site is situated in the same area of Santa Cruz Valley as Bartholomew's quarry and has a similar elevation, approximately 105m. This quarry has been identified as La Pastora and appears to have been abandoned since 1987. At the time of the study, portions of Bartholomew's quarry had been abandoned for 12 years.

Most of the plant species growing on vertical rock faces at Bartholomew's hillside quarry are few in number. Only the following are common: *Ochroma pyramidale* (Bois Flot), *Cordia curassavica* (Black Sage), *Pluchea carolinensis* (Geritout) and *Pteris vittata* (Fern). All of the plants here are true pioneer species aiding in the breakdown of the bedrock through the action of their roots which penetrate the cracks and crevices trying to find anchorage. Only a single vine was observed, *Jacquemontia pentantha* (Convolvulaceae). The best represented families are the Compositae (Composites), Gramineae (Grasses), Leguminosae (Legumes) and Polypodiaceae (Ferns). At the Union College control site vines were more prominent on the rock face especially those belonging to the family Leguminosae while at La Pastora the grass *Eragrostis ciliaris* and the fern *Nephrolepis multiflora* were common on the vertical rock surface.

The terraces at Bartholomew's quarry were created in order to stabilize the vertical slope. They contain a relatively large number of herbaceous plants compared to the other growth forms with the Euphorbiaceae (Euphorbs) and Gramineae (Grass) families being prominent in this regard. Two other important families here are the Composites and the Legumes. The presence of *Muntingia calabura* (Elaeocarpaceae) reflects the higher levels of calcium and more neutral pH at the site (see Table 3). At La Pastora control quarry the Legumes *Aeschynomene sensitiva* and *Alysicarpus vaginalis* are common on the dry terraces. No prominent terraces are present at

the Union College quarry.

The rubble slopes in the abandoned portions of Bartholomew's hillside site have very unstable surfaces some of which are well vegetated, others only sparsely so. The loose rubble is easily dislodged making the vegetation cover rather vunerable and subject to burial by minor landslides. The Compositae and Leguminosae Families are the best represented. *Pueraria phaseoloides* (Kudzu), belonging to the latter family, is a common vine together with *Ipomoea nil* (Convolvulaceae). Shrubs and herbaceous plants, however, make up the major portion of the vegetation cover on these slopes. The slopes at the Union College quarry are stabilized by rehabilitation efforts, e.g. *Bambusa vulgaris* (Bamboo), *Gliricidia sepium*, with the Composites and Legumes also being important families here, as well as the Melastomataceae. *Muntingia calabura*, however, is absent from the Union College site.

In the sediment outflow area at Bartholomew's, as was the case on the terraces, herbaceous plants are the predominant growth form. Here, however, the Cyperaceae (Sedge) family is the most prominent, reflecting the wetter conditions, followed by the Gramineae, Leguminosae and Compositae. Vines like *Ipomoea nil* and *Pueraria phaseoloides* (Kudzu) are also common. Frequent deposits of sediment prevent stabilization in this area. No equivalent areas were examined at the control sites.

B. FAUNAL ACTIVITY

Habitats

All three study sites have provided, and are still providing, an environment that sustains wildlife, i.e., plants and animals. Although the natural conditions have been drastically altered by the quarry operations, natural communities still exist in these areas.

Both the Garibdass quarry complex and Yeates deep quarry have small streams flowing through the study area. This aquatic habitat attracts a variety of animals that require wetter conditions in order to survive, for example the tortoises. Yeates also has a number of ponds that were created by the quarry excavations and are now in various stages of stabilization. These provide a habitat for small fish and the plankton upon which they feed (Jackson 1993).

The three quarries also have forest communities in various stages of degradation that are situated within the study area and surround parts of the site. These too serve as habitats for plants and animals including the birds, bats and epiphytes that frequent the tree canopy and the insects and micro-organisms that act as decomposers. Here, there are communities within communities occupying habitats within habitats. At Garibdass quarry, the forest community is severely degraded and broken up into isolated patches. Very few mature forest trees remain at this quarry complex. Most of the trees present are small secondary growth species that have managed to survive where quarry operations were minimal, usually on ground with thin sand and gravel deposits that were not in large enough quantities to warrant excavation. At Yeates, the marginal forest on the north and west boundaries of the study area is all that remains. This forest was badly damaged by fire in recent times and is currently regenerating with second growth species in the understory. Many trees that formed the upper canopy were killed by the fire but are still standing within the forest. The best forest is found at Bartholomew's on the mountain ridge above the excavation site. This forest is mature secondary growth that once was part of a large estate. The forest has been occasionally affected by fire but still has large thriving trees present.

The poorest habitats at the Valencia sites are the gravel heaps and flat dry ground that have little vegetation cover, no trees or shrubs beyond the seedling or sapling stage, no soil or organic matter, and maximum exposure to sun, wind and rain. Even these severely degraded sites support some animal life, for example lizards and insects. At Bartholomew's and the control sites, the poorest habitats are the exposed bedrock surfaces where little chemical or physical weathering has taken place. The simplest forms of life here are the lichens that are attached to the rock surface and the mosses that start to accumulate soil.

Observations of Animal Life

The Valencia Wildlife Sanctuary is the habitat for a number of lowland forest birds as well as mammals and reptiles. Some of the mammals reported for the area include *Mazama americana* (Red Brocket Deer), *Tayassu tajacu* (Quenk or Wild Hog), *Dasyprocta*

agouti (Agouti) and *Dasypus novemcinctus* (Tattoo or Armadillo) while some of the reptiles are *Tupinambis negropunctatus* (Matte), *Iguana iguana* (Iguana), *Geochelone denticulata* (Morocoy or Tortoise) and various species of snake (IUCN 1982). At the upper end of the Santa Cruz Valley the same variety of animal life can be found except that the birds are more likely to be highland forest dwellers. One addition to the mammals would be *Agouti paca* (Lappe) while the Brocket Deer may be absent (IUCN 1982).

During the course of the field work a number of observations were made concerning animal activity. Either direct sightings took place or indirect evidence was encountered. Although mammals are usually difficult to see, evidence of their presence is not, as they leave tell-tale signs in their droppings, footprints and browsing, e.g. nibbled fruits and seeds.

At Garibdass quarry complex, mammal observations included the Tayra or Highwoods Dog (*Eira barbara*) near the stream flowing from the study area as well as some Brocket Deer tracks adjacent to the two-acre detailed sampling site. Bird sightings included a pair of White Hawks (*Leucopternis albicollis)* near the two-acre block and an immature hawk in the vicinity of Tattoo Trace. Evidence of amphibian activity was a batch of frog eggs in one of the intermittent pockets of water inside the two-acre block. At Yeates deep quarry, birds seen were a Great Blue Heron (*Ardea herodias*) and some Tyrant Flycatchers while reptiles included the Caiman (*Caiman crocodilus*). All these sightings were in the pond areas. On some of the higher ground, i.e. ridges and flats, several bird nests were observed in the small trees and taller shrubs as well as the nests of insects, e.g., ants, wasps and termites. At Bartholomew's hillside quarry, large termite nests were seen inside the forest above the excavated site.

DEVELOPMENT OPTIONS: CONSERVATION OF EXISTING FEATURES

Wherever environmental rehabilitation work is undertaken it is important not to remove or destroy features of the landscape that can be beneficial to the rehabilitation process and which might be incorporated into the development proposals for the site. This would apply to both physical and biological aspects of the area such as bodies of water, rocky escarpments and outcrops, and patches of vegetation that may not have been too severely damaged during the period when the site was being exploited for whatever purpose. The relic vegetation may contain plant species of the original natural community and hence will be a valuable seed source for recolonizing other areas of the site. These patches of vegetation may also harbor animals that can assist in seed dispersal as well as micro-organisms that can improve soil conditions.

Garibdass

All the ridges at this abandoned quarry site which are well elevated and covered in dense vegetation containing trees and shrubs should be left undisturbed in the rehabilitation process. This also applies to portions of the stream edge that are well vegetated. At the time of the study, the Garibdass quarry had been abandoned for approximately ten years and nature had made little progress in revegetating the most disturbed parts. Those areas, therefore, that have dense well-established vegetation should not be tampered with in the light of the slow recovery rates. The relic trees in the area also should be left standing for the positive role they play in maintaining environmental quality.

Yeates

At Yeates deep quarry, the ponds that now have dense fringes of vegetation around their borders and beyond should be left alone. One of these ponds had good water quality with a thriving population of small fish (Jackson 1993). The fire-damaged forest that partially surrounds the quarry should be allowed to regenerate naturally. Even the tall dead trees in this community should be left standing so that the organic matter they contain will be recycled within the stand.

Bartholomew's

The limestone quarry has an excellent second growth forest stand covering the ridge above the excavation area. This forest should be kept intact for proper watershed management. Parts of the forest are already threatened by shifting cultivators.

REVEGETATION UTILIZING NATIVE SPECIES

If the three abandoned quarries were left to their

own devices, soil would develop over a period of time and plant communities would undergo succession to reach a state of dynamic equilibrium with their environment. The severity of the disturbance will determine the rate at which recovery takes place. The Valencia sites, especially Garibdass, are very retarded in their natural development whereas Bartholomew's shows signs of a faster recovery owing to the more favorable environmental conditions that exist there. In order to speed up rehabilitation at these sites and increase their potential for resource management, the following development options are recommended.

Garibdass can be developed for agroforestry or a mixed forest stand. In order to determine which is the better choice, experimental plots should be set up to test each option and a control site set aside to monitor progress in the test plots. Initially, a ground cover of herbaceous species would be planted in the experimental plots to be followed later by shrubs and trees. A time frame of ten years is proposed for this development.

Two options are suggested for Yeates abandoned quarry. The first proposal is to develop the site for recreational or commercial ventures and the second is to initially use the area as a landfill site then later develop it for agroforestry or mixed forest. With the risk of toxic contaminants in a landfill, perhaps the former would be the preferred choice.

The best option for Bartholomew's limestone quarry is to leave it alone and let it recover naturally to a wooded hillside. If development is to be considered, then the area has some potential for residential or commercial buildings.

In the light of these options, revegetation of the sites using native plants is now considered bearing in mind that some introduced exotic species could be part of the rehabilitation plan. These non-native species, however, are beyond the scope of this study.

Garibdass

All the areas at the Garibdass quarry complex that have sparce vegetation cover should be re-contoured in order to facilitate the setting up of experimental plots where agroforestry and mixed forest stands can be established. These areas would include the gravel heaps and flats that constitute dry ground at the site. In addition, those sparsely vegetated depressions that are periodically flooded should be converted to permanent ponds with inflow and outflow channels. Areas where dense vegetation now occurs on ridges or borders streams should be left alone. In altering the terrain for the experimental plots, the gravel heaps could be levelled and dry hollows filled in to create a gently undulating land surface with appropriate drainage channels. Tailings (pitrun) from the hillside limestone quarries could be utilized by mixing this material with the sand and gravel spoils at Garibdass. Once these engineering works are completed, the revegetation of the site can commence. Initially only an herbaceous ground cover is needed in order to stabilize the surface and prevent erosion. Vines and grasses together with some legumes are suitable as early colonizers. All of these plants occur naturally at the site and could be utilized in the early stages of rehabilitation. These include:

Mandevilla hirsuta (vine)
Mikania micrantha (vine)
Mikania scabra (vine)
Davilla aspera (vine)
Andropogon bicornis (grass)
Andropogon selloanus (grass)
Homolepis aturensis (grass)
Paspalum virgatum (grass)
Desmodium adscendens (legume)
Mimosa pudica (legume)
Banisteriopsis leptocarpa (vine)
Nepsera aquatica (herb)
Pterolepis glomerata (herb)
Sauvagesia erecta (herb)
Passiflora laurifolia (vine)
Coccocypselum guianense (herb)
Achetaria guianensis (herb)
Cissus erosa (vine)

One plant to be avoided in this early stage because it tends to form dense cover and is difficult to eradicate, is the fern *Dicranopteris pectinata.* It is important to utilize a mixture of plants and not create pure stands of one species. The greater the diversity, the healthier the stand which in turn speeds up recovery. There will also be a tendency for other species, even shrubs and trees, to colonize the plots. This should not be discouraged as it will enhance the diversity of the

site.

Once a good herbaceous cover is in place soil conditions will start to improve and native woody plants can be introduced into the section designated for mixed forest while agroforestry species can be established in the section set aside for that purpose. Early successional native trees and shrubs that are already found at the abandoned quarry site include:

Ochroma pyramidale (Bois Flot)
Cordia curassavica (Black Sage)
Terminalia amazonia (White Olivier)
Alchornea triplinervia (Honeywood)
Maprounea guianensis (Petite Feuille)
Vismia cayennensis (Black Kiskidee)
Vismia guianensis (Kiskidee)
Vismia laxiflora (Kiskidee)
Lacistema aggregatum
Byrsonima coriacea (Serrette)
Cecropia peltata (Bois Canon)
Pisonia eggersiana (Jiggerwood)
Isertia parviflora (Wild Ixora)
Trema micranthum

These species will want to be encouraged in the mixed forest plot but kept in check in the agroforestry section. *Trema micranthum* is a multi-purpose species that in addition to reafforestation can be used for shade, wood, pulp and fodder. It is particularly useful as a pioneer species on poor soils in barren areas (BOSTID 1980).

As time progresses, later successional native trees will become established in the mixed forest experimental area either on their own or through artifical regeneration. These species too are already growing at the abandoned quarry:

Didymopanax morototoni (Jereton)
Tabebuia stenocalyx (Wild Calabash)
Protium guianensis (Incense)
Diospyros irensis (Bois Charbon)
Erythroxylum carthagense
Clusia palmicida (Matapal)
Ormosia monosperma (Jumbie Bead)
Henriettea multiflora (Sardine)
Virola surinamensis (Cajuca)
Euterpe precatoria (Manac Palm)
Parinari campestris (Bois Bande)
Amaioua corymbosa (Camayung)
Laetia procera (Bois Toucan)
Simarouba amara (Marouba)

In addition to those listed above, some of the original forest trees still found in this area could be planted at the site in the later successional stages. These include *Mora excelsa* (Mora), *Pentaclethra macroloba* (Bois Mulatre), *Carapa guianensis* (Crappo), *Oenocarpus bataua* (Palma Real) and *Manicaria saccifera* (Timite) all of which are important socio-economic species.

Yeates

In considering the first option for this site where it would be developed as a recreational or commercial venture, it would be necessary to enhance the areas around the existing ponds. If the ponds are to be used for fishing, then fast growing shade trees, e.g., *Samanea saman* (Saman), should be planted and boardwalks constructed to minimize damage in the wetter sections of the site. Dense vegetation already exists around some of the ponds and should be left undisturbed as this forms an effective buffer zone and protects the quality of water in the pond . Where sparsely vegetated gravel heaps and flats occur some landscaping will be required and should follow the same format as already proposed for the Garibdass quarry. Once these areas have been graded, then a revegetation plan can be put into effect. Here the object is to create an environment that is conducive to recreational pursuits. Therefore, unpleasant vegetation, species that are thorny, urticating or poisonous must be kept out. As an additional bonus, that would enhance the recreational value of the area, the forest on the north and west sides of the site should be protected and made accessible with nature trails.

Conversely, if the site is to be developed as a commercial venture to raise tropical fish or caiman (BOSTID 1983a) in the ponds or for using the water in the ponds for horticulture in order to grow orchids or cut flowers, e.g., Anthuriums and Ginger Lilies, then controlled access to the ponds must be maintained to protect the quality of the water. In the case of horticulture where a lot of infrastructure, i.e., covered garden beds or greenhouses, would be required,

then the sparsely vegetated dry ground at the site could be levelled to accommodate these facilities.

Pursuing the option of initially utilizing the area for a landfill site would preclude eventually using the site for recreational development. Instead, the land could later be developed as an agroforestry or mixed forest stand. The landfill option is attractive because of the shortage of space for refuse dumps in Trinidad. Also the ponds at the site contain only surface water and are not connected to any aquifers (Jackson 1993) thus making them suitable for landfill. The overpopulated east-west corridor needs additional landfill sites, especially at its eastern end to accommodate the expanding communities of Arima and Sangre Grande. Site preparation to convert the area for landfill would require utilizing the gravel heaps already present as overburden to bury the rubbish. In addition, a buffer zone of vegetation, fast growing trees and shrubs, would be needed to segregate the area from the public and control access to the site.

Once the area's capacity for landfill has been exhausted, then the terrain must be prepared for conversion to agroforestry or mixed forest. To begin with, most of the land will already be level following the landfill phase so little landscaping will be needed. Revegetating the area would follow the same procedure as described for Garibdass quarry and require an initial cover of herbaceous plants before the site is ready for agroforestry or mixed forest. Nearly all the native species that were listed as ground cover plants for revegetation at Garibdass are also presently growing at Yeates, the only exception being *Davilla aspera,* a vine which was not picked up in the survey at the latter site. Two additional candidates found at Yeates , can be placed on the list of herbaceous plants, namely *Odontadenia nitida,* a vine, and *Hyptis atrorubens,* an herb.

Following the initial revegetation phase, either agroforestry species can be introduced or natural succession to a mixed forest can be encouraged. If the latter option is followed, then early successional native trees and shrubs will become established either naturally or through artifical regeneration. Again, many of the species already listed for Garibdass are also growing at Yeates. In addition to these, the following early successional native trees and shrubs found at Yeates can be included in the list: *Eupatorium odoratum* (Christmas Bush), *Pisonia salicifolia* (Jiggerwood), *Flemingia strobilifera* (Wild Hops) and *Pithecellobium jupunba* (Puni). The latter two are legumes.

As the mixed forest community becomes more stable, late successional species will become the dominant plants. About half of the late successional native trees recorded at Yeates also were found at Garibdass. In addition, the following species occurring at Yeates can be placed on the list: *Chrysobalanus icaco* (Fat Pork), *Clusia nemorosa* (Matapal), *Pisonia cuspidata* (Jiggerwood), *Hirtella paniculata*, a small tree belonging to the Rosaceae family, and *Calliandra guildingii* (Niaure). Other *Calliandra* species in the tropics have been recommended for soil improvement and reafforestation projects as they can grow well on marginal soil and tolerate extended dry spells. They also compete successfully with course grasses when the latter dominate the vegetation cover (BOSTID 1983b).

Bartholomew's

This hillside quarry presents the fewest problems in terms of rehabilitation. With environmental conditions here being more favorable, a faster natural recovery takes place. Aside from stabilizing the rock face to ensure that no rock falls occur, the area at the base of the quarry, which includes spoil heaps and sediment outflow, could be restored to some extent. After levelling the basal area, herbaceous cover will quickly stabilize the spoil material which should contain enough calcium (see Table 3) to prevent acidic conditions. Grasses will be one of the early invasive species along with Composites, Euphorbs and Legumes. As a result, no ecological rehabilitation effort is needed at this initial stage of plant succession.

Once the herbaceous cover is well established at the base of the quarry, it may be desirous to speed up recovery in this area. Some of the early sucession native shrubs and trees, already present at the site, could be planted here. These include:

Ochroma pyramidale (Bois Flot)
Cordia curassavica (Black Sage)
Eupatorium odoratum (Christmas Bush)
Pluchea carolinensis (Geritout)

Muntingia calabura
Hura crepitans (Sandbox)
Cassia fruticosa (legume)
Coursetia arborea (legume)
Flemingia strobilifera (legume)
Cecropia peltata (Bois Canon)
Ficus yoponensis (Figuier)
**Psidium guajava* (Guava)
Lantana camara (Kayakeet)
* non-native but naturalized

Muntingia calabura grows well where limestone deposits occur (BOSTID 1980). It is abundant at the limestone quarries in the Arima Valley, and occurs at La Pastora and Bartholomew's quarry in the Santa Cruz Valley. It was absent, however, at the Union College quarry which may indicate that limestone is no longer present at this site or that chance dispersal has favored other species.

Additional early succession shrubs and trees found at La Pastora control site that could be included in the above list are *Croton gossypiifolius* (Bois Sang), *Citharexylum fruticosum* (White Fiddlewood), and the legumes *Aeschynomene sensitiva* and *Crotalaria retusa* .

With an abundant seed source from the nearby forest, late succession native trees would be able to establish at the base of the quarry. Species for consideration here that were not found in the forest above the quarry but were recorded for the control sites include *Erythrina pallida* (Wild Immortelle), *Platymiscium trinitatis* (Roble), *Carapa guianensis* (Crappo) and *Genipa americana* (Juniper). The former two are legumes and were found at La Pastora while the latter two were recorded for the Union College quarry.

In their study of the Lady Young Quarry (McClean Monument), the Trinidad and Tobago Field Naturalists' Club's Botany Group (Quesnel *et al.* 1996) found the legumes *Lonchocarpus punctatus* and *Coursetia arborea* (see list above) growing well at the site.

ENVIRONMENTAL IMPACT OF REHIBILITATION

Engineering Works and Landscaping

During the early phases of rehabilitation when the terrain at the abandoned quarry site has to be physically altered in order to improve the area for revegetation, some of the problems normally generated during quarry operations will be repeated, e.g. noise, dust, contamination of ground and surface water, obstruction of surface drainage. Steps, therefore, need to be taken to minimize the harmful effects generated by this activity.

Noise levels are the most difficult to control as heavy machinery, bulldozers and graders, will be needed to move and recontour suface material. In the test sites covered by this study, the Valencia quarries are remote from large population centers and residential areas. Some housing does occur in the vicinity of Bartholomew's hillside quarry but this is the area requiring the least amount of rehabilitation work.
Dust is a problem in the dry season which is a more favorable time for rehabilitation work as it minimizes erosion of surface material by heavy rainfall. Dust levels can be controlled to some extent by periodically spraying the rehabilitation area with water.
Contamination of ground and surface water can be avoided if drainage is channelled into temporary sediment ponds during the physical rehabilitation. As both the Valencia sites have streams flowing through them and Yeates has several ponds, these will have to be protected from harmful sediments by constructing temporary barriers along their borders to prevent an influx of contaminated water. If the establishment of ponds in the sparsely vegetated depressions at Garibdass is to be one of the rehabilitation options, these could initially serve as sediment collecting areas.

In recontouring the land, proper drainage will be an essential part of the landscape design. Unnecessary flooding of well-vegetated lowland should be avoided by constructing an effective drainage system that can handle varying amounts of rainfall. Inadequate drainage will have harmful effects on the plants, especially trees that cannot tolerate prolonged inundation.

Revegetation

When considering this aspect of rehabilitation work, in terms of environmental impact, care must be taken to ensure that the species introduced are compatible with their new environment. For example,

some hillside trees, like *Cordia alliodora* (Cypre), do not grow well in lowland regions while other species, such as *Machaerium robinifolium* (Saltfish Wood), do well in drier habitats and avoid wetter areas (Quesnel *et al.* 1996).

Special caution and attention should be given to exotic or non-native plants. When these are removed from their original habitat where they have existed in harmony with their environment as either neutral or benificial species and placed in a new setting where natural controls are no longer in place, they may become detrimental, usually as invasive species growing out of control or escaping into other parts of the region where they can pose a threat to agriculture. This problem is more likely to occur when native species are ignored in the rehabilitation process as has happened in the Forestry sector. When rehabilitation to a mixed forest is being considered as an option, there are lots of good native species to choose from as indicated in this study. In terms of agroforestry, the indigenous choices are more limited as most of the food crops, orchard and plantation species grown in Trinidad have been introduced from other parts of the world.

In assessing the environmental impact of revegetation at the three study sites attention should be given to public access to the area, to visual impact and to pollution control. Access to the site will be determined by what type of development option is chosen. At Garibdass, public access should be restricted if mixed forestry or agroforestry are being considered. Fire, predial larceny, squatting and uncontrolled cutting, e.g., slash and burn, have been and will continue to be serious environmental threats in Trinidad. If any reafforestation program is to succeed then these detrimental practices have to be curtailed. Squatters have already moved onto land adjacent to the study sites at Garibdass and Yeates.

Access to Yeates will need to be restricted only if the landfill option followed by agro- or mixed forestry is chosen. The recreational or commercial options will require that public access be controlled to minimize excessive visitor impact on the environment around the ponds and adjacent forest. In the wetter areas this can be done by the use of well-maintained boardwalks while in the forest clearly marked nature trails can reduce visitor impact.

Visual impact at the study sites can immediately be enhanced by removing all the derelict machinery, abandoned vehicles and rubbish that has accumulated in the areas. The visual impact with respect to revegetation will be aesthetically pleasing to a greater or lesser extent depending on the option, greater in the case of recreational fishing and nature trails, less so with respect to horticultural development. Visual impact will be a problem only in the case of the landfill option. Here remedial measures can be taken by fencing the area with fast growing ornamental shrubs or small trees.

Pollution control measures need to be taken to assure the quality of water in the streams at the two Valencia sites and in particular in the ponds at Yeates. The success of the recreational or commercial ventures at this latter site will depend on a good supply of fresh water. The ponds should be continually tested and monitored in order to maintain high standards of water quality. With respect to the landfill option, strict pollution control measures will be required to prevent contamination of nearby rivers e.g., the Quare. The types of waste material dumped at the site will have to be carefully controlled. Toxic chemicals, radioactive material, heavy metals, e.g., lead from batteries, and other known harmful waste products should not be dumped at the site as these may later cause serious contamination problems.

ADDITIONAL REHABILITATION MEASURES

Research

More research work is needed on rehabilitation of quarried land in the tropics. The local campus of The University of the West Indies could be the venue for this work in Trinidad. One student research project at St. Augustine has identified five tree species as good initiators of succession at abandoned quarry sites. These are *Acacia mangium, Leucaena leucocephala, Citharexylum fruticosum* (White Fiddlewood), *Muntingia calabura* and *Coursetia arborea.* These species are fast growing deep- rooted evergreens with a high leaf fall and produce abundant seed. They can colonize the poorest land surfaces, even bedrock. These trees are able to set in motion a self-sustaining nutrient cycle which in turn can benefit other plants that are in close proximity. The object is to circumvent

the costly process of reintroducing topsoil to a degraded site. Other species that can short circuit the slow process of succession need to be identified.

Drainage

Revegetation should never be initiated until proper drainage has been established at a site. This ensures that no erosion or flooding will damage the vegetation cover. The problems encountered at the Arena sand pit in this regard and the high financial cost incurred (Ramdial 1983) should serve as an effective warning to those involved in quarry rehabilitation.

Existing Vegetation

Do not tamper with existing well-vegetated areas at the rehabilitation site. These serve as useful seed sources and habitats for a variety of wildlife from birds to micro-organisms. The temptation may be to start from scratch with the rehabilitation work and bulldoze all existing features. This attitude should be avoided. Make use of what is available and incorporate these features into the rehabilitation plan.

Inter-agency/Ministry Co-operation

There needs to be more co-operation between government ministries and agencies that deal with quarry rehabilitation. The Ministry of Energy as the principal advisory agency to quarry operators needs to work more closely with the Forestry Division, the principal agency responsible for rehabilitation work. For example, the Ministry of Energy has received little or no directive from Forestry as to back filling operations at the quarry sites. The Ministry of Energy, therefore, has not given firm directives to the quarry operators on this matter.

Native Species

Nature does not produce useless species. Too often the attitude has been that unless a tree has timber value, then it must be treated as "bush" or a weed and chopped down. Many of these 'useless species' have unknown attributes that contribute to the maintenance of dynamic plant communities (Comeau 1991). In plant succession, as a component of rehabilitation work, all species have importance whether as soil builders, e.g., mosses, or habitat engineers, e.g., climax species. The sooner it is understood the important roles they play the faster the possibility of solving the problems associated with the rehabilitation of derelict land.

ACKNOWLEDGEMENTS

I wish to thank the following for their generous support: Tim Jackson, freelance environmental consultant, who worked closely with me on all aspects of the study; Winston Johnson, Senior Technician at the National Herbarium who put in long hours at the study sites and later at the Herbarium identifying the plant species; Yasmin Comeau, Curator of the National Herbarium, for providing working space, searching out relevant literature and proof reading parts of the manuscript; Tyrone Kalpee, Trinidad and Tobago Biological Society, who provided stimulating discussion and valuable insights into revegetating abandoned quarry sites; Howard John, Ministry of Energy and Mines, for interesting insights about quarrying in Trinidad; Kevin Marshall, NIHERST, for providing a bibliography on quarrying in Trinidad and Tobago; Capildeo Ramsarran, Assistant Conservator of Forest, for providing transport and technical services; Anthony Montserin, Chief Surveyor, Forestry Division, and Malcom Spence, Agricultural Engineer, for collecting soil samples at the study sites; Selwyn Griffith, Soil Science Dept., U.W.I., for providing analytical data on the soil samples from each site; and Ted Burleigh, WS Atkins International Limited, and Patrick Haynes, a colleague whom I worked with in St. Lucia, for getting me seriously interested in quarry rehabilitation.

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