Vegetation and Soil Development in Rehabilitated Quarries in Hong Kong

ZHANG, Hao

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ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

Thesis Committee

Prof. L.M. Chu (Supervisor)

Prof. S.W. Chiu (Internal examiner)

Prof. K.C. Chau (Internal examiner)

Prof. N.M. Dickinson (External examiner)

Abstract

To evaluate the ecological succession in the floristic composition and structure of closed quarries, studies of the current vegetation development and seed dynamics were carried out in the three quarries, namely Turret Hill Quarry (TH), Lam Tei Quarry (LT) and Shek O Quarry (SO). The floristic composition shows that the species richness and Shannon index were higher on older phases than other younger phases in the overstorey and understorey vegetation. Although planted exotic species dominated the overstorey at different phases, some native species became more dominant in the understorey, and the importance value of native species accounted for more than 50%. Seed rain results show that older sites had higher seed number and seed species than younger sites. In terms of number of seeds, half were dispersed by birds, while 23% and 27% were dispersed by wind and civets, respectively. Seed germination experiment shows that most species from all twelve woody species had higher germination in SO, though most emerging seedlings finally died under the field condition. In the soil seed bank study, high seed species and density were recorded on older sites. Non-woody species predominated on all phases of the three quarries, but some pioneer tree and shrub species were better represented on older sites.

Ecological changes in soil covers were studied in terms of physical, chemical and biological properties in the three quarries. Results show that all soils were classified as sand loam in texture, and high bulk density and low total porosity were

common problems. Soils were strongly acidic to moderately acidic in reaction. Organic C, total N, extractable NO_3^- and extractable cations increased with increasing rehabilitation age, but others did not show similar trends. The results of mineral N flux in soil show that ammonification predominated over nitrification in TH and LT, while nitrification predominated in SO in wet season. In dry season, ammonification predominated over nitrification in all phases, except TH. Net N mineralization increased with age. The results of soil microbial study show that older sites had the highest total microbial abundance and biomass C and N, while those in younger sites were low. Metabolic abilities of soil microbes developed gradually with ages in SO, but TH and LT had the similar patterns of carbon source utilization. The group of G^- bacteria dominated in all sites, in which cy19:0 represented more than 15% of the total extracted FAMEs. The group of fungi and AM fungi decreased with increasing ages in the three quarries.

Lacks of seed rain and seed bank were major factors limiting vegetation regeneration. Physical and chemical problems of cover soils are still severe even after 10 years of rehabilitation. Therefore, adding native species with fleshy fruits to attract birds, and leguminous species to assist in the buildup of nitrogen capital should be recommended. Application of organic composts should be considered by quarry contractors and managers during early rehabilitation period to improve soil structure and raise nutrient storage capacities.

摘要

本研究選取香港三個石礦場，即呂婆山、藍地和石澳，爲研究地點，對三個石礦場各個修復階段上的植被組成和結構，以及植物種子的動態進行了生態學研究，以此來評價退化石礦場上植被的生態演替。植被組成結果顯示，在喬木層和灌木層中，植物的豐富度和香農指數在修復年份長的區域中大過修復年份短的區域。儘管，種植的外來品種在喬木層中佔有一定的優勢度，一些鄉土樹種開始在灌木層中佔有一定優勢度，鄉土樹種的重要值均超過百分之五十以上。種子雨研究結果顯示，修復年份長的區域收集到較高的種子數量和品種數量。根據種子的個體數，一半的種子由鳥來傳播，百分之二十三的種子由風傳播，而剩餘百分之二十七由風和鼯貓來傳播。種子發芽實驗結果顯示，在十二個木本植物的種子中，大多數種子能夠在石澳石礦場四個不同階段的區域中發芽，然後這些發芽的幼苗在幼苗階段大多數死亡。土壤種子庫結果顯示，修復年限長的區域記錄到高的種子品種和種子密度。三個石礦場中，土壤種子庫中以草本植物的種子佔有優勢，而木本植物的種子所佔優勢較小，但是一些先鋒喬木和灌木種類較好的出現在修復年齡長的區域。

基於土壤的物理、化學和生物特性，本文對三個石礦場不同修復區域的土壤生態變化進行了研究。結果顯示，所有土壤均被分類爲砂壤土，具有高的容重和低的總孔隙度。土壤顯示強酸至中等強度酸性。土壤有機碳、總氮、有效硝態氮和可提取陽離子均隨著修復年限的增加而增加，其他營養元素沒有相似趨勢。氮

的礦化結果顯示，在雨水季節，呂婆山和藍地石礦場土壤的氨化作用佔優勢于硝化作用，而石澳石礦場土壤的硝化作用強于氨化作用。在干旱季節，藍地和石澳石礦場所有土壤的氨化作用佔優勢于硝化作用，而呂婆山石礦場土壤的硝化作用強于氨化作用。三個石礦場土壤中的淨氮的礦化隨著修復年限的增加而增加。土壤微生物研究結果顯示，修復年齡長的區域土壤具有較高總的微生物豐富度和碳、氮生物量，而在新修復的區域中表現爲低。石澳石礦場中土壤微生物的代謝能力隨著修復年限的增加而逐步增加，但是呂婆山和藍地石礦場各個修復區域土壤具有相似的碳源利用模式。革蘭氏陰性細菌在三個石礦場各個修復區域均佔有較高的優勢，其中 19 碳直鏈脂肪在總提取的肪酸甲基脂中佔百分之十五以上的比例。真菌和菌根真菌在三個石礦場的土壤中，隨著修復年限的增加而下降。

缺少種子雨和種子庫爲影響植被更新的主要因素。經過十年的修復，石礦場內的土壤物理和化學特性依舊未有很大改善。因此，本研究建議在早期修復過程中，人工種植具有新鮮果實的鄉土樹種以及增加氮庫的豆科植物。同時，修復石礦場的承建商及管理者應該重視有機堆肥的應該，特別是在石礦場早期的修復階段，這樣有利於土壤結構改善和營養積累。

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Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

Sustainable development has become an internationally important issue. Central to the idea of sustainability is the notion that long-term thinking is essential to ensuring that the world remains suitable for future generations. Economy, society and environment are the important components for sustainable development, and they are interrelated and interact with each other (Farley and Gaddis, 2007; Norgaard et al., 2007). Over the past century, we have changed our environment more rapidly and extensively than in any comparable period of time in human history. The expansion of human population leads to large exploitation of natural resources continuously, from woods to minerals, leaving scars of different disturbance levels. Logging and deforestation have a serious impact on the original ecosystem and secondary succession is involved in restoring those habitats. It is widely recognized that natural habitats are being degraded at a rapid and accelerating pace (Bawa and Dayanandan, 1997; Halle and Fattorini, 2004). In the tropics, annually 1 to 4% of forests are destroyed and there are million hectares of degraded land awaiting restoration (Hamilton, 1990; Dobson et al., 1997). Seriously damaged lands not only lose control over resources, but also the capacity for self regeneration, and are unable to prevent further degradation. Therefore, the science of restoration ecology and the practice of ecological restoration are going to be major tools to mitigate the adverse effects of

human activity on ecosystems.

1.1 Restoration ecology

1.1.1 Definition of restoration ecology

Ecological restoration has been practiced in some forms for centuries. Various terms similar to restoration are adopted by different researchers and professional sectors (Hamilton, 1990; Harrington and Howell, 1990; Malakoff, 2004), according to variations in definition and project scale (Jackson et al., 1995). The Society for Ecological Restoration International's Primer on Ecological Restoration defines ecological restoration as the 'the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed' (SER, 2004), which is a broader concept. The goal of ecological restoration is a resilient ecosystem that is self-sustaining with respect to species composition, structure and function (SER, 2004). In this sense, ecological restoration can be viewed as an attempt to recover a natural range of ecosystem composition, structure and dynamics (Allen et al., 2002; Palmer et al., 2005). Restoration ecology is the discipline of scientific inquiry dealing with the restoration of ecological systems. The simplest restoration involves removing a perturbation and allowing the ecosystem to recover via natural ecological processes. More often, however, restoration requires multiple efforts, because multiple perturbations have pushed ecosystems beyond their ability to recover spontaneously.

1.1.2 Restoration, rehabilitation and reclamation

Successful restoration of a disturbed ecosystem is the acid test of our understanding of that ecosystem (Bradshaw, 1987). Strictly speaking, ecological restoration attempts to return a system to some historical states (Bradshaw, 1987; Rosales et al., 1997), both in structure and function of the ecosystem (Figure 1.1). However, this is ideal and rarely achievable (Aronson et al., 1993; Fang and Peng, 1997). Therefore, a more realistic goal is to move a degraded system to an ecological state that is within some acceptable limits relative to a less disturbed system.

In that case, a broader definition of the term that is equivalent to 'rehabilitation' is widely accepted. Rehabilitation creates a habit that is close to the original one without completely returning to the original structure and function (Figure 1.1) (e.g. reforestation with different species composition) (Bradshaw, 1987). Most local restoration projects merely aim to revegetate an area and let the regeneration of other species happened spontaneously without management, and hence, they all belong to rehabilitation.

In fact, there are other terminologies to describe objectives for improving ecological restoration of damaged lands. Reclamation is a term used by many practitioners which is defined as the making of land fit for cultivation (Figure 1.1). There is no implication of returning to an original state but rather to a useful one.

Reclaim or replace may therefore be involved and require continuing inputs of fertilizers, herbicides, energy and water.

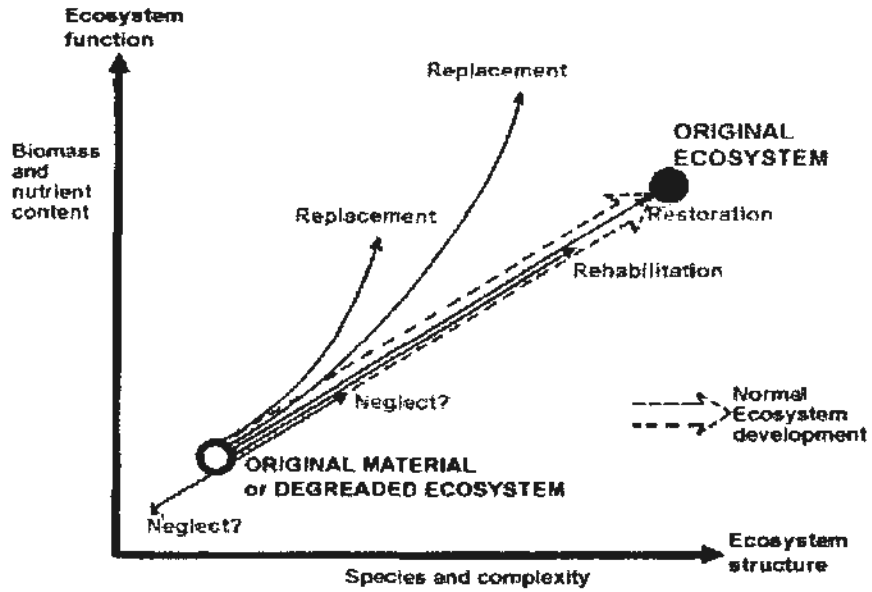


Figure 1.1 Ecosystem development on degraded lands (Bradshaw, 1984)

1.1.3 Targets in restoration ecology

The primary goals of many restoration projects are to stop further degradation of land and return it into visually pleasant and harmonic form by revegetation. Plant canopy provides cover to the unfavourable substratum and improves the microclimate (e.g. temperature), which allow succession to proceed or accelerate. Vegetation cover prevents erosion and nutrient depletion that may affect succession (Hamilton, 1990; Sotir, 1990; Virgonia, 1990; Fang and Peng, 1997; Parrotta et al., 1997). It also reduces the possible hazard to public (e.g. landslide) (Dutton et al., 1992; Kirkbride and Forbs, 1994; Wang and Tang, 1999). In some cases, self-sustainability of the

ecosystem may be included as a restoration objective, but in reality the major concern will go to cost-effectiveness rather than ecological benefits. In short, human inputs in restoration accelerate the natural succession on degraded sites that will otherwise be obscured or arrested by various barriers or stresses (Parrotta et al., 1997).

Defining restoration goals is the most important step in the planning process (Pastorok et al., 1997). It is suggested that three simple types of goal could be considered for designing restoration prescriptions: species, ecosystem functions and ecosystem services (Ehrenfeld, 2000). A species-level approach may rescue particular species from extinction, locally or globally, and could definitely be said to increase biodiversity. A number of targets, for example keystone species, endangered species and assemblages, can be used to design a restoration scheme. The ecosystem functions approach offers the potential to explicitly recognize the need for different components of ecosystems to be connected and working effectively. The types of processes and pools which may be examined include material and energy flows, biotic components, abiotic components and ecosystem architecture. Ecosystem service approach is a combination of the species and functional approaches (Ehrenfeld, 2000). Therefore, devising suitable targets incorporating all three categories will provide a greater chance of ecological restoration for the damaged lands.

1.1.4 Ecological approaches for restoration

There are numerous technological approaches for improving degraded lands. Programs designed to improve the ecological status and productivity of damaged lands usually contain ecological concepts. Ecologically based approaches direct vegetation change through the enlightened application of ecological principles (Bradshaw, 1983). These approaches seek to create communities and landscapes that persist and develop toward desired conditions which increases and sustains advantageous biological interactions within their ecosystems. For example degraded ecosystems, with damaged biotic components, have diminished control over the essential hydrologic and nutrient cycling processes. Restoring hydrologic functioning and the mechanisms that regulate resource movement are necessary prime considerations during the design of ecological restoration. The recovery and maintenance of ecological processes is the key to ecosystem restoration (Bradshaw, 1996). This approach often has lower initial investments, but requires considerably more time to achieve management goals.

1.2 Rehabilitation of closed quarries

1.2.1 Quarries in Hong Kong and southern China

With the rapid development of agriculture, industry and mining, the demand for all kinds of rocks and stones increases consistently, which leads to the development of

quarries in both size and number. Quarries not only occupy and destroy land resources, but also result in the loss of biodiversity, soil degradation, loss of water and soil, and destruction of ecosystems and landscape (Xia and Cai, 2002). Currently, the large number of abandoned quarries presents challenges for restoration of these degraded habitats. Therefore, ecological rehabilitation of quarries has become important parts in the sustainable development strategy of many countries including China (Dudka and Adriano, 1997; Lin et al., 1998).

Since the 1980s, many quarries in China have been exploited to provide large quantities of construction materials. In Hong Kong, there are three active quarries, namely the Anderson Road Quarry, Shek O Quarry and Lam Tei Quarry, producing substantial quantity of rock products to meet the needs of the construction works every year. For example, they met over 40% of the 12.5 million tonnes of total demand for rock products in 2002 (CEDD, 2007). Excessive quarrying seriously destroys ecological environment, natural resources and landscape. In the late 1980s, the concept of quarrying changed significantly and the government began to pay much attention to the ecological restoration of quarries. Quarries are thus identified as areas of degraded landscape which require improvement and rehabilitation. At present, the three quarries are being rehabilitated to attractive green areas which will be suitable for a variety of uses beneficial to the community. The improvement works

typically involve major engineering construction, mass tree planting and erosion control (CEDD, 2007). In the adjacent Guangdong province, quarries developed rapidly since the late 1980s and the number of quarries increased to 10,000, occupying 3,000 ha of land (Gao et al., 2005). From 1999, the Guangdong government began to rehabilitate quarries by planting vegetation and improving soil quality. Up till now, 3,272 old quarries have been shut down in the province, 2,659 of which needed restoration, and 2,500 ha of land needed to be rehabilitated (Mi and Lin, 2004).

Revegetation has been a general rehabilitation practice for closed quarries. Exotic species such as *Acacia confusa*, *A. auriculiformis*, *A. magium*, *Lophostemon confertus* and *Eucalyptus torelliana* were planted extensively on these quarries for their more promising performance. Different species are planted which serve to fulfil different ultimate ecological goals and fit different afteruses. To rehabilitate a closed quarry successfully, the first step is to select its afteruse (Gilman et al., 1985), and set the ultimate ecological goal. Therefore, it could be identified if there is any major limitation on-site which would require special treatment (Bradshaw, 1998).

1.2.2 Afteruse and ultimate ecological goal

The afteruse of a completed quarry is mainly decided by the local authority, which is based on local needs, public concerns and financial support. Rehabilitated

quarries next to urban areas are desirable for parks and other recreational uses. Other than this, quarries can be transformed into other land uses, e.g. residential areas (Hooper, 1992; Kirkbride and Forbes, 1994). Attention should also be paid to the value of these degraded areas in conservation due to their low accessibility by the public, because they can be developed into refuges for endangered plants or extended habitat for wildlife (Falk, 1990; Kendle and Bradshaw, 1992).

Once afteruse has been chosen, the following steps of rehabilitation would be much easier. For example, when a green zone is expected in a closed quarry, there is no more to do except hydroseeding and leaving it for the processes of natural succession (Gilman et al., 1985; Bradshaw, 1997, 1998 and 2000). If a closed quarry is to be transformed to an ecological park, great investments will have to be taken and further restoration of the pre-disturbed ecosystem is required.

1.2.3 Factors limiting rehabilitation

One management option for degraded quarries is to remove existing stresses and allow the ecosystem to rehabilitate naturally. A critical factor in the rehabilitation of quarries is establishing and maintaining an effective stand on the final cover soil (Jim, 2001; Yuan et al., 2006). However, the success of revegetation is not always guaranteed and poor growth of planted species is frequently recorded, which is probably related to the poor soil status prevailing on the quarry sites (Bradshaw, 1997;

Clemente et al., 2004; Yuan et al., 2006).

1.2.3.1 Physical problems of soil cover

In Hong Kong, the landform in quarries is similar, with completely decomposed granite (CDG) forming the soil cover (Tsang, 1997). The soil is often very poor in physical properties. It is sandy in texture owing to the higher proportion of unweathered quartz compared with many other soil types in Hong Kong (Chau and Marafa, 1999; Chan, 2001). Some studies also showed that the soil has high bulk density, and low porosity to retain water and to facilitate soil aeration due to low organic content to aggregate the particles into a crumb structure (Bradshaw and Chadwick, 1980; Dobson and Moffat, 1993). Compaction is another problem for the soil cover in quarries, because of the use of heavy machinery (e.g. earthscraper) during landscaping works. This leads to a low infiltration rate and the soil tends to harden when dry (Dobson and Moffat, 1993). The large surface runoff leads to serious erosion. Granite soil is therefore known as one of the most erosive soil type (Claassen and Zasoski, 1998) and this makes its revegetation much more difficult.

1.2.3.2 Shallow soil cover

Shallow soil is another factor that limits vegetation development in quarries. Normally, soil depth of at least 1 m is recommended for vegetation development on degraded sites, as the roots of most species penetrated as far as 1 m depth (Cairney

and Hobson, 1998). However, the soil in quarries in Hong Kong is much shallower (about 60 cm), which hinders sustainable tree development by restricting root growth, anchorage, and water and nutrient uptake (Wilson, 1991).

1.2.3.3 Drought and waterlogging

Coarse textured soil may suffer from drought, especially in dry seasons (Grant, 1983; Brady and Weil, 1999). In shallow soils, the total available water reservoir may be too small to support tree growth due to the reason of drought in a dry winter. In compact soils, hydraulic conductivity, matric potential and infiltration are reduced, which thus limit water supply to plant and consequently vegetation development (Taylor and Bar, 1991). In summer, the soil cover may still be too thin to hold excessive water and thus cause ponding and flooding after heavy rain (Wilson, 1985; Dobson and Moffat, 1993). On the other hand, compacted soils inhibit free drainage of water and cause seasonal waterlogging during summer (Dobson and Moffat, 1993).

1.2.3.4 Nutrient deficiencies

Deficiencies of essential nutrients are serious in the granitic soil cover (Wong, 1988; Liu, 1999). Among the nutrients, nitrogen is usually the major limiting factor (Claassen and Marler, 1998; Bradshaw, 1998 and 2000). The soil total nitrogen only made up to about 200 $\mu g\ g^{-1}$ for the granitic soil cover in Tai Lam plantation in Hong Kong (Tsang, 1997). Granitic soils are mostly acidic in reaction and pH ranged from

4.66 to 4.74 in Hong Kong (Chau and Lo, 1980; Chau and Chan, 2000). Phosphorus deficiency is also reported on such substratum due to low pH and high aluminium content (Chau and Lo, 1980). CDG is low in cation exchange capacity (CEC) since the major components of its parent rock are weakly weathered. The chemical components for the weathering product are low with few plant nutrients. In addition, the weathered minerals are also subjected to leaching and soluble nutrient ions would be lost easily (Bradshaw and Chadwick, 1980).

1.2.4 Species selection

In Hong Kong, the aims of revegetation are mainly the control of erosion and provision of greening. Fast-growing and stress-tolerant species are the priority choices due to limited budget. They are mainly exotic species from the dry regions of Australia, with only few natives such as *Pinus massoniana*, *Liquidambar formosana* and *Castanopsis fissa* (Nicholson, 1996). After the large-scale infection of *P. massoniana* with nematodes in the late 1970s, this species was eliminated from the list and the remaining natives comprised only a small proportion of the total number planted (Corlett and Truner, 1997). Although more native species have been tried, exotics like *Acacia* spp., *Eucalyptus* spp. and *Lophostemon confertus* still dominated in plantation projects, especially on degraded sites like quarries, borrow areas and landfills (Chan et al., 1991; Kirkbride and Forbs, 1994; Chong, 1999; Lui, 1999).

Exotic plants have been preferred in plantation for more than 60 years in Hong Kong (Wang, 1995), as most of them are able to tolerate adverse conditions, e.g. drought and low fertility. Fast-growing nitrogen-fixer like *Acacia* spp. and *Casuarina equisetifolia* enrich the soil with nitrogen from the atmosphere through soil microbial communities. Other species like *Lophostemon confertus* and *Eucalyptus* spp. have high regeneration ability, and are able to recover from injury and fire (Kirkbride, 1983). Thus, these exotics are widely accepted as a guarantee to successful revegetation.

However, the recruitment of other species at the understory in exotic plantations is slow, and most exotics do not attract local wildlife which are important dispersers for many plant species. The exotics fail to provide suitable fruits for local birds and mammals, and they are not suitable locations for nesting and roosting (Kwok and Corlett, 2000). Comparing pure *Acacia* and *Eucalyptus* woodlands and mixed forest, it is clear that the diversity of vegetation, insects, birds and soil microbes were all lower in the exotic monoculture (Wang and Pang, 1997). The pure *Pinus* or *Eucalyptus* woodland was unable to reverse the acidity of eroded soil and even have degrading effect on soil fertility and structure (Wang and Pang, 1997). Therefore, it is generally believed that fully natural communities could not be established with exotic species (Diamond, 1987).

Native species could enhance the speed of restoration. They also provide attractive shelter and feeding places for local wildlife, which are threatened by habitat destruction. The animals in turn help the natural regeneration through pollen and seed dissemination (Jordano, 1992). These animals include insects (e.g. butterfly), birds and mammals. Native trees can be divided into two groups: pioneer species, which represent only 20% of the diversity in tropical forests and late-successional species, which represent about 80% of the tropical forest diversity (Swaine and Whitmore, 1988). In practice, planting late-successional species which could provide a variety of food resources for animals is a preferable reforestation measure, compared with reliance on a low diversity pioneer plantation in disturbed sites (Martinez-Garze and Howe, 2003). However, succession theory predicts that late-successional species will tend to fail when introduced into a disturbed or open site (Ashby, 1993), which means planting late-successional species in degraded sites should not be a good rehabilitation measure. With the development of restoration ecology in recent 20 years, there are some researches which assessed the growth performance of late-successional species in different disturbed or open sites. It is suggested that many late-successional species grow and survive well in early successional habitats if they get into abandoned pastures (Hardwick et al., 1997; Loik and Holl, 2001; Camargo et al., 2002; Hooper et al., 2002; Carpenter et al., 2004; Garza et al., 2005; Zhang, 2005).

There were only a few systematic studies on the growth of natives in Hong Kong. One large-scale trial started in 1994 in Tung Chung by the former Agriculture and Fisheries Department (Wong, 2003a). This study showed the favourable performance of several natives (*Schima superba*, *Reevesia thyrsoidea* and *Tutcheria spectabilis*). In another study, native species *Cyclobalanopsis neglecta* and *Choerospondia axillaries* were recommended (Hau, 2001). There are many species that are overlooked and needed to be explored. Up to now there are only a few native species that have been proved to be suitable and commonly used in quarries (Table 1.1). A reason for this is the insufficient supply of seedlings (Lay et al., 1999), which depends on seed source and viability (Parrotta et al., 1997). In addition, the lack of artificial silviculture measure (e.g. weeding, removing understorey competition and adding fertilizers) is another reason for the failure of native species (Wong, 2003a). These aftercare measures should be emphasized in the early growth phase of the native species when they are planted in degraded sites (Zhaung and Corlett, 1997; Wong, 2003a).

Table 1.1 Common natives in rehabilitation projects in Hong Kong (Wong, 2003a)

Species names	Family	Form	Anderson Road Quarry	Shek O Quarry	Lam Tei Quarry
Castanopsis fissa	Fagaceae	tree	*	*	
Celtis sinensis	Ulmaceae	tree		*	*
Ficus microcarpa	Moraceae	tree	*		
Gordonia axilliaris	Theaceae	tree		*	*
Liquidambar formosana	Hamamelidaceae	tree		*	
Macaranga tanarius	Euphorbiaceae	tree	*		
Melastoma sanguineum	Meastomataceae	shrub	*	*	*
Rhaphiolepis indica	Rosaceae	shrub	*		*
Rhodomyrius tomentosa	Myrtaceae	shrub	*	*	
Sapium discolor	Euphorbiaceae	tree			
Sapium sebiferum	Euphorbiaceae	tree		*	*
Schefflera octophylla	Araliaceae	tree		*	
Schima superba	Theaceae	tree		*	*
Sterculia lanceolata	Sterculiaceae	tree			

1.3 Knowledge learned from natural regeneration

Restoration returns a habitat exactly the same as that before destruction, both in structure and function of the ecosystem (Rosales et al., 1997). This is hardly practicable (Fang and Peng, 1997), not to say within a scale of ten years. In most situations, the process of natural succession is slow on disturbed sites, and it is common for 50 or 100 years to elapse before a satisfactory vegetation and soil cover

develop (Cullen et al., 1998). However, spontaneous succession is still a suitable tool for restoration of various disturbed sites. If the disturbed site is small, surrounded by natural vegetation, and conditions were not principally altered, spontaneous revegetation is especially advantageous (Prach et al., 2001). Jan et al. (2003) concluded that spontaneous succession could be resulted in the reasonable time of about 20 years to semi-natural vegetation. In general, primary forest succession can be described in terms of a series of colonization stages. Plant recolonization is mainly determined by factors related to the type and intensity of previous land use, such as soil conditions for germination, the presence of soil-stored seed and opportunities for seeds to disperse to the site (Guariguata and Ostertag, 2001). Wijdeven and Kuzee (2000) compared dramatic differences in both seed density and composition of the soil seed bank between abandoned pasture and nearby secondary forest. The seed bank of abandoned pasture was dominated by grasses, herbs and a few tree species, while the forest soil seed bank consisted mainly of shrubs and trees. The overriding factor preventing the reestablishment of forest in cleared or disturbed areas is a lack of seed of forest species (Duncan and Chapman, 1999; Ingle, 2003). In addition, research at various disturbed sites demonstrated that many factors may impede forest seed recruitment, including lack of soil nutrients, soil compaction, competition with pasture grass, seasonal drought and high seed and seedling predation (Aide and Cavelier,

1994; Nepstad et al., 1996). Holl (1999) assessed the different factors such as seed rain, seed germination, microclimate and soil physical and chemical parameters in limiting forest regeneration in abandoned pastures, and suggested that the most important limitation in abandoned pasture is a lack of seed dispersal. Several other studies have also indicated that lack of seed dispersal, particularly of animal-dispersed seeds, is a primary factor limiting tropical forest recovery in large disturbed areas (Hardwick et al., 1997; Zimmerman et al., 2000).

Hong Kong is an extreme example of tropical landscape degradation, with no substantial remnants of the original forest cover. Au et al. (2006) assessed the quantity and quality of the seed rain of woody taxa in fire-maintained grassland, shrubland and secondary forest in Hong Kong. Their results suggested that birds were inferred to be the major dispersal agent for 99.8% of the seeds trapped in the grassland site and the seed rain was adequate for the development of woody vegetation cover. Therefore, native trees or shrubs invaded and developed on quarries without tree planting could give some hints at species selection. They probably represent the group dispersed by birds and mammals, which simultaneously can withstand the harsh environment on closed quarries.

1.4 Project objectives and long-term significances

1.4.1 Knowledge gap

Quarry is the main type of degraded sites in southern China and its ecological development plays an important role in the development of theory and practice of restoration ecology. It is therefore essential to design restoration experiments that both enrich knowledge of restoration ecology and inform management strategies to facilitate recovery of these degraded sites.

Some studies suggested that a number of factors may impede forest succession in degraded tropical sites. These factors include low rates of seed recruitment, seed and seedling predation, poor germination condition, seasonal drought and poor soil condition (Holl, 1999; Ingle, 2003). However, the relative importance of these factors in limiting recovery varied greatly among different study cases. For example, in tropical pasture, the most important limitation was a lack of forest seed availability; in contrast, seed rain was adequate for the development of woody vegetation cover in degraded grassland in Hong Kong (Holl, 1999). Quarry is a unique and extreme degraded site which is challenging to restore. However, the information of factors limiting vegetation regeneration in quarries is lacking.

The development of community diversity and ecosystem functioning has become an important issue in quarries (Grime, 1997; Loreau, 2000). However, most studies

only take into account diversity, structure and productivity of the aboveground compartment of terrestrial ecosystems. Less attention has been paid to the belowground soil microorganisms (Zak et al., 1994). Soil microorganisms play a key role in maintaining soil quality and ecosystem health due to their involvement in organic matter dynamics, nutrient cycling and decomposition (Mummey et al., 2002). They can also be sensitive biological markers and be used to assess disturbed or contaminated soils (Anderson, 2003; Hartley et al., 2008). Therefore, by characterizing soil microbial diversity and function, it allows us to better understand and manipulate ecosystem functioning.

At present, there are three quarries in operation in Hong Kong, viz Anderson Road, Shek O and Lam Tei. These quarries are rehabilitated progressively based on new contracts, which typically involved major engineering construction, mass planting and erosion control. Exotic species with rapid growth rate used to be the first choice for planting, however, exotic plantation might maintain low community complexity and diversity (Blakesley et al., 2002). At present, studies on quarries in south China and Hong Kong mainly focus in the fields such as the introduction of eco-technology and engineering (Gao et al, 2005), and the investigation of vegetation and soil properties (Wang and Song, 1999; Shu et al., 2003; Yuan et al., 2005). However, there is a paucity of information regarding 1) the ecological succession in

the floristic composition and structure in quarries, 2) the ecological development in soil physical and chemical properties, soil microbial community composition, structure and function after planting of exotic species, 3) the relationship between vegetation and soil microbial community in quarries.

1.4.2 Objectives

Therefore, the objectives of this study are as follows:

1) to assess the succession on the floristic diversity in the rehabilitated quarries;
2) to determine the spatial pattern of seed input to the rehabilitated quarries and identify the major seed dispersal agents involved;
3) to study the regeneration potentials of the established species from soil seed bank;
4) to examine variations in soil physical and chemical properties, in soil mineralization process and in soil microbial community;
5) to interpret the relationships between vegetation and soil properties after planting exotic species in rehabilitated quarries.

The results obtained will fill the missing link in the field of ecological development of vegetation and soil in quarries, which can provide recommendations on the management strategies for the restoration of our local quarries as well as abandoned quarries in the nearby Guangdong province and other provinces in southern China.

1.5 Study sites

1.5.1 General description

Three quarries, namely Turret Hill Quarry (TH), Lam Tei Quarry (LT) and Shek O Quarry (SO), were selected for this study (Figure 1.2). TH is a closed quarry, while the latter two are still in operation but have finished phases being restored progressively. Each quarry therefore has a number of phases which were rehabilitated at different time.

It is believed that quarries are relatively free from pollutants that may hinder plant growth (Chan et al., 1991; Chan et al., 1997), as compared to landfills and some other degraded lands. Vandalism by human beings is also minimum in quarries as they are usually situated at quite remote locations, so the performance of plants should adequately reflect the environmental and edaphic properties of the sites.

Although the final reinstated soil on the three sites are CDG, their parent materials are of different plutonic types. The granite of TH belongs to Sha Tin Granite of the Kwai Chung Suite, and the granite of LT is Tai Lam Granite of the Lamma Suite, while that of SO is Po Toi Granite of the Lion Rock Suite (Luo, 2007). They were developed in middle Mezosoic, but the former two consists of prophyritic medium-grained to equigranular fine-grained lecogranite, while the latter includes coarse- to fine-grained biotite monzogranite (Sewell, 1999). However soil forming

processes such as weathering are the main factors that govern the soil properties (Brady and Weil, 1999), so the minor difference between the parent materials in these three sites can be neglected.

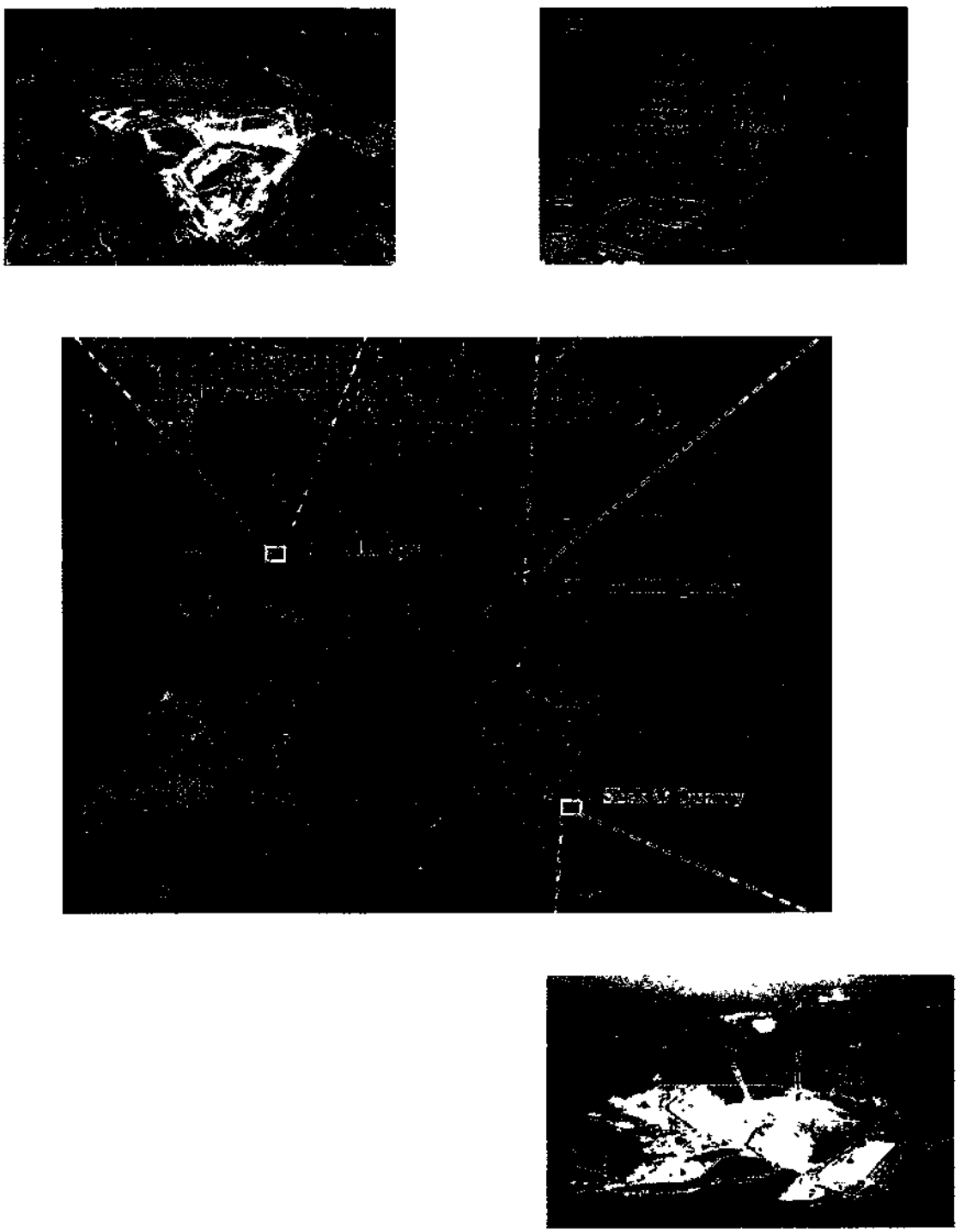


Figure 1.2 Locations of the three quarries studied in this project

1.5.2 Rehabilitation of the three quarries

Turret Hill quarry

Turret Hill quarry is located at the northeast of Sha Tin New Town, covering an area of 25 hectares. The quarry was established in the mid-1960s. The rehabilitation contract (No. GC/88/04) was signed in April 1989 and completed in June 1995 (CEDD, 2007). The final landform consists of benches at 20 m vertical intervals and the existing steep quarry face is flattened to about 40°. There was one phase adopted for this study (TH94) (Figure 1.3 a).

Lam Tei quarry

Lam Tei quarry is located about 3 km northeast from Tuen Mun Town in the New Territories. It has an area about 30.5 ha, of which 23.5 ha are to be rehabilitated. The contract (No. 444/81) was started in January 1982 and was scheduled to be completed in June 2007. A new rehabilitation contact (No. GE/2006/03) was signed in October 2006 for completion in July 2015. The final landform consists of 9 benches separated by 15 m high cutslopes and 2 new benches separated by 10 m high cutslopes. Between the benches, rock slopes of 60° - 70° were formed. There were three phases adopted for this study, LT 98, LT 01 and LT 04 (rehabilitated in 1998, 2001 and 2004, respectively) (Figure 1.3 b).

Shek O quarry

Shek O quarry is located on the west coast of the Cape D'Agular Peninsula on the Hong Kong Island. It covers an area of 45 ha in which 30 hectares are to be rehabilitated. The contract (No. GE/93/14) was signed in March 1994 and the works were originally scheduled for completion in December 2009. There is no clear boundary between phases as scree slope was adopted for the land formation. Therefore an area in SO represents slope of different age within a period before the completion of the whole area. However photographs could still be employed to identify ages of each slope compartment. Four scree slopes, encoded SO98, SO01, SO04 and SO06 were included in this study (Figure 1.3 c).

In total, 8 rehabilitated sites were studied and the general characteristics of the study sites are listed in Table 1.2.

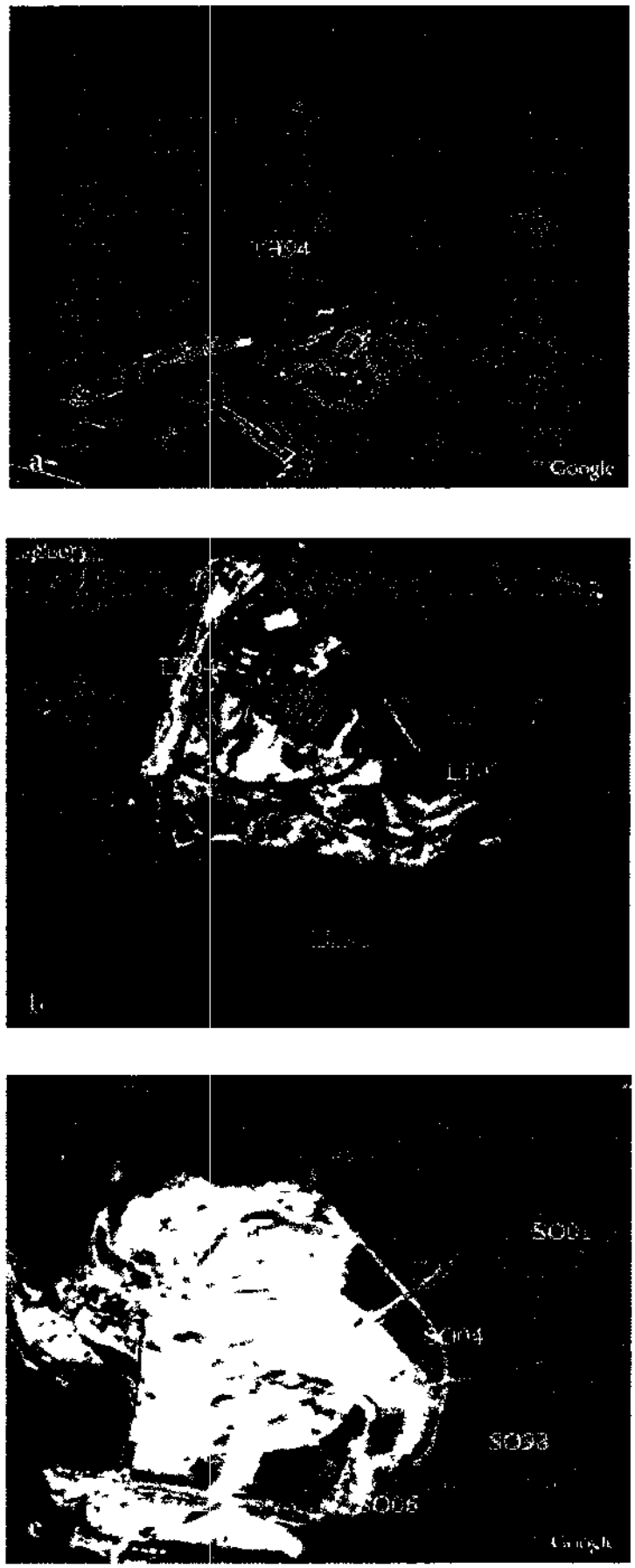


Figure 1.3 Different phases on TH (a), LT (b) and SO(c). Photos were from Google (http //maps.google.com).

Table 1.2 General characteristics of sampling sites in the three quarries

Sites	Year of closure	Restoration age (y) (Year of study 2007)	Aspect	Altitude (m)	Slope (°)	Engineering construction	The nearest vegetation type	Distance to the nearest vegetation (m)
TH94	1994	13	SE	67	2	Bench slope	Secondary forest	75
LT98	1998	9	N	111	2	Bench slope	*Pinus* plantation	120
LT01	2001	6	E	88	0	Bench slope	*Pinus* plantation	420
LT04	2004	3	SE	65	0	Bench slope	*Pinus* plantation	500
SO98	1998	9	E	94	28	Scree slope	Secondary forest	60
SO01	2001	6	S	107	26	Scree slope	Secondary forest	400
SO04	2004	3	SW	66	24	Scree slope	Secondary forest	280
SO06	2006	1	S	35	18	Scree slope	Secondary forest	140

1.5.3 Landscape master plan in the three quarries

The landscape master plan was designed by the quarry operators in association with other experts to establish a landscape strategy to recontour and revegetate the degraded quarry. The landscape master plan included ecological construction, soil type and depth, hydroseeding mix, planting methodology, and water management.

Before rock excavation, the soil cover was first removed and stored in stock pilings *in situ* in the three quarries. After excavation, the soil covers were reinstated and major recontouring works were done. Recontouring schemes of the three sites were different. For TH and LT, bench slope was used as the main framework of the final landform, while scree slope was adopted for SO.

Bench slopes are formed on benches between rock faces. On the bench, a layer of gravel is laid on a base layer formed by shot rocks. The final cover is a layer of CDG with a depth of around 600 mm (compromising between plant requirement and engineering constraints) compacted by machinery; the soil slopes form was less than 20^{o} generally. In the lastest Lam Tei quarry rehabilitation, the berms shall have a width of not less than 10 m and shall be covered by not less than 1000 mm thick soil. The soil is protected from erosion by non-degradable geotextile (Enkamat®) before hydroseeding and tree planting (Yu and Lam, 1998) (Figure 1.4, Plate 1.1a).

Scree slope is formed similarly. Benches between rock faces are layered with

broken and shattered rock fragments, above which the soil is separated by non-biodegradable geotextile fabric (Terram 1000). The thickness of the soil layer is also around 600 mm and is composed of CDG forming slopes of 35°- 45°. It is also protected by erosion control mat (Geomat), but in contrast it is biodegradable as it is made of plant fibers. Hydroseeding and tree planting are then carried out (Kirkbride and Forbes, 1994) (Figure 1.5, Plate 1.1b).

The three quarries were hydroseeded with a seed mix of grasses before tree planting. The grasses included *Cynodon dactylon* (15 g m^{-2}), *Paspalum notatum* (10 g m^{-2}), *Chloris gayana* (5 g m^{-2}), *Eragrostis curvula* (20 g m^{-2}). No trees and shrubs were used in the hydroseeding.

After hydroseeding, conventional planting of the slopes was carried out progressively from the top of the hill to the bottom. Exotic species which are fast growing and have high survival rate were used; seedlings with a height of 150-600 mm were planting at 1.5 m spacing. The site design mixes varied according to habitat, with shaded slopes, slopes in full sun and gravel-channel slopes. The main exotic species planted in the three quarries are shown in Table 1.3. *Casuarina equisetifolia* and *Eucalyptus citriodora* were the main species adopted in TH and LT, but *Calliandra haematocephala* was only used at LT01. *Acacia* species were widely adopted in SO. The plants were watered thoroughly before being planted into soil pits.

Watering was applied in the initial two years to encourage deep root growth (Lam and Siu, 2002; Man et al., 2003).

Table 1.3 Main exotic species planted in the three quarries

	TH 94	LT 98	LT 01	LT 04	SO 98	SO 01	SO 04	SO 06
Acacia auriculiformis					*	*	*	*
Acacia confusa	*	*	*	*	*	*	*	*
Acacia mangium					*	*	*	
Calliandra haematocephala			*					
Casuarina equisetifolia	*	*	*	*				
Eucalyptus citriodora	*	*	*				*	
Eucalyptus tereticornis		*	*		*	*	*	
Lophostemon confertus		*	*		*	*	*	

* planted in this phase

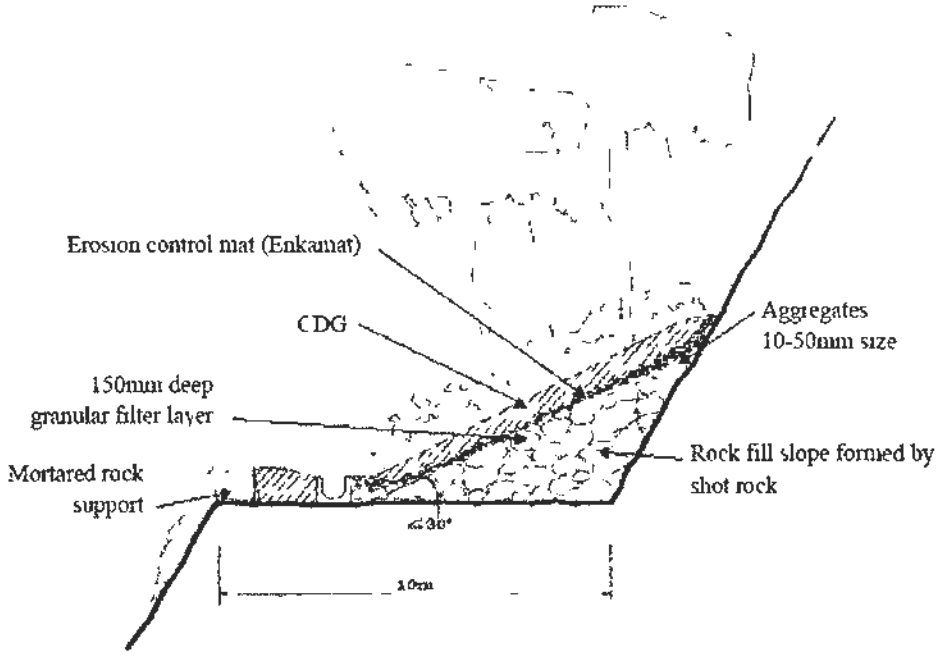


Figure 1.4 Bench slope profile in TH and LT

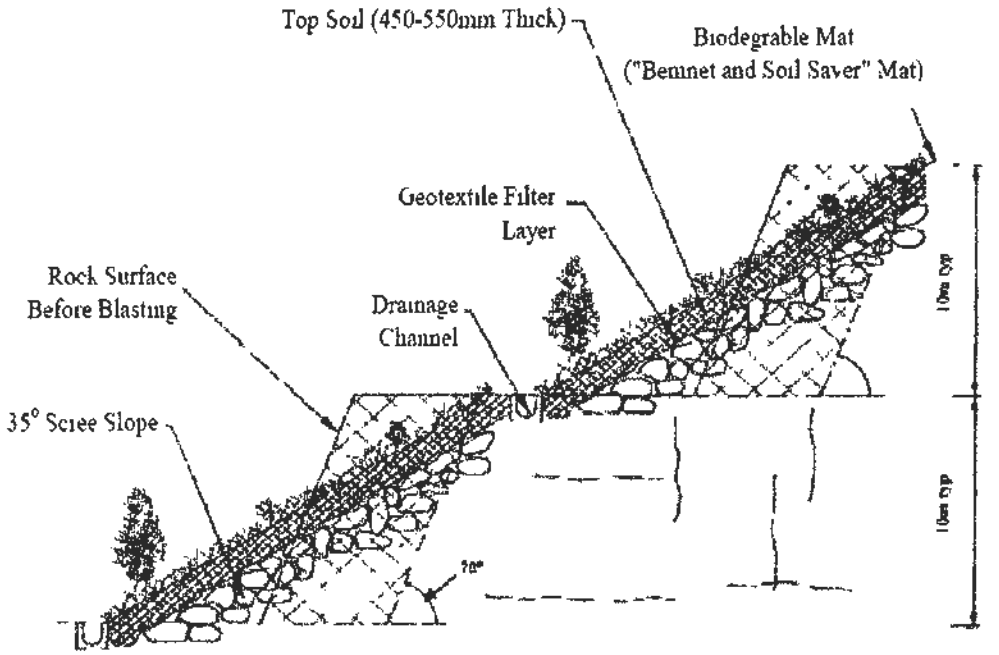


Figure 1.5 Scree slope profile in SO

1.5.4 Site specificity and representativeness

The purpose of selecting these three quarries for the study is to assess the general problems faced during rehabilitation of these degraded lands in Hong Kong and to describe a more representative picture on the nature of these degraded landscapes. The final reinstated soils on the three sites are completely decomposed granite (CDG) and their parent materials are different plutonic types. However this minor difference between parent materials is negligible. Nevertheless, attention should be paid to the unavoidable variations in aspects, the engineering construction and planted exotic species. At TH and LT, bench slope is used, while SO comprises of scree slope. Only exotic species were planted after hydroseeding during the first year of rehabilitation of the three quarries. *Eucalyptus* spp. and *Casuarina equisetifolia* are widely used in TH and LT, but *Calliandra haemaocephala* was only applied in LT01. In SO, *Acacia* spp. are the major species planted.

Chapter 2 Vegetation Composition and Development in Rehabilitated Quarries

2.1 Introduction

Quarry rehabilitation requires both physical and biological interventions. The biological rehabilitation includes hydroseeding and tree planting, the major function of which is to create less harsh habitats on degraded lands by enhancing soil properties and reducing competition of weeds by shading, thereby promoting successful invasion and establishment of native species (Lugo, 1997; Parrotta et al., 1997; Zhuang and Yao, 1999; Chu, 2008). Establishment and development of the planted species is greatly affected by the properties of the final cover soil which provides anchorage, support, water and nutrients required for plant growth (Lugo, 1992). Poor vegetation growth is frequently reported, which could be attributed to poor edaphic condition like high temperature, drought and poor physical properties (Wong and Yu, 1989; Dobson and Moffat, 1993; Chan et al., 1998; Hutchings et al., 2006).

Efforts in revegetating degraded lands in Hong Kong aim at giving a greening effect and controlling erosion. Fast growing species which are tolerant to drought and poor soil quality may be of great advantages (Dobson and Moffat, 1993 and 1995). Planting trials have suggested that nitrogen-fixing species such as *Acacia* spp. and

Casuarina equisetifloia could grow on degraded lands (Tong and Wong, 1984; Wong and Yu, 1989; Stacey et al., 1992). These exotic species are characterized by extensive root system, drought resistance and heat tolerance properties, and the ability to survive in harsh sites with shallow and infertile soils (Jim, 1993).

The ecological value of exotic plants is always a subject of debate. The drawbacks of exotic plantation include simplified stand structure, low stability, low resource use efficiency, low level of biodiversity and displacement of native species (Poore and Fries, 1985; Lugo, 1997). In addition, exotic plantations may be vulnerable to pathogens (Mcnalled et al., 1998; Peng, 1999). Nevertheless, most plantations are capable of modifying the physical and biological conditions of the site, and accelerating secondary forest succession (Parrotta et al., 1997; Zhuang and Yau, 1997; Lui, 1999; Au, 2001; Kong, 2003). A change in floristic composition and structural characteristics of the understorey can be expected during successional development of the restored community (Keenan et al., 1997; Powers et al., 1997). Therefore, understanding the recruitment of native species in the understorey of plantations is crucial during the period of secondary succession in these exotic plantations. At present, there is a knowledge gap in the status of invasion underneath the exotic plantations in rehabilitated quarries.

The objectives of the present experiment are to assess changes in floristic

composition, diversity and structure along a successional gradient, and to characterize the vegetation performance on the various phases in the three quarries based on the existing vegetation composition to show the achievement of the revegetation. It is hoped that by understanding the vegetation succession in rehabilitated quarries, appropriate site management strategy could be recommended to speed up the succession.

2.2 Materials and methods

Vegetation cover and floristic analysis for species density and frequency were investigated on TH, LT and SO in June 2008 using the frame quadrat methods. Within each phase of the three quarries, four 10 m × 10 m plots were randomly placed at least 10 m away from each plot (Zhuang, 1997). Consequently, 4 plots in TH, 12 plots in LT and16 plots in SO were chosen.

2.2.1 Vegetation cover

The coverage of woody species (trees and shrubs) and understorey vegetation (grasses and herbs) within the plot were determined separately. The woody species coverage was determined by standing at the centre of each plot and counted at four cardinal directions around the sampling point by the densitometer method (Korhonen, et al., 2006). The coverage of herbs and grasses was measured from photos taken from 1 m × 1 m quadrat using grid cells.

2.2.2 Floristic composition analysis

A stratified random sampling procedure was used in vegetation study. The diameter at breast height (dbh), tree height and species name of all the tree taller than 2 m in each plot were measured and recorded. Two 5 m × 5 m quadrats in each plot were randomly set and the species name and height of shrubs and small trees (1-2 m in height) were recorded. Four 1 m × 1 m quadrats in each plot were randomly set and the species name and coverage of herb species were recorded. Plant species were identified and named with reference to the Check List of Hong Kong Plants (Anon. 2002).

2.2.3 Data analysis

The data from floristic analysis was calculated for diversity, evenness and similarity for inter-site comparison.

The diversity index of the species in each area was calculated from Shannon index, H' (Magurran, 1988) as

$$H' = -\Sigma\, pi \ln pi$$

where Pi = relative cover of species i

Evenness index J of the plant species was computed according to Pielou (1966) as

$$J = H'/\ln s$$

where H' = Shannon-Wiener diversity index

s = number of species

The coefficient of similarity between sites (Magurran, 1988) were determined as

$Ss = 2\,a / b + c$

where a = number of species common to both quadrats

b = number of species in one quadrat

c = number of species in another quadrat

The importance value for each species was also calculated (Mueller-Dombois and Ellenberg, 1974) after determining the relative abundance (RA), relative frequency (RF) and relative dominance (RD).

$IV = (RA + RF + RD) \times 100 / 3$

where RA= number of seedlings for each species/ total seedlings in each site

RF= number of quadrats for each species/ total quadrats in each site

RD= basal area at breast height for each species/ total basal area in each site

The importance value for each species in understorey was calculated as $IV = (RA + RF) \times 100 / 2$, because of no data for relative dominance (RD).

One-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) test at $p<0.05$ was used to determine any significant

difference between means of different phases.

Ordination analysis was carried out to study the association of vegetation samples in terms of their similarity of species composition (Gauch, 1982). The abundance of woody species was analyzed using DECORANA (Hill, 1979) which is a computer program for detrended correspondence analysis (DCA) and reciprocal averaging. DCA is popular among field ecologists, presumably because it can reduce the problem of axis length distortions, the so-called 'arch effect' (Jongman et al., 1995). The results of ordination analysis are expressed with the species or sites plotted against two axes, each axis corresponding to a dimension in space (Kent and Coker, 1994). DCA was run with the Canoco 4.5 software (Centre for Biometry, Wageningen, Netherlands).

2.3 Results

2.3.1 General description of the vegetation

The results of the vegetation surveys are shown in Tables 2.1 and 2.2. There were totally 113 species found at the three quarries, in which 82 species belonged to woody species, and 31 species were herbaceous species. Forty woody species were found at the SO98 which was the highest among the sites (Table 2.3). TH94, SO01 and LT98 followed, which had 35, 29 and 24 woody plants respectively. LT04 and SO06 had the lowest number of woody species. In the herbaceous layer, TH94 had the highest

number of herbaceous species, while LT04 and SO06 had the lowest number though their difference was not obvious among the old rehabilitated phases such as SO98, LT98 and LT01 (Table 2.3).

A summary of the gross coverage of the vegetation is shown in Table 2.3. The highest coverage of woody plants was found at SO98 (87.3%) and LT01 (82.3%), followed by TH94 (54.4%), LT98 (61.6%) and SO01 (44.2%). The lowest coverage occurred at LT04, SO04 and SO06. Herbaceous coverage was the highest at the phase of SO06, which was up to 81.3%. The newly rehabilitated phase of LT04 also had high coverage (55.3%), while LT01 and SO98 had the lowest, which was the reversed trend compared with the coverage of woody plants. The gross vegetation coverage, which was the sum of the coverage of the woody and herbaceous plant species, descended in the following order: LT01 > SO98 > LT98 > TH94 > SO06 > SO01 > LT04 > SO04.

Table 2.1 Density and occurrence frequency of woody species in the three study sites

	TH94		LT98		LT01		LT04		SO98		SO01		SO04		SO06	
	No. of ind. 100 m^{-2}	Frequency* (%)	No. of ind. 100 m^{-2}	Frequency (%)	No. of ind. 100 m^{-2}	Frequency (%)	No. of ind. 100 m^{-2}	Frequency (%)	No. of ind. 100 m^{-2}	Frequency (%)	No. of ind. 100 m^{-2}	Frequency (%)	No. of ind. 100 m^{-2}	Frequency (%)	No. of ind. 100 m^{-2}	Frequency (%)
Abutilon striatum	-	-	-	-	-	-	-	-	0.25	0.06	-	-	-	-	-	-
Acacia auriculiformis	0.25	0.06	-	-	3.00	0.44	-	-	1.75	0.31	9.75	0.75	2.52	0.37	6.25	0.44
Acacia confusa	8.00	0.91	8.00	0.88	2.52	0.52	5.75	0.88	7.25	0.81	8.25	0.75	5.25	0.88	22.8	1.00
Acacia mangium	-	-	-	-	-	-	-	-	1.03	0.25	3.52	0.25	1.25	0.31	-	-
Acronychia pedunculata	-	-	0.25	0.06	-	-	-	-	-	-	-	-	-	-	-	-
Aglaia odorata	1.25	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alangium chinense	0.25	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Albizia lebbeck	1.00	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aporosa dioica	0.75	0.06	-	-	-	-	-	-	0.75	0.19	-	-	-	-	-	-
Baeckea frutescens	-	-	-	-	0.25	0.06	-	-	-	-	-	-	-	-	-	-
Bauhinia championii	-	-	-	-	1.53	0.25	-	-	-	-	-	-	-	-	-	-

Table 2.1 (continued)

Bischofia javanica	0.54	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bombax ceiba	0.52	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Breynia fruticosa	-	-	1.25	0.19	-	-	-	-	1.54	0.25	-	-	-	-	-	-
Bridelia tomentosa	7.50	0.75	-	-	-	-	-	-	26.5	0.81	1.00	0.19	-	-	-	-
Calliandra haematocephala	-	-	-	-	28.5	1.00	-	-	-	-	-	-	-	-	-	-
Camellia oleifera	-	-	-	-	-	-	-	-	0.25	0.06	-	-	-	-	-	-
Cassia siamea	0.75	0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Casuarina equisetifolia	0.25	0.06	4.25	0.69	2.25	0.44	1.75	0.44	-	-	-	-	-	-	-	-
Celtis sinensis	1.00	0.25	0.25	0.06	2.00	0.44	-	-	14.8	0.63	1.75	0.38	1.00	0.25	-	-
Celtis timorensis	-	-	-	-	-	-	-	-	4.00	0.49	-	-	-	-	-	-
Cinnamomum camphora	-	-	-	-	-	-	1.50	0.24	-	-	2.25	0.26	-	-	-	-
Cratoxylum cochinchinense	-	-	0.75	0.19	-	-	-	-	-	-	-	-	-	-	-	-
Dalbergia hancei	1.00	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dalbergia odorifera	-	-	-	-	-	-	-	-	-	-	-	-	4	0.45	-	-

Table 2.1 (continued)

Desmodium gangeticum	0.50	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Desmodium heterocarpon	-	-	-	-	-	-	1.75	0.25	-	-	15.5	0.75	22.5	0.75	26.3	0.25
Desmos chinensis	-	-	-	-	-	-	-	-	0.25	0.06	-	-	-	-	-	-
Endospermum chinense	-	-	-	-	-	-	-	-	0.50	0.12	-	-	-	-	-	-
Eucalyptus citriodora	6.25	0.88	4.50	0.69	0.25	0.06	-	-	-	-	-	-	0.50	0.13	-	-
Eucalyptus tereticornis	-	-	4.25	0.37	4.00	0.69	-	-	6.25	0.63	5.00	0.31	6.50	0.75	-	-
Garcinia oblongifolia	-	-	-	-	-	-	-	-	0.75	0.06	-	-	-	-	-	-
Gardenia jasminoides	-	-	-	-	-	-	-	-	1.25	0.13	2.00	0.19	-	-	-	-
Gnetum luofuense	-	-	-	-	0.75	0.19	-	-	-	-	-	-	-	-	-	-
Gordonia axillaris	-	-	-	-	2.75	0.25	0.25	0.06	-	-	0.25	0.06	0.25	0.06	-	-
Helicteres angustifolia	-	-	0.75	0.19	-	-	0.25	0.06	1.00	0.06	-	-	-	-	-	-
Hibiscus tiliaceus	-	-	-	-	-	-	-	-	1.50	0.25	-	-	-	-	-	-
Homalium cochinchinensis	-	-	-	-	-	-	-	-	-	-	-	-	0.25	0.06	-	-
Lantana camara	24.8	1.00	0.25	0.06	-	-	1.75	0.13	0.25	0.69	1.75	0.31	-	-	-	-

Table 2.1 (continued)

Leucaena leucocephala	37.7	0.94	-	-	-	-	0.75	0.06	65.5	0.88	19.7	0.59	2.00	0.43	1.25	0.24
Ligustrum sinense	2.00	0.19	-	-	-	-	0.25	0.06	6.25	0.63	0.75	0.19	-	-	-	-
Litsea glutinosa	-	-	-	-	-	-	-	-	0.25	0.06	1.00	0.25	1.25	0.19	-	-
Litsea rotundifolia var. *oblongifolia*	0.25	0.06	0.25	0.06	-	-	-	-	-	-	0.50	0.06	-	-	-	-
Lonicera japonica	-	-	0.25	0.06	-	-	-	-	-	-	-	-	-	-	-	-
Lophostemon confertus	-	-	5.00	0.63	0.75	0.19	-	-	3.25	0.44	0.75	0.06	3.00	0.45	-	-
Macaranga tanarius	5.50	0.45	-	-	0.25	0.06	-	-	4.75	0.40	4.25	0.38	5.00	0.63	-	-
Machilus chinensis	-	-	-	-	-	-	-	-	0.25	0.06	-	-	-	-	-	-
Mallotus apelta	6.00	0.58	-	-	-	-	-	-	0.50	0.12	0.25	0.06	0.25	0.06	-	-
Melastoma candidum	-	-	0.25	0.06	-	-	-	-	-	-	-	-	-	-	-	-
Melastoma sanguineum	-	-	1.50	0.19	-	-	-	-	-	-	0.75	0.19	-	-	-	-
Melia azedarach	12.5	0.37	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microcos paniculata	1.25	0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mimosa pudica	0.25	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.1 (continued)

Murraya paniculata	4.25	0.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ormosia pinnata	-	-	-	-	-	-	-	-	-	-	0.75	0.18	0.25	0.06	-	-
Pavetta hongkongensis	-	-	-	-	-	-	-	-	0.25	0.06	-	-	-	-	-	-
Phyllanthus emblica	0.25	0.06	-	-	-	-	-	-	1.00	0.13	12.5	0.68	-	-	-	-
Pinus elliottii	-	-	-	-	0.25	0.06	-	-	-	-	-	-	-	-	-	-
Psychotria asiatica	-	-	-	-	-	-	-	-	0.50	0.06	-	-	-	-	-	-
Rhaphiolepis indica	-	-	29.5	1.00	42.3	1.00	-	-	6.00	0.37	6.75	0.56	-	-	-	-
Rhodomyrtus tomentosa	-	-	0.50	0.06	-	-	-	-	6.75	0.25	5.75	0.38	0.25	0.06	-	-
Rhus chinensis	-	-	-	-	-	-	-	-	6.75	0.24	20.75	0.71	7.00	0.34	-	-
Rhus succedanea	0.25	0.06	0.25	0.06	-	-	-	-	0.25	0.06	-	-	-	-	-	-
Sageretia thea	0.75	0.06	-	-	-	-	-	-	1.75	0.19	-	-	-	-	-	-
Sapium sebiferum	-	-	-	-	-	-	1.75	0.44	-	-	-	-	-	-	-	-
Schefflera arboricola	1.00	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Schefflera heptaphylla	0.25	0.06	0.25	0.06	-	-	-	-	-	-	0.50	0.13	-	-	-	-

Table 2.1 (continued)

Schima superba	-	-	0.75	0.13	1.00	0.26	-	-	-	-	-	-	-	-	-	-
Scolopia chinensis	-	-	-	-	-	-	-	-	0.25	0.06	-	-	-	-	-	-
Sida rhombifolia	0.75	0.06	-	-	-	-	-	-	2.75	0.06	-	-	-	-	-	-
Smilax china	-	-	0.25	0.06	-	-	-	-	-	-	-	-	-	-	-	-
Stachytarpheta jamaicensis	-	-	-	-	-	-	0.75	0.13	3.75	0.06	1.00	0.06	-	-	0.50	0.06
Sterculia lanceolata	-	-	-	-	-	-	-	-	1.00	0.25	0.50	0.13	0.25	0.06	-	-
Strychnos cathayensis	0.25	0.06	0.25	0.06	-	-	-	-	-	-	-	-	-	-	-	-
Syzygium jambos	-	-	-	-	-	-	-	-	-	-	0.25	0.06	3.00	0.25	-	-
Trema tomentosa	1.00	0.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Uraria crinita	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.25	0.06
Urena lobata	0.25	0.06	-	-	-	-	-	-	-	-	-	-	0.25	0.06	-	-
Wikstroemia indica	0.25	0.06	1.25	0.19	-	-	-	-	-	-	-	-	-	-	0.81	-
Zanthoxylum avicennae	-	-	0.50	0.12	2.50	0.50	-	-	2.75	0.31	0.25	0.06	-	-	-	-
Unknown	-	-	-	-	-	-	-	-	0.25	0.06	-	-	-	-	-	-

* Frequency data obtained from 5 m × 5 m quadrats in the three quarries

Table 2.2 Plant coverage and occurrence frequency of the herbaceous and graminoid plants in the three study sites

	TH94		LT98		LT01		LT04		SO98		SO01		SO04		SO06	
	Coverage (%)	Frequency* (%)	Coverage (%)	Frequency (%)	Coverage (%)	Frequency (%)	Coverage (%)	Frequency (%)	Coverage (%)	Frequency (%)	Coverage (%)	Frequency (%)	Coverage (%)	Frequency (%)	Coverage (%)	Frequency (%)
Achyranthes aspera	-	-	0.10	12.5	0.30	18.8	-	-	-	-	-	-	-	-	-	-
Adiantum flabellulatum	-	-	0.10	6.30	-	-	-	-	-	-	-	-	-	-	-	-
Ageratum conyzoides	5.40	68.8	7.30	68.8	5.30	56.3	-	-	2.40	18.8	11.7	100	16.3	93.8	15.9	81.3
Aspidistra elatior	-	-	-	-	-	-	-	-	0.32	6.34	-	-	-	-	-	-
Bidens alba	5.62	37.5	7.20	100	7.20	68.8	23.1	100	1.00	18.8	0.80	12.5	1.32	12.5	3.12	18.8
Cynodon dactylon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.1	81.3
Dicliptera chinensis	-	-	-	-	-	-	-	-	0.84	6.32	-	-	-	-	-	-
Digitaria sanguinalis	2.80	25.0	-	-	-	-	2.50	6.30	-	-	-	-	3.10	12.5	-	-
Eclipta prostrata	0.10	6.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Emilia sonchifolia	0.20	6.30	-	-	-	-	-	-	-	-	-	-	0.80	18.8	-	-
Erigeron karvinskianus	0.10	6.32	-	-	-	-	-	-	-	-	-	-	-	-	0.64	12.5

Table 2.2 (continued)

Hackelochloa granularis	-	-	-	-	-	-	-	-	0.65	6.34	-	-	-	-	-	-
Hedyotis corymbosa	-	-	-	-	0.10	6.30	-	-	-	-	-	-	-	-	-	-
Ipomoea triloba	3.10	50.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lophatherum gracile	6.10	56.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lygodium japonicum	-	-	8.30	62.5	0.60	6.32	-	-	-	-	-	-	-	-	-	-
Mikania micrantha	-	-	-	-	-	-	3.12	12.5	-	-	-	-	-	-	-	-
Miscanthus floridulus	-	-	0.64	6.30	-	-	10.9	31.3	1.60	12.5	-	-	0.80	12.5	-	-
Ophiopogon japonicus	-	-	1.30	37.5	-	-	-	-	2.80	12.5	-	-	-	-	-	-
Oxalis corniculata	1.00	18.8	-	-	-	-	-	-	0.90	6.30	-	-	-	-	-	-
Paederia scandens	3.80	43.8	1.90	50.0	3.40	50.0	-	-	1.60	68.8	-	-	0.60	12.5	-	-
Parthenocissus dalzielii	2.50	43.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paspalum notatum	1.90	12.5	0.30	6.30	6.90	93.8	14.4	75.0	-	-	7.50	37.5	10.0	50.0	33.8	100
Pluchea indica	-	-	-	-	-	-	-	-	1.00	0.06	-	-	-	-	-	-
Polygonum perfoliatum	0.30	6.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.2 (continued)

Pteris ensiformis	0.30	6.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pueraria phaseoloides	-	-	-	-	0.60	6.30	-	-	-	-	-	-	-	-	-	-
Rhynchelytrum repens	5.64	25.2	-	-	2.50	12.5	-	-	-	-	7.80	31.3	7.20	81.3	9.70	43.8
Saccharum arundinaceum	-	-	0.32	6.32	0.30	6.30	-	-	-	-	0.90	12.5	3.40	31.3	-	-
Scleria corymbosa	2.50	6.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Setaria plicata	-	-	-	-	-	-	-	-	-	-	-	-	0.60	6.30	-	-
Unknown 1	-	-	-	-	-	-	-	-	-	-	11.9	43.8	-	-	-	-
Unknown 2	-	-	-	-	-	-	-	-	-	-	-	-	0.80	25.0	-	-

* Frequency data obtained from 1 m × 1 m quadrats in the three quarries

Table 2.3 Summary of the vegetation coverage in the three quarries

Site	Total no. of woody species	Total no. of herbs and grasses	Total coverage (%) of woody plants	Total coverage (%) of herbs and grasses	Gross average coverage (%)
TH94	35	16	54.4b	41.2c	95.6b
LT98	24	10	61.6b	34.3cd	95.9b
LT01	17	10	82.3a	27.9d	110a
LT04	11	5	23.5cd	55.3b	78.8cd
SO98	40	9	87.3a	13.8c	101ab
SO01	29	6	44.2c	40.6c	84.8c
SO04	21	11	11.4d	54.5b	65.9d
SO06	6	6	4.20e	81.3a	85.5c

Mean values followed by the same letter within a column are not significantly different at p=0.05 level according to the Tukey's HSD test

2.3.2 Stand characteristics of overstorey vegetation

2.3.2.1 Growth performance of overstorey vegetation

The species number, density, mean tree height and mean basal area at breast height are shown in Table 2.4. The species number generally increased with age of the plantations, in which the oldest sites (TH94 and SO98) had the highest species number, while the newest sites (LT04 and SO06) were lowest. A similar pattern was found for tree density in old rehabilitated sites, for example SO98 and TH94, which had the highest density. However, SO quarry had higher density, compared with TH

and LT rehabilitated in the same year. It was also found that the mean height of trees increased with age of rehabilitated sites. TH and LT generally had taller trees than SO of the same rehabilitated year, which was the reverse for density. At SO, mean basal area increased drastically from 2.3 m^2 and 5.8 m^2 in SO06 and SO04 to 39.4 m^2 in SO01 and peaked at 46.8 m^2 in SO98. However, LT01 had higher mean basal area than LT98 and TH94. In general, LT had higher basal area than SO at the same rehabilitated year, except for LT98 and SO98.

Table 2.4 Growth performance of overstorey vegetation in the three quarries

Site	Species number	Density (number ha^{-1})	Mean height (m)	Mean basal area (m^2 ha^{-1})
TH94	18	5000b	4.82ab	26.8b
LT98	8	2480c	5.34a	28.3b
LT01	10	1400d	3.91c	40.6a
LT04	7	1030d	3.40cd	13.9c
SO98	18	6880a	4.34b	46.8a
SO01	9	3430bc	3.92c	39.4a
SO04	11	1780cd	2.64d	5.80d
SO06	3	1980cd	2.35d	2.32d

Mean values followed by the same letter within a column are not significantly different at p=0.05 level according to the Tukey's HSD test

The distributions of tree height in the three quarries are shown in Figure 2.1. Growth distribution patterns differed among the three quarries, being more widely dispersed in older stands (TH94, LT98, LT01, SO98 and SO01) than younger stands (LT04, SO04 and SO06). The growth conditions within plantations tend to increase with the age of stands, resulting in a wider distribution in older stands. The distribution patterns among TH and LT were similar, in which the trees with height of 4-7 m were dominant in the overstorey vegetation. However, the number of trees with height of 3-4 m was higher than that of trees with height of 4-7 m in SO, which indicated there were higher number of young trees in SO than in TH and LT of the same rehabilitation year.

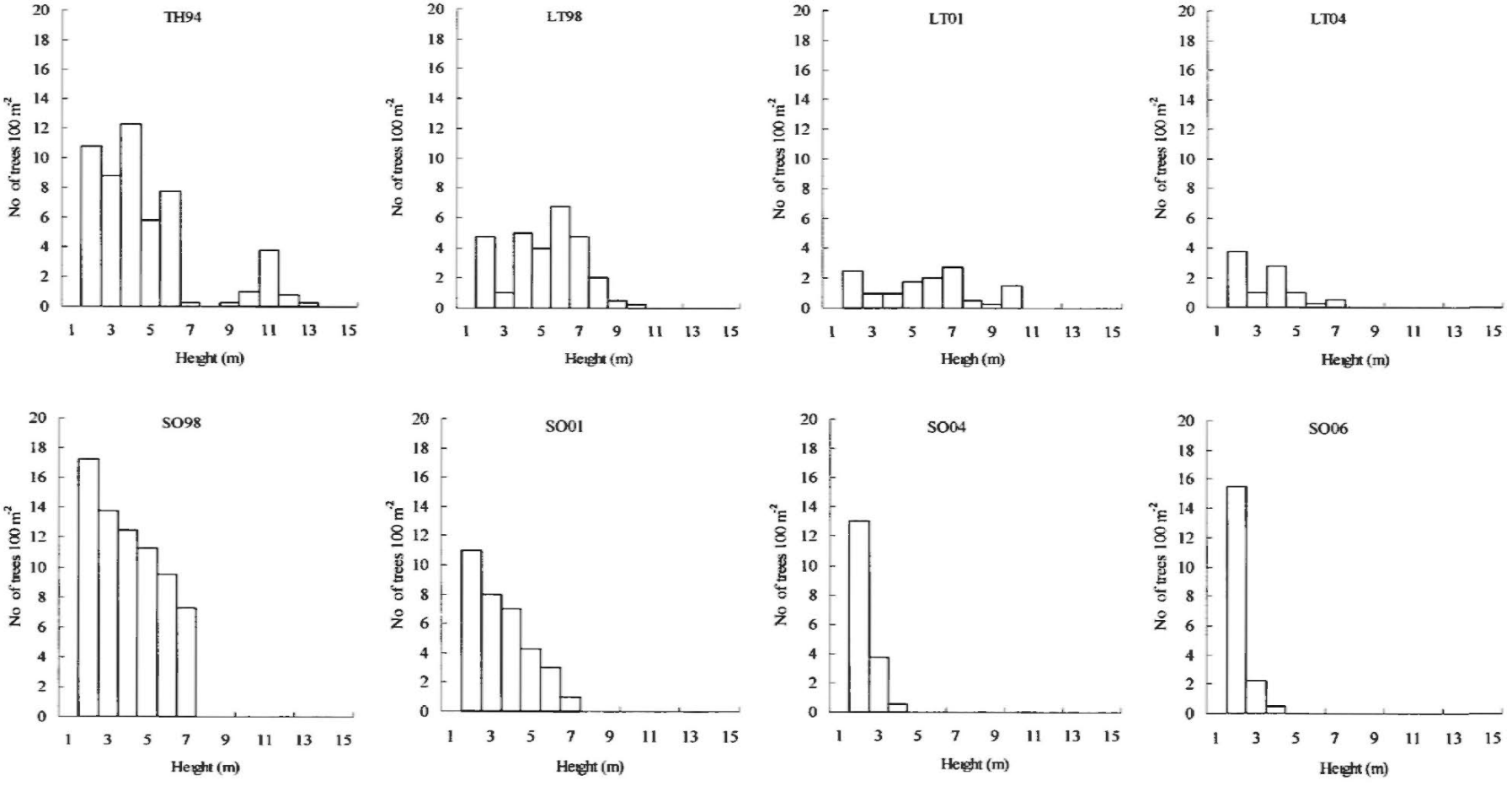


Figure 2.1 Height distribution of overstorey trees at different phases in the three quarries

2.3.2.2 Floristic composition of overstorey vegetation

The rankings according to the importance value of each species on each phase among the three quarries are shown in Table 2.5.

Eighteen species were recorded at TH94, in which most of them were natural invaders with ecosystem development. *Eucalyptus citriodora*, *Acacia confusa* and *Leucaena leucocephala* were the most important species according to the relative density, frequency and dominance, in which *Eucalyptus citriodora* and *Acacia confusa* were planted in revegetation and *Leucaena leucocephala* had spontaneously invaded (Table 2.5a). Nevertheless, some native species, for example *Bridelia tomentosa*, *Macaranga tanarius*, *Mallotus apelta*, *Ligustrum sinense*, *Microcos paniculata*, *Trema tomentosa*, *Schefflera heptaphylla* and *Celtis sinensis* had colonized at TH94. They accounted for 32.7% of the total importance value.

Eight species were recorded at LT98, in which *Acacia confusa*, *Eucalyptus citriodora*, *Casuarina equisetifolia* and *Lophostemon confertus* were the planted species at revegetation (Table 2.5b). These four exotic species accounted for 82.3% among all trees, according to the importance value. There were only three native species that had spontaneously invaded the site, for example *Rhaphiolepis indica*, *Schima superba* and *Cratoxylum cochinchinense*.

Ten species were identified at LT01, among which *Eucalyptus tereticornis*,

Acacia auriculiformis, *A. confusa*, *Casuarina equisetifolia*, *Lophostemon confertus*, *Eucalyptus citriodora* and *Pinus elliottii* were planted during revegetation (Table 2.5c). There were three native species that had spontaneously invaded in this site.

There were seven species, which included six planted species and one invaded species at LT04 (Table 2.5d).

Eighteen species were found at SO98. The planted species, *Acacia confusa*, *Eucalyptus tereticornis*, *A. auriculiformis*, *Lophostemon confertus* and *A. mangium*, still played an important role on vegetation cover (Table 2.5e). *Leucaena leucocephala* was the most frequent and abundant. Nevertheless, there was an increasing area being covered by the invading species of *Bridelia tomentosa*, *Ligustrum sinense*, *Macaranga tanarius*, *Celtis sinensis*, *Hibiscus tiliaceus*, *Rhus chinensis*, *Endospermum chinense*, *Phyllanthus emblica*, *Mallotus apelta*, *Celtis timorensis*, *Pavetta hongkongensis* and *Rhaphiolepis indica*. These native species accounted for 35.2% of the total in terms of the importance value.

Nine species were recorded at SO01, in which *Acacia auriculiformis*, *A. confusa*, *Eucalyptus tereticornis*, *A. mangium* and *Lophostemon confertus* were the planted species during the beginning of revegetation (Table 2.5f). These five exotic species accounted for 75.58% among all trees, according to the importance value. In LT98, there were only three native species which had spontaneously invaded, *Phyllanthus*

emblica, Cinnamomum camphora, Rhus chinensis. *Leucaena leucocephala*, the exotic species, was the invaded species. The importance value of this species was relatively low.

Eleven species were identified at SO04, in which *Acacia confusa*, *Eucalyptus tereticornis*, *A. auriculiformis*, *A. mangium*, *Lophostemon confertus*, *Dalbergia odorifera*, *Eucalyptus citriodora*, *Ormosia pinnata* were planted (Table 2.5g). *Dalbergia odorifera* and *Ormosia pinnata* were used to compare the performance between native and exotic species. However, most of them died because of high temperature and low soil moisture.

Two planted species (*Acacia confusa* and *A. auriculiformis*) and one natural invaded species (*Leucaena leucocephala*) were found at LT06 (Table 2.5h).

Table 2.5a Ranking of species according to the importance value (IV) at TH94

Species	RA (%)	RF (%)	RD (%)	IV
*Eucalyptus citriodora**	11.5	87.5	31.1	43.4
*Acacia confusa**	14.5	81.3	23.5	39.7
Leucaena leucocephala	29.0	68.8	13.3	37.0
Bridelia tomentosa	8.50	50.0	7.26	21.9
Macaranga tanarius	9.00	37.5	2.43	16.3
Mallotus apelta	8.50	37.5	2.44	16.2
*Albizia lebbeck**	2.00	25.0	12.0	12.9
*Melia azedarach**	10.0	25.0	1.26	12.1
Ligustrum sinense	1.50	18.8	3.67	7.97
Microcos paniculata	1.00	12.5	0.96	4.82
Trema tomentosa	1.00	12.5	0.26	4.59
*Cassia siamea**	0.50	6.25	1.20	2.65
Schefflera heptaphylla	0.50	6.25	0.27	2.34
*Acacia auriculiformis**	0.50	6.25	0.24	2.33
*Bombax ceiba**	0.50	6.25	0.15	2.30
*Casuarina equisetifolia**	0.50	6.25	0.08	2.28
*Aglaia odorata**	0.50	6.25	0.01	2.25
Celtis sinensis	0.50	6.25	0.01	2.25

* denotes planted species; RA: relative abundance; RF: relative frequency; RD: relative dominance

Table 2.5b Ranking of species according to the importance value (IV) at LT98

Species	RA (%)	RF (%)	RD (%)	IV
*Acacia confusa**	30.3	87.5	57.0	58.3
*Eucalyptus citriodora**	17.2	68.8	10.8	32.2
*Casuarina equisetifolia**	16.2	62.5	17.7	32.1
*Lophostemon confertus**	18.2	62.5	9.6	30.1
Rhaphiolepis indica	7.07	31.3	0.35	12.9
*Eucalyptus tereticornis**	7.07	25.0	4.25	12.1
Schima superba	3.03	12.5	0.30	5.28
Cratoxylum cochinchinense	1.01	6.25	0.11	2.46

* denotes planted species; RA: relative abundance; RF: relative frequency; RD: relative dominance

Table 2.5c Ranking of species according to the importance value (IV) at LT01

Species	RA (%)	RF (%)	RD (%)	IV
*Eucalyptus tereticornis**	26.8	68.8	9.58	35.0
*Acacia auriculiformis**	21.4	43.8	46.2	37.1
*Acacia confusa**	17.9	50.0	35.8	34.6
*Casuarina equisetifolia**	16.1	43.8	7.41	22.4
*Lophostemon confertus**	5.36	18.8	0.41	8.17
Rhaphiolepis indica	3.57	12.5	0.06	5.38
Schima superba	3.57	12.5	0.03	5.37
*Eucalyptus citriodora**	1.79	6.25	0.36	2.80
*Pinus elliottii**	1.79	6.25	0.12	2.72
Gordonia axillaris	1.79	6.25	0.02	2.68

* denotes planted species; RA: relative abundance; RF: relative frequency; RD: relative dominance

Table 2.5d Ranking of species according to the importance value (IV) at LT04

Species	RA (%)	RF (%)	RD (%)	IV
*Acacia confusa**	51.2	87.5	82.9	73.9
*Casuarina equisetifolia**	17.1	43.8	11.0	23.9
*Sapium sebiferum**	14.6	37.5	2.63	18.3
*Cinnamomum camphora**	7.32	12.5	0.37	6.73
*Eucalyptus tereticornis**	4.88	12.5	1.69	6.35
*Acacia auriculiformis**	2.44	6.25	1.38	3.36
Leucaena leucocephala	2.44	6.25	0.09	2.93

* denotes planted species; RA: relative abundance; RF: relative frequency; RD: relative dominance

Table 2.5c Ranking of species according to the importance value (IV) at SO98

Species	RA (%)	RF (%)	RD (%)	IV
Leucaena leucocephala	50.0	87.5	13.7	50.4
*Acacia confusa**	10.2	75.0	53.0	46.1
*Eucalyptus tereticornis**	9.12	62.5	9.59	27.1
Bridelia tomentosa	8.03	68.8	0.46	25.8
Ligustrum sinense	4.38	50.0	0.91	18.4
*Acacia auriculiformis**	2.55	31.3	13.4	15.7
*Lophostemon confertus**	3.65	37.5	1.39	14.2
Macaranga tanarius	3.28	31.3	0.93	11.8
*Acacia mangium**	1.46	25.0	3.37	9.94
Celtis sinensis	1.46	25.0	0.04	8.83
Hibiscus tiliaceus	1.82	18.8	2.67	7.75
Rhus chinensis	1.82	6.25	0.31	2.79
Endospermum chinense	0.36	6.25	0.07	2.23

Table 2.5e (continued)

Phyllanthus emblica	0.36	6.25	0.02	2.21
Mallotus apelta	0.36	6.25	0.02	2.21
Celtis timorensis	0.36	6.25	0.02	2.21
Pavetta hongkongensis	0.36	6.25	0.02	2.21
Rhaphiolepis indica	0.36	6.25	0.01	2.21

* denotes planted species; RA: relative abundance; RF: relative frequency; RD: relative dominance

Table 2.5f Ranking of species according to the importance value (IV) at SO01

Species	RA (%)	RF (%)	RD (%)	IV
*Acacia auriculiformis**	28.5	75.0	36.5	46.6
*Acacia confusa**	22.6	68.8	36.3	42.6
*Eucalyptus tereticornis**	14.6	31.3	8.32	18.1
*Acacia mangium**	10.2	25.0	12.9	16.1
Phyllanthus emblica	8.03	31.3	2.00	13.8
Cinnamomum camphora	5.11	25.0	1.27	10.5
Leucaena leucocephala	6.57	18.8	1.73	9.02
Rhus chinensis	2.92	18.8	0.70	7.46
*Lophostemon confertus**	1.46	6.25	0.27	2.66

* denotes planted species; RA: relative abundance; RF: relative frequency; RD: relative dominance

Table 2.5g Ranking of species according to the importance value (IV) at SO04

Species	RA (%)	RF (%)	RD (%)	IV
*Acacia confusa**	25.0	100	49.8	58.3
*Eucalyptus tereticornis**	27.8	75.0	7.10	36.6
*Acacia auriculiformis**	12.5	31.3	34.9	26.2
*Acacia mangium**	6.94	31.3	6.40	14.9
*Lophostemon confertus**	6.94	31.3	0.55	12.9
*Dalbergia odorifera**	6.94	31.3	0.34	12.9
Rhus chinensis	4.17	18.8	0.23	7.72
Macaranga tanarius	2.78	12.5	0.38	5.22
*Eucalyptus citriodora**	2.78	12.5	0.24	5.17
Leucaena leucocephala	2.78	12.5	0.04	5.10
*Ormosia pinnata**	1.39	6.25	0.02	2.55

* denotes planted species; RA: relative abundance; RF: relative frequency; RD: relative dominance

Table 2.5h Ranking of species according to the importance value (IV) at SO06

Species	RA (%)	RF (%)	RD (%)	IV
*Acacia confusa**	63.0	62.5	53.8	59.8
*Acacia auriculiformis**	34.3	43.8	45.5	41.2
Leucaena leucocephala	2.74	6.25	0.74	3.24

* denotes planted species; RA: relative abundance; RF: relative frequency; RD: relative dominance

2.3.3 Stand characteristics of understorey vegetation

2.3.3.1 Growth performance of understorey vegetation

Species richness, density and mean tree height of the understorey vegetation are shown in Table 2.6. Species richness generally increased with the age of plantations, in which the oldest sites (TH94 and SO98) had the highest species number of 31 and 35 respectively. Younger sites (LT04 and SO06) were low in their understorey woody species, which were 10 and 6, respectively. A different pattern was found for the density of woody species. SO98 had the highest density among the three quarries, and the density increased with increasing rehabilitation years at SO. Among TH and LT, LT01 had a density higher than LT98 and TH94. In general, SO had higher density than TH and LT of the same rehabilitation year. The mean height of woody species generally increased with the age of plantations, but the differences among the younger sites were not obvious.

The structure of the woody understorey was exemplified in the distribution graphs of height. The height distributions for woody species among the three quarries are shown in Figure 2.2. Growth patterns were more widely dispersed in the older stands (TH94, LT98, LT01, SO98 and SO01) than the younger stands (LT04, SO04 and SO06). The distribution patterns for old sites were similar, in which the woody species of 0.6-1.6 m tall dominated in the understorey vegetation. The distribution

patterns among the young sites were similar, in which the number of woody species decreased with the increased height of trees.

Table 2.6 Growth performance of understorey vegetation in the three quarries

Site	Species number	Density (number ha^{-1})	Mean height (m)
TH94	31	7930b	1.23a
LT98	23	4050c	1.09ab
LT01	11	8080b	1.01ab
LT04	10	725d	0.76c
SO98	35	11700a	1.09ab
SO01	27	9380ab	0.86b
SO04	18	4850c	0.82b
SO06	6	4730c	0.74c

Mean values followed by the same letter within a column are not significantly different at p=0.05 level according to the Tukey's HSD test

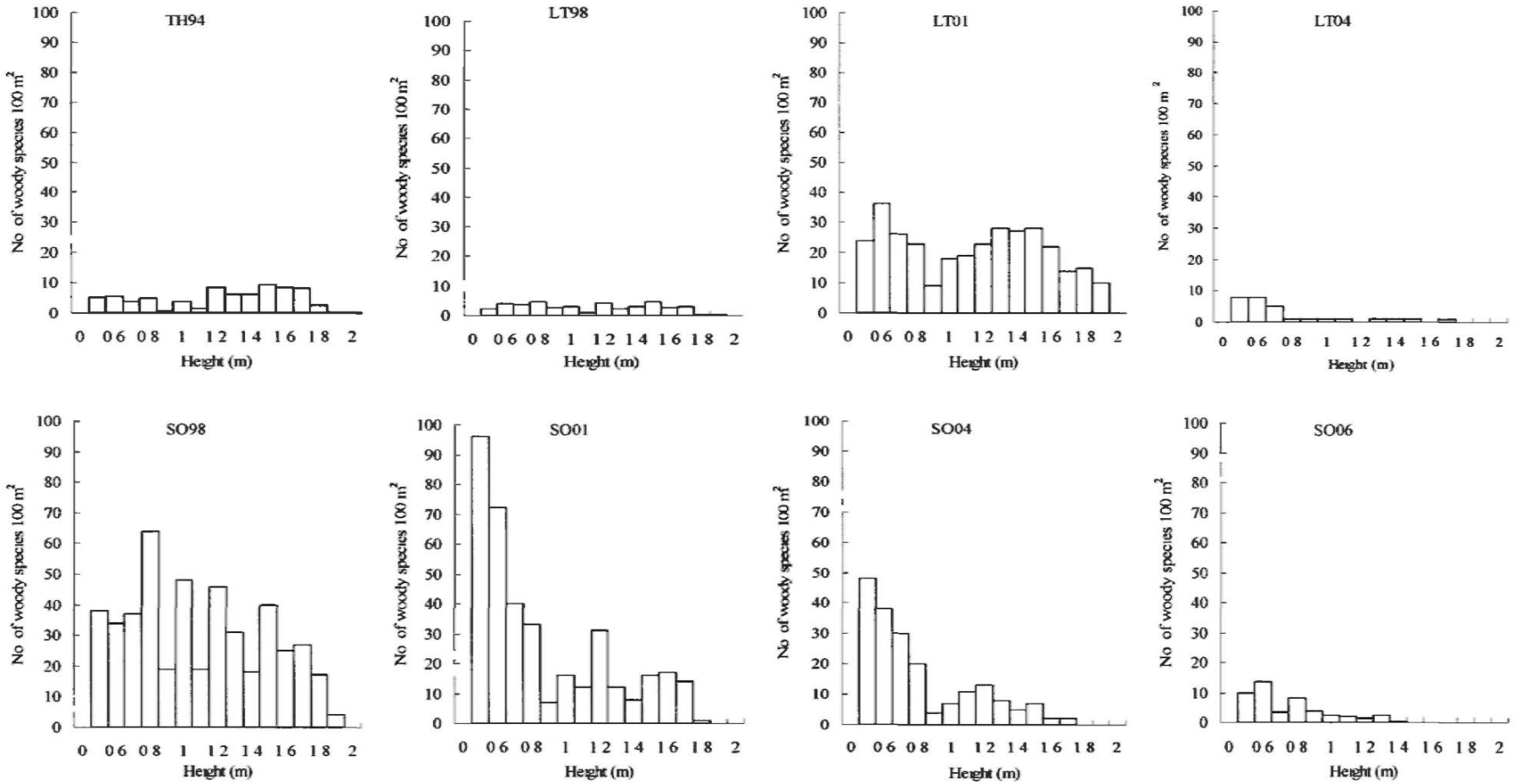


Figure 2.2 Height distribution of woody understories at different phases in the three quarries

2.3.3.2 Floristic composition of understorey vegetation

The rankings according to the importance value of each woody species on each phase among the three quarries are shown in Table 2.7.

Thirty one woody species were recorded at TH94, in which 20 species were native species (Table 2.7a). *Lantana camara* and *Leucaena leucocephala* were the most dominant species in the understory vegetation and importance value were 65.6 and 61.5, respectively. However, with the ecological succession, the native species *Bridelia tomentosa*, *Mallotus apelta*, *Ligustrum sinense*, *Microcos paniculata*, *Celtis sinensis* and *Macaranga tanarius* were becoming more dominant in the understorey vegetation at TH94. The native species accounted for 43.1% of the total importance value.

Twenty three woody species were recorded at LT98, in which *Eucalyptus tereticornis*, *Acacia confusa*, *Lophostemon confertus*, *E. citriodora*, *Lantana camara* and *Casuarina equisetifolia* were exotic (Table 2.7b). These six exotic species had regenerated from the overstorey vegetation, accouting for 19.2% of the total importance value. The other 17 species were native species, among which *Rhaphiolepis indica*, *Melastoma sanguineum*, *Wikstroemia indica*, *Breynia fruticosa*, *Helicteres angustifolia*, *Cratoxylum cochinchinense* and *Rhodomyrtus tomentosa* were the dominant species. The native species at LT98 accounted for 80.8% of the total importance value in the understorey vegetation.

Eleven woody species were identified at LT01, in which *Calliandra haematocephala* and *Eucalyptus tereticornis* were the exotic species that had

regenerated from the overstorey vegetation (Table 2.7c). There were nine native species which had spontaneously invaded in this site. According to the importance value, *Rhaphiolepis indica*, *Calliandra haematocephala*, *Zanthoxylum avicennae* and *Celtis sinensis* were the dominant woody species in the understorey vegetation.

At LT04, there were ten woody species, which included four planted exotic species and six invaded native species (Table 2.7d). According to the importance value, *Desmodium heterocarpon*, *Lantana camara*, *Cinnamomum camphora* and *Stachytarpheta jamaicensis* were the dominant woody species.

High species number was found at SO98 where 35 species were identified. This was also caused by natural invasion during ecosystem development. The exotic, *Leucaena leucocephala*, played an important role on vegetation cover (Table 2.7e). However, there was an increasing area being covered by *Bridelia tomentosa*, *Celtis sinensis*, *Celtis sinensis*, *Rhaphiolepis indica*, *Zanthoxylum avicennae*, *Rhodomyrtus tomentosa*, *Ligustrum sinense*, *Breynia fruticosa*, *Sterculia lanceolata*, *Rhus chinensis*, *Macaranga tanarius* and *Sageretia thea*, which were naturally invaded native species. All the native species accounted for 85.0% of the total importance value.

Twenty seven species were recorded at SO01, dominated by *Desmodium heterocarpon*, *Rhus chinensis*, *Phyllanthus emblica*, *Leucaena leucocephala*, *Rhaphiolepis indica*, *Rhodomyrtus tomentosa*, *Macaranga tanarius*, *Celtis sinensis*, *Lantana camara* and *Litsea glutinosa* (Table 2.7f). There were seven exotic species and the other native species accounted for 83.3% of the total importance value. .

Eighteen species were identified at SO04, in which *Leucaena leucocephala*,

Lophostemon confertus, *Eucalyptus tereticornis*, *Acacia confusa* and *A. auriculiformis* were exotic (Table 2.7g). The remaining thirteen species were invaded native species. The native species accounted for 78.6% among all trees according to the importance value.

There were five species, which included two exotic species (*Acacia confusa* and *Leucaena leucocephala*) and three natural invaded native species (*Desmodium heterocarpon*, *Stachytarpheta jamaicensis*, *Uraria crinita*) at LT06 (Table 2.7h).

Table 2.7a Ranking of species according to the importance value (IV) at TH94

Species	RD (%)	RF (%)	IV
*Lantana camara**	31.2	100	65.6
*Leucaena leucocephala**	29.3	93.8	61.5
*Murraya paniculata**	5.36	56.3	30.8
Bridelia tomentosa	4.10	50.0	27.1
Mallotus apelta	2.21	37.5	19.9
*Melia azedarach**	9.46	25.0	17.2
Ligustrum sinense	1.58	18.8	10.2
*Acacia confusa**	0.95	18.8	9.85
Microcos paniculata	0.95	18.8	9.85
Celtis sinensis	0.95	18.8	9.85
Macaranga tanarius	1.26	12.5	6.88
*Aglaia odorata**	1.26	12.5	6.88
Dalbergia hancei	1.26	12.5	6.88
*Cassia siamea**	0.63	12.50	6.57
Trema tomentosa	0.63	12.5	6.57
Aporosa dioica	0.95	6.25	3.60
Sida rhombifolia	0.95	6.25	3.60

Table 2.7a (continued)

Sageretia thea	0.95	6.25	3.60
*Eucalyptus citriodora**	0.63	6.25	3.44
Desmodium gangeticum	0.63	6.25	3.44
Bischofia javanica	0.63	6.25	3.44
*Schefflera arboricola**	1.26	6.25	3.76
Phyllanthus emblica	0.32	6.25	3.28
Rhus succedanea	0.32	6.25	3.28
Strychnos cathayensis	0.32	6.25	3.28
Litsea rotundifolia var. *oblongifolia*	0.32	6.25	3.28
Urena lobata	0.32	6.25	3.28
*Mimosa pudica**	0.32	6.25	3.28
*Bombax ceiba**	0.32	6.25	3.28
Alangium chinense	0.32	6.25	3.28
Wikstroemia indica	0.32	6.25	3.28

* denotes exotic species; RD: relative dominance; RF: relative frequency.

Table 2.7b Ranking of species according to the importance value (IV) at LT98

Species	RD (%)	RF (%)	IV
Rhaphiolepis indica	68.5	81.3	74.9
*Eucalyptus tereticornis**	6.17	25.0	15.6
Melastoma sanguineum	3.70	18.8	11.2
Wikstroemia indica	3.09	18.8	10.9
Breynia fruticosa	3.09	18.8	10.9
Helicteres angustifolia	1.85	18.8	10.3
*Acacia confusa**	1.23	12.5	6.87
Cratoxylum cochinchinense	1.23	12.5	6.87
*Lophostemon confertus**	1.23	12.5	6.87
Zanthoxylum avicennae	1.23	6.25	6.87
Rhodomyrtus tomentosa	0.62	6.25	3.74
*Eucalyptus citriodora**	0.62	6.25	3.43
Schefflera heptaphylla	0.62	6.25	3.43
Rhus succedanea	0.62	6.25	3.43
Smilax china	0.62	6.25	3.43
Strychnos cathayensis	0.62	6.25	3.43
Melastoma candidum	0.62	6.25	3.43
*Lantana camara**	0.62	6.25	3.43
Litsea rotundifolia var. *oblongifolia*	0.62	6.25	3.43
Acronychia pedunculata	0.62	6.25	3.43
Lonicera japonica	0.62	6.25	3.43
Celtis sinensis	0.62	6.25	3.43
*Casuarina equisetifolia**	0.62	6.25	3.43

* denotes exotic species; RD: relative dominance; RF: relative frequency.

Table 2.7c Ranking of species according to the importance value (IV) at LT01

Species	RD (%)	RF (%)	IV
Rhaphiolepis indica	51.7	100	75.9
*Calliandra haematocephala**	35.3	100	67.7
Zanthoxylum avicennae	3.10	50.0	26.6
Celtis sinensis	2.48	43.8	23.1
Bauhinia corymbosa	1.86	25.0	13.4
Gordonia axillaris	3.10	18.8	10.9
Gnetum luofuense	0.93	18.8	9.84
Schima superba	0.62	12.5	6.56
Baeckea frutescens	0.31	6.25	3.28
*Eucalyptus tereticornis**	0.31	6.25	3.28
Macaranga tanarius	0.31	6.25	3.28

* denotes exotic species; RD: relative dominance; RF: relative frequency.

Table 2.7d Ranking of species according to the importance value (IV) at LT04

Species	RD (%)	RF (%)	IV
Desmodium heterocarpon	24.1	25.0	24.6
*Lantana camara**	24.1	12.5	18.3
Cinnamomum camphora	10.3	18.8	14.6
*Stachytarpheta jamaicensis**	10.3	12.5	11.4
*Acacia confusa**	6.90	12.5	9.70
*Leucaena leucocephala**	6.90	6.25	6.57
Phyllanthus reticulatus	6.90	6.25	6.57
Sapium sebiferum	3.45	6.25	4.85
Helicteres angustifolia	3.45	6.25	4.85
Ligustrum sinense	3.45	6.25	4.85

* denotes exotic species; RD: relative dominance; RF: relative frequency.

Table 2.7e Ranking of species according to the importance value (IV) at SO98

Species	RD (%)	RF (%)	IV
*Leucaena leucocephala**	26.8	43.8	35.3
Bridelia tomentosa	18.0	50.0	34.0
Celtis sinensis	11.8	50.0	30.9
Celtis timorensis	3.21	43.8	23.5
Rhaphiolepis indica	4.93	31.3	18.1
Zanthoxylum avicennae	2.36	31.3	16.8
Rhodomyrtus tomentosa	5.78	25.0	15.4
Ligustrum sinense	2.78	25.0	13.9
Breynia fruticosa	1.28	25.0	13.1
Sterculia lanceolata	0.86	25.0	12.9
Rhus chinensis	4.71	18.8	11.7
Macaranga tanarius	2.14	18.8	10.5
Sageretia thea	1.50	18.8	10.1
Aporosa dioica	0.64	18.8	9.70
Gardenia jasminoides	1.07	12.5	6.79
Phyllanthus emblica	0.64	12.5	6.57
*Stachytarpheta jamaicensis**	3.21	6.25	4.73
Sida rhombifolia	2.36	6.25	4.30
Helicteres angustifolia	0.86	6.25	3.55
Pluchea indica	0.86	6.25	3.55
*Lophostemon confertus**	0.64	6.25	3.45
Garcinia oblongifolia	0.64	6.25	3.45
Psychotria asiatica	0.43	6.25	3.34
*Abutilon striatum**	0.21	6.25	3.23
Litsea monopetala	0.21	6.25	3.23

Table 2.7e (continued)

*Acacia confusa**	0.21	6.25	3.23
Rhus succedanea	0.21	6.25	3.23
Hibiscus tiliaceus	0.21	6.25	3.23
Endospermum chinense	0.21	6.25	3.23
Camellia oleifera	0.21	6.25	3.23
Scolopia chinensis	0.21	6.25	3.23
Mallotus apelta	0.21	6.25	3.23
Machilus chinensis	0.21	6.25	3.23
Desmos chinensis	0.21	6.25	3.23
Unknown	0.21	6.25	3.23

* denotes exotic species; RD: relative dominance; RF: relative frequency.

Table 2.7f Ranking of species according to the importance value (IV) at SO01

Species	RD (%)	RF (%)	IV
Desmodium heterocarpon	16.5	75.0	45.8
Rhus chinensis	21.1	62.5	41.8
Phyllanthus emblica	10.4	68.8	39.6
*Leucaena leucocephala**	18.7	50.0	34.3
Rhaphiolepis indica	7.20	56.3	31.7
Rhodomyrtus tomentosa	6.13	37.5	21.8
Macaranga tanarius	4.53	37.5	21.0
Celtis sinensis	1.87	37.5	19.7
*Lantana camara**	1.87	31.3	16.6
Litsea glutinosa	1.07	25.0	13.0
Gardenia jasminoides	2.13	18.8	10.4
Bridelia tomentosa	1.07	18.8	9.91
Melastoma sanguineum	0.80	18.8	9.78

Table 2.7f (continued)

Ligustrum sinense	0.80	18.8	9.78
*Ormosia pinnata**	0.53	12.5	9.78
Schefflera heptaphylla	0.53	12.5	6.52
Cinnamomum camphora	0.53	12.5	6.52
*Acacia confusa**	0.53	12.5	6.52
Sterculia lanceolata	0.53	12.5	6.52
*Stachytarpheta jamaicensis**	1.07	6.25	3.66
Litsea rotundifolia var. *oblongifolia*	0.53	6.25	3.39
*Syzygium jambos**	0.27	6.25	3.26
Zanthoxylum avicennae	0.27	6.25	3.26
*Lophostemon confertus**	0.27	6.25	3.26
Mallotus apelta	0.27	6.25	3.26
Gordonia axillaris	0.27	6.25	3.26

* denotes exotic species; RD: relative dominance; RF: relative frequency.

Table 2.7g Ranking of species according to the importance value (IV) at SO04

Species	RD (%)	RF (%)	IV
Desmodium heterocarpon	46.4	75.0	60.7
Macaranga tanarius	9.28	56.3	32.8
Dalbergia odorifera	5.67	37.5	21.6
*Leucaena leucocephala**	3.09	37.5	20.3
Rhus chinensis	12.9	25.0	18.9
Syzygium jambos	6.19	25.0	15.6
*Lophostemon confertus**	3.61	25.0	14.3
Celtis sinensis	2.06	25.0	13.5
*Eucalyptus tereticornis**	3.09	18.8	10.9
Litsea glutinosa	2.58	18.8	10.7
*Acacia confusa**	1.55	6.25	3.90

Table 2.7g (continued)

Sterculia lanceolata	0.52	6.25	3.38
Rhodomyrtus tomentosa	0.52	6.25	3.38
Urena lobata	0.52	6.25	3.38
Mallotus apelta	0.52	6.25	3.38
Homalium cochinchinensis	0.52	6.25	3.38
Gordonia axillaris	0.52	6.25	3.38
*Acacia auriculiformis**	0.52	6.25	3.38

* denotes exotic species; RD: relative dominance; RF: relative frequency.

Table 2.7h Ranking of species according to the importance (IV) value at SO06

Species	RD (%)	RF (%)	IV
Desmodium heterocarpon	55.6	25.0	40.3
*Acacia confusa**	23.8	56.3	40.0
*Leucaena leucocephala**	17.5	6.25	10.2
Stachytarpheta jamaicensis	1.59	18.8	3.65
Uraria crinita	1.06	6.25	3.39

* denotes exotic species; RD: relative dominance; RF: relative frequency.

2.3.4 Ecological indices among the three quarries

Shannon index and evenness were calculated from the floristic composition on each site (Table 2.8). In overstorey layer, Shannon indices were highest at TH94 (1.72), LT98 (1.69) and SO98 (1.66). LT01, SO01 and SO04 had relatively high Shannon indices, but the differences were not obvious. The younger plantations, for example LT04 and SO06, had the lowest Shannon indices. LT98 had the highest evenness, followed by LT04, SO01 and SO04. However, the older sites, TH94 and SO98, had the lowest evenness. Evenness was the lowest at SO06.

In understorey layer, SO98 and SO01 had the highest Shannon indices among the three quarries. Shannon indices were higher at TH94 and SO04 than at LT98, LT01, LT04 and SO06. In general, Shannon indices increased with age of the rehabilitated quarries. However, all sites at SO had more woody species in the understorey vegetation than that of TH and LT. The differences of evenness among TH94, LT04, SO98, SO01, SO04 were not obvious, which meant that woody species were more widely distributed in these sites. However, the evenness was low at LT98, LT01 and SO06, which meant that some species were patchy on sites.

For the herbaceous layer, SO06 had the highest Shannon index, followed by TH94, LT98, LT01 and SO04. SO98 and SO01 had the lowest Shannon indices. Evenness decreased with age of the rehabilitated quarries.

Table 2.8 Diversity of aboveground vegetation in the three quarries

Sites	Overstorey layer		Understorey layer		Herbaceous layer	
	Shannon index (H')	Evenness (E)	Shannon index (H')	Evenness (E)	Shannon index (H')	Evenness (E)
TH94	1.72a	0.74b	1.85b	0.76a	1.28ab	0.53b
LT98	1.69a	0.93a	1.27c	0.59b	1.15b	0.51b
LT01	1.35c	0.74b	1.07c	0.58b	1.24ab	0.56b
LT04	1.13c	0.87a	1.00c	0.69ab	0.95b	0.72a
SO98	1.66ab	0.70b	2.10a	0.76a	0.88c	0.39c
SO01	1.52b	0.89a	1.98a	0.74a	0.87c	0.49c
SO04	1.57b	0.88a	1.48bc	0.72a	1.25ab	0.61ab
SO06	0.45d	0.59c	0.45d	0.34c	1.37a	0.78a

Mean values followed by the same letter within a column are not significantly different at p=0.05 level according to the Tukey's HSD test.

Similarity indices for woody species among the three quarries were calculated according to the number of each species (Table 2.9). Higher similarities were found between SO98 and SO01, and between LT98 and LT01. However, the newly rehabilitated sites (LT04 and SO06) had low similarities comparable to the older sites (TH94, LT98 and SO98).

Table 2.9 Similarity index of aboveground vegetation in the three quarries

	TH94	LT98	LT01	LT04	SO98	SO01	SO04	SO06
TH94	1.00							
LT98	0.33	1.00						
LT01	0.28	0.52	1.00					
LT04	0.21	0.28	0.23	1.00				
SO98	0.36	0.39	0.29	0.25	1.00			
SO01	0.37	0.43	0.45	0.39	0.55	1.00		
SO04	0.36	0.36	0.47	0.33	0.42	0.46	1.00	
SO06	0.29	0.22	0.31	0.43	0.20	0.38	0.36	1.00

The similarity among sites is shown in the ordination plots from Detrended Correspondence Analysis (DCA) (Figure 2.3). It was weighted according to the abundance of each woody species in the site. The different sites were separated along the first and second axes. The recently rehabilitated SO04 and SO06 sites were far away from the origin, and the older sites of SO98 and SO01 occurred in the middle of the first axis and LT98 and LT01 in the right of biplot. Fifty five native species were mostly located at the older sites of TH94, LT98, LT01 SO98 and SO01. Overlapping of native species among these old sites indicates higher similarity among them.

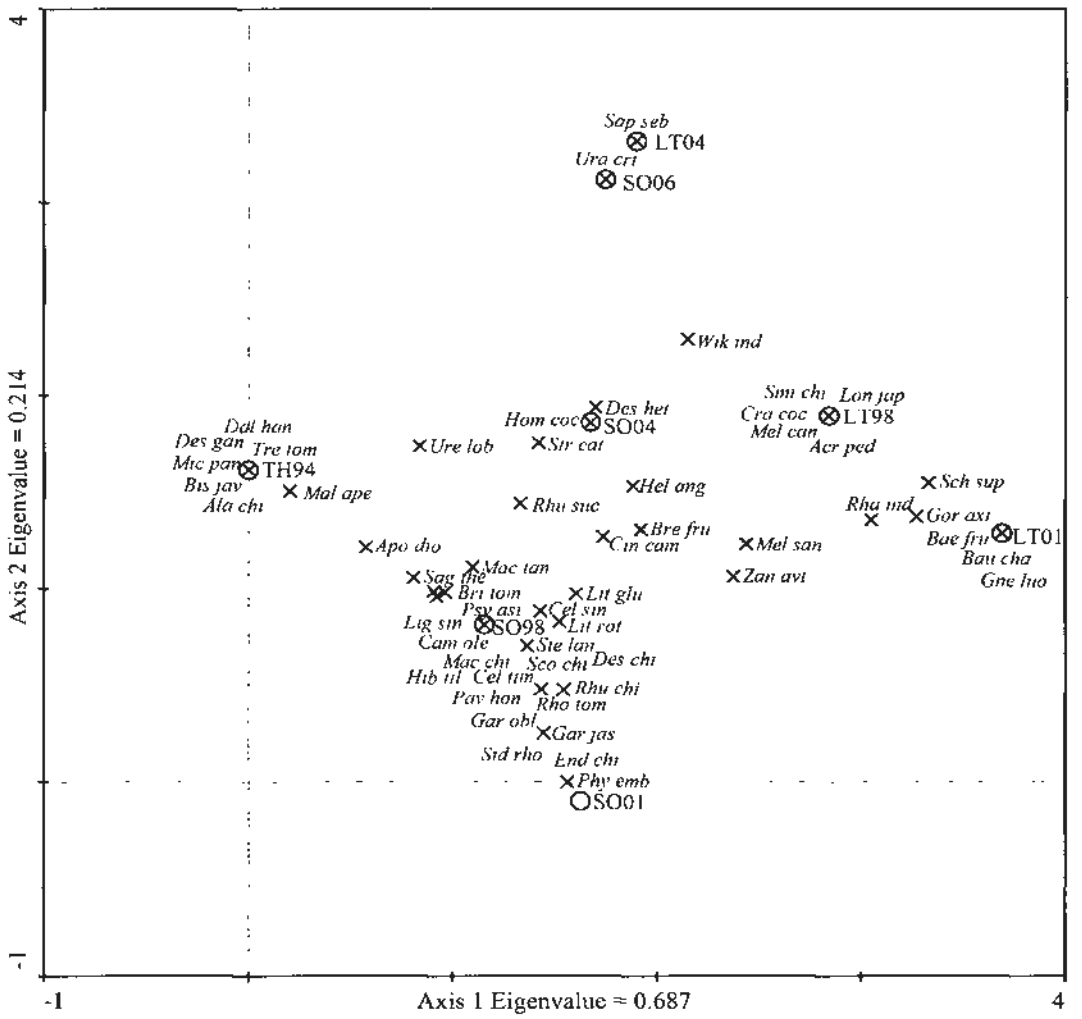


Figure 2.3 The first two axes of the DCA ordination for eight phases and native species in the three quarries. Species names are indicated with the three first letters of genus and species

Abbreviations for species are: *Acronychia pedunculata* (*Acr ped*); *Alangium chinense* (*Ala chi*); *Aporusa dioica* (*Apo dio*); *Baeckea frutescens* (*Bae fru*); *Bauhinia championii* (*Bau cha*); *Bischofia javanica* (*Bis jav*); *Breynia fruticosa* (*Bre fru*); *Bridelia tomentosa* (*Bri tom*); *Camellia oleifera* (*Cam ole*); *Celtis sinensis* (*Cel sin*); *Celtis timorensis* (*Cel tim*); *Cinnamomum camphora* (*Cin cam*); *Cratoxylum cochinchinense* (*Cra coc*); *Dalbergia hancei* (*Dal han*); *Desmodium gangeticum* (*Des gan*); *Desmodium heterocarpon* (*Des het*); *Desmos chinensis* (*Des chi*); *Endospermum chinense* (*End chi*); *Garcinia oblongifolia* (*Gar obl*); *Gardenia jasminoides* (*Gar jas*); *Gnetum luofuense* (*Gne luo*); *Gordonia axillaris* (*Gor axi*); *Helicteres angustifolia* (*Hel ang*); *Hibiscus tiliaceus* (*Hib til*); *Homalium cochinchinensis* (*Hom coc*); *Ligustrum sinense* (*Lig sin*); *Litsea glutinosa* (*Lit glu*); *Litsea rotundifolia* (*Lit rot*);

Lonicera japonica (*Lon jap*); *Macaranga tanarius* (*Mac tan*); *Machilus chinensis* (*Mac chi*); *Mallotus apelta* (*Mal ape*); *Melastoma candidum* (*Mel can*); *Melastoma sanguineum* (*Mel san*); *Microcos paniculata* (*Mic pan*); *Pavetta hongkongensis* (*Pav hon*); *Phyllanthus emblica* (*Phy emb*); *Psychotria asiatica* (*Psy asi*); *Rhaphiolepis indica* (*Rha ind*); *Rhodomyrtus tomentosa* (*Rho tom*); *Rhus chinensis* (Rhu chi); *Rhus succedanea* (*Rhu suc*); *Sageretia thea* (*Sag the*); *Sapium sebiferum* (*Sap seb*); *Schima superba* (*Sch sup*); *Scolopia chinensis* (*Sco chi*); *Sida rhombifolia* (*Sid rho*); *Smilax china* (*Smi chi*); *Sterculia lanceolata* (*Ste lan*); *Strychnos cathayensis* (*Str cat*); *Trema tomentosa* (*Tre tom*); *Uraria crinita* (*Ura cri*); *Urena lobata* (*Ure lob*); *Wikstroemia indica* (*Wik ind*); *Zanthoxylum avicennae* (*Zan avi*).

2.4 Discussion

2.4.1 The potential role of reforestation

There was increasing evidence that reforestation can play an important role in facilitating long-term ecosystem rehabilitation and accelerating forest succession, particularly in the severely degraded and eroded areas (Guariguata et al., 1995; Kuusipalo et al., 1995; Fimbel and Fimbel, 1996; Brockerhoff et al., 2001; Hartley, 2002; Carnus et al., 2006; Brockerhoff et al., 2008). Exotic plant species that are fast growing and hardy were heavily used in south China to produce rapid stands. In our study, the planted exotic species, such as *Eucalyptus* spp., *Acacia* spp. and *Casuarina equisetifolia*, became dominant species in the plantation and their species number, density, and mean height of planted exotic species generally increased with the ecological development in the three quarries (Table 2.4), which agrees reasonably well with that of *Acacia* spp. and *Lophostemon confertus* plantations in Hong Kong (Chau and Au, 2002; Lee et al., 2005). Some native species (for example *Bridelia tomentosa*, *Ligustrum sinense*, *Macaranga tanarius*, *Celtis sinensis*, *Rhus succedanea*,

Mallotus apelta and *Cinnamomum camphora*) were becoming dominant species in the overstorey vegetation, which can be explained that the plantation has a nursing effect on promoting the recruitment and growth of native species (Robinson and Handel, 1993; Zhuang, 1997).

Most studies found that plantations can increase the vegetation structural complexity, and improve the understorey microclimatic conditions, and build up litter and humus layers during early stages (Yu et al., 1994; Srivastava, 1994; Parrotta et al., 1997). These increased seed inputs from surrounding native forests by attracting seed dispersers (Ingle, 2003; Angel et al., 2006). In our study, many woody species occurred in the understorey in the three quarries, and they were often more abundant and dominant in the older sites than the younger sites (Figure 2.5). It is confirmed that exotic plantations can catalyze the regeneration of native flora in their understories (Keenan et al., 1997; Geldenhuys, 1997; Fang and Peng, 1997; Aide et al., 2000). Therefore, reforestation is a common and efficient approach used to accelerate forest formation in quarries or other degraded lands in south China.

2.4.2 Species diversity and composition in the understorey

Biodiversity emphasized species richness and Shannon index (Haggar et al., 1997; Keenan et al., 1997). In our study, species richness and Shannon index largely increased with age of the stands. Shannon indices of the three quarries ranged from 1.00 to 1.85 for TH and LT, and from 0.45 to 2.10 for SO (Table 2.8), which were relatively low compared with *Acacia confusa* and *Lophostemon confertus* plantations (1.30-2.66), lowland secondary forests (2.52), montane forests (2.66) and Fung Shui

Woods (2.99) in Hong Kong (Zhuang, 1997; Zhuang and Yau, 1998). This suggests that simply reforestation with exotic species in the early stages of rehabilitation in quarries is not sufficient to restore natural forest diversity. In these three quarries, it was also found that diversity was lower in TH than in SO compared within similar rehabilitation age. This is perhaps attributable to the different exotic species and engineering construction adopted in the quarries. *Eucalyptus tereticornis* and *Casuarina equisetifolia* were widely planted in TH and LT, and leguminous *Acacia confusa* and *A. auriculiformis* were major species planted in SO. Both *Eucalyptus* spp. and *Casuarina equisetifolia* had shallow root system and serious growth decline in TH and LT (personal observation). In addition, bench slopes were used for recontouring in TH and LT. Compared with scree slopes in SO, bench slopes had shallower soil and discontinuous soil covers (Zhang and Chu, 2010). Therefore, plantations with *Eucalyptus* spp. and *Casuarina equisetifolia* in TH and LT adopted bench slopes had harsher microhabitat than in SO, which prevented the establishment of native species. However, the high species diversity of SO98 and SO01 clearly suggest that *Acacia* plantation was capable of creating a growth environment that can attract the recolonization of native species during the process of ecological development. Therefore, the use of native species mixed with *Acacia* species in the early stages of revegetation should be recommended as an efficient reforestation approach for quarries.

The number of individual plants recorded in the understorey varied among the three quarries. SO98 and LT01 had the highest density in the understorey. With the

exception of LT01, it increased with age of the plantation (Table 2.6). Owing to a difference in the growth environment, such as canopy characteristic as well as soil physical and chemical properties (Lugo, 1992; Parrotta, 1995; Lee et al., 2005), each site was dominated by a few species. Woody species like *Bridelia tomentosa*, *Mallotus apelta*, *Aporosa dioica*, *Celtis sinensis*, *Rhus succedanea*, *Sageretia thea*, *Litsea glutinosa*, *Machilus chinensis* and *Sterculia lanceolata* are present in the older plantations, while species like *Rhaphiolepis indica*, *Macaranga tanarius*, *Desmodium heterocarpon*, *Rhus chinensis* and *Rhodomyrtus tomentosa* occur in the younger plantations. Better regeneration in old rehabilitated sites is very probably a reflection of better site conditions for plant growth. In the young sites, the invaded native species are light-demanding early successional species that are common in shrublands in Hong Kong, and their presence presumably reflects the generally lower degree of canopy closure in plantations (Hau and Corlett, 2002; Lee et al., 2005). With the ecological development in quarries, some very common secondary forest species, like *Bridelia tomentosa*, *Mallotus apelta*, *Aporosa dioica*, *Celtis sinensis*, *Rhus succedanea* and *Sageretia thea*, occur in the plantations, being confined to sites with good soil conditions and near to natural seed sources. These species are shade-tolerant hence they grow well in the relatively closed canopy and the abundance notably increases with the age of plantations. There is also an increase of mid- to late-successional species in SO98 and SO01, such as *Litsea glutinosa*, *Machilus chinensis* and *Sterculia lanceolata*. They belong to the families of Lauraceae and Sterculiaceae that are commonly represented in the native forests of the region (Corlett, 1992;

Zhuang, 1993). The representation of mid- to late- successional species is indeed a proof that the plantations in SO are approaching the conditions of a native woodland during the ecological succession.

2.5 Conclusions

With ecological development, the vegetation coverage, species number, tree density, mean tree height and mean basal area in the overstorey vegetation increased progressively with stand ages in the three quarries. Although planted exotic species dominated the overstorey in the three quarries, some native tree species, e.g. *Bridelia tomentosa*, *Ligustrum sinense*, *Macaranga tanarius*, *Celtis sinensis*, *Rhus succedanea*, *Mallotus apelta* and *Cinnamomum camphora* were becoming dominant species in older sites. These native species could be potential candidates for the early enrichment. *Acacia* plantation had a better nursing effect on promoting the recruitment for native species. Therefore, the use of native species mixed with *Acacia* species in the early stages of revegetation should be recommended as an efficient reforestation approach for quarries. According to personal observation, the *Eucalyptus* spp. and *Casuarina equisetifolia* of the plantations had shallow root systems and growth decline was serious in TH and LT, which led to a harsher microhabitat and prevented the establishment of native species. The use of these exotic trees and bench slopes should be cautions for further adoption in quarry rehabilitation, especial in south China.

Many woody species naturally occurred in the understorey in the three quarries, and were often more abundant and dominant in older sites than in young sites. Some secondary forest species occurred in the old rehabilitated sites. However, diversity of

understorey vegetation in the three quarries was relatively lower than in plantations, secondary forests and Fung Shui Woods. Therefore, adding native species with fleshy fruits for attracting seed dispersers in enrichment planting should be considered in older sites in order to increase biodiversity of plantations and accelerate natural succession.

Chapter 3 Vegetation Regeneration in Quarries: A Study of Seed Rain, Seed Germination and Seedling Survival

3.1 Introduction

Seed dispersal refers to the movement of seeds or fruits, beginning with seed releasing from the parent plant and ending with seed landing at the spot where it will eventually germinate or die (Holthuijzen et al., 1987; Wang and Smith, 2002). It has been widely accepted that seed dispersal has several ecological advantages, including 1) escape from high mortality caused by density- or distance-dependent factors; 2) dispersal to particular sites with a relatively high probability of survival (Wenny, 2001). Hence, seed dispersal dynamics can presumably influence plant processes ranging from the recruitment of new habitats to maintenance of diversity (Hewitt and Kellman, 2002; Brunet, 2004; Lindenmayer and Hobbs, 2004). Plants have evolved different dispersal modes (e.g. wind, ballistic, gravity) and agents (e.g. birds, bats, primates, rodents, ants and ungulates) (Stiles, 1992; Corlett, 1992; Dudgeon and Corlett, 1994; Wuderle, 1997; Dennis and Westcott, 2006; Gonzales et al., 2009).

Seed dispersal plays an important role in the maintenance of plant diversity in intact forests. It has been increasingly recognized as an essential process that can accelerate natural regeneration in disturbed and degraded landscapes (Kabera, 2000; Tabarelli and Peres, 2002; Howe and Miriti, 2004; Moran et al., 2004). Factors which influence the composition of seed deposition include the distance from seed sources in the surrounding forest (Ingle, 2003; Clark et al., 2005; Weir and Corlett, 2007), spatial pattern of dispersal by the dispersal agents involved (Medellin and Gaona, 1999;

Galindo-Gonzalez et al., 2000; Ingle, 2003; Arteaga et al., 2006; Au et al., 2006), and landscape features such as perch availability or 'nurse plants' for birds (Nepstad et al., 1991; Kolb, 1993; Debusche and Isenmann, 1994; Shiels and Walker, 2003; Zanini and Ganade, 2005).

For both wind- and vertebrate-dispersed seeds, a decrease in seed input with distance from source vegetation has been documented (Holl, 1999; Ingle, 2003; Clark et al., 2005). However, input of bat-dispersed forest seeds declined less with distance from forest edge than input of bird-dispersed seeds (Ferguson et al., 1999; Moran et al., 2004; Arteaga et al., 2006). In tropical and subtropical rainforests, most woody species produce fleshy fruits which attract vertebrate seed dispersers. Fruit bats are major dispersal agents for Neotropical pioneer trees (Uhl, 1987; Medellin and Gaona, 1999; Corlett, 2002). In Southeast Asia, birds are more important than bats, but wind disperses the majority of seeds into successional vegetation (Corlett, 1991; Ingle, 2003). In Hong Kong, birds are the major dispersal agents for 85% of the seed taxa and 99% of the total number of seeds in degraded landscape (Au et al., 2006; Lee et al., 2008). Artificial perching structures have been proved to increase the number of seeds dispersed (Shiels and Walker, 2003; Zanini and Ganade, 2005). However, they do not overcome other barriers to seedling recruitment such as drought stress, nutrient limitation and competition with aggressive existing vegetation in degraded landscape (Holl, 1999; Laterra and Solbrig, 2001; Meehan et al., 2005). Many factors may impede forest seed recruitment, including soil nutrient shortage, soil compaction, competition with pasture grass, seasonal drought, and high seed and seedling

predation (Aide and Cavelier, 1994; Nepstad et al., 1996; Holl, 1999). However, the relative importance of these factors in limiting regeneration varied greatly among different studies.

Quarry is a seriously degraded site and there is a paucity of information on limiting factors for vegetation regeneration. The major aim of this experiment was to investigate the importance of limiting factors for vegetation regeneration in the early stages of our local quarries, including seed rain, seed germination, seedling survival and microclimate. It was hoped that findings obtained could help predict the vegetation development in our local quarries.

3.2 Materials and methods

3.2.1 Seed rain study

All eight phases of the three quarries (TH94, LT98, LT01, LT04, SO98, SO01, SO04 and SO06) were chosen for the seed rain study. There were different ways of measuring seed rain through different types of seed traps, but there was no trap that can provide a perfect measure (Kollmann and Goetze, 1998). Funnel traps had been described as the best trapping method, which can collect the highest number of seeds (Kollmann and Goetze, 1998), but tray traps were well used in grasslands in Hong Kong to collect woody species (Au et al., 2006). In order to provide a reliable estimate of the annual seed rain, sampling was conducted using two different types of seed traps, including funnel traps and tray traps. Within each site, 20 seed traps, including 10 seed trays and 10 seed funnels, were randomly set at least 10 m apart. Funnel traps and tray traps were placed on the ground in order to sample the seed rain

from all vegetation layers including low-ground shrubs. Each seed tray consisted of a PVC tray which had a surface area of 0.15 m^2 (50 cm × 30 cm), with holes drilled at the base to drain out rainwater. The trays were lined with a white cloth to prevent small seeds being washed out from the holes and for easy collection of the seeds. The trays were covered by wire mesh (mesh size 1.5 cm × 1.5 cm) to exclude rodents. Each seed funnel consisted of a PVC funnel which had a diameter of 26 cm and the surface area was 0.05 m^2. The funnel was fixed on a PVC pipe with lateral bore holes (1 cm) to allow drainage. At the bottom of the funnel the seeds were caught in a filter gauze bag of 0.1 mm mesh size fixed with an elastic band at the base of the funnel. The funnels were covered by wire mesh (mesh size 1.5 cm × 1.5 cm) to exclude rodents.

The sites were visited every month from May 2007 to April 2008 for a period of 12 months. At each visit, the cloths were collected and replaced. Seeds were separated, counted and identified in the laboratory. Only seeds of woody species were counted. Due to the design of the seed traps, some wind-dispersed seeds could be blown away and may be underrepresented (Lee et al., 2008). Seeds of planted exotic species were not included in this study because they did not represent dispersal.

3.2.2 Seed germination, seedling survival rate and microclimate

In order to determine whether seeds of woody species would germinate if dispersed into the quarry, the experiments of seed germination and seedling survival were carried out at the different phases in SO. The different phases included SO98, SO01, SO04 and SO06.

3.2.2.1 Seed germination and seedling survival

Twelve species including nine native species and three exotic species were tested; most of the native species were found in the study of seed rain and the three exotics were species widely used in early artificial planting (Table 3.1). All seeds were collected from the secondary forests and plantations nearby SO. Thirty seeds of each species were buried 1-2 cm below surface in a 8 cm × 8 cm × 7 cm pot filled with the *in situ* quarry soil. Three pots were placed in each phase at least 10 m apart for each species as three replicates. Each pot was covered with a 1.5 cm metal mesh to prevent seed predation by small rodents. An additional control pot without seeds was placed at each site. In addition, thirty seeds of each species were sown in a seed tray filled with quarry soil to determine seed germination rate under favorable conditions in a greenhouse and there were three replicates for each species. Trays were irrigated daily in the greenhouse, but there was no irrigation in the SO phases. Seed germination was considered successful for counting after the first pair of true leaves had emerged. This experiment began in January 2009. Seed germination was checked and recorded once a month for four months until April 2009. The survival rate of emerged seedlings was further monitored weekly for a month in May 2009.

Table 3.1 The twelve species studied for *in-situ* germination at SO and their life form and origin

Scientific name	Family name	Life form	Origin
Acacia auriculiformis	Mimosaceae	Tree	Exotic
Acacia confusa	Mimosaceae	Tree	Exotic
Acer tutcheri	Aceraceae	Tree	Native
Castanopsis fissa	Fagaceae	Tree	Native
Cinnamomum camphora	Lauraceae	Tree	Native
Dalbergia odorifera	Fabaceae	Tree	Native
Daphniphyllum calycinum	Daphniphyllaceae	Shrub	Native
Gordonia axillaris	Theaceae	Shrub	Native
Myrsine seguinii	Myrsinaceae	Shrub	Native
Pinus elliottii	Pinaceae	Tree	Exotic
Pinus massoniana	Pinaceae	Tree	Native
Rhaphiolepis indica	Rosaceae	Shrub	Native

3.2.2.2 Microclimate

The microclimatic conditions at the same location as the seed germination study were determined. Air temperature was recorded at 5 cm and 1 m from ground level using a commercial thermograph. Soil temperature was recorded at a depth of 5 cm using a Thermometer 2103 temperature probe (Jenway, UK). Soil moisture was measured from 0-5 cm soil using a MPM-160-B moisture probe (ICT International Pty Ltd, Australia). All measurements were made between 1100 and 1300 h on four to six clear days each month. All parameters were calculated as an average value per month from January 2009 to May 2009.

3.2.3 Statistical analysis

One-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) test at $p<0.05$ was used to determine any significant difference between means of different quarry phases. Pearson correlation coefficients at $p<0.05$ between seed germination, seedling survival and microclimate were also calculated.

3.3 Results

3.3.1 Seed rain

There were 1,741 seeds from 35 woody species collected from the two traps in the three quarries in the one-year study (Table 3.2). Seed number was highest in SO98 (522 seeds), followed by TH94 (381 seeds), SO01 (263 seeds), LT98 (259 seeds), LT01 (206 seeds) and SO04 (110 seeds), respectively. No seeds of woody species were found at LT04 and SO06 in the one-year period. The eight phases varied greatly in the number of seed species and their seed rain density. The total number of seed taxa collected was highest in SO98 (14), followed by TH94 (12), LT98 (8) and SO01 (7). LT01 and SO04 had less than five species. Mean seed rain density ranged from 8 seeds $m^{-2} y^{-1}$ at SO04 to 34 seeds $m^{-2} y^{-1}$ at SO98.

Table 3.2 Seeds of woody taxa in two traps at different phases in the three quarries

	TH94	LT98	LT01	LT04	SO98	SO01	SO04	SO06
Total no. of seeds	381	259	206	0	522	263	110	0
No. of seed taxa	12	8	4	0	14	7	1	0
Seed rain density (seeds $m^{-2} y^{-1}$)	27	16	14	0	34	17	8	0

The 35 woody species belonged to five climbers, fourteen shrubs and sixteen tree species (Table 3.3). There was no seed taxon that was common to all the sites. *Rhaphiolepis indica*, *Leucaena leucocephala* and *Rhodomyrtus tomentosa* were trapped in more than three sites; however, other species only appeared in one or two sites. *R. indica* was the species collected in five sites, except the young site SO04. *L. leucocephala* was found in the older sites (TH94, SO98 and SO01), and it was most abundant. Twenty eight species only were found in one site. Regarding to seed trapping methods, tray method could catch higher number of seeds than funnel method (Table 3.3). There were 14 woody species found in funnel trays in all eight sites and seed rain of woody species was lower in funnel traps than in tray traps. Therefore, the seasonal pattern of seed rain was also calculated as the total of the two methods.

Table 3.3 Seed rain (no. m^{-2} y^{-1}) of woody species for the different phases in the three quarries

Species	Growth habit*	TH94		LT98		LT01		SO98		SO01		SO04	
		Tray	Funnel	Tray	Funnel	Tray	Funnel	Tray	Funnel	Tray	Funnel	Tray	Funnel
Acronychia pedunculata	T	-	-	0.278	-	-	-	-	-	-	-	-	-
Aporusa dioica	T	-	-	-	-	-	-	0.833	0.333	-	-	-	-
Bridelia tomentosa	T	1.78	1.33	-	-	-	-	-	-	-	-	-	-
Celtis sinensis	T	0.278	-	-	-	-	-	0.667	-	-	-	-	-
Choerospondias axillaris	T	1.16	-	-	-	-	-	-	-	-	-	-	-
Cratoxylum cochinchinense	T	-	-	-	-	3.72	-	-	-	-	-	-	-
Daphniphyllum calycinum	S	-	-	-	-	-	-	0.722	0.167	-	-	-	-
Desmodium heterocarpon	S	-	-	-	-	-	-	-	-	-	-	5.00	3.33
Desmos chinensis	S	-	-	-	-	-	-	0.500	-	-	-	-	-
Diospyros morrisiana	T	0.722	-	-	-	-	-	-	-	-	-	-	-
Embelia ribes	C	0.389	-	-	-	-	-	-	-	-	-	-	-
Glochidion eriocarpum	S	0.278	-	-	-	-	-	-	-	-	-	-	-
Gnetum luofuense	C	-	-	-	-	-	-	-	-	0.722	-	-	-
Gordonia axillaris	S	-	-	-	-	-	-	-	-	0.611	-	-	-

Table 3.3 (continued)

Ilex pubescens	S	-	-	-	-	-	-	2.89	2.17	-	-	-	-
Lantana camara#	S	2.50	2.17	-	-	3.56	1.67	-	-	-	-	-	-
Leucaena leucocephala#	T	4.78	2.00	-	-	-	-	7.56	2.50	5	-	-	-
Ligustrum sinense	S	2.67	1.00	-	-	-	-	-	-	-	-	-	-
Litsea glutinosa	T	-	-	-	-	-	-	0.222	-	-	-	-	-
Litsea rotundifolia var. *oblongifolia*	S	-	-	0.722	-	-	-	-	-	-	-	-	-
Macaranga tanarius	T	-	-	-	-	0.889	0.333	-	-	-	-	-	-
Mallotus apelta	T	0.389	-	-	-	-	-	-	-	-	-	-	-
Melastoma candidum	S	-	-	2.06	-	-	-	-	-	-	-	-	-
Melicope pteleifolia	T	-	-	0.222	-	-	-	-	-	-	-	-	-
Microcos paniculata	T	-	-	-	-	-	-	0.444	0.50	-	-	-	-
Psychotria asiatica	S	-	-	-	-	-	-	0.611	0.167	-	-	-	-
Psychotria serpens	C	-	-	-	-	-	-	-	-	0.333	-	-	-
Rhaphiolepis indica	S	2.83	1.50	3.11	1.17	2.33	0.833	3.83	1.83	2.28	2.33	-	-
Rhodomyrtus tomentosa	S	-	-	6.17	2.00	-	-	5.39	-	4.28	1.33	-	-
Rhus chinensis	S	-	-	-	-	-	-	-	-	0.167	-	-	-

Table 3.3 (continued)

Rhus succedanea	T	-	-	-	-	-	-	0.667	-	-	-	-	-	
Schefflera heptaphylla	T	-	-	-	-	-	-	1.28	0.333	-	-	-	-	
Smilax china	C	0.722	-	-	-	-	-	-	-	-	-	-	-	
Smilax glabra	C	-	-	0.167	-	-	-	-	-	-	-	-	-	
Zanthoxylum avicennae	T	-	-	0.611	-	-	-	0.722	-	-	-	-	-	

# denotes exotic species; *T= Tree, S= Shrub, C= Climber.

The seasonal pattern of seed rain among the six phases in one year is shown in Figure 3.1. There were no woody seeds during the non-fruiting season (April-August) for all sites in the three quarries. Most seed rains occurred between September to March, particular from December to January. Seed rain in SO98 reached a peak of 1,727 seeds $m^{-2} y^{-1}$ in January. The highest values for TH94, LT98 and SO01 were 920, 740 and 746 seeds $m^{-2} y^{-1}$ in January respectively. However, seed rain in LT01 and SO04 reached a peak in December with 720 and 453 seeds $m^{-2} y^{-1}$ respectively.

Of the total 35 woody species trapped, five species were wind-dispersed (Table 3.4). For example, *L. leucocephala* was dispersed by wind at LT94 and SO98; *Gordonia axillaris* and *Desmodium heterocarpon* were dispersed into SO01 and SO04 respectively, while *Macaranga tanarius* and *Cratoxylum cochinchinense* were dispersed into LT01. Three species were dispersed by civets (Table 3.4). For example, civet faeces were found in the seed traps at TH94 and SO01, which included seeds of *Choerospondias axillaris*, *Diospyros morrisiana* in TH94 and *Gnetum luofuense* in SO01. The remaining 27 species were mainly dispersed by birds, while in a few cases some species were also dispersed by civets and fruit bats, for example *Rhodomyrtus tomentosa*, *Acronychia pedunculata*, *Microcos paniculata* and *Schefflera heptaphylla*. In terms of number of seeds, half of the seeds were dispersed by birds, and 23% and 27% were dispersed by wind and civets, respectively.

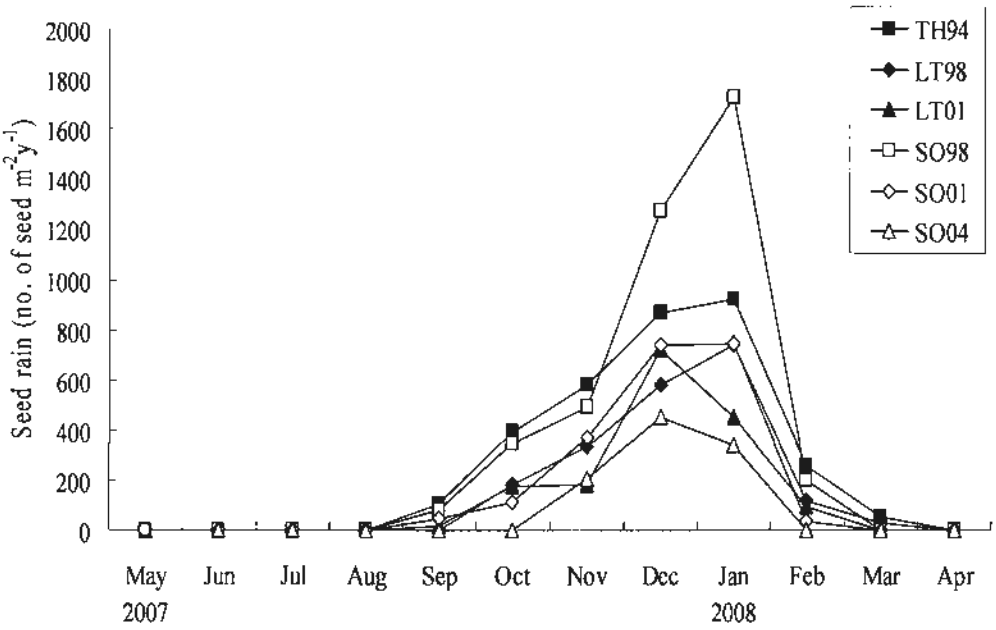


Figure 3.1 Seed rain (seed m^{-2} y^{-1}) from May 2007 to April 2008 in the three quarries

The total seed rain for each quarry is listed in Table 3.4. In summary, there were more seed taxa and seed number in SO than in other two quarries. *R. indica* was the only species which was dispersed into three quarries, while *L. leucocephala*, *R. tomentosa*, *Lantana camara*, *Celtis sinensis*, *Zanthoxylum avicennae* were dispersed into two quarries (TH and SO). The remaining species was only dispersed in one quarry.

Table 3.4 Summary of dispersal agents and seeds arriving (ha^{-1} y^{-1}) in the three quarries

Species	Seeds arriving (ha^{-1} y^{-1})			
	Dispersal agents*	TH	LT	SO
Acronychia pedunculata	B, F	-	2780	-
Aporusa dioica	B	-	-	5830
Bridelia tomentosa	B	15550	-	-
Celtis sinensis	B	2780	-	6670
Choerospondias axillaris	C	11600	-	-
Cratoxylum cochinchinense	W	-	37200	-
Daphniphyllum calycinum	B	-	-	4445
Desmodium heterocarpon	W	-	-	41650
Desmos chinensis	B	-	-	5000
Diospyros morrisiana	C	7220	-	-
Embelia ribes	B	3890	-	-
Glochidion eriocarpum	B	2780	-	-
Gnetum luofuense	C	-	-	7220
Gordonia axillaris	W	-	-	6110
Ilex pubescens	B	-	-	25300
Lantana camara	B	23350	26150	-
Leucaena leucocephala	W	33900	-	50200
Ligustrum sinense	B	18350	-	-
Litsea glutinosa	B	-	-	2220
Litsea rotundifolia var. *oblongifolia*	B	-	7220	-
Macaranga tanarius	W	-	6110	-
Mallotus apelta	B	3890	-	-
Melastoma candidum	B	-	20600	-
Melicope pteleifolia	B	-	2220	-
Microcos paniculata	B, C	-	-	4720
Psychotria asiatica	B	-	-	3890
Psychotria serpens	B	-	-	3330
Rhaphiolepis indica	B	21650	18610	25675
Rhodomyrtus tomentosa	B, C	-	40850	36667
Rhus chinensis	B	-	-	1670
Rhus succedanea	B	-	-	6670
Schefflera heptaphylla	B, F	-	-	8065
Smilax china	B	7220	-	-
Smilax glabra	B	-	1670	-
Zanthoxylum avicennae	B	-	6110	7220

* Dispersal agents: B= Bird, C= Civet, F= Fruit bat, W= Wind (Corlett, 1996).

3.3.2 *In-situ* seed germination and seedling survival

The mean percentage for seed germination on sites is listed in Figure 3.2. Seed germination was higher for all species in greenhouse than in SO. *Daphniphyllum calycinum* had the highest seed germination for all phases in SO (83.3% - 100%), the differences between different phases and greenhouse were not significant. *Rhaphiolepis indica* and *Myrsine seguinii* had higher seed germination at different phases (50% - 85%). *Dalbergia odorifera*, *Acacia confusa*, *Castanopsis fissa*, *Pinus massoniana* and *Acer tutcheri* had high germination in the greenhouse (71.2% - 82.2%), though these species had lower seed germination at SO (0% - 56.7%). Seed of *Acacia confusa* only germinated at SO98 (13.3%) but not in other SO sites. *Gordonia axillaris* and *Acacia auriculiformis* had low seed germination in greenhouse (37.9% - 55%) and different SO sites (0% - 43.3%). In summary, seed germination of all species was higher in older sites (SO98 and SO01) than younger sites (SO04 and SO06).

Seedling survival rates for the twelve species are shown in Figure 3.3. After seed germination, most emerging seedlings of all species could survive in the greenhouse and the survival rates exceeded 80%. However, the survival rate reduced rapidly for all species in the field condition of different SO phases. All emerging seedlings of *Pinus massoniana*, *Pinus elliottii*, *Acer tutcheri*, *Acacia confusa*, *Acacia auriculiformis* and *Gordonia axillaris* finally died in all SO sites. *Daphniphyllum calycinum* and *Cinnamomum camphora* had higher seedling survival rate at SO98 and SO01. *Rhaphiolepis indica* and *Cinnamomum camphora* could survive in all four sites,

but *Rhaphiolepis indica* had low survival rate for the emerging seedlings in all four sites. *Castanopsis fissa* and *Myrsine seguinii* had low survival rate and the seedlings of these two species could not survive at SO06. In summary, the seedling survival rates were lower at younger sites (SO04 and SO06) than at older sites (SO98 and SO01).

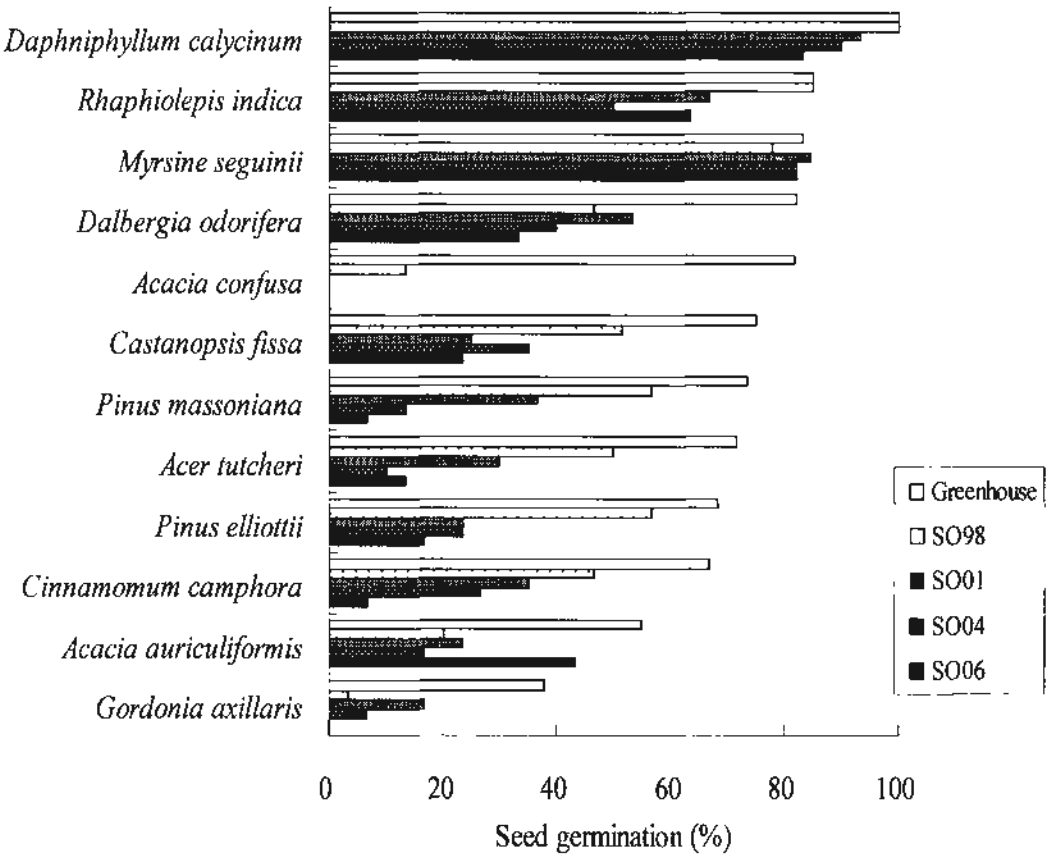


Figure 3.2 Mean seed germination of woody species in greenhouse and various phases of SO

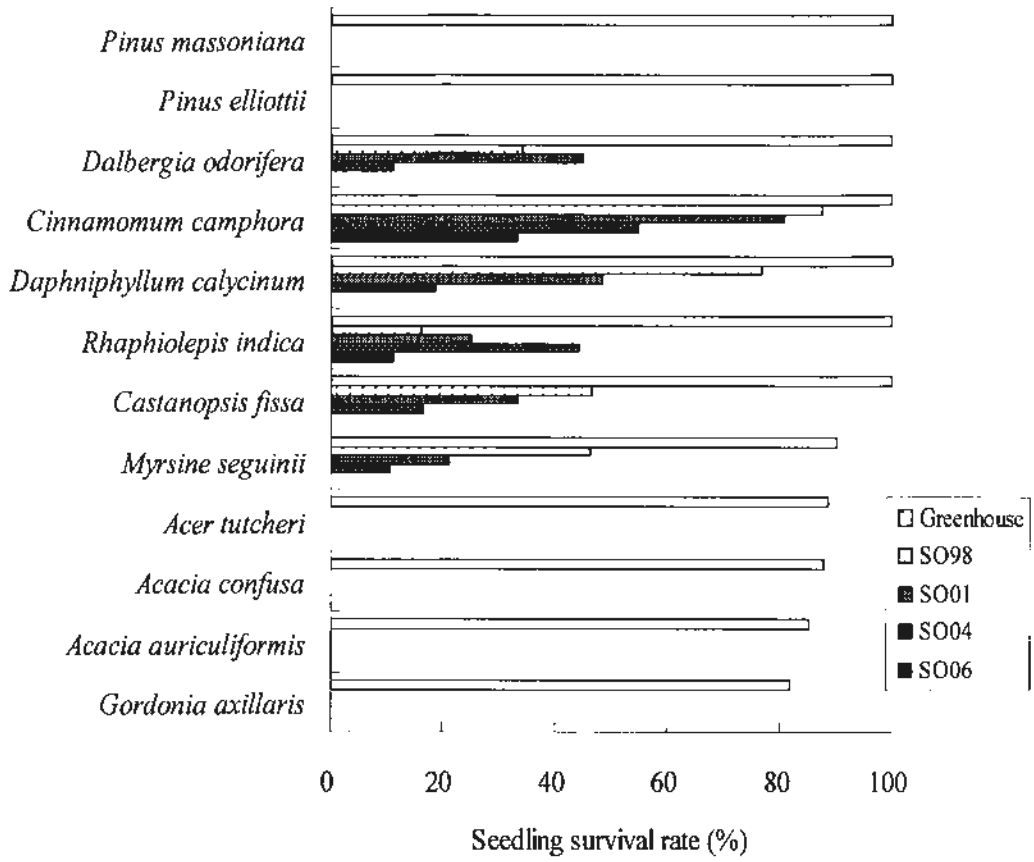


Figure 3.3 Mean seedling survival rate of woody species in various phases of SO

3.3.3 Microclimate

Microclimate measurements are shown in Table 3.5. During seed germination period, air temperature at 5 cm from ground decreased with increasing ages of SO phases; the difference between younger sites (SO04 and SO06) and older sites (SO98 and SO01) was 3-4°C. Air temperature at 1 m level had the similar pattern, but the difference among four sites was not obvious. Soil temperature was higher in SOO6 and SO04 than in SO01 and SO98, and their differences were about 2-3°C. Soil moisture increased with age, and the differences between younger and older sites were significant ($p<0.05$).

During seedling development in May, all microclimate parameters had similar

patterns as the seed germination period. However, air temperature at 5 cm level increased for 4.1-6.8°C, and air temperature at 1 m level increased 3.7-5.1°C, and soil temperature increased 2.5-3°C. In summary, air and soil temperatures were high inyounger sites than older sites. With the increasing temperature, soil moisture reduced accordingly and it was less than 11% for the four sites in May. Compared with the seed germination period, soil moisture decreased about half in the seedling development period.

Table 3.5 Air temperature, soil temperature and soil moisture in the four sites at SO

Sites	Seed germination period (January- April)				Seedling development period (May)			
	Temperature(°C)			Soil moisture (%)	Temperature (°C)			Soil moisture (%)
	Air		Soil		Air		Soil	
	5 cm	1 m	-5 cm	-5 cm	5 cm	1 m	-5 cm	-5 cm
SO98	20.6a	19.6a	19.8a	19.6a	24.7c	23.3b	22.3b	10.9a
SO01	21.3a	19.8a	20.8a	16.5a	27.6bc	24.9ab	23.3ab	9.39a
SO04	24.7a	20.8a	22.7a	13.0ab	30.1ab	25.9a	25.2ab	4.97b
SO06	24.8a	21.4a	23.3a	9.75b	31.6a	25.2a	26.3a	2.59b

Mean values followed by the same letter in a column are not significantly different at p=0.05 level by the Tukey's HSD test.

3.3.4 Relationship between seed germination and seedling survival with microclimate

The relationships of seed germination and seedling survival with microclimatic variables are shown in Table 3.6. Seed germination was significantly correlated with air temperature and soil moisture ($p<0.05$). Seedling survival was significantly

correlated with all microclimatic parameters ($p<0.05$).

Table 3.6 Pearson correlation coefficients among seed germination and seedling survival with air temperature, soil temperature and soil moisture

	Air T (°C)		Soil T (°C)	Soil moisture (%)
	5 cm	1 m	-5 cm	
Seed germination	-0.522*	-0.450*	-0.188	-0.592*
Seedling survival	-0.490*	-0.500*	-0.280*	0.304*

*$p<0.05$

3.4 Discussion

3.4.1 Seed rain

The study showed clearly that tray traps were more efficient to catch seeds than funnel traps. A total of 1,741 seeds from 35 woody species were collected at the eight quarry sites, which was lower than in degraded hillsides in Hong Kong (Hau, 1999) and other degraded sites elsewhere (Nepstad, 1989; Kolb, 1993; McClanahan and Wolfe, 1993; Otero-Arnaiz et al., 1999; Toh et al., 1999). The number of seeds and seed species in the seed rains varied among the six phases. TH94 and SO98 had higher seed number and seed species (Table 3.2), the seed number of which (381 and 522) was similar to a spontaneous secondary forest (511) and a 30 years old *Lophostemon confertus* plantation (562) in Hong Kong (Au et al., 2006; Lee et al., 2008). However, seed species was fewer in TH94 (12) and SO98 (14) than the secondary forest (42) and *L. confertus* plantation (17) (Au et al., 2006; Lee et al., 2008). The seed rains in LT98, LT01, SO01 and SO04 were similar to those of a local grassland which had 225 seeds and 9 seed species (Au et al., 2006). TH94 and SO98

were old among the eight quarry sites and had more diverse understorey and complex structure (Chapter 2), which were likely to be more attractive to birds (Wunderle, 1997). The distance closed to the nearby secondary forest was less than 100 m for both sites (Table 1.2), which could explain why these two sites had more seeds and seed species dispersed by birds (Sisk, 1991; Cardoso da Silva et al., 1996; Weir and Corlett, 2007). LT98, LT01, SO01 and SO04 were far their away from seed resources, and the largest distances were up to 400m (Table 1.2). The dominant avian seed dispersers in Hong Kong were the bulbuls (*Pycnonotus* spp.) (Corlett, 2002; Dudgeon and Corlett, 2004; Lee et al., 2008), and they dispersed most seeds within only 100 m (Weir and Corlett, 2007), which may explain that these sites had lower seed number and seed species dispersed by birds. Accordingly, wind-dispersed taxa became a very important component in these sites, for example *Gordonia axillaris* and *Desmodium heterocarpon* were found in SO01 and SO04, and *Macaranga tanarius* and *Cratoxylum cochinchinense* found in LT01. In this study, seeds of *Choerospondias axillaris*, *Diospyros morrisiana* and *Gnetum luofuense* were found in civet faeces at TH94 and LT01. The masked palm civet (*Paguma larvata*), small Indian civet (*Viverricula indica*) and muntjac (*Muntiacue* sp.) were common and known to disperse seeds in Hong Kong (Corlett, 1996; Dudgeon and Corlett, 2004; Au et al., 2006) and they acted as seed dispersers for these large seeds in our study.

In summary, seed rains of the three quarries were either low in abundance and species richness, which was similar to the case that forest plant species were rarely found in recently abandoned pastures, and the seeds of most tropical forest plants

would lose viability rapidly (Garwood, 1989; Vazquez-Yane and Orozco-Segovia, 1993; Holl 1999). Therefore, our study demonstrates that lack of seed dispersal was a major factor limiting vegetation regeneration in our local quarries. Effects on faciltating vegetation recovery must focus on strategies to enhance seed dispersal, such as planting trees that rapidly mature and fruit, thereby attracting seed dispersers.

3.4.2 Seed germination, seedling survival and microclimate

When seed dispersal appeared to be a major limiting factor for vegetation regeneration, a critical question to ask was whether woody species dispersed into the quarries were able to germinate. In our study, most seeds from twelve woody species could germinate in SO and also had a high germination in the field condition. Therefore, our results suggested that poor seed germination was not a major limiting factor for vegetation regeneration, which agreed with the result in abandoned pasture (Holl, 1999). Seed germination for all species was higher in older sites than in younger sites, which was in line with other studies that many woody species could germinate under shade (Vazquez-Yanes and Orozco-Segovia, 1993; Aid and Cavelier, 1994; Gonzalez Montagut, 1996; Metcalfe, 1996). *Daphniphyllum calycinum*, *Rhaphiolepis indica* and *Myrsine seguinii* also had high seed germination in younger sites, which may be attributed to the high light condition which favored germination of these early-successional woody species (Everham et al., 1996).

Although seed germination was not a limiting factor in the field, our study found that most emerging seedlings of all twelve species had a low survival rate under the field condition. However, higher temperature and lower moisture availability in

tropical pastures than in tropical forests may limit seedling survival and growth (Uhl, 1987; Nepstad et al., 1991 and 1996). Our results also found that seedling survival had significant correlations with air temperature, soil temperature and soil moisture (Table 3.6). Adverse microclimate such as high temperature and low moisture in summer was a limiting factor for seedling establishment in our local quarries.

3.5 Conclusions

It is clear that vegetation regeneration in rehabilitated quarries is limited at all early colonization stages: recruitment, establishment and survival. Seed rains of the three quarries were low in abundance and species richness. Lack of woody species seeds was a major factor limiting vegetation regeneration in our local quarries. Birds were the main seed dispersers in the three quarries, however, wind- and civet-dispersed taxa became very important components in the sites which were far away from the nearby secondary forest. Therefore, planting woody species that rapidly mature and fruit to attract seed dispersers should be recommended.

If barriers to seed dispersal are overcome, a number of factors may influence seed germination as well as seedling survival. Air temperature and soil temperature increased and soil moisture decreased during summer period, and most emerging seedlings finally died under high temperature and low soil moisture. Therefore, the adverse microclimate was a limiting factor for seedling establishment in our local quarries.

Chapter 4 Seed Bank Composition and Development in Rehabilitated Quarries

4.1 Introduction

Most plant species have the capacity to produce seeds that can remain dormant in the soil for several years to several decades (Holthuijzen et al., 1987). The mature viable seed reserves present in the soil or on the soil surface are defined as the soil seed banks (Roberts and Vankat, 1991). Soil seed bank can be either transient, with seeds that germinate within a year after dispersal, or persistent with seeds that remain in the soil for more than one year (Thompson and Grime, 1979; Leck et al., 1989). The different types of seed bank are related to species characters (Pierce and Cowling, 1991). There is evidence that most late-successional trees and shrubs are mostly represented in the transient soil seed bank. The persistent soil seed banks predominantly contain seeds of early-successional and light-demanding species (Simpson et al., 1989; Grandin, 2001; Walck et al., 2005). Soil seed banks reflect partly the history of the vegetation and can play an important role in its regeneration or restoration after disturbances (Kalamees and Zobel, 1998; Augusto et al., 2001; Chang et al., 2001; Luzuriage et al., 2005; Solomon et al., 2006; Wassie and Teketay, 2006; Zobel et al., 2007). Their ecological role is twofold: 1) to manage the composition and structure of existing vegetation; 2) to restore or establish native vegetation.

The dynamics of a soil seed bank include recruitment into the dormant seed bank population through seed dispersal, loss from the dormant seed bank through seed

predation or death, and formation of a seedling bank through germination (Bossuyt et al., 2006). Horizontal movement of seeds is commonly a result of animal activity or wind (Dostal, 2005). In tropical and subtropical rainforests, fruit bats and birds are major dispersal agents (Galindo-Gonzalez et al., 2000; Ingle, 2003), but wind can also disperse the majority of seeds into successional vegetation (Au et al., 2006). Seed predation may have a significant impact on seed bank (Hulme, 1998). Small mammals and ants are typical seed predators (Hau, 1997; Xiao et al., 2006). The storage of viable seeds in the soil for long periods depends on their dormancy. There are five dormancy types including physiological, morphological, morphophysiological, physical and combinational (physical + physiological) (Thompson and Grim, 1979; Leck et al., 1989).

The similarity between the species composition of the seed bank and that of the associated plant community has long been a controversy (Brown, 1998; Touzard et al., 2002; Shu et al., 2003; Luo and Wang, 2006). A lack of resemblance between the species present in the seed bank and in the current vegetation has been observed in a range of vegetation types. However, in many frequently disturbed habitats, the species composition of the seed bank is usually similar to that of the vegetation and mainly consists of annual species (Bossuyt and Hermy, 2003; Shaukat and Siddiqui, 2004; Bossuyt et al., 2006). Some studies reported relatively good representation of late-successional forest species in the seed bank, which shows the potential significance of the seed bank in community regeneration, while others argued that due to the scarcity of typical forest species in the seed bank, its significance as the source

of seeds is negligible for vegetation regeneration in disturbed habitats (Pickett and McDonnell, 1989; Hulme, 1998; Bossuyt and Hermy, 2001; Godefroid et al., 2006). Therefore, some forest species will have to be reintroduced by means of sowing and transplanting (De Villiers et al., 2003).

Maintaining ecosystem stability, especially of vegetation, is important in quarry rehabilitation, as in most cases the closed quarries are for amenity purpose. Seed bank analysis is a good method for examining the self-sustainability of species on quarries by studying the regeneration potentials of species in terms of seed characteristics. This study aims to determine the development of seed bank after hydroseeding and tree planting, and to assess the regeneration potentials of the established species on the different sites of the rehabilitated quarries.

4.2 Materials and methods

4.2.1 Seed bank sampling

Soil seed bank was sampled in January 2007. At that time, seeds that were released from the previous autumn and winter had a natural cold stratification, and there had not been an opportunity for the seeds to germinate in the spring. The sampling was done to measure both persistent and transient seed banks (Leckie et al., 2000). The method used was developed by Lavorel et al. (1993) which involved random sampling. Sampling sites are the same as sites selection. Within each site, 10 cm × 10 cm quadrats were randomly set at least 10 m apart. There were 20 quadrats at SO98, LT98 and TH94, 15 quadrats at SO01 and LT01 and 10 quadrats at SO04, SO06 and LT04. The majority of viable seeds were normally concentrated in the first

few centimeters of the ground with fewer seeds found up to 10 cm (Leckie et al., 2000). In this study, soils were sampled in the quadrats at the depth of 0-5 cm and 5-10 cm, to yield a total volume of 500 cm^3. Altogether, 240 soil samples were collected. Soil samples were then sorted to eliminate plant fragments and stones, and kept in polythene bags before the experiment of seedling emergence.

4.2.2 Seed emergence technique

The density and composition of the seed bank were determined by observing seedling emergence. The 'emergence method' was chosen for analysis of the seed bank because the primary goal was to determine the abundance and distribution of viable seeds that could germinate under field conditions. Elutriation which included nonviable seeds, gave higher estimates of seed density than emergence (Gross, 1990), but, the 'emergence method' gave an accurate assessment on the number of viable species and the relative abundance of seeds (Poiani and Johnson, 1988). Therefore, direct greenhouse germination was the most appropriate method for measuring the seed bank composition because of its simplicity and complete listing of viable species (Ter Heerdt et al., 1996).

The seedling emergence study began in February 2007. Each soil sample was spread out on a 24 cm × 16 cm × 4 cm seed tray. The trays were placed in a completely randomized design in a greenhouse where the temperature and moisture were kept consistent at 25°C and 70%, respectively. To quantify germination of seeds blown onto the experimental trays, five control trays were also placed randomly. All trays were watered as necessary to keep the soil moist. Emerging seedlings were

identified, counted and removed. Seedlings that cannot be identified would be individually transplanted to pots to allow growth and flowering for further identification. Seed germination was discontinued when no further seedling emergence was recorded for one month.

4.2.3 Data analysis

Two different aspects of seed bank were analyzed: composition and properties. Composition is simply the number of seedlings of each species in each quadrat and the relative abundance of each species accounted in all taxa. The importance value for each species was also calculated (Mueller-Dombois and Ellenberg, 1974) after determining the relative abundance (RA), relative frequency (RF) and relative dominance (RD).

For the importance value for each species, please refer to Section 2.2.3 in Chapter 2.

To characterize the seed bank of each site as a whole, the mean species richness, mean seed density (seeds m^{-2}), and the mean species diversity from all the quadrates within one site were calculated. The Shannon index, evenness index were used to assess species diversity for inter-site comparison. The similarity was assessed between species composition of the seed bank and of the aboveground vegetation.

For the diversity index of the species and the coefficient of similarity (Ss) between seed bank and aboveground vegetation in each area, please refer to 2.2.3 in Chapter 2.

Ordination analysis was carried out to study the association of emerging

seedlings in terms of their similarity of species composition and their associated environmental conditions (Gauch, 1982), so that they can be used to evaluate trends through time as well as space (Franklin, 1995). For the detailed information, please refer to 2.2.3 in Chapter 2.

4.2.4 Statistical analysis

The differences in seed density between the three quarries were determined by one-way analysis of variance (ANOVA) by Statistical Package for Social Science (SPSS) for windows Release 7.5 using an IBM 586 PC. Tukey's Honestly Significant Difference (HSD) was calculated whenever appropriate. DCA was run with the Canoco 4.5 software (Centre for Biometry, Wageningen, Netherlands).

4.3 Results

4.3.1 General description of the soil seed banks

Thirty species were found at the surface 5 cm soils of SO98 and LT01, which was the largest number among different phases of the three quarries (Table 4.1). TH94, LT98 and SO01 followed, with 23, 22 and 18 species, respectively. LT04 and SO06 had the lowest plant species. In the 5-10 cm soil, SO98 had the highest species number, while the difference of the number of plant species was not obvious among older phases such as LT98 and LT01. However, TH94, LT04, SO04 and SO06 were low in terms of the number of plant species. There were no seedlings found in the control treatment.

A summary of the number of viable seeds is also shown in Table 4.1. The highest seed density was found at LT98 and LT01 at the two depths. SO98 and SO01 followed.

The lowest seed density occurred at LT04, SO04 and SO06 at 0-5 cm soil, and TH94, LT04, SO04 and SO06 at 5-10 cm soil.

A total of 3,489 seedlings from 64 species were recorded at eight phases of the three quarries, which belonged to 20 families and 49 genera. The relative abundance of the seedlings from the soil samples from different phase sites in the three quarries are shown in Table 4.2. The soil seed banks are dominated by a few annual species, for example *Ageratum conyzoides*, *Kyllinga brevifolia*, *Cynodon dactylon*, *Ageratum houstonianum* and *Digitaria heterantha*. The total abundance of these five species in soil seed bank accounted for more than 50% of the total at the two depths for each phase (Table 4.2). These five species belonged to the three families of Compositae, Cyperaceae and Poaceae. There were 22 pioneer woody species represented in older phases (TH94, LT98 and SO98) in the three quarries, which included *Melastoma sanguineum*, *Desmodium heterocarpon* and *Melastoma candidum*.

Table 4.1 Species number and viable seed density of soil seed bank at different phases in the three quarries

Sites	0-5 cm		5-10 cm	
	Number of species	Number of viable seeds (seeds m^{-2})	Number of species	Number of viable seeds (seeds m^{-2})
TH94	23	1620c	8	173c
LT98	22	3210ab	15	1270a
LT01	30	4350a	15	1130a
LT04	14	630d	5	470b
SO98	30	2870b	21	790ab
SO01	18	2430b	10	540b
SO04	9	660d	6	180c
SO06	3	420d	2	120c

Mean values followed by the same letter within a column are not significantly different at p=0.05 level according to the Tukey's HSD test

Table 4.2 The relative abundance (%) of plant species in soil seed bank at different phases in the three quarries

Species	TH94		LT98		LT01		LT04		SO98		SO01		SO04		SO06	
	0-5cm	5-10cm	0-5cm	5-10cm	0-5cm	5-10cm	0-5cm	5-10cm	0-5cm	5-10cm	0-5cm	5-10cm	0-5cm	5-10cm	0-5cm	5-10cm
*Acacia auriculiformis**	-	-	-	-	1.07	-	-	-	-	-	-	-	-	-	-	-
*Acacia confusa**	-	-	-	-	1.69	1.18	-	-	-	-	-	-	-	-	-	-
Ageratum conyzoides	23.5	42.3	22.6	18.6	9.97	8.28	46.0	66.0	39.4	39.2	43.4	42.0	12.1	-	-	-
Ageratum houstonianum	31.5	11.5	0.62	5.14	1.53	1.18	1.59	-	0.52	0.63	-	-	-	-	-	-
Bidens alba	1.23	7.69	3.59	2.37	1.53	4.14	19.1	19.2	-	-	-	-	-	-	-	-
*Buddleja lindleyana**	-	-	-	-	1.69	-	1.59	-	2.09	-	-	-	-	-	-	-
*Callicarpa longissima**	-	-	-	-	-	-	-	-	1.05	1.27	-	-	-	-	-	-
*Casuarina equisetifolia**	-	-	-	-	0.92	0.59	-	-	-	-	-	-	-	-	-	-
*Celtis sinensis**	-	-	-	-	-	-	-	-	1.92	-	-	-	-	-	-	-
Conyza bonariensis	0.31	-	0.94	-	0.31	2.37	1.59	-	2.09	-	2.75	3.70	-	-	-	-
Cynodon dactylon	2.16	11.5	0.94	-	0.92	2.96	1.59	-	4.71	4.43	8.24	14.8	28.8	38.9	52.4	-
Cyperus halpan	4.94	7.69	11.7	-	1.99	1.78	1.59	4.26	-	-	-	-	-	-	-	-
Cyperus iria	1.23	-	0.16	0.40	-	-	-	8.51	-	6.96	-	-	-	-	-	-
*Desmodium gangeticum**	-	-	-	-	1.69	-	-	-	-	-	-	-	-	-	-	-

Table 4.2 (continued)

*Desmodium heterocarpon**	0.31	-	0.31	0.40	-	-	-	-	2.79	3.80	3.85	2.47	3.03	-	-	-
Digitaria longiflora	2.16	-	0.47	-	-	-	1.59	-	1.05	1.27	-	7.41	-	-	40.5	66.7
Digitaria sanguinalis	-	11.5	-	-	-	-	-	-	-	-	-	7.41	-	-	-	-
Eleusine indica	-	-	-	-	-	-	-	-	2.09	1.27	3.57	-	-	-	-	-
*Embelia laeta**	-	-	-	-	-	-	-	-	1.05	-	-	-	-	-	-	-
Emilia sonchifolia	-	-	-	-	-	-	-	-	-	-	-	-	1.52	5.56	-	-
Epaltes australis	-	-	-	-	-	-	-	-	-	-	1.37	-	-	-	-	-
Eragrostis tenella	-	-	0.78	0.40	-	-	3.17	-	1.57	-	-	-	-	-	-	-
*Ficus hispida**	0.31	-	-	-	-	-	-	-	2.44	-	-	-	-	-	-	-
*Ficus variolosa**	-	-	-	-	-	-	-	-	2.44	0.63	-	-	-	-	-	-
Fimbristylis miliacea	-	-	1.72	-	-	-	-	-	-	-	-	-	-	-	-	-
Fimbristylis thomsonii	20.7	-	2.81	2.37	12.1	7.69	6.35	-	1.05	-	-	-	-	-	-	-
Gahnia tristis	-	-	-	-	0.31	-	-	-	-	-	-	-	-	-	-	-
Gnaphalium penslvanicum	-	-	0.16	-	-	-	-	-	-	-	-	-	-	-	-	-
Hedyotis acutangula	-	-		-	-	-	-	-	-	-	1.65	-	-	-	-	-
Hedyotis corymbosa	-	-	0.47	-	-	-	-	-	-	1.27	-	-	-	-	-	-
Hedyotis diffusa	-	-	7.33	1.98	0.31	-	3.17	-	2.27	5.06	-	-	-	-	-	-

Table 4.2 (continued)

Hypolytrum nemorum	-	-	-	-	0.92	-	-	-	-	-	-	-	-	-	-	-
Imperata koenigii	0.31	-	-	-	-	-	3.17	-	1.05	-	3.30	-	6.06	5.56	-	-
Ixeris repens	-	-	-	-	0.92	-	-	-	-	-	-	-	-	-	-	-
Kyllinga brevifolia	4.63	-	27.5	56.1	45.3	53.9	-	-	6.81	4.43	1.65	-	-	-	-	-
*Leucaena leucocephala**	0.31	-	-	-	-	-	-	-	2.09	0.63	-	-	-	-	-	-
Lindernia antipoda	-	-	-	-	-	-	-	-	1.92	0.63	-	-	-	-	-	-
Lindernia crustacea	0.93	-	8.58	2.37	2.91	1.18	-	-	2.09	9.49	3.02	-	-	-	-	-
*Macaranga tanarius**	-	-	0.16	-	-	-	-	-	2.27	0.63	3.02	-	-	-	-	-
*Mallotus apelta**	0.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mariscus umbellatus	-	-	-	-	-	-	-	-	-	-	1.65	-	-	-	-	-
*Melastoma candidum**	0.31	-	3.90	3.95	1.99	-	-	-	-	-	3.30	-	-	-	-	-
*Melastoma sanguineum**	0.93	-	1.09	0.79	1.99	-	-	-	3.84	-	-	1.23	-	-	-	-
Mikania micrantha	0.93	3.85	-	-	0.15	0.59	-	-	0.87	-	-	-	-	-	-	-
*Mimosa pudica**	-	-	-	-	-	-	-	-	2.27	-	-	-	-	-	-	-
Oxalis corniculata	-	-	3.74	3.16	1.99	10.7	7.94	2.13	1.75	10.1	7.14	18.5	15.2	27.8	7.14	-
Paspalum conjugatum	0.31	-	-	-	-	1.18	-	-	-	0.63	3.02	-	-	-	-	-
*Phyllanthus reticulates**	-	-	-	-	1.69	-	-	-	1.05	0.63	-	-	-	-	-	-

Table 4.2 (continued)

Polygonum perfoliatum	1.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
*Psychotria asiatica**	-	-	-	-	0.92	-	-	-	-	-	-	-	-	-	-	-
Pycreus polystachyus	-	-	-	-	-	-	-	-	-	-	1.65	-	-	-	-	-
*Raphiolepis indica**	-	-	-	-	-	-	-	-	2.27	-	-	-	-	-	-	-
Rhynchelytrum repens	-	3.85	-	-	-	-	-	-	1.05	-	3.02	1.23	12.1	-	-	33.3
Rhynchospora rubra	-	-	-	-	0.61	-	-	-	-	-	-	-	4.55	-	-	-
Sacciolepis indica	-	-	-	0.79	0.92	2.37	-	-	-	-	-	1.23	16.7	22.2	-	-
Sesbania cannabina	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solanum americanum	-	-	-	-	1.69	-	-	-	-	5.7	4.4	-	-	-	-	-
*Solanum torvum**	-	-	-	-	-	-	-	-	2.09	-	-	-	-	-	-	-
Synedrella nodiflora	-	-	-	-	0.15	-	-	-	-	-	-	-	-	-	-	-
*Triumfetta rhomboidea**	0.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vernonia cinerea	-	-	0.47	-	-	-	1.59	-	-	1.27		-	-	-	-	-
Youngia japonica	-	-	-	-	0.92	-	-	-	-	-	-	-	-	-	-	-
Unknown 1	-	-	-	1.19	-	-	-	-	-	-	-	-	-	-	-	-
Unknown 2	-	-	-	-	0.92	-	-	-	-	-	-	-	-	-	-	-

* denotes woody species

4.3.2 Composition of the soil seed banks

The ranking according to the importance value of each species on each phase among the three quarries is shown in Table 4.3.

Twenty five species were recorded at the two depths in TH94. In 0-5 cm depth, *Ageratum conyzoides*, *A. houstonianum* and *Fimbristylis thomsonii* were the most important species according to their relative density and relative frequency, and these three species accounted for 53.4% of the total importance value. Nevertheless, some woody species, for example *Melastoma sanguineum*, *Mallotus apelta*, *Triumfetta rhomboidea*, *Desmodium heterocarpon*, *M. candidum*, *Ficus hispida* and *Leucaena leucocephala* were found at TH94. These woody species accounted for 8.2% of the total importance value. In 5-10 cm depth, all eight species were herbs and *Ageratum conyzoides* was the dominant species.

Twenty four species were identified at the two depths in LT98. In 0-5 cm depth, *Ageratum conyzoides*, *Kyllinga brevifolia*, *Oxalis corniculata*, *Bidens alba*, *Lindernia crustacean*, *Cyperus halpan* and *Hedyotis diffusa* were the dominant species according to the importance value, which accounted for 70.6% of the total importance value. There were four woody species in this site, i.e. *Melastoma candidum*, *M. sanguineum*, *Desmodium heterocarpon* and *Macaranga tanarius* which accounted for 19.4% of the total importance value. In 5-10 cm depth, *Kyllinga brevifolia* and *Ageratum conyzoides* were the dominant species.

There were 31 species in LT01, in which 30 species occurred in 0-5 cm depth and 15 species were from 5-10 cm soil. *Kyllinga brevifolia*, *Cyperus halpan*, *Oxalis*

corniculata, *Fimbristylis thomsonii*, *Ageratum conyzoides*, *Cynodon dactylon* and *Lindernia crustacean* were the dominant species in 0-5 cm and accounted for 44.1% of the total importance value. Nine woody species, for example *Melastoma sanguineum*, *M. candidum*, *Acacia auriculiformis*, *A. confusa*, *Casuarina equisetifolia*, *Psychotria asiatica*, *Desmodium gangeticum*, *Buddleja lindleyana* and *Phyllanthus reticulatus*, were found in 0-5 cm depth and the percentage of these woody species was 34.9% of the total importance value. *Kyllinga brevifolia*, *Oxalis corniculata*, *Ageratum conyzoides* and *Bidens alba* were the dominant species, and only two exotic woody species (*Acacia confusa* and *Casuarina equisetifolia*) occurred in 5-10 cm depth because of erosion effect.

There were fifteen species found in LT04, all of which were grasses and herbs. *Ageratum conyzoides* and *Bidens alba* were the dominant species at both soil.

Regarding SO, the species number was the highest at SO98 with thirty six species at two depths. At 0-5 cm depth, *Ageratum conyzoides*, *Cynodon dactylon*, *Kyllinga brevifolia*, *Melastoma sanguineum* and *Desmodium heterocarpon* were the dominant species, in which *M. sanguineum* and *D. heterocarpon* were woody species. Besides, twelve other woody species were found, including *Ficus hispida*, *Ficus variolosa*, *Macaranga tanarius*, *Mimosa pudica*, *Raphiolepis indica*, *Solanum torvum*, *Buddleja lindleyana*, *Leucaena leucocephala*, *Embelia laeta*, *Celtis sinensis*, *Phyllanthus reticulates* and *Callicarpa longissima*. These woody species accounted for 44.2% of the total importance value. At 5-10 cm depth, *Ageratum conyzoides* and *Oxalis corniculata* were the dominant species and some woody species also occurred,

for example *Desmodium heterocarpo*, *Leucaena leucocephala*, *Phyllanthus reticulates* and *Callicarpa longissima*.

Twenty two species were recorded at SO01. *Ageratum conyzoides*, *Oxalis corniculata* and *Cynodon dactylon* were the three dominant species at the two depths. There were three woody species in 0-5 cm depth (viz. *Melastoma candidum*, *Desmodium heterocarpon* and *Macaranga tanarius*), while two woody species (*Desmodium heterocarpon* and *Melastoma sanguineum*) occurred in 5-10 cm depth.

There were nine species at SO04. *Cynodon dactylon*, *Sacciolepis indica* and *Oxalis corniculata* dominated at the two depths. Four species were identified at SO06. *Cynodon dactylon*, *Digitaria longiflora* and *Oxalis corniculata* were found at 0-5 cm while *Digitaria longiflora* and *Rhynchelytrum repens* were found at 5-10 cm.

Table 4.3a Ranking of species according to the importance value (IV) at TH94

Species	0-5 cm			5-10 cm		
	RD (%)	RF (%)	IV	RD (%)	RF (%)	IV
Ageratum conyzoides	23.5	70.0	46.7	42.3	35.0	38.7
Ageratum houstonianum	31.5	55.0	43.2	11.5	5.00	8.27
Fimbristylis thomsonii	20.7	45.0	32.8	-	-	-
Cyperus halpan	4.94	30.0	17.5	7.69	10.0	8.85
Digitaria longiflora	2.16	20.0	11.1	-	-	-
Bidens alba	1.23	20.0	10.6	7.69	10.0	8.85
Lindernia crustacea	0.93	15.0	7.96	-	-	-
Mikania micrantha	0.93	15.0	7.96	3.85	5.00	4.42
Kyllinga brevifolia	4.63	10.0	7.31	-	-	-
Cynodon dactylon	2.16	10.0	6.08	11.5	15.0	13.3
Cyperus iria	1.23	10.0	5.62	-	-	-
Polygonum perfoliatum	1.85	5.00	3.43	-	-	-
Melastoma sanguineum	0.93	5.00	2.96	-	-	-
Sesbania cannabina	0.62	5.00	2.81	-	-	-
Mallotus apelta	0.31	5.00	2.65	-	-	-
Imperata koenigii	0.31	5.00	2.65	-	-	-
Triumfetta rhomboidea	0.31	5.00	2.65	-	-	-
Conyza bonariensis	0.31	5.00	2.65	-	-	-
Desmodium heterocarpon	0.31	5.00	2.65	-	-	-
Melastoma candidum	0.31	5.00	2.65	-	-	-
Ficus hispida	0.31	5.00	2.65	-	-	-
Paspalum conjugatum	0.31	5.00	2.65	-	-	-
Leucaena leucocephala	0.31	5.00	2.65	-	-	-
Rhynchelytrum repens	-	-	-	3.85	5.00	4.42
Digitaria sanguinalis	-	-	-	11.5	15.0	13.3

Table 4.3b Ranking of species according to the importance value (IV) at LT98

Species	0-5 cm			5-10 cm		
	RD (%)	RF (%)	IV	RD (%)	RF (%)	IV
Ageratum conyzoides	22.6	80.0	51.3	18.6	70.0	44.3
Kyllinga brevifolia	27.5	60.0	43.7	56.1	70.0	63.1
Oxalis corniculata	3.74	50.0	26.9	3.16	30.0	16.6
Bidens alba	3.59	50.0	26.8	2.37	15.0	8.69
Lindernia crustacea	8.58	45.0	26.8	2.37	20.0	11.2
Cyperus halpan	11.7	40.0	25.9	-	-	-
Hedyotis diffusa	7.33	35.0	21.2	1.98	15.0	8.49
Fimbristylis thomsonii	2.81	25.0	13.9	2.37	20.0	11.2
Eragrostis tenella	0.78	25.0	12.9	0.40	5.00	2.70
Melastoma candidum	3.90	20.0	12.0	3.95	15.0	9.48
Cynodon dactylon	0.94	15.0	7.97	-	-	-
Conyza bonariensis	0.94	15.0	7.97	-	-	-
Melastoma sanguineum	1.09	10.0	5.55	0.79	10.0	5.40
Ageratum houstonianum	0.62	10.0	5.31	5.14	25.0	15.1
Vernonia cinerea	0.47	10.0	5.23	-	-	-
Desmodium heterocarpon	0.31	10.0	5.16	0.40	5.00	2.70
Fimbristylis miliacea	1.72	5.00	3.36	-	-	-
Hedyotis corymbosa	0.47	5.00	2.73	-	-	-
Digitaria longiflora	0.47	5.00	2.73	-	-	-
Macaranga tanarius	0.16	5.00	2.58	-	-	-
Gnaphalium penslvanicum	0.16	5.00	2.58	-	-	-
Cyperus iria	0.16	5.00	2.58	0.40	5.00	2.70
Sacciolepis indica	-	-	-	0.79	10.0	5.40
Unknown 1	-	-	-	1.19	5.00	3.09

Table 4.3c Ranking of species according to the importance value (IV) at LT01

Species	0-5 cm			5-10 cm		
	RD (%)	RF (%)	IV	RD (%)	RF (%)	IV
Kyllinga brevifolia	45.3	53.3	49.3	53.9	33.3	43.6
Cyperus halpan	1.99	60.0	31.0	1.78	20.0	10.9
Oxalis corniculata	1.99	46.7	24.3	10.7	60.0	35.3
Fimbristylis thomsonii	12.1	33.3	22.7	7.69	13.3	10.5
Ageratum conyzoides	9.97	40.0	25.0	8.28	33.3	20.8
Bidens alba	1.53	33.3	17.4	4.1	33.3	18.7
Cynodon dactylon	0.92	26.7	13.8	2.96	26.7	14.8
Lindernia crustacea	2.91	26.7	14.8	1.18	6.67	3.93
Ageratum houstonianum	1.53	13.3	7.43	1.18	13.3	7.26
Sacciolepis indica	0.92	13.3	7.13	2.37	13.3	7.85
Melastoma sanguineum	1.99	46.7	24.3	-	-	-
Melastoma candidum	1.99	53.3	27.7	-	-	-
Hedyotis diffusa	0.31	13.3	6.82	-	-	-
Acacia auriculiformis	1.07	26.7	13.9	-	-	-
Conyza bonariensis	0.31	13.3	6.82	2.37	20.0	11.2
Acacia confusa	1.69	26.7	14.2	1.18	13.3	7.26
Rhynchospora rubra	0.61	6.67	3.64	-	-	-
Gahnia tristis	0.31	6.67	3.49	-	-	-
Hypolytrum nemorum	0.92	13.3	7.13	-	-	-
Solanum americanum	1.69	33.3	17.5	-	-	-
Casuarina equisetifolia	0.92	26.7	13.8	0.59	6.67	3.63
Ixeris repens	0.92	20.0	10.5	-	-	-
Psychotria asiatica	0.92	20.0	10.5	-	-	-
Synedrella nodiflora	0.15	6.67	3.41	-	-	-
Mikania micrantha	0.15	6.67	3.41	0.59	6.67	3.63
Desmodium gangeticum	1.69	33.3	17.5	-	-	-

Table 4.3c (continued)

Buddleja lindleyana	1.69	40.0	20.8	-	-	-
Phyllanthus reticulatus	1.69	26.7	14.2	-	-	-
Youngia japonica	0.92	13.3	7.13	-	-	-
Paspalum conjugatum	-	-	-	1.18	13.3	7.26
Unknown 2	0.92	20.0	10.5	-	-	-

Table 4.3d Ranking of species according to the importance value (IV) at LT04

Species	0-5 cm			5-10 cm		
	RD (%)	RF (%)	IV	RD (%)	RF (%)	IV
Ageratum conyzoides	46.0	60.0	53.0	66.0	80.0	73.0
Bidens alba	19.1	60.0	39.5	19.2	60.0	39.6
Fimbristylis thomsonii	6.35	30.0	18.2	-	-	-
Imperata koenigii	3.17	20.0	11.6	-	-	-
Vernonia cinerea	1.59	10.0	5.79	-	-	-
Cyperus halpan	1.59	10.0	5.79	4.26	20.0	12.1
Conyza bonariensis	1.59	10.0	5.79	-	-	-
Oxalis corniculata	7.94	30.0	19.0	2.13	10.0	6.06
Hedyotis diffusa	3.17	10.0	6.59	-	-	-
Eragrostis tenella	3.17	10.0	6.59	-	-	-
Cynodon dactylon	1.59	10.0	5.79	-	-	-
Ageratum houstonianum	1.59	10.0	5.79	-	-	-
Buddleja lindleyana	1.59	10.0	5.79	-	-	-
Digitaria longiflora	1.59	10.0	5.79	-	-	-
Cyperus iria	-	-	-	8.51	40.0	24.3

Table 4.3e Ranking of species according to the importance value (IV) at SO98

Species	0-5 cm			5-10 cm		
	RD (%)	RF (%)	IV	RD (%)	RF (%)	IV
Ageratum conyzoides	39.4	100	69.7	39.2	75.0	57.1
Cynodon dactylon	4.71	55.0	29.9	4.43	15.0	9.7
Kyllinga brevifolia	6.81	40.0	23.4	4.43	20.0	12.2
Melastoma sanguineum	3.84	60.0	31.9	-	-	-
Oxalis corniculata	1.75	35.0	18.4	10.1	55.0	32.6
Desmodium heterocarpon	2.79	40.0	21.4	3.80	25.0	14.4
Ficus hispida	2.44	35.0	18.7	-	-	-
Ficus variolosa	2.44	35.0	18.7	0.63	5.00	2.82
Macaranga tanarius	2.27	30.0	16.1	0.63	5.00	2.82
Mimosa pudica	2.27	30.0	16.1	-	-	-
Raphiolepis indica	2.27	30.0	16.1	-	-	-
Mikania micrantha	0.87	10.0	5.44	-	-	-
Hedyotis diffusa	2.27	20.0	11.1	5.06	15.0	10.0
Solanum torvum	2.09	25.0	13.6	-	-	-
Eleusine indica	2.09	20.0	11.1	-	-	-
Lindernia crustacea	2.09	35.0	18.6	9.49	15.0	12.3
Conyza bonariensis	2.09	25.0	13.6	-	-	-
Buddleja lindleyana	2.09	25.0	13.6	-	-	-
Leucaena leucocephala	2.09	25.0	13.6	0.63	5.00	2.82
Eragrostis tenella	1.57	20.0	10.8	-	-	-
Ageratum houstonianum	0.52	15.0	7.76	0.63	5.00	2.82
Embelia laeta	1.05	10.0	5.52	-	-	-
Imperata koenigii	1.05	15.0	8.02	-	-	-
Celtis sinensis	1.92	25.0	13.5	-	-	-
Fimbristylis thomsonii	1.05	20.0	10.5	-	-	-
Lindernia antipoda	1.92	30.0	16.0	0.63	5.00	2.82

Table 4.3e (continued)

Phyllanthus reticulatus	1.05	25.0	13.0	0.63	5.00	2.82
Rhynchelytrum repens	1.05	25.0	13.0	-	-	-
Digitaria longiflora	1.05	25.0	13.0	1.27	10.0	5.63
Callicarpa longissima	1.05	20.0	10.5	1.27	10.0	5.63
Cyperus iria	-	-	-	6.96	20.0	13.5
Solanum americanum	-	-	-	5.70	10.0	7.85
Eleusine indica	-	-	-	1.27	10.0	5.63
Hedyotis corymbosa	-	-	-	1.27	10.0	5.63
Vernonia cinerea	-	-	-	1.27	5.00	3.13
Paspalum conjugatum	-	-	-	0.63	5.00	2.82

Table 4.3f Ranking of species according to the importance value (IV) at SO01

Species	0-5 cm			5-10 cm		
	RD (%)	RF (%)	IV	RD (%)	RF (%)	IV
Ageratum conyzoides	43.4	100	71.7	42.0	53.3	47.7
Oxalis corniculata	7.14	86.7	46.9	18.5	66.7	42.6
Cynodon dactylon	8.24	80.0	44.1	14.8	53.3	34.1
Solanum americanum	4.40	60.0	32.2	-	-	-
Melastoma candidum	3.30	60.0	31.7	-	-	-
Imperata koenigii	3.30	60.0	31.7	-	-	-
Desmodium heterocarpon	3.85	53.3	28.6	2.47	13.3	7.90
Macaranga tanarius	3.02	53.3	28.2	-	-	-
Eleusine indica	3.57	46.7	25.1	-	-	-
Rhynchelytrum repens	3.02	46.7	24.8	1.23	6.67	3.95
Paspalum conjugatum	3.02	46.7	24.8	-	-	-
Lindernia crustacea	3.02	46.7	24.8	-	-	-
Conyza bonariensis	2.75	33.3	18.0	3.70	6.67	5.19
Mariscus umbellatus	1.65	33.3	17.5	-	-	-

Table 4.3f (continued)

Pycreus polystachyus	1.65	33.3	17.5	-	-	-
Kyllinga brevifolia	1.65	26.7	14.2	-	-	-
Hedyotis acutangula	1.65	20.0	10.8	-	-	-
Epaltes australis	1.37	20.0	10.7	-	-	-
Digitaria longiflora	-	-	-	7.41	26.7	17.0
Digitaria sanguinalis	-	-	-	7.41	20.0	13.7
Melastoma sanguineum	-	-	-	1.23	6.67	3.95
Sacciolepis indica	-	-	-	1.23	6.67	3.95

Table 4.3g Ranking of species according to the importance value (IV) at SO04

Species	0-5 cm			5-10 cm		
	RD (%)	RF (%)	IV	RD (%)	RF (%)	IV
Cynodon dactylon	28.8	35.0	31.9	38.9	35.0	36.9
Sacciolepis indica	16.7	35.0	25.8	22.2	15.0	18.6
Oxalis corniculata	15.2	35.0	25.1	27.8	15.0	21.4
Ageratum conyzoides	12.1	20.0	16.1	-	-	-
Rhynchelytrum repens	12.1	10.0	11.1	-	-	-
Imperata koenigii	6.06	15.0	10.5	5.56	5.00	5.28
Rhynchospora rubra	4.55	10.0	7.27	-	-	-
Desmodium heterocarpon	3.03	5.00	4.02	-	-	-
Emilia sonchifolia	1.52	5.00	3.26	5.56	5.00	5.28

Table 4.3h Ranking of species according to the importance value (IV) at SO06

Species	0-5 cm			5-10 cm		
	RD (%)	RF (%)	IV	RD (%)	RF (%)	IV
Cynodon dactylon	52.4	30.0	41.2	-	-	-
Digitaria longiflora	40.5	30.0	35.2	66.7	30.0	48.3
Oxalis corniculata	7.14	5.00	6.07	-	-	-
Rhynchelytrum repens	-	-	-	33.3	15.0	24.2

4.3.3 Ecological indices among the three quarries

Shannon index and evenness were determined from the seed bank composition in each site. Table 4.4 shows the indices of diversity and evenness.

In 0-5 cm depth, SO98 had the highest Shannon index among the three quarries. Shannon index were higher at LT98, LT01, and SO01. SO06 had the lowest Shannon index. In general, Shannon index increased with the increasing rehabilitation ages in SO, but the trend was not obvious in LT. The younger sites SO04 and SO06 had the higher evenness and the difference of evenness among LT98, SO98 and SO01 was not obvious. TH94 and LTO1 had the lowest evenness, which meant some plant seeds were patchy in distribution in these sites.

In 5-10 cm depth, SO98 also had the highest Shannon index and TH94, LT01 and SO01 followed. LT04, SO04 and SO06 had the low diversity. TH94, SO04 and SO06 had the higher evenness, and SO98 and SO01 followed. The low evenness occurred in LT98, LT01 and LT04.

The similarity among sites is shown in the sample ordination plots from Detrended Correspondence Analysis, DCA (Fig. 4.1). It was weighted according to the relative abundance of each species in the site. The different sites were remarkably separated along the first and second axes, and three groups were well distinguished. For example the recently rehabilitated SO04 and SO06 sites were far away from the origin, and the group of older sites (SO98 and SO01) occurred in the middle of the first axis, and the third group of TH94, LT98 and LT01 was located in the left of biplot. Seed bank composition in the older sites was greatly different from those of

younger sites. Twenty two woody species were mostly located at the older rehabilitated sites (TH94, LT98 and SO98). Overlapping of woody species among these old sites indicated that similarity was high among sites. Higher similarity was obtained between SO98 and SO01, and between LT98 and LT01 (Fig. 4.1).

Table 4.4 Diversity and evenness of soil seed bank at two depths at different phases in the three quarries

Sites	0-5 cm		5-10 cm	
	Shannon index (H')	Evenness (E)	Shannon index (H')	Evenness (E)
TH94	1.99b	0.63b	1.75b	0.84ab
LT98	2.21ab	0.72ab	1.56bc	0.58c
LT01	2.23ab	0.65b	1.73b	0.64c
LT04	1.83bc	0.69b	1.01cd	0.63c
SO98	2.62a	0.77ab	2.22a	0.73b
SO01	2.21ab	0.76ab	1.72b	0.74b
SO04	1.93b	0.88a	1.37c	0.85ab
SO06	0.89c	0.81a	0.63d	0.91a

Mean values followed by the same letter within a column are not significantly different at p=0.05 level according to the Tukey's HSD test

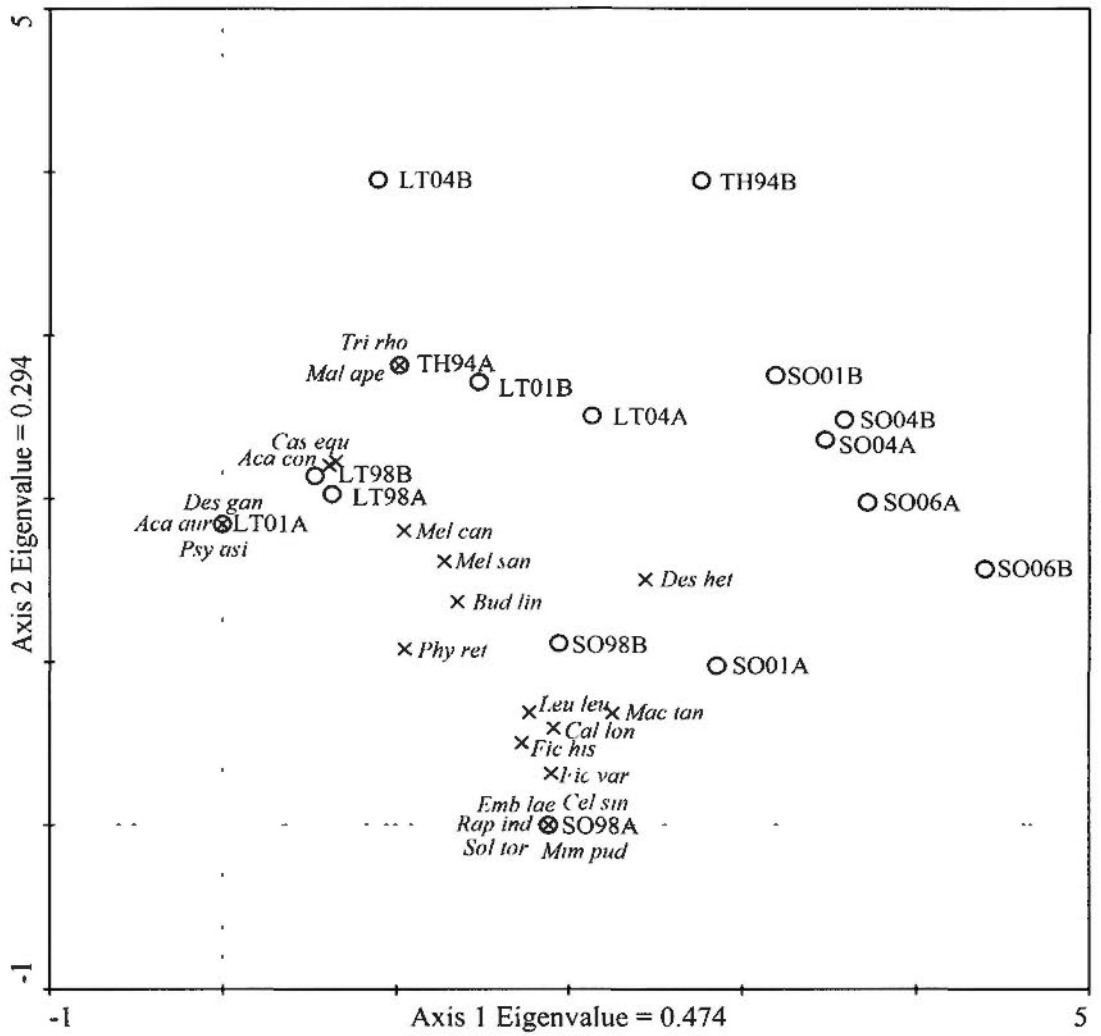


Figure 4.1 The first two axes of the DCA ordination for the woody species in soil seed bank of the eight quarry sites. A denotes 0-5 cm depth; B denotes 5-10 cm depth. Species names are abbreviated with the first three letters of genus and species

Abbreviations for species are, *Acacia auriculiformis* (*Aca aur*); *Acacia confusa* (*Aca con*); *Buddleja lindleyana* (*Bud lin*); *Callicarpa longissima* (*Cal lon*); *Casuarina equisetifolia* (*Cas equ*); *Celtis sinensis* (*Cel sin*); *Desmodium gangeticum* (*Des gan*); *Desmodium heterocarpon* (*Des het*); *Embelia laeta* (*Emb lae*); *Ficus hispida* (*Fic his*); *Ficus variolosa* (*Fic var*); *Leucaena leucocephala* (*Leu leu*); *Macaranga tanarius* (*Mac tan*); *Mallotus apelta* (*Mal ape*); *Melastoma candidum* (*Mel can*); *Melastoma sanguineum* (*Mel san*); *Mimosa pudica* (*Mim pud*); *Phyllanthus reticulates* (*Phy ret*); *Psychotria asiatica* (*Psy asi*); *Raphiolepis indica* (*Rap ind*); *Solanum torvum* (*Sol tor*); *Triumfetta rhomboidea* (*Tri rho*).

4.3.4 Similarity between seed banks and aboveground vegetation

Species composition of seed banks was compared with that of the aboveground vegetation. A total of 64 species was recorded from the seed bank, of which 20 species established themselves in the vegetation on the three quarries (Table 4.2). Table 4.5 shows the index for similarity between vegetation and seed banks at the three quarries. In general, low scores for similarity index were observed in all sites. The similarity was higher in TH94, SO04 and SO06, while the differences among other sites were not obvious.

Table 4.5 Similarity index between seed bank and vegetation in the three quarries

TH94	LT98	LT01	LT04	SO98	SO01	SO04	SO06
0.182	0.138	0.138	0.129	0.143	0.140	0.195	0.235

4.4 Discussion

4.4.1 Ecological development of seed bank composition

Seed banks of many ecosystems contain both transient and persistent components. The persistent seed bank is composed of small-sized, long-lived, dormant seeds that have the capacity to remain viable for a longer period of time (Fenner, 1987; Teketay and Granstrom, 1995; Osumi and Sakurai, 1997). The transient seed bank is composed of short-lived, nondormant seeds that do not remain in a viable condition for more than one year (Thompson and Grime, 1979; Baskin and

Baskin, 1998). Of the 64 species recorded in the present study, 42 species belonged to herbaceous and graminoid plants and only 22 species belonged to woody species, in which most herbaceous and graminoid species presumably contributed to the persistent seed bank and some woody species represented the transient component. The result was consistent with that at the disturbed habitats some proportion of species had persistent seed banks while some formed the transient component (Thompson and Grime, 1979).

Our results show that younger sites (LT04, SO04 and SO06) mainly consisted of seeds from grasses and sedges (*Cynodon dactylon*, *Fimbristylis thomsonii*), with the occasional presence of legumes (*Desmodium heterocarpon*) and composites (*Ageratum conyzoides*). These species are mainly ruderal plants and are specialized for invading most open areas and wastelands (Fenner, 1987). Seeds of ruderal species are usually produced in a large quantity and are small-sized and compact. These enable the long distance dispersal of seeds by wind and animals, and increase the ease of being buried in deeper soil (Grandin and Rydin, 1998).

With ecological development, exotic tree planting rapidly converted the ecosystem from a open grassland to closed plantation, which led to the change in understorey composition. Some annual ruderals were gradually excluded from the ecosystem, and some perennial herbs and woody species dominated, which could be

explained that there is a shift from wind and animal mediated seed dispersal to a more typically animal and gravity dispersal (Pierce and Cowling, 1991; Hammond and Brown, 1995). In our study, increases in abundance of woody species were observed in the seed banks in older quarries (TH94, LT98 and SO98) (Fig. 4.1). Seeds of most woody species are produced in a small number and are short-lived and non-dormant (Crawley, 1997; Rees, 1997; Grandin and Rydin, 1998). Therefore, a transient seed bank was formed in older sites, with seeds dispersed mostly by animal and gravity (Pickett and McDonnell, 1989; Pierce and Cowling, 1991; Hammond and Brown, 1995).

With ecological development, species richness of seed bank increased at the three quarries. Species richness, ranging from 3 to 10 for younger sites (LT04, SO04 and SO06), which was similar with the results (6-10 species) in newly rehabilitated landfill (Lui, 1999), while the seed banks of older sites (TH94, LT98 and SO98) had 22-30 species, which was lower than 32-66 species in the seed banks in woodland (Lui, 1999). Low seed densities, ranging from 420 to 660 seeds m^2 for 0-5 cm depth and 120 to 470 seed m^2 for 5-10 cm depth, were also found on younger sites, which result was higher than seed densities of 191 seeds m^2 in landfill (Lui, 1999), but lower than seed densities of 761 seeds m^2 in a prairie in Kansas (Rice, 1989). The seed densities of older sites, which ranged from 1620 to 4346 seeds m^2, were lower than

that of woodland (5550 seeds m^2) (Lui, 1999). Therefore, ecological development favors the increase in species richness and seed density for the seed banks, as seeds from both on-site and off-site species are continuously accumulating in the soil.

Our results show a significant correlation in species richness and density with depth (Table 4.1). Overall species and seed numbers were lower in the lower layer than in the upper layer, which was consistent with other studies (e.g., Bossuye et al., 2002; Olano et al., 2002). It is evident that some woody species (e.g. *Melastoma candidum*, *Melastoma sanguineum* and *Desmodium heterocarpon*) form a long-term persistent seed bank, as they were recorded in the lower soil layer and deeply buried seeds are older than shallow ones (Thompson et al., 1997), which may be the effect of erosion in the rehabilitated quarries.

4.4.2 Relationship between vegetation and seed bank composition

Most studies of grasslands predominated by perennial grasses had found few similarities between the seed bank and the vegetation (Peco et al., 1998; Egan and Ungar, 2000). Our study also found there was no close relationship between the relative proportion of species in the seed bank and vegetation at the three quarries. The weak similarity between vegetation and seed bank was attributed to the great proportion of species which were absent from the vegetation, the seeds of which had a significant viability in the ground in relation to their strategies as opportunistic species

(Touzard et al., 2002). Species mainly from families of Compositae, Cyperaceae and Poaceae were predominant in the seed banks at the three quarries, most of which were ruderals. However, some annual ruderal plants were gradually excluded from the aboveground vegetation because of the closed canopy during ecological development, such as TH94, LT98, SO98 and SO01. In Finland, Kiirikki (1993) found that even after a period of abandonment of 21 years, the seed bank was still dominated by species common in the early stages of succession. Our results supported that seed banks contained seeds that had disappeared in the aboveground vegetation in early successional stages (Van Der Valk and Davis, 1976; Kiirikki, 1993). Another explanation of the dissimilarity between vegetation and seed bank comes from species that were only present in the vegetation but absent in the seed bank. During ecological development, many woody species naturally occurred in the understorey of the rehabilitated quarries; however these woody species could not contribute to seed bank because of their immaturity. In addition, some woody species identified as having a persistent seed bank did not always emerge as seedlings.

4.4.3 Woody species composition in the seed bank

Sixty four species were recorded in the seed bank of the three quarries and only twenty-two species belonged to woody species (Table 4.1). These 22 woody species were better represented at older sites (TH94, LT98 and SO98) (Fig. 4.1). In these

woody species, there were 6 exotic species, *Acacia auriculiformis*, *A. confusa*, *Casuarina equisetifolia*, *Mimosa pudica*, *Solanum torvum* and *Leucaena leucocephala*, among which the first three were trees planted and their seeds accumulated on-site in the seed banks. Other 16 native woody species naturally occurred in the quarries, in which *Melastoma sanguineum*, *Ficus hispida*, *Ficus variolosa*, *Rhaphiolepis indica*, *Celtis sinensis*, *Embelia laeta*, *Callicarpa longissima*, *M. candidum*, *Mallotus apelta* and *Psychotria asiatica* were dispersed by birds (Corlett, 1992; Zhuang, 1993; Hau and Corlett, 2002), and *Desmodium heterocarpon*, *Macaranga tanarius*, *Buddleja lindleyana* and *D. gangeticum* were dispersed by wind or rat (Corlett, 1992; Zhuang, 1993; Hau and Corlett, 2002). Although these woody species did not predominate in the quarry during the past ten years, they still could give some hints in selecting species for quarry revegetation. Our study suggests artificial planting some fast growing native species which have fruits to attract birds in the early years of rehabilitation and sowing some late successional species to increase the diveristy of soil seed bank and accelerate vegetation succession should be recommended in the older plantation.

4.5 Conclusions

Ruderal plants (*Ageratum conyzoides*, *Kyllinga brevifolia*, *Cynodon dactylon*, *Ageratum houstonianum* and *Digitaria heterantha*) were the top five species in terms

of relative abundance in soil seed banks in the three quarries. However, some ruderal plants were gradually excluded from the ecosystem during ecological development, and some perennial herbs and woody species were dominant. At the same time, species richness of seed bank increased with the increasing ages in the three quarries. Therefore, ecological development favors the increase in species richness and seed density for soil seed banks. Twenty two woody species were recorded in the seed bank of the three quarries and they were better represented in older sites. Although these woody species did not predominate in the rehabilitated quarries in the past ten years, they still could give some hints in selecting species for quarry revegetation.

Chapter 5 Soil Physical and Chemical Status

5.1 Introduction

Soil development is closely related to vegetation development in terrestrial ecosystems. Soil can provide macro- and micro- nutrients for normal plant growth and propagation, on the other hand, plants can return the nutrients through litter fall as well as root exudate and sloughing to surface soil. Soil development determines the success of ecosystem rehabilitation in degraded lands (Aber, 1990a and b).

In a closed quarry, one of the most important factors affecting ecosystem restoration is soil quality. Soil not only provides physical and chemical support for plant growth, but also biological characteristics for ecosystem structure and function. Therefore, specific soil properties on a degraded land determine which level of ecosystem can develop and how far this development will progress (Bradshaw, 1997). In Hong Kong, cover soil of rehabilitated quarries is usually imported from local borrow area and sometimes mixed with substandard materials. It is mainly derived from decomposing granitic, which has a relatively low soil quality (Chau and Lo, 1980; Webb, 1991; Chau and Marafa, 1999; Chau and Chan 2000; Chan, 2001). Because of its high availability and low price, it is widely used as the major natural soil material for local rehabilitation projects in Hong Kong (Jim, 1996). These granitic

soils are also vulnerable to erosion under heavy rains, above which natural vegetation was poorly developed (Flower et al., 1981; Jim, 2001).

At present, there are two general measures to solve the problems of poor soil properties. One is short term, in which fertilizers with high organic contents, N, P and K are applied to overcome nutrient deficiency (Bradshaw, 1998 and 2000). Biological improvement by planting fast growing and N-fixing species for soil development on degraded land is a natural process which can proceed without human aid (Bradshaw, 1997). Although the process is slow and development of the ecosystem can be unexpected in some occasions, the soil ameliorative effects of plantations are well studied. In Hong Kong, monoculture *Acacia* plantations aged 2-35 years was capable of ameliorating soil organic matter and N (Fung, 1995; Tsang, 1997; Au, 2001). Plantation tends to accumulate more biomass and nutrients in the litter and their root systems accelerate the buildup of organic matter through enhancement of aboveground litter production (Parrotta, 1992; Parrotta et al, 1997), thus contributing a faster restoration of the soil quality (Lugo, 1992).

The present experiment was carried out on the different phases for which they represent different ages of ecosystem development on the three quarries. By comparing soil physical and chemical properties of the study sites of different ages, it would provide more information on processes of soil development after revegetation

under subtropical climate.

5.2 Materials and methods

5.2.1 Sample collection

Soil sampling was carried out on TH, LT and SO in June-August 2007 by the systematic random sampling method. On each phase of the three quarries, six 30 m transects were randomly set. The sampling points were respectively set in 0 m, 10 m, 20 m and 30 m along the transect. 2.5 cm diameter soil cores were taken from 0-5 and 5-10 cm depths at each sampling point, and then were mixed into a composite sample respectively for two depths. There are total 6 soil samples for each depth taken from each site. Soil samples were transported in aseptic sealed plastic bags. Another sample was collected by soil coring at each sampling point to obtain an undisturbed core for the determination of bulk density and porosity.

5.2.2 Soil analysis

Soil samples collected were returned to the laboratory. Subsamples of fresh soils were passed through 0.5-mm sieve and stored at 4 ± 1°C in the refrigerator for the determination of mineral N and available P. The remaining samples were air-dried at room temperature for two weeks and passed through a 2-mm and 0.25-mm mesh size stainless steel sieve prior to laboratory analysis. The 2-mm sieved soil samples were used for the analysis of soil texture, pH, electrical conductivity and exchangeable

cations (K, Na, Ca, Mg), while the 0.25-mm sieved fractions were used for the determination of total N, organic C and total P.

5.2.2.1 Soil texture

Soil texture was determined by Bouyoucos hydrometer method (Allen, 1974), which measured the decrease in density of the suspension as soil particles settle. Fifty grams of 2 mm air dry soil was mixed with 5% Calgon solution (sodium hexametaphosphate). The mixture was stirred at high speed for 15 minutes and made up with water to 1,000 ml. Hydrometer reading was taken at 4 minutes 48 second and 5 hours after start of sedimentation for calculation of silt plus clay and clay contents, respectively (Grimshaw, 1989). The soil textural class was determined following the USDA classification system.

5.2.2.2 Bulk density and total porosity

Soil samples collected were oven dried at 105°C for 3 days to determine the oven-dried weight. Volume of the soil core was equal to inner volume the soil corer. Soil bulk density could be calculated as the following formula (Blake and Hartge, 1986):

Bulk density (Mg m^{-3}) = Soil oven-dried weight / soil core volume

Total porosity of the soil was calculated with the following formula:

Total porosity (%) = (1-Bulk density/ Particle density) × 100% (Landon, 1991)

where particle density is equivalent to 2.65 Mg m^{-3}

5.2.2.3 Soil pH and electrical conductivity

Soil pH and electrical conductivity were determined using a pH meter (Orion Research Inc., Boston, USA) and conductivity meter (Orion Research Inc., Boston, USA). Ten grams of 2 mm air dry soil with distilled water at a soil: water ration of 1:2.5 (w/v) were mixed, which then were shaken for 10 minutes and left to stand for 30 minutes. The supernatant liquid was measured using the meter.

5.2.2.4 Organic C

Soil organic C was determined by an automated TOC Analyzer (Shimazu, TOC-500, Japan). Fifty microgram of 0.25-mm air dry soil was used.

5.2.2.5 N

Total Kjeldhal N was determined by Kjeldhal digestion method. One gram of 0.25-mm air dry soil was digested in concentrated sulphuric acid at 360°C, with the addition of Kjeldhal tablets (including copper sulphate and potassium sulfate) to catalyse the reaction (Bremner and Mulvaney, 1982). TKN content was determined based on the salicylate-hypochlorite method using a SAN^{plus} Segmented Flow Analyzer (Skalar Analytical B.V., Breda, Netherlands).

Extractable NH_4-N and NO_3-N were determined by salicylate-hypochlorite

method and cadmium reduction method respectively. Ten grams of 0.5-mm sieved fresh soil were extracted with 2 M potassium chloride at 150 rpm for 1 hour (Keeney, 1982). The extract was filtered through Whatman 6 filter paper. The filtrate was determined by using a SAN^{plus} Segmented Flow Analyzer (Skalar Analytical B.V., Breda, Netherlands).

C:N ratio was obtained by dividing organic C by TKN.

5.2.2.6 P

The digest for TKN determination was also used for TP determination. TP content was determined by molybdenum blue method using a SAN^{plus} Segmented Flow Analyzer (Skalar Analytical B.V., Breda, Netherlands).

Extractable P was determined by molybdenum blue method by using a SAN^{plus} Segmented Flow Analyzer (Skalar Analytical B.V., Breda, Netherlands) after extraction with Troug's reagent (diluted and buffered sulphuric acid) at 150 rpm for 30 minutes (Allen, 1974).

5.2.2.7 Extractable cations

Five grams of 2-mm air-dried soil were extracted with 100 ml 1 M ammonium acetate at pH 7 (Knudsen et al., 1982). After shaking for one hour, the extract was filtered through Whatman 6 filter paper. The filtrate was then analyzed for K, Ca, Na and Mg using a Varian Spectr AA-300 Atomic Absorption Spectrophotometer.

5.2.3 Statistical analysis

The soil physical and chemical properties were summarized using principal component analysis (PCA). The relationships between plant parameters and soil properties were analyzed using redundancy analysis (RDA) (van den Wollenberg, 1997; Ramette, 2007). In RDA, soil properties were used as species and plant richness and coverage were used as environmental variables, which allowed the relationships between the plant variables and soil parameters to be directly compared. With the Monte Carlo permutation test (number of permutations), the significance of the plant variables in accounting for the observed variance of the soil parameters could be assessed with *P*-values (Leps and Smilauer, 2003). In the RDA diagram, the arrow of variables pointing in the same direction indicated positive correlation and opposite direction denoted negative correlation, and perpendicular direction was uncorrelated. The length of the arrow was a measure of the relative importance of the plant variables in explaining variances of the soil parameters.

The treatment effects were carried out with one-way analysis of variance (ANOVA), and the Tukey's Honestly Significant Difference (HSD) test at the 5% level was used to determine the statistical significance between sites. The statistical difference between soil depths was separately tested by the paired-samples t-test. All data (except RDA) were analyzed by Statistical Package for the Social Science (SPSS)

for Windows Release 12.0 and RDA was run with the Canoco 4.5 software (Centre for Biometry, Wageningen, Netherlands).

5.3 Results

5.3.1 Soil physical properties

5.3.1.1 Bulk density and porosity

High bulk density of cover soil is a common problem in the three quarries, because of compaction by operation of heavy machinery. Soil of 5-10 cm in LT04 and those of both depths in SO06 had bulk density greater than 1.80 Mg m^{-3}, while bulk densities of other sites were within the range from 1.22 Mg m^{-3} in SO98 to 1.73 Mg m^{-3} in SO04 (Table 5.1).

The corresponding values for total porosity were also found to be low in younger sites, for example LT04, SO04 and SO06. Older sites (TH94, LT98 and SO98) had higher porosity than LT01 and SO01. Soil total porosity of all sites was within the critical range for plant growth from 53.9% in SO98 to 26.0% in SO06 (Table 5.1).

5.3.1.2 Soil texture

Soils in all eight sites were classified as sandy loam at both depths, with very high contents of sand and relatively low silt and clay (Table 5.1). The textural type was coarser in the phases of SO than those in LT with respect to the higher sand fraction. Clay content was comparably low at the eight quarry sites. Such a textual

composition indicated that most pores were large and easily emptied by gravitational drainage. The development time of the eight sites at three quarries is too short to reduce the differences among soils physically.

Table 5.1 Physical properties of cover soil (top 10 cm) in the three quarries

Sites	Bulk density ($Mg\ m^{-3}$)	Total porosity (%)	Clay (%)	Silt (%)	Sand (%)	Soil textural class
0-5 cm						
TH94	1.33cd	49.8ab	9.61b	7.87b	82.5a	Loamy sand
LT98	1.35cd	49.1ab	12.7ab	9.24b	78.1ab	Loamy sand
LT01	1.44c	45.7cd	12.4ab	15.8a	71.8b	Loamy sand
LT04	1.70b	35.9d	12.3ab	7.03b	80.7a	Loamy sand
SO98	1.22d	53.9a	10.2ab	9.26b	80.6a	Loamy sand
SO01	1.39c	47.6ab	10.0ab	6.83b	83.2a	Loamy sand
SO04	1.54b	41.9abc	13.4a	7.84b	78.8ab	Loamy sand
SO06	1.85a	30.2d	11.6ab	4.83c	83.6a	Loamy sand
5-10 cm						
TH94	1.51e	43.0c	9.02b	5.89b	85.1a	Loamy sand
LT98	1.48e	44.2b	14.8a	7.82b	77.4ab	Loamy sand
LT01	1.59d	40.0f	11.2ab	14.5a	74.3b	Loamy sand
LT04	1.84b	30.6a	12.3ab	8.69b	79.0ab	Loamy sand
SO98	1.43f	46.0b	11.7ab	8.57b	79.8ab	Loamy sand
SO01	1.48e	44.2e	11.7ab	7.45b	80.8ab	Loamy sand
SO04	1.73c	34.7g	11.8ab	5.31b	82.9a	Loamy sand
SO06	1.96a	26.0	11.8ab	4.87b	83.4a	Loamy sand

Mean values followed by the same letter within a column are not significantly different at p=0.05 level for the soils at each depth according to Tukey's HSD test

5.3.2 Soil chemical properties

5.3.2.1 pH and electrical conductivity

Soils were strongly acidic to moderately acidic in reaction, with pH value ranging from 4.16 to 6.21 in 0-5 cm depth and 3.76 to 5.80 in 5-10 cm depth (Table 5.2). Soils from LT04, SO04, SO06 are moderately acidic, and TH94, LT98, LT01, SO01 were strongly acidic.

Electrical conductivity of cover soil varied from 53.8 μs cm^{-1} (SO06) to 148.8 μs cm^{-1} (SO98) at 0-5 cm, and from 38.2 μs cm^{-1} (SO06) to 82.4 μs cm^{-1} (SO98) at 5-10 cm (Table 5.2). Higher values were detected on SO98, SO01 and TH94, in which vegetation growth encourages the accumulation of ions in soil.

5.3.2.2 Organic C

Soil organic C contents of all eight phases in the three quarries were very low and accumulated slowly along time. In 0-5 cm soil, SO98 had the highest content of organic C (28.1 g kg^{-1}), followed by TH94 (27.1 g kg^{-1}) and SO01 (20.0 g kg^{-1}). However, low content of organic C occurred at LT04 (11.9 g kg^{-1}), SO04 (12.9 g kg^{-1}) and SO06 (6.23 g kg^{-1}), which were younger in terms of rehabilitation age (Table 5.2). In 5-10 cm soil, SO98, TH94 and SO01 had higher content of organic C, while SO04 and SO06 had lower content. At all eight phases, the 0-5 cm soil contained higher content of organic C than 5-10 cm soil. Intra-layer differences were significantly

found in all sites (t-test, $p<0.05$). The accumulation of organic C in 5-10 cm depth increased with the age of the plantations. LT01 had 3.52 times higher organic C at 0-5 cm than at 5-10 cm, which was higher than those of TH94 (2.53 times) and LT98 (2.45 times), while SO04 had 2.79 times higher organic C at 0-5 cm than at 5-10 cm, which was higher than those of SO98 (2.29 times) and SO01 (2.02 times)

5.3.2.3 N and C:N ratio

In all soil nutrients, N is required in the greatest amount for plants and it is the nutrient element most often limiting. Only very low levels of TKN were present in the soils of the eight sites (Table 5.2). In 0-5 cm, SO98 had the highest content of TKN (2.41 g kg^{-1}), followed by TH94 (2.01 g kg^{-1}) and SO01 (1.56 g kg^{-1}). SO06 had the lowest content (0.49 g kg^{-1}), and the differences between other phases were not significant. In 5-10 cm, SO98, TH94 (0.87 g kg^{-1}) and SO01 (0.85 g kg^{-1}) had higher contents of TKN, and other phases did not show significant difference. In all eight phases, 0-5 cm soils had higher content of TKN than 5-10 cm soils (t-test, $p<0.05$). Intra-layer differences showed that LT01 and SO04 had 2.72 times and 2.79 times respectively higher TKN at 0-5 cm than at 5-10 cm, which were higher than those of TH94 (2.31 times), LT98 (2.37 times), SO98 (2.36 times) and SO01 (1.84 times).

Table 5.2 Chemical properties of cover soil (top 10 cm) in the three quarries (n=6)

Site	pH	EC ($\mu s\ cm^{-1}$)	OC ($g\ kg^{-1}$)	TKN ($g\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)	TP ($g\ kg^{-1}$)	Ext. P ($mg\ kg^{-1}$)	Ext. K ($mg\ kg^{-1}$)	Ext. Ca ($mg\ kg^{-1}$)	Ext. Mg ($mg\ kg^{-1}$)	Ext. Na ($mg\ kg^{-1}$)
0-5 cm												
TH94	4.16d	107ab	27.1a	2.01a	6.88b	9.80a	0.35a	12.3c	69.4c	791bc	40.5b	32.0c
LT98	4.62c	62.4cd	14.7bc	1.02bc	6.54b	4.84c	0.22bc	15.5bc	93.4bc	600c	31.4bc	35.2c
LT01	4.95c	69.7cd	14.3bc	0.98bc	6.91b	4.81c	0.21c	13.7bc	63.5c	955b	30.1c	37.1c
LT04	6.10a	85.0bc	11.9bc	0.96bc	7.51b	3.39cd	0.27abc	21.9a	73.0c	558c	32.6bc	37.8c
SO98	5.63b	149a	28.1a	2.41a	7.24b	7.47ab	0.37a	15.1bc	162a	1183a	75.5a	97.2a
SO01	5.18b	101bc	20.0ab	1.56ab	7.14b	5.33bc	0.32ab	15.7bc	104b	726bc	41.0b	84.7ab
SO04	5.24b	57.7cd	12.9bc	0.99bc	11.7a	3.15cd	0.29abc	15.9b	106b	523cd	41.5b	82.7ab
SO06	6.21a	53.8d	6.23c	0.49c	7.28b	1.86d	0.31abc	17.1b	90.4bc	466d	37.3bc	73.8b
5-10 cm												
TH94	3.90c	69.1a	10.7ab	0.87a	6.73b	3.41ab	0.29a	14.4b	47.4bc	527a	37.3b	20.6b
LT98	4.30b	46.2bc	5.98bc	0.43bc	6.71b	2.11cd	0.23b	14.0b	53.4bc	312b	26.8e	21.2b
LT01	4.54b	43.7bc	4.06c	0.36c	6.24b	2.39cd	0.18c	14.8b	42.3c	622a	26.0e	22.7b
LT04	5.66a	53.7bc	5.20c	0.38c	6.49b	1.66de	0.28a	19.0a	49.7bc	322b	28.7de	19.9b
SO98	4.64b	82.4a	13.9a	1.02a	6.60b	3.98a	0.30a	15.5b	100a	675a	43.6a	69.4a
SO01	3.76c	62.9ab	11.3a	0.85ab	6.91b	2.89bc	0.27a	15.7b	58.6bc	179b	35.4bc	69.6a
SO04	4.65b	40.8cd	4.63c	0.34c	6.59b	1.57de	0.23b	15.1b	69.2b	272b	36.3b	71.6a
SO06	5.80a	38.2d	3.12c	0.24c	10.7a	0.99e	0.22b	15.3b	64.4bc	313b	31.9cd	64.2a

Mean values followed by the same letter within a column are not significantly different at p=0.05 level for the soils at each depth according to the Tukey's HSD test

Linear regression was performed to ascertain the relationship between TKN and soil organic matter at three quarries and to assess the possible source of N. All the data from the two depths were pooled for the analysis (Table 5.3). All the regression coefficients (R^2) were significant at $p<0.01$, which indicated a significant relationship between TKN and soil organic matter. It was expected because SOM is the storehouse of TKN in unfertilized ecosystems. The regression coefficient was the highest in SO98 (R^2 =0.992). However, the regression coefficient was lower in SO01 than other sites, which implied that sources other than SOM had also contributed to soil TKN on-site or nitrogen was as a limiting factor.

Table 5.3 Linear regression of TKN (%, y) with SOM (%, x) in the three quarries

	y = ax + b	R^2	p
TH94	y = 0.037x + 0.221	0.973	< 0.01
LT98	y = 0.040x + 0.021	0.981	< 0.01
LT01	y = 0.038x + 0.066	0.957	< 0.01
LT04	y = 0.050x + 0.060	0.964	< 0.01
SO98	y = 0.046x + 0.151	0.992	< 0.01
SO01	y = 0.048x - 0.087	0.905	< 0.01
SO04	y = 0.044x + 0.000	0.983	< 0.01
SO06	y = 0.042x + 0.020	0.966	< 0.01

Most plants absorb mineral N (NH_4-N and NO_3-N) from the soil for their growth, the concentrations of which followed the different pattern of soil organic C and TKN in the quarry sites. In 0-5 cm soils, SO04 and SO06 had the higher concentration of NH_4-N, but other phases did not show any significant differences (Table 5.2). In 5-10 cm soils, there were no significant differences among all eight phases. SO04 and SO06 had the higher NH_4-N at 0-5 cm depth than that of 5-10 cm, but the difference between the two depths is not significant.

The pattern of NO_3-N was different from NH_4-N. In 0-5 cm soils, TH94, SO98 and SO01 had higher concentration of NO_3-N, and younger sites (SO04, LT04 and SO06) were low in NO_3-N (Table 5.2). In 5-10 cm soils, the similar results were found as that of 0-5 cm.

C:N ratio fluctuated substantially among the eight soils in three quarries. In 0-5 cm depth, the C:N ratio of soils ranged from 11.5 of SO98 to 14.6 of LT01. And in 5-10 cm soils, the C:N ratio ranged from 11.24 of SO98 to 13.90 of LT98 (Table 5.4). TH94, LT98, LT01 and SO98 had higher C:N ratio at 0-5 cm depth than at 5-10 cm depth, which implied that older sites had higher percentage of organic C at 0-5 cm depth soils than 5-10 cm depth. However, LT04, SO01, SO04 and SO06 had higher C:N ration at 5-10 cm depth than at 0-5 cm depth, which could be explained that younger sites had lower percentage of total N at 5-10 cm than 0-5 cm soils.

Table 5.4 C:N ratio of the soils in the three quarries

	TH94	LT98	LT01	LT04	SO98	SO01	SO04	SO06
0-5 cm	13.3	14.4	14.6	12.4	11.5	13.0	12.9	12.6
5-10 cm	12.3	13.9	12.3	13.4	11.2	13.4	13.5	12.9

5.3.2.4 P

The highest soil TP content was again found in SO98 (0.37 g kg^{-1}), followed by TH94 (0.35 g kg^{-1}) and SO01 (0.32 g kg^{-1}) at 0-5 cm depth. The newly rehabilitated sites (SO04 and SO06) had high content of total phosphorus. The low concentration of TP occurred at LT98 and LT01. At 5-10 cm depth, the trend was similar as the results of 0-5 cm depth.

The soils contained appreciably low levels of extractable P (Table 5.2). In the uppermost layer, LT04 had the highest extractable P (21.9 mg kg^{-1}), but there was no significant difference among other phases in the three quarries. The trend for the lower layers was similar to the upper layer. There was a slight increase in TH94, LT01, SO98, SO01, and a slight decrease in LT98, LT04, SO04 and SO06 with depth of the soils.

Totally, younger phases (LT04 and SO06) had higher extractable P than older phases (TH94, LT98 and SO98). A large amount of extractable P could have been complexed into unavailable form under soil pH of 3.7- 4.5. In this study, the older phases had more acidic soil than the new phases, so it was not surprising that the new

phases had the higher concentration of extractble P.

5.3.2.5 Extractable cation contents

The extractable cation contents of soils among the three quarries had the similar trend. Contents of the four extractable cations were higher in SO than in TH and LT (Table 5.2). SO98 had the highest extractable K, Ca, Mg and Na at the two depths. The older phases (TH94, LT98, LT01 and SO01) had relatively higher concentration of the four cations, while younger sites (LT04, SO04 and SO06) had lower concentrations. The concentration of extractable Ca was the highest among four extractable cations, and the concentration of extractable Na was low.

5.3.3 PCA analysis for the soil physical and chemical properties

Principal component analysis (PCA), using physical and chemical parameters of two soil depths, revealed a scattered distribution for all sites (Figures 5.1). For 0-5 cm soils, the first principal component (PC1) accounted for more than 40% of the variance, and the second accounted for about 20% for all soil samples (Figures 5.1a). PC1 was accounted mostly by bulk density, total organic C, TKN, TP, extractable NO_3^- and electrical conductivity, while PC2 was by extractable sodium, extractable K and extractable Mg. The biplot of PCA clearly identified four groups, i.e. TH94; LT98 and LT01; SO98 and SO01; LT04, SO04 and SO06. PC1 clearly separated soils from older sites and younger sites. PC2 mainly separated soils of SO from TH and LT.

For 5-10 cm soils, the first and second principal components accounted for more than 60% of the variance (Figures 5.1b). PC1 was accounted mostly by electrical conductivity, bulk density, total organic C, TKN and TP, while PC2 was by silt, sand and extractable Na. The biplot of PCA also shows that four groups could be identified, i.e. TH94; LT98, LT01 and LT04; SO98 and SO01; SO04 and SO06. PC1 clearly separated soils from SO and both TH and LT, while PC2 mainly separated soils from older sites and younger sites. The results show that the distribution for the soils of different phases among the three quarries was similar at two depths.

5.3.4 RDA of plant community and soil properties

The results of RDA show that all plant community structure (species richness and coverage) significantly correlated with soil properties (physical and chemical parameters) (Figure 5.2). Significant parameters included woody species richness (P=0.002), grass richness (P=0.002), native species richness (P=0.002), woody species coverage (P=0.002), and grass coverage (P=0.038). Electrical conductivity, total porosity, organic C, TKN, TP, extractable Ca and extractable NO_3-N were positively correlated with woody species richness and native species richness. Bulk density, pH, extractable contents of NH_4-N and P were positively correlated with grass coverage, while they had negative correlations with grass richness and woody species coverage.

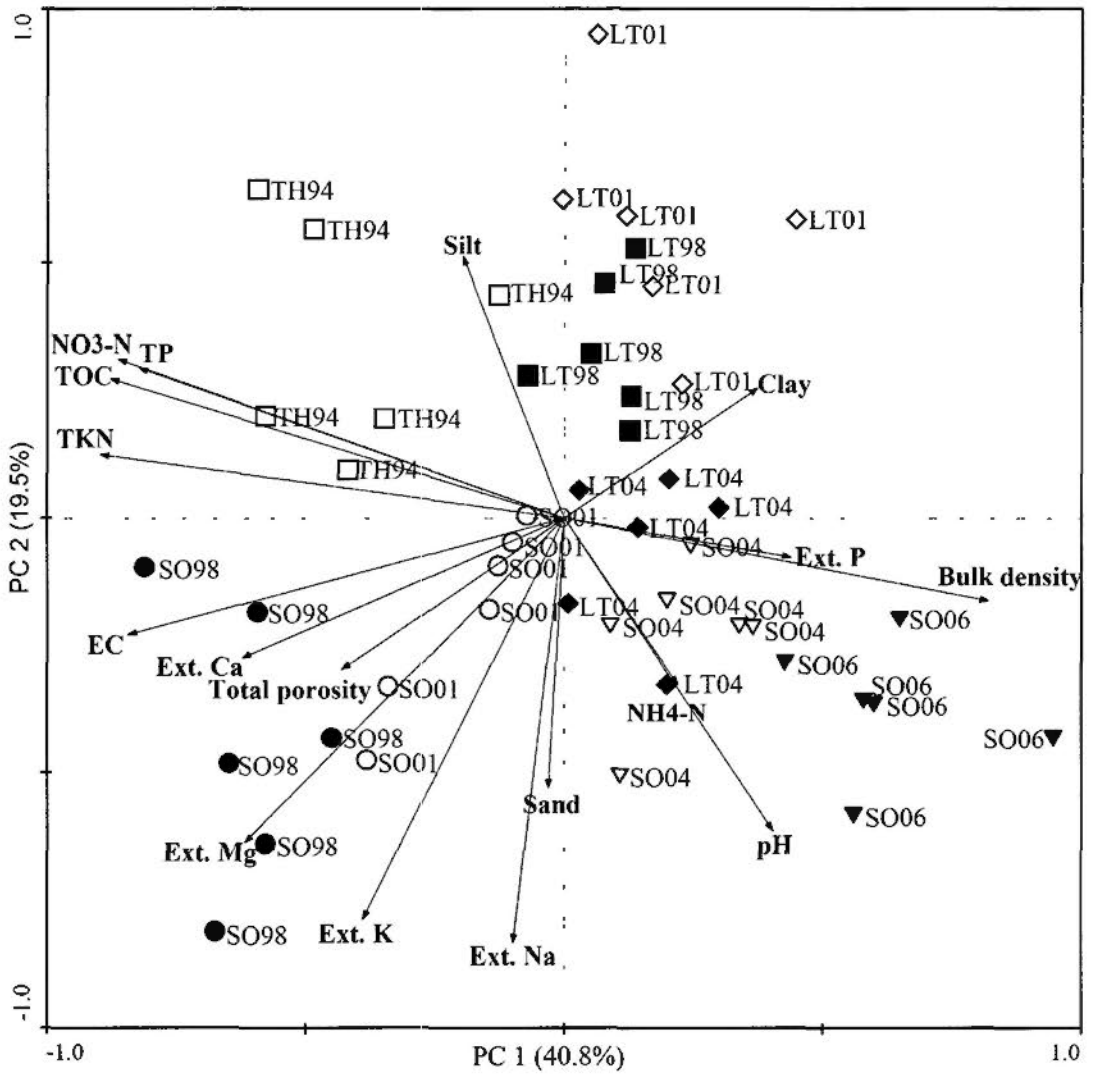


Figure 5.1a Biplot of principal component analysis (PCA) for soil physical and chemical properties at 0-5 cm depth for the soils in the three quarries

Abbreviations: EC: electrical conductivity, OC: organic C, TKN: total Kjeldhal N, TP: total P, NH_4-N: extractable NH_4-N, NO_3-N: extractable NO_3-N, Ext. P: extractable P, Ext. K: extractable K, Ext. Ca: extractable Ca, Ext. Mg: extractable Mg, Ext. Na: extractable Na.

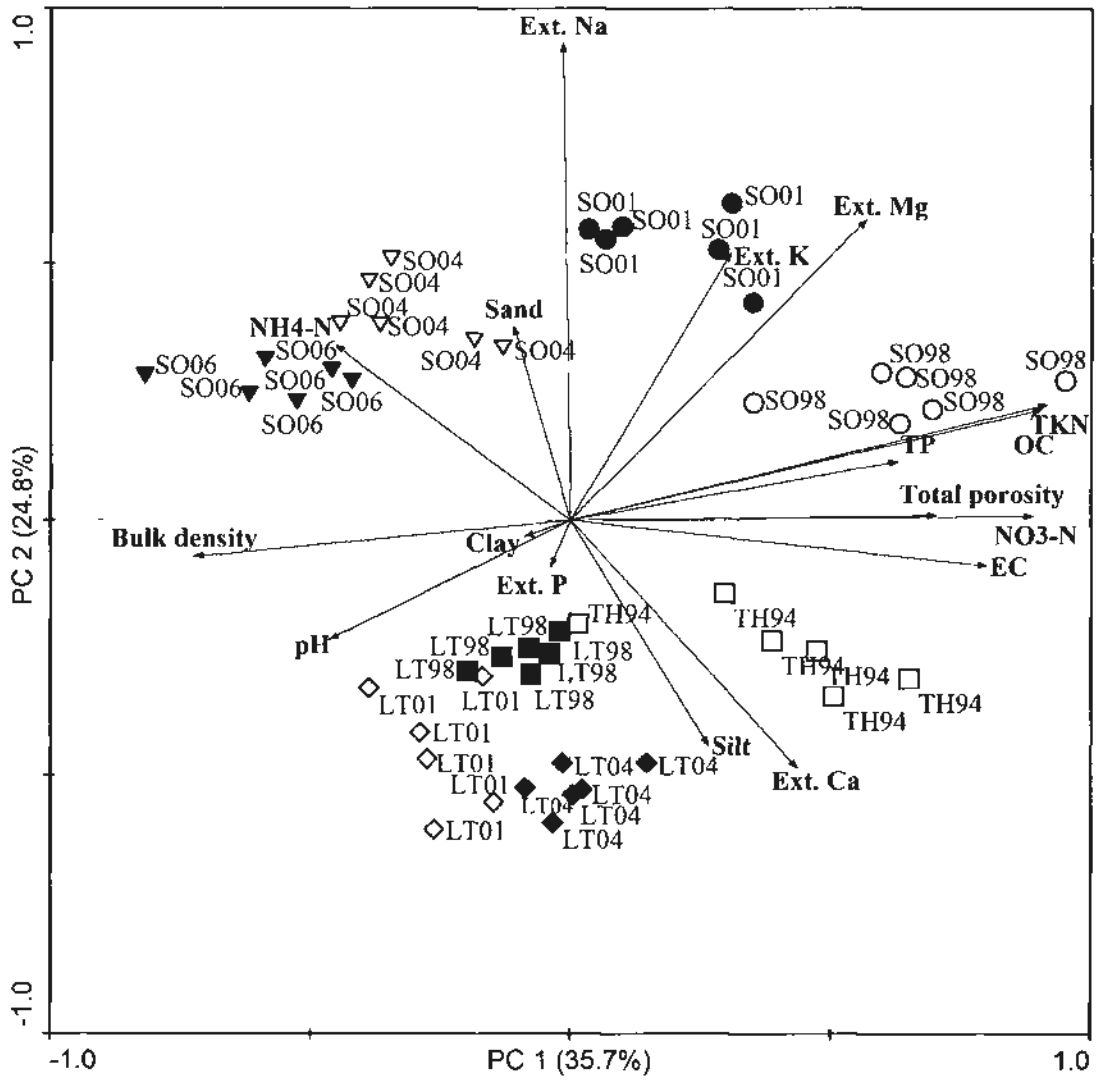


Figure 5.1b Biplot of principal component analysis (PCA) for soil physical and chemical properties at 5-10 cm depth for the soils in the three quarries

Abbreviations: EC: electrical conductivity, OC: organic C, TKN: total Kjeldhal N, TP: total P, NH_4-N: extractable NH_4-N, NO_3-N: extractable NO_3-N, Ext. P: extractable P, Ext. K: extractable K, Ext. Ca: extractable Ca, Ext. Mg: extractable Mg, Ext. Na: extractable Na.

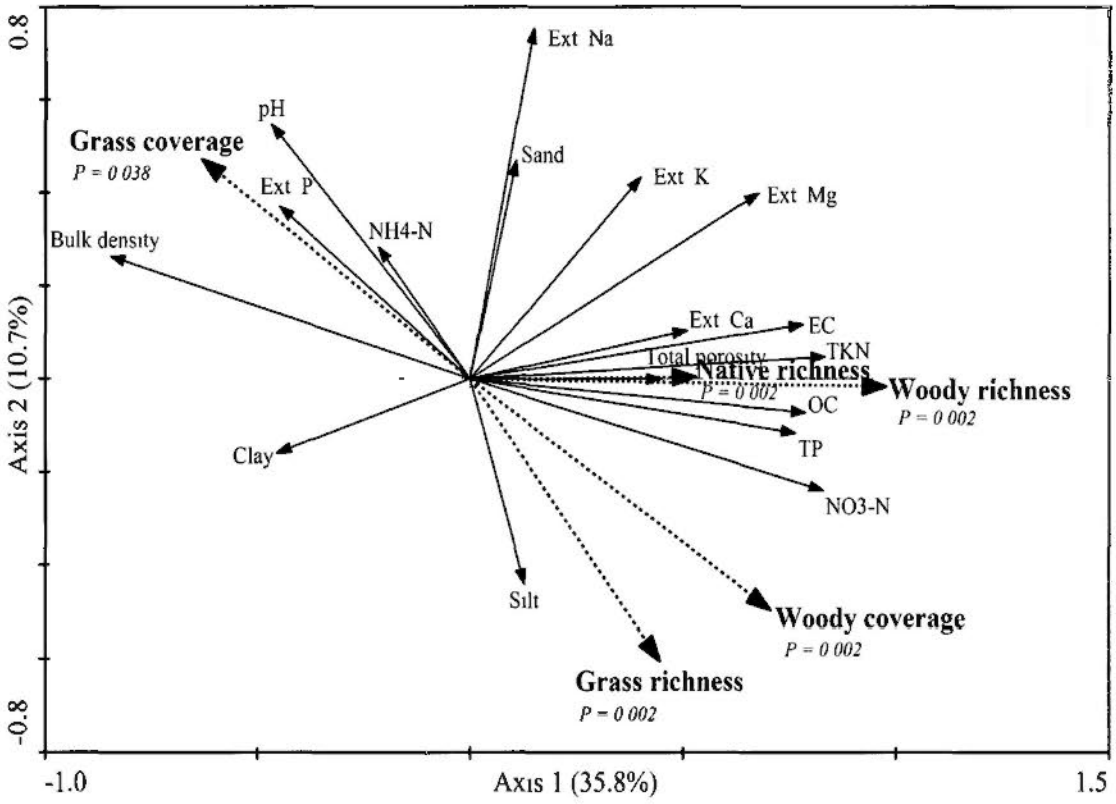


Figure 5.2 Biplot of the first two RDA axes of plant community structure and soil parameters in the three quarries. The soil parameters (expressed as response variables in the RDA analysis) were presented as solid line vectors, and the plant parameters (explanatory variables) were presented as dotted line vectors

Abbreviations: EC: electrical conductivity, OC: organic C, TKN: total Kjeldhal N, TP: total P, NH_4-N: extractable NH_4-N, NO_3-N: extractable NO_3-N, Ext. P: extractable P, Ext. K: extractable K, Ext. Ca: extractable Ca, Ext. Mg: extractable Mg, Ext. Na: extractable Na.

5.4 Discussion

5.4.1 Soil nutrient status and its comparison with other degraded sites

The retrospective method was used to study the development of soil in rehabilitated quarries. It was difficult to truly describe the ameliorative effects on the soils in each plantation during different rehabilitation periods, because of the absence of zero-time approach. Therefore, an indirect assessment was used to compare the results with other studies. The chemical properties of the soils were compared against the ratings for topical soils described by Landon (1991). Only the top 5 cm soil was included in the comparison (Table 5.5). The soils were strongly to moderately acidic in reaction. The contents of organic C, TKN and extractable P were all within the low level for all eight phases in the three quarries. However, the content of extractable Mg was within medium rating, and the soils were deficient in extractable K and Ca.

The present findings (top 5 cm soil) were also compared with the soil properties of locally restored borrow areas (Tsang, 1997), restored landfills (Lui, 1999), fire-disturbed hills (Marafa and Chau, 1999), *Pinus massoniana* woodland (Tsang, 1997) and Feng Shui forest (Marafa and Chau, 1999) (Table 5.6). Soils of all the three quarries mostly resembled recently developed borrow area and landfills, which were acidic, and deficient in organic carbon and major nutrients.

Overall, the soils among the three quarries had a higher pH (4.16-6.21) than that

of borrow area and fire-disturbed hills (Table 5.6). Acidity was unlikely affected by age of the vegetation because the soils underneath *Pinus* woodland aged 50 years and Feng Shui forest aged 200 years had pH of 4.33 and 4.40 respectively. The plantation soils in the three quarries contained much higher organic C (0.62-2.81%) than soils in the borrow areas (0.18-0.37%) and landfills (0.23-1.64%), but the contents were lower than those of the *Pinus* woodland and Feng Shui forest. TKN had a similar trend as organic C with comparison with other degraded lands, but the contents in older sites (TH94, LT98, SO98 and SO01) were higher than that of *Pinus* woodland aged more than 50 years. This was perhaps attributable to the different exotic species adopted in the quarries. *Casuarina equisetifolia* and *Acacia* spp. which are N_2-fixing species were major species planted in the three quarries. It was well documented that these species can fix atmospheric N and tend to accumulate more N in the soil than non-nitrogen-fixers (Kahindi et al., 1997; Crews and Peoples, 2005). Overall mineral N content (9.14-14.71 $\mu g\ g^{-1}$) was lower than that of landfills (14.1-30.8 $\mu g\ g^{-1}$) and woodlands and Feng Shui forest (28.8-30.8 $\mu g\ g^{-1}$), but much higher than the borrow areas (2.85-5.48 $\mu g\ g^{-1}$). The trends for TP, extractable P and four extractable cations were not obvious when compared among different degraded lands, but extractable P and extractable Mg were lower than those of Feng Shui forest.

Table 5.5 Comparison of the soils against critical levels described by Landon (1991)

Parameters	Rating*			Present study#								Remarks
	Low	Medium	High	TH94	LT98	LT01	LT04	SO98	SO01	SO04	SO06	
pH	<5.5	5.5-7.0	>7.0	4.16	4.62	4.95	6.10	5.63	5.18	5.24	6.21	Strongly acidic
Organic C (%)	<4	4-10	>10	2.71	1.47	1.43	1.19	2.81	2.00	1.29	0.62	Low
TKN (mg g^{-1})	<2	2-5	>5	2.01	1.02	0.98	0.96	2.41	1.56	0.99	0.49	Low to medium
Extractable P (μg g^{-1})	<20	20-40	>40	12.3	15.5	13.7	21.9	15.1	15.7	15.9	17.1	Low
Extractable K (μg g^{-1})	<78.2	78.2-235	>235	69.4	93.4	63.5	72. 9	161.8	104.0	105.9	90.4	Low to medium
Extractable Ca (μg g^{-1})	<800	800-2000	>2000	791.2	600	955	558	1183	726	523	466	Low to medium
Extractable Mg (μg g^{-1})	<30	30-60	>60	40.5	31.4	30.1	32.6	75.5	41.0	41.5	37.3	Medium
Extractable Na (μg g^{-1})	-	-	>230	32.0	35.1	37.1	37.8	97.2	84.7	82.7	73.8	Normal

* Rating after Landon (1991)

Values are contents of the 0-5 cm soil layer (n=6)

Table 5.6 Chemical properties of cover soil in the three quarries and other degraded lands in Hong Kong

	Present study								Tsang, 1997a				Lui, 1999b				Marafa and Chau, 1999c		
	TH94	LT98	LT01	LT04	SO98	SO01	SO04	SO06	BS	R95	R94	TTE	G97	G96	W95	W92	NB	OB	MTL
Site age	13	9	6	3	9	6	3	1	0	1	2	>50	1	2	3	6	0	6	>200
pH	4.16	4.62	4.95	6.10	5.63	5.18	5.24	6.21	4.49	4.89	4.48	4.33	5.32	5.00	5.65	6.39	4.90	4.57	4.40
Organic C (%)	2.71	1.47	1.43	1.19	2.81	2.00	1.29	0.62	0.18	0.34	0.37	3.61	0.23	0.25	1.25	1.64	-	-	4.06
TKN (mg g^{-1})	2.01	1.02	0.98	0.96	2.41	1.56	0.99	0.49	0.01	0.01	0.01	1.40	0.04	0.04	0.13	0.17	0.21	0.28	3.70
Extractable NH_4-N (μg g^{-1})	6.88	6.54	6.91	7.51	7.24	7.14	11.7	7.28	2.56	5.33	4.11	27.9	11.1	17.3	18.6	13.6	6.60	14.8	11.3
Extractable NO_3-N (μg g^{-1})	9.80	4.84	4.81	3.39	7.47	5.33	3.15	1.86	0.29	0.15	0.68	0.84	3.02	3.50	3.91	17.2	4.10	9.70	20.6
TP (mg g^{-1})	0.35	0.22	0.21	0.27	0.37	0.32	0.29	0.31	trace	0.01	0.01	0.01	0.01	0.01	0.11	0.25	0.20	0.30	-
Extractable P (μg g^{-1})	12.3	15.5	13.7	21.9	15.1	15.7	15.9	17.1	trace	26.62	3.02	14.7	19.2	19.4	20.1	21.4	-	-	56.4
Extractable K (μg g^{-1})	69.4	93.4	63.5	73.0	162	104	106	90.4	23.5	46.9	23.5	39.1	49.3	56.4	65.4	116	82.1	66.5	70.4
Extractable Ca (μg g^{-1})	791	600	955	558	1183	726	523	466	28.1	269	140	253	105	7.91	32.4	120	80.2	96.2	172
Extractable Mg (μg g^{-1})	40.5	31.4	30.1	32.6	75.5	41.0	41.5	37.3	51.0	26.7	7.29	26.7	21.1	25.8	43.3	157	17.0	41.3	82.6
Extractable Na (μg g^{-1})	32.0	35.2	37.1	37.8	97.2	84.7	82.7	73.8	4.59	6.89	4.59	-	27.1	25.6	11.7	24.5	6.89	16.1	-

a Soil from Tai Tong Borrow Area (BS: bare soil; R94 and R95: soil under mixed plantations planted in 1994 and 1995 respectively; TTE: *Pinus massoniana* woodland at Tai Tong East Borrow Area) (Tsang, 1997)

b Soil from four phases of Pillar Point Valley Landfill (G96 and G97: grassland with hydroseeding in 1996 and 1997; W92 and W95: woodland with tree planted in 1992 and 1995) (Lui, 1999)

c Soil from two fire-disturbed sites on Tai Mo Shan (NB: new burnt site; OB: old burnt site; MTL: Mui Tsz Lam feng shui forest) (Chau and Marafa, 1999)

5.4.2 Soil development in rehabilitated quarries

The problem of strong acidity in soils was serious in south China and Hong Kong (Yu, 1990; Li et al., 1996). In this study, soils were strongly acidic to moderately acidic in reaction. Cover soils of the three quarries were originated from decomposed granite which is acidic in nature. Soil acidity could thus be an inherent nature of the parent rock. In addition, vegetation development can acidify soil by uptake and redistribution of the cationic bases (Jobbagy and Jackson, 2003; Duan et al., 2004). Some studies showed that the process of acidification was linked to the process of organic matter accumulation (Berendse et al., 1998; Sykora et al., 2004). This could explain the more acidic soil in older sites than younger sites in the three quarries.

Low cation nutrient and their limited changs in soils were prevalent in tropical and subtropical areas, probably due to the weathering of parent materials and leaching of soluble nutrients (Yu, 1990; Li et al., 1996). This study would focus on the discussion of soil organic carbon and TKN, which are expected to change with age of the plantations along the vegetation gradient. In out study, all soils were assumed to be substandard soils with poor organic matter and nutrient contents (Table 5.5). Vegetation developed on such soil should overcome the problems of nutrient deficiency and drought due to the low water holding capacity. Hydroseeding and

planting exotic trees could establish quick vegetation coverage on the bare ground. The fast growing vegetation coverage could stabilize soil structure and ameliorate extreme microclimate of the exposed soil surface. At the same time, plant litter input also led to the accumulation of nutrient and organic matter in the surface soil. Our results show that organic C, TKN and TP increased with the increasing rehabilitation age at the two depths in the studied quarries (Figures 5.1). This was consistent with the findings from other quarries, where significantly higher C and N were accumulated in the older sites (Sourkova et al., 2005; Pietrzykowski and Krzaklewski, 2007). RDA shows organic C, TKN and TP are significantly correlated with richness of woody species and grass species (Figure 5.3). On the other hand, the intra-layer differences of organic C and TKN in the older plantations (TH94, LT98, SO98) were lower than those in the younger sites (LT01 and SO04), which was expected to narrow down with increasing age of the plantations (Kong, 2003). With the secondary succession after planting exotic species in the quarries, increasing species richness had positive effects on organic matter accumulation via continuous litter production and root decay (Berendse et al., 1998; Brady and Weil, 1999). Diverse and higher litter production and longer time for organic matter accumulation in older quarries were suggested to be the reason for the higher organic C, TKN and TP. In addition to high amount of litter production, modified microclimate in the quarries by vegetation

coverage also favored the accumulation of organic matter via enhanced humification (Torreta and Takeda, 1999; Deng et al., 2009). RDA also shows that woody species coverage has a positive effect on organic C and TKN and TP (Figure 5.2).

Tree species commonly employed in restoring degraded land in Hong Kong are usually exotic pioneer tree species, which are prolific litter producers (Chong, 1999). They are fast growing and are able to withstand adverse site conditions. Some planted tree species such as the *Acacia* spp. can utilize atmospheric N and are known to have high capacity in improving soil fertility (Fung, 1995; Animon et al., 1999; Zhuang and Yau, 1999). In SO, *Acacia confusa* and *A. auriculiformis* which are leguminous species were the dominant species, which can explain the higher contents of total N, extractable NH_4-N and NO_3-N in SO than LT when compared within the same rehabilitated age (Table 5.2). A major objective of plantation establishment was to improve soil productivity as a result of ecological rehabilitation. However, our soil study showed that the accumulation of organic C and N was still very slow in these plantations. Therefore, our study suggested that inclusion of some native species in enrichment planting would accumulate diverse litter and enhance the activity of soil microbial communities, which could consequently speed up humification and further improve soil productivity..

5.5 Conclusions

Physical problems are still serious in the three quarries even after 10 years rehabilitation. High bulk density and low porosity of cover soils restrict the moisture-holding capacity and restrict root development for plant growth.

In chemical terms, the contents of organic C, TKN and TP were low and accumulated slowly along time in the three quarries. RDA shows that contents of these nutrients were significantly and positively correlated with woody species and native species richness. Therefore, with the secondary succession after planting exotic species in quarries, increasing floristic diversity had positive effects on organic matter accumulation. However, the soils lack readily available nutrients, particularly N and P, whose nutrients positively correlated with grass coverage and were more pH-dependent. It was therefore expected that vegetation on these soils faces the deficiency of available nutrients even if rehabilitation after 10 years.

Chapter 6 N Mineralization in Rehabilitated Quarries

6.1 Introduction

In forest ecosystem, soil N plays an important role in supplying mineral N to aboveground vegetation (Vitousek and Howarth, 1991; Vitousek et al., 1997). However, more than 90% of soil N is present in organic form, which is not available to plants (Chapin, 2002). The supply capability of inorganic N in soil mainly depends on three processes, namely mineralization, immobilization and transfer. The process of mineralization converts organic N to simple inorganic forms by the actions of microbial and faunal decomposers (Paul, 2007), which are necessary for plant growth (Brady and Weil, 2002). The process of immobilization is the reverse of mineralization, in which inorganic N is transformed to organic form in plant tissues and microbial cells. In natural ecosystems, these two processes are concurrent. For a natural forest, N availability not only depends on N storage, but also N efficiency. Litter and root exudates, as N storage in a forest, can not provide mineral N to plants because of its organic form. Soil microbes and fauna can break down plant residues and release mineral nutrients to soil, in which N is converted from organic into inorganic forms (ammonium and nitrate). Since mineral nutrient pool in soil is usually small (Barber, 1995), especially in tropical and subtropical ecosystems, rates of decomposition and mineralization determine the amount of nutrients available for

vegetation development.

Degradation of forests leads to the change of composition and structure of vegetation in local areas and directly influence the biogeochemistry cycle of C, N and P (Dupouey et al., 2002; Guo and Gifford, 2002; Fraterrigo et al., 2005). In temperate and tropical forests, forest degradation could decrease 40%-50% soil C and 8% soil N (Davidson and Ackerman, 1993; Compton et al., 1998; Guo and Gifford, 2002). At the same time, degraded land has a great impact on soil N mineralization mainly through modifying plant composition and abundance and soil physical, chemical and biological characteristics (Rhoades and Coleman, 1999). It has been widely recognized that degradation results in N loss in soils and these losses are caused by increased rate of N mineralization (Bloomfield et al., 1982; Claassen and Zasoski, 1998; Biederman and Whisenant, 2009), which can be due to changes in microenvironment and substrate quality, reduced nitrogen uptake by plants or increased loss by leaching and erosion. In general, N dynamic fluctuates with changes in temperature, moisture, pH level, C:N ratio and vegetation (Sierra, 1997; Breuer et al., 2002; Ri and Prentice, 2008).

In some highly degraded lands, N is especially limiting, because organic matter in the cover soil is removed or lost by human disturbance. In order to restore these lands as quickly as possible, N is usually replenished by external sources in the early

stage of rehabilitation in some countries (Thailand and China), for example in the form of soil amendment or artificial fertilizer, because mineral N is especially limiting (Wong, 2003b). In contrast, N input to a natural ecosystem mainly comes from the process of fixation and atmospheric deposition (Brady and Weil, 2002). However, degraded lands in Hong Kong, for example quarry or landfill, were covered up with a soil layer and revegetated by hydroseeding and exotic tree planting for erosion control and aesthetic purpose. The soil layer used as the final cover is mainly decomposed granite from local borrow areas, which is inherently low in major plant nutrients (particularly N). Usually no soil amendment is added, because of heavy labor pay in Hong Kong (Hau, 1999). Therefore, N mineralization in quarry plays an important role in determining amount of N available for aboveground vegetation development.

From the findings in previous chapters, cover soil of rehabilitated quarries was considered to be poor in nutrient and organic matter contents even after more than ten years of rehabilitation (TH94 and LT98). N may be the most limiting nutrient in ecological development in rehabilitated quarries. However, the results did not give any information on N turnover. Implications on nutrient availability of vegetation in the ecosystem could not be made by just considering the soil nutrient capital. Therefore, N availability can be crucial to ecosystem rehabilitation.

In situ N mineralization study was carried out at TH (TH94), LT (LT98, LT01,

LT04) and SO (SO98, SO01, SO04, SO06). Net N mineralization, leaching loss and plant uptake of mineral N in the cover soil of the rehabilitated quarries were investigated. The objective of this study was to evaluate soil N mineralization process among different phases in quarries. It was hoped that findings obtained can provide suggestions on the soil N dynamics and its management strategy of our local quarries.

6.2 Materials and methods

6.2.1 *In situ* soil incubation

The *in situ* sequential soil coring method (Raison et al., 1987) was used to study soil mineral N fluxes. Incubation experiments were carried out separately in the wet and dry season in one year (2008-2009). Four 30 m transects were randomly set in each phase of the three quarries respectively. The sampling points were respectively set in soil at a depth of 10 cm in 0 m, 10 m, 20 m and 30 m along the transect. Twelve samples were taken from each site, with the sampling points following the locations of soil physical and chemical study to reduce variation in this study.

At the start of each incubation (Time 0), thirty six aluminium tubes, which was 5 cm in diameter and 15 cm in length, were inserted into a depth of 10 cm (Figure 6.1) in each site. Twelve soil cores were taken out at the start (T1) of each incubation period, and other 24 soil cores were left and incubated *in situ*, in which half of the soil cores were covered (C1) with plastic sheet cover while another half were left

uncovered (O1). The tubes were left for *in situ* incubation for three weeks in wet and dry seasons, from June to July 2008 (wet) and from January to February 2009 (dry) respectively. At the end of each incubation period (Time 1), 12 new soil cores (T2) were collected, and other 24 incubated as covered (C2) and uncovered soil cores (O2) were also collected.

The duration of the incubation experiments and the weather conditions in the wet and dry season during 2008-2009 are shown in Figure 6.2. In the wet season, the mean temperature maintained at 27.2°C and average rainfall was 39.9 mm per day (Figure 6.2). The weather was cool and dry between January to February 2009, and the mean temperature was at 17.6°C and there was no rainfall in the dry season (Figure 6.2).

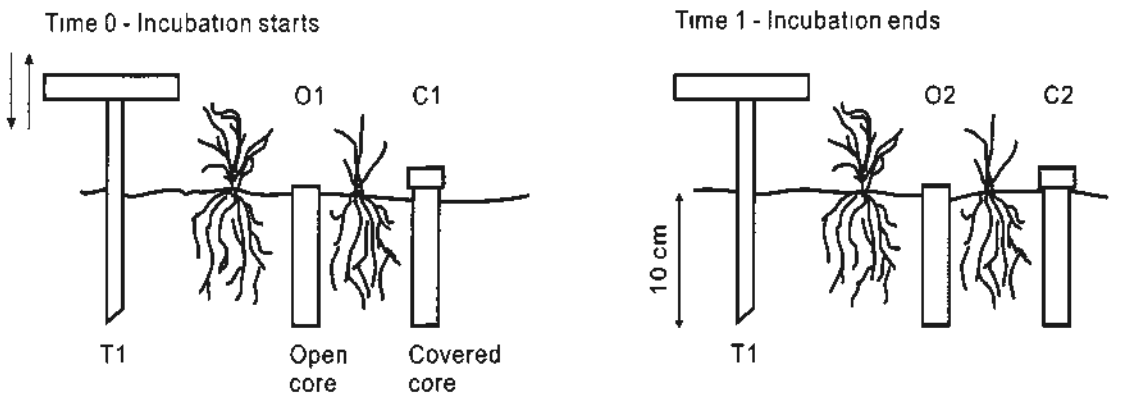


Figure 6.1 Sequential soil coring method in determining *in situ* N mineralization (Raison et al., 1987)

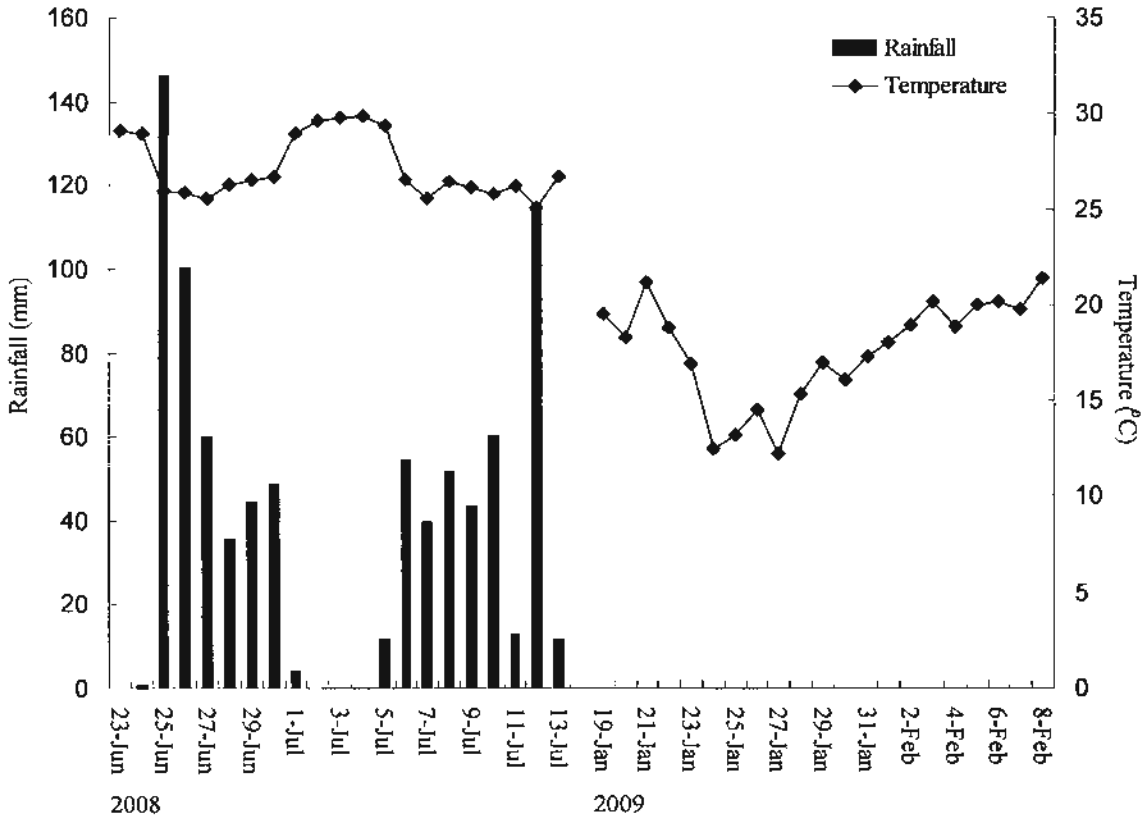


Figure 6.2 Daily rainfall and mean temperature during the wet and dry seasons (data from Hong Kong Observatory)

6.2.2 Chemical analysis

Collected soil samples were transported in aseptic sealed plastic bags and returned to the laboratory and kept in the refrigerator at 4°C. Each soil sample was ground and sifted through a 2-mm sieve to remove gravels and litter. The sieved samples were stored in polythene bags at 4°C prior to soil chemical analysis. Soil extractable NH_4-N and NO_3-N were extracted with 2 M potassium chloride at 150 rpm for 1 hour (Keeney, 1982), determined by salicylate-hypochlorite method and cadmium reduction method respectively, using SAN^{plus} segmented flow analyzer

(Skalar Analytical B.V., Breda, Netherland).

6.2.3 Determination of N mineralization, leaching and uptake

Net N mineralization was calculated as net changes in mineral N content of the covered soil core after incubation. Plant uptake of N was calculated as the differences in mineral N content of the incubated open soil core and soil not enclosed in metal tube at the end of incubation period. Leaching of mineral N was calculated as the difference in mineral N content of the covered and open soil cores after incubation.

Net N mineralization, leaching loss and plant uptake of mineral N were calculated by the following formulae (Raison et al., 1987),

- Net N mineralization (N_{min})

Net ammonification: $\Delta NH_4\text{-}N$ = net ammonification during incubation

$$= NH_4\text{-}N_{(C2)} - NH_4\text{-}N_{(T1)}$$

Net nitrification: $\Delta NO_3\text{-}N$ = net nitrification during incubation

$$= NO_3\text{-}N_{(C2)} - NO_3\text{-}N_{(T1)}$$

Net N mineralization N_{min} = Net ammonification + Net nitirfication

$$= \Delta NH_4\text{-}N + \Delta NO_3\text{-}N$$

- Leaching loss of N ($N_{leaching}$)

Leaching of ammonium-N: $NH_4\text{-}N_{leaching}$ = leaching of ammonium during incubation

$$= NH_4\text{-}N_{(C2)} - NH_4\text{-}N_{(O2)}$$

Leaching of nitrate-N: $NO_x\text{-}N_{leaching}$ = leaching of nitrate during incubation

$$= NO_3\text{-}N_{(C2)} - NO_3\text{-}N_{(O2)}$$

Leaching of net N: $N_{leaching}$ = leaching of N during incuabtion

$= NH_4\text{-}N_{leaching} + NO_3\text{-}N_{leaching}$

- Plant uptake of N (N_{uptake})

Uptake of ammonium-N: $NH_4\text{-}N_{uptake}$ = uptake of ammonium during incubation

$= NH_4\text{-}N_{(O2)} - NH_4\text{-}N_{(T2)}$

Uptake of nitrate-N: $NO_3\text{-}N_{uptake}$ = uptake of nitrate during incubation

$= NO_3\text{-}N_{(O2)} - NO_3\text{-}N_{(T2)}$

Uptake of net N: $N_{uptake} = NH_4\text{-}N_{uptake} + NO_3\text{-}N_{uptake}$

6.2.4 Environmental conditions

Some environmental parameters were also measured. These included litter thickness, litter cover, ground cover and bare ground cover. Measurements were taken at twelve sampling points as in situ soil incubation methods. Litter cover, ground cover and bare ground cover were visually estimated from four 1.0 m × 1.0 m quadrats placed randomly around each sampling point. Twelve measurements of litter thickness were also taken at each sampling point.

6.2.5 Statistical analysis

The treatment effects were carried out with one-way analysis of variance (ANOVA), and the Tukey's Honestly Significant Difference (HSD) test at the 5% level was used to determine the statistical significance between sites. Pearson correlation coefficients were used to denote the significant differences among

different parameters. All data were analyzed by Statistical Package for the Social Science (SPSS) for Windows Release 12.0.

6.3 Results

6.3.1 Net ammonification, NH_4-N leaching and uptake

In the wet season, net ammonification was detected at TH94, LT01, LT04, SO04 and SO06 (Table 6.1). Overall, LT01 and LT04 had the highest net ammonification ($p<0.05$), and SO06 had the lowest. However, immobilization of NH_4-N occurred at LT98, SO98 and SO01. Immobilization of NH_4-N was much stronger in SO98 and SO01 than in LT98. In the dry season, mineralization of NH_4-N was detected at all quarry sites (Table 6.1). Ammonification rate was highest in SO98 soils was the highest and lowest in SO06, while other soils did not show any significant difference ($p>0.05$).

In the wet season, leaching of NH_4-N was detected at all phases of the three quarries, except at LT04 and SO01. LT98 and LT01 had the highest leaching of NH_4-N, while SO98, SO04 and SO06 had the lowest. In the dry season, leaching of NH_4-N was not detected at all phases in three quarries.

No uptake was detected in all phases, except at LT04 and SO04 during the wet season. However, plant uptake of NH_4-N occurred at all sites during the dry season. Vegetation of SO98 could take up the highest NH_4-N, and LT04, SO04 and SO06 had

the lowest uptake of NH_4-N by aboveground vegetation.

Table 6.1 Net ammonification, NH_4-N leaching and NH_4-N uptake ($\mu g\ g^{-1}\ day^{-1}$) in soils of different phases in the three quarries

Sites	Net Ammonification*		Leaching of NH_4-N		Uptake of NH_4-N	
	Wet	Dry	Wet	Dry	Wet	Dry
TH94	0.149b	0.235b	0.202b	-0.012a	-0.181bc	0.101bc
LT98	-0.056cd	0.277b	0.969a	-0.111a	-0.319c	0.118bc
LT01	0.680a	0.241b	0.200b	-0.065a	-0.200bc	0.318b
LT04	0.528a	0.147b	-0.054cd	-0.039a	0.221a	0.022c
SO98	-0.192d	0.555a	0.063bc	-0.467b	-0.573d	0.683a
SO01	-0.159d	0.192b	-0.152d	-0.163a	-0.368c	0.164bc
SO04	0.160b	0.151b	0.129bc	-0.108a	0.148a	0.078bc
SO06	0.081bc	0.108c	0.084bc	-0.131a	-0.114b	0.063bc

Mean values followed by the same letter in a column are not significantly different at p=0.05 level by the Tukey's HSD test

* Negative values for ammonification denote immobilization, while those of leaching and uptake are of no biological meaning (Nadelhoffer et al., 1984)

6.3.2 Net nitrification, NO_3-N leaching and uptake

Different nitrification patterns were found between the wet and dry seasons (Table 6.2). Net nitrification was detected in all phases, except soil of TH94 in the wet season. Net NO_3-N mineralization was higher in SO98 and SO01 than others. In the dry season, however, only SO98 had net nitrification, and immobilization of NO_3-N

occurred in the other phases in three quarries. TH94 had the highest immobilization of NO_3-N and there were no significant differences among others.

In the wet season, leaching of NO_3-N was detected at all phases in three quarries. The highest leaching rate was recorded in SO98, and other phases did not show any significant difference ($p>0.05$). However, leaching of NO_3-N did not occur at all phases in three quarries in the dry season.

Table 6.2 Net nitrification, NO_3-N leaching and NO_3-N uptake ($\mu g\ g^{-1}\ day^{-1}$) in soils of different phases in the three quarries

Sites	Net nitrification*		Leaching of NO_3-N		Uptake of NO_3-N	
	Wet	Dry	Wet	Dry	Wet	Dry
TH94	-0.076d	-0.352c	0.039b	-0.194c	-0.026b	0.277b
LT98	0.143cd	-0.052b	0.204b	-0.058a	0.005ab	0.037c
LT01	0.170c	-0.052b	0.180b	-0.049a	0.050ab	0.041c
LT04	0.122cd	-0.037b	0.067b	-0.014a	0.045ab	0.014c
SO98	1.266a	0.534a	1.092a	-0.465d	-0.484b	0.596a
SO01	0.464b	-0.046b	0.248b	-0.175bc	0.181a	0.110bc
SO04	0.205c	-0.019b	0.149b	-0.070ab	0.039ab	0.016c
SO06	0.168c	-0.076b	0.147b	-0.031a	0.063ab	0.040c

Mean values followed by the same letter in a column are not significantly different at $p=0.05$ level by the Tukey's HSD test

* Negative values for nitrification denote immobilization, while those of leaching and uptake are of no biological meaning (Nadelhoffer et al., 1984)

No uptake was detected at TH94 and SO98 in the wet season, and vegetation of LT01, LT04, SO01 and SO06 could take up higher NO_3-N than LT98, SO04. Plant uptake of NH_4-N occurred at all sites in three quarries during the dry season. Vegetation of SO98 could take up the highest NO_3-N and TH94 and SO01 had higher uptake of NO_3-N, while other phases had no significant difference ($p>0.05$).

6.3.3 Net N mineralization, N leaching and uptake

Ammonification predominated over nitrification in TH and LT, while nitrification predominated in SO in the wet season. However, ammonification predominated over nitrification in all phases, except TH94 in the dry season (Tables 6.1 and 6.2). Net N mineralization at SO98 was the highest in the wet and dry seasons, and TH94 had the lowest net N mineralization in the wet season, and N immobilization in the dry season (Table 6.3). Net N mineralization at LT01, LT04, SO01, SO04 and SO06 was higher in the wet season than in the dry season, but LT98 was the reverse. In the wet season, net N mineralization increased with increasing age in SO, while these trends were not obvious in LT and TH; LT98 had lower net N mineralization than LT01 and LT04. In the dry season, net N mineralization increased with age in TH and SO.

Leaching loss of N occurred at all sites in the wet season, but did not occur in the dry season. LT98 and SO98 had the highest leaching loss of N in the wet season, and

others did not have any significant difference.

In the wet season, plants took up more NO_3-N than NH_4-N in LT98, LT01, SO01 and SO06 (Tables 6.1 and 6.2). N uptake by vegetation only occurred in LT04 and SO04. In the dry season, plants took up more NH_4-N than NO_3-N in all phases, except TH94 (Tables 6.1 and 6.2). N uptake by vegetation occurred in all phases. Vegetation at SO98 had the highest uptake of N and others had no significant difference.

Table 6.3 Net N mineralization, N leaching and N uptake ($\mu g\ g^{-1}\ day^{-1}$) in soils of different phases in the three quarries

Sites	Mineralization*		Leaching		Uptake	
	Wet	Dry	Wet	Dry	Wet	Dry
TH94	0.073d	-0.117c	0.241b	-0.206bc	-0.207c	0.378b
LT98	0.087d	0.225b	1.173a	-0.169b	-0.314c	0.155bc
LT01	0.850ab	0.189b	0.380b	-0.114b	-0.150c	0.359b
LT04	0.650b	0.110bc	0.013c	-0.053a	0.266a	0.036c
SO98	1.074a	1.089a	1.155a	-0.932d	-1.057c	1.279a
SO01	0.305d	0.146bc	0.096	-0.338c	-0.187c	0.274bc
SO04	0.365cd	0.132bc	0.278b	-0.178b	0.187b	0.094c
SO06	0.249d	0.102bc	0.231b	-0.162b	-0.051bc	0.103bc

Mean values followed by the same letter in a column are not significantly different at p=0.05 level by the Tukey's HSD test

* Negative values for nitrification denote immobilization, while those of leaching and uptake are of no biological meaning (Nadelhoffer et al., 1984)

6.3.4 Microhabitat conditions

The microhabitat conditions of the three quarries are given in Table 6.4. The highest litter thickness was found in LT04 and SO06 (3.18 cm and 3.32 cm) which were the new phases covering with some annual grasses. The differences among other phases were not obvious. In general, litter thickness did not correlate with rehabilitation age. Litter cover varied over a wide range at the eight phases, from 25.7% to 72.1%. SO98 and LT01 had the highest litter cover, while the younger sites (LT04, SO04 and SO06) had the low litter cover. Similarly, ground cover also varied widely, from 13.8% to 81.3%. However, the younger phases (LT04, SO04 and SO06) had the higher ground cover than old phases (SO98 and LT01), which was the reverse for litter cover. SO06 was densely covered by litter and grasses on ground without any bare ground, while SO01 had the greatest bare ground cover. The differences among other phases were not obvious.

Table 6.4 Microhabitat conditions for different phases in the three quarries

	Litter thickness (cm)	Litter cover (%)	Ground cover (%)	Bare ground cover (%)
TH94	1.85e	52.8c	41.2c	5.96d
LT98	2.53c	57.7b	34.2d	8.13c
LT01	2.39cd	72.3a	24.9e	2.79e
LT04	3.18a	38.9d	55.3b	5.79d
SO98	2.87b	72.1a	13.8g	14.2b
SO01	1.94e	54.7c	20.6f	24.7a
SO04	2.25d	40.3d	54.5b	5.25d
SO06	3.32a	25.7e	81.3a	0.00f

Mean values followed by the same letter in a column are not significantly different at p=0.05 level by the Tukey's HSD test

6.3.5 Relationship of N mineralization with climate, soil, microhabitat and vegetation characteristics

It was found that net NH_4^+ mineralization was significantly correlated with two climatic variables, four edaphic properties, two microhabitat condition (ground cover and bare ground cover) and two vegetation characteristics (woody species richness and native species richness) ($p<0.05$) (Table 6.5). Net NO_3^- mineralization was significantly correlated with all parameters ($p<0.05$) except pH, organic C and litter depth ($p>0.05$). Net N mineralization was significantly correlated with all vegetation characteristics and climatic variables, but three soil parameters (soil moisture, pH and C:N ratio) and two microhabitat variables (litter cover and ground cover) ($p<0.05$).

Table 6.5 Pearson correlation coefficients among climatic variables, soil properties, microhabitat conditions and vegetation characteristics with net ammonification, nitrification and N mineralization (n=192)

	Climatic variables#		Soil properties						Microhabitat conditions				Vegetation characteristics		
	Rainfall	Air temperature	Soil moisture	Total porosity	pH	OC	TN	C:N	Litter thickness	Litter cover	Ground cover	Bare ground cover	Woody species richness	Grass richness	Native species richness
Net NH_4^+ mineralization	-0.184*	-0.184*	-0.138	-0.397*	-0.189	-0.207*	-0.294*	0.230*	0.138	-0.036	0.209*	-0.553*	-0.516*	-0.005	-0.331*
Net NO_3^- mineralization	0.407*	0.407*	0.396*	0.336*	0.072	0.167	0.303*	-0.545*	0.180	0.440*	-0.501*	0.477*	0.489*	-0.220*	0.543*
Net N mineralization	0.263*	0.263*	0.283*	0.038	0.224*	0.011	0.084	-0.385*	0.295	0.429*	-0.355*	0.062	0.103*	-0.232*	0.305*

*$p<0.05$. #Data of climatic variables from Hong Kong Observatory; Data of soil properties from Chapter 5; Data of vegetation characteristics from Chapter 2

6.4 Discussion

6.4.1 Factors influencing ammonification

Soil ammonification is an extremely complicated process and there are many direct and indirect influencing factors. The direct factors include the availability of dissolved organic nitrogen (DON), activity of soil microbes, and their relative demands for C and N (Carreiro et al., 2000; Saiya-Cork et al., 2002; Bardgett et al., 2003; Bardgett, 2005). Soil organic matter is the important nutrient resources for net N mineralization in soils. The quality and quantity of organic matter, including its relative amounts and forms of C and N, are the major determinants of the substrate available for decomposition and N mineralization (Stevenson, 1994; Chapin, et al., 2002; Madritch and Cardinale, 2007). In many ecosystems, litter was an important reserve of soil organic matter. Therefore, the quality and quantity of litter in its ecosystem indirectly control soil net N mineralization (Arunachalam et al., 1998; Maithani et al., 1996 and 1997; Kramer et al., 2003). In addition, environmental conditions (e.g. climate and soil properties) and biological factors (e.g. plant functionality, community characteristics) are the main controlling factor to determine the quality and quantity of litter in an ecosystem (Knoepp and Swank, 1998; Maithani et al., 1998; Owen et al., 2003; Pajuste and Frey, 2003). Therefore, these interactive factors indirectly influence the process of net N mineralization (Figure 6.3) (Puri and

Ashman, 1998; Sierra, 2002; Prez et al., 2004).

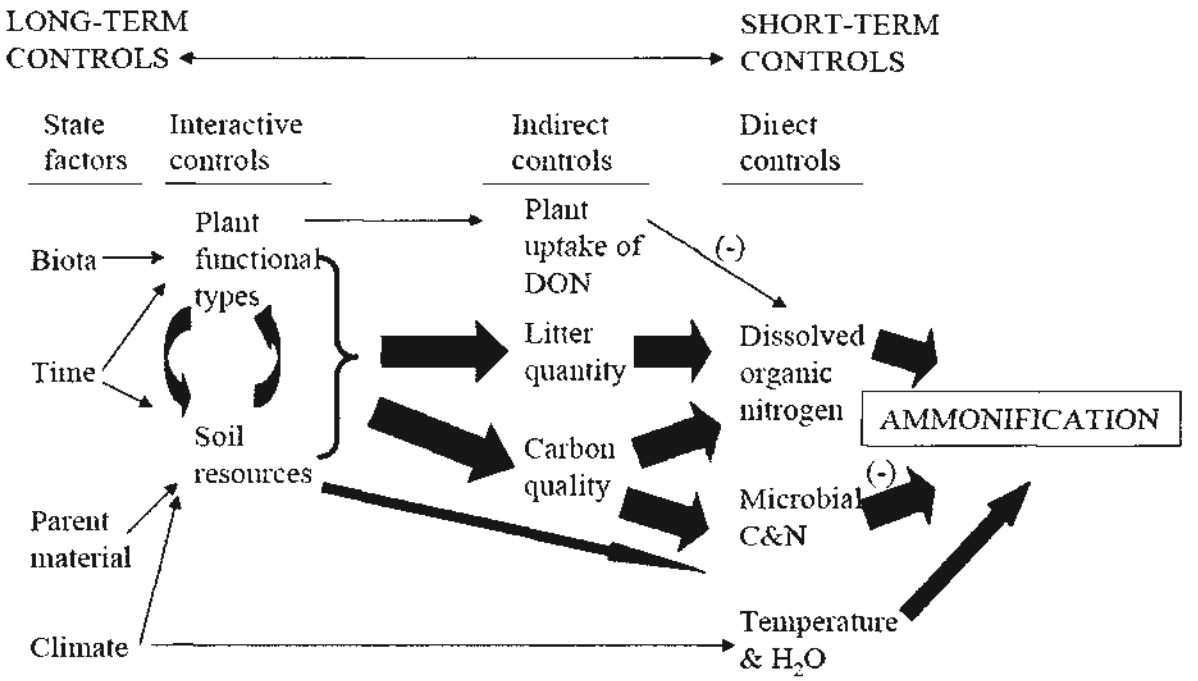


Figure 6.3 The major factors controlling ammonification in soils

Thickness of the arrows indicates the strength of effects. The influence of one factor on another is positive unless otherwise indicated (-) (modified from Chapin et al., 2002)

In degraded lands, human disturbance changed the direct and indirect influencing factors of soil N mineralization, which made marked change in ammonification. In the rehabilitated quarries, the decomposed granite from borrow areas was used as the final soil cover and exotic tree species were widely adopted for erosion control. The change of environmental conditions could significantly increase soil temperature and decrease soil organic matter (Wong, 2003a), which transitionally influenced the activity of soil microbes and led to the change of ammonification. In our study, it was found that

LT01, LT04, SO04 and SO06 had net ammonification in the wet season, while immobilization of NH_4^+ occurred at LT98, SO98 and SO01. Both mineralization and immobilization of NH_4^+ occurred simultaneously in the three quarries, which could be explained by the direct control factors. The balance between mineralization and immobilization was determined by a range of factors such as the availability of DON and ingestion by soil animals, but one factor of high importance was the relative demand by microbes for N and C. Theoretically, when microbes were predominately C-limited, net ammonification occurred, whereas net immobilization occurred when their growth was limited by N (Nadelhoffer et al., 1985; Bardgett, 2005). In the three quarries, those newly rehabilitated phases had relatively low organic C which led to net ammonification, while the older sites had lower proportion of N which led to net immobilization. In addition, the demand by microbes for C and N was determined by the C:N ratio of the organic substrate they were utilizing (Nadelhoffer et al., 1985; Bardgett, 2005). The C:N ratio in microbial biomass was about 10:1 and microbes required substrates with a C:N ratio of about 25:1 to meet their N requirement (Kaye and Hart, 1997; Chapin, et al., 2002; Bardgett, 2005). At higher C:N ratios, microbes import N to meet their growth requirements, and at lower C:N ratios N exceeds microbial growth requirements and is secreted into the litter and soil (Chapin et al., 2002). In the dry season, mineralization of NH_4^+ was detected at all sites in three

quarries, which could be explained that the microbial activity was low in winter and N exceeds microbial growth requirements. Significant correlation between C:N ratio and net ammonification was also found in this study (Table 6.5).

6.4.2 Factors influencing nitrification

Nitrification was the process by which NH_4^+ was oxidized to NO_2^- and subsequently to NO_3^-. This process is carried out by two main groups of autotrophic bacteria, in which one group was from *Nitrosomonas* and the other group was from *Nitros-* genera, *Nitrobacter* and other *Nitro-* genera. Heterotrophic nitrification is also known to occur, especially by fungi in forest soils. The process of nitrification is mainly influenced by several soil factors, in which the availability of NH_4^+, which is the sole energy source for autotrophic nitrifiers, is the most important direct determinant of nitrification rate (Robertson and Vitouosek, 1981; Robertson, 1989; Chapin et al., 2002). Oxygen is also an important factor controlling nitrification because most nitrifiers require oxygen for oxidation of NH_4^+. Therefore, factors that influenced the diffusion of O_2 through soil, such as moisture and soil structure, would also affect rates of nitrification in soil (Brooks et al., 1996). In addition, controls of influencing the above two direct factors, for example plant NH_4^+ uptake, litter quantity, C quality, root and microbial respiration, soil temperature and texture, have an indirect effect on soil nitrification. Similar to mechanism of ammonification, plant functional

types and soil resources had an interactive influence on soil nitrification (Figure 6.4).

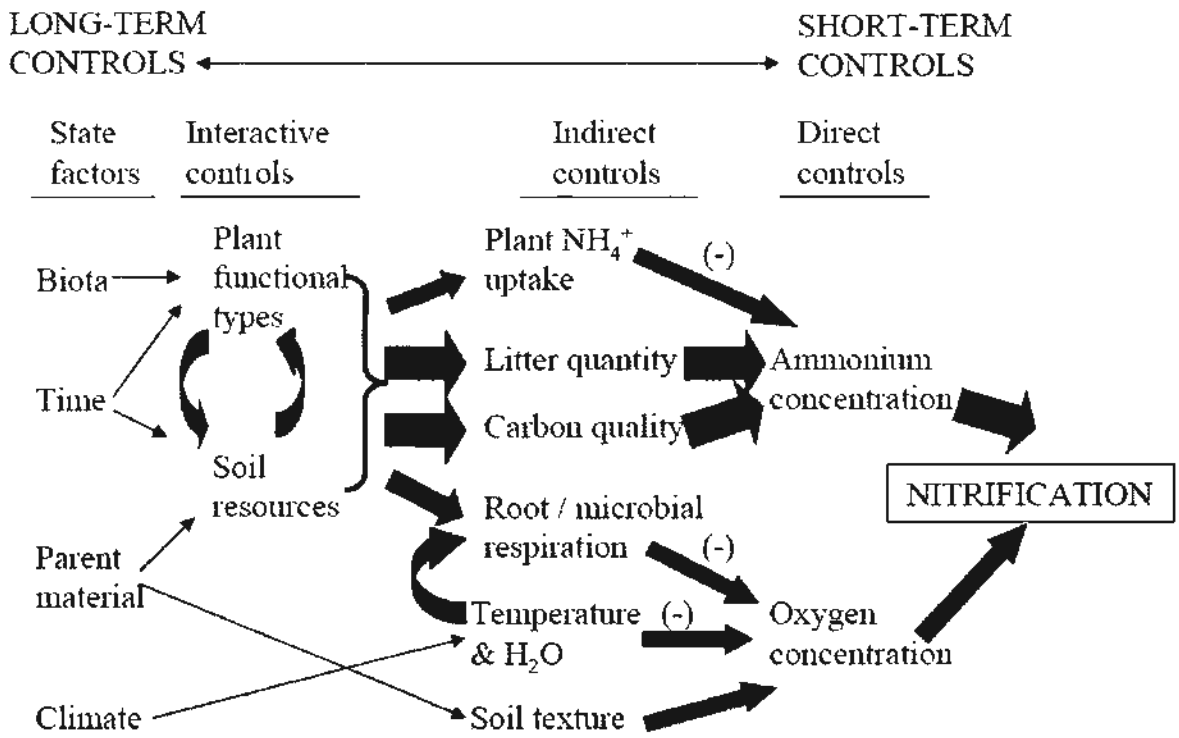


Figure 6.4 The major factors controlling nitrification in soils

Thickness of the arrows indicates the strength of effects. The influence of one factor on another is positive unless otherwise indicated (-) (modified from Chapin et al., 2002)

In quarries, the high soil bulk density, coarse soil texture and low soil interspace could lead to decreasing soil oxygen. The soil physical changes could finally result in a decrease of nitrifiers' respiration and soil nitrification. In the dry season, only SO98 had net nitrification and other phases had immobilization of NO_3^-. This result could be explained that the soil texture of most phases was coarse and the provision of NH_4^+ and oxygen were not enough, which induced a decrease in soil nitrification. However,

with the ecological development in SO98, the soil structure was improved and the provision of NH_4^+ was also increased, which led to the occurrence of net nitrification. In the wet season, the availability of NH_4^+ was high because of N fixation, which could provide energy source for autotrophic ntirifiers. Therefore, there was the net nitrification in most phases of the three quarries.

6.4.3 Effects of vegetation composition on net mineralization

The composition and dynamics of plant community are important biological factors that control soil net mineralization. Different plants could influence the condition of shade, biological N-fixers, quality and quantity of litter and the activity and diversity of soil fauna and microbes, which further influenced soil nutrient recycling (Wardle et al., 1999; Craine et al., 2002; Knops et al., 2002; Innes et al., 2004; Bezemer et al., 2006; Manning et al., 2008). When a natural forest was disturbed by human being and was changed to a secondary forest, shrubland and grassland, most dominant species of a natural forest were removed or disappearing, which could make an ultimate change of species composition and structure. In most degraded lands, the plant functional types are the pioneer species, for example grass species and conifers. These pioneer species are absolutely different from the previous dominant species and had a different influence on ecosystem function. Therefore, different plants potentially affected N cycling of the ecosystem through controlling N

input and loss (Knops et al., 2002). A study which compared the N mineralization potential of soil under legume and non-legume plantations showed higher mineralization potential under legume trees (Li et al., 2001).

In this study, it was found that in the wet season net N mineralization increased with increasing age in SO, which was consistent with proportion of mineral N that increased with site age (Schwenke et al., 2000). However, LT01 and LT04 had higher net mineralization than TH94 and LT98. This was perhaps attributable to the different exotic species adopted in the quarries. *Eucalyptus tereticornis* and *Casuarina equisetifolia* were planted in TH and LT, while the leguminous *Calliandra haemaocephala* predominated in LT01. *Acacia confusa* and *A. auriculiformis* which are legumes were major species planted in SO. *Acacia* spp. and *Casuarina equisetifolia* are fast growing plants with N-fixing capacity. Compared with leguminous species, *Eucalyptus tereticornis* often produces litter with low nutrient contents and the ability of N transformation was low (Guo and Sims, 1999). Our study shows that the capability of N cycling for about 10-year old plantations of *Eucalyptus tereticornis* and *Casuarina equisetifolia* was declining. In the early stage of rehabilitation in quarries, pioneer species such as grasses which have low nutrient concentrations and transformation rates were the main composition of aboveground vegetation (Chapter 2). Hence, the capability of soil ammonification and nitrification

was low. With ecological development, some native species naturally invaded the older sites and those native species had higher nutrient contents in their litter and higher transforming rate, which can return more nutrients into soil and accelcratc the soil mineralization. Significant correlation between species richness (especially native species) and potential N mineralization was also found in this study (Table 6.5). Therefore, our study recommended that artificial planting of some native species on the older sites in our local quarries which could increase species diversity would further accelerate nutrient cycling.

In three quarries, bench slopes was used for recontouring in TH and LT, and scree slope was used in SO. Compared with scree slope, bench slope had shallower soil and discontinuous soil covers with different rehabilitated phases, which resulted in lower fluxes of soil nutrients and poorer recruitment of soil microbes. In addition, environmental factors, for example heavy rainfall and high temperature, should have stronger effects on soil covers, hence poorer soil quality on bench slope than on scree slope. In this study, LT01 and LT04 had higher net N mineralization than LT98 and TH94, which could bc explained that the plantation on bench slopc was declining during the process of secondary succession in rehabilitated quarries and a decline in soil mineralization would probably occur. Besides the possible effect of bench slopes, uptake and leaching of mineral N were also significantly higher in LT98 than in LT01

and LTO4, which might affect net N mineralization.

6.5 Conclusions

The seasonal pattern of soil N mineralization may control soil fertility and affect plant growth. This study demonstrates patterns of seasonal variation in soil mineralization, leaching and uptake of N. Wet season had high rainfall which leached out N, and N uptake by vegetation only occurred in newly rehabilitated sites, while plants took up NO_3^- and NH_4^+ in all phases in dry season. Microbes were the major players in soil N mineralization, and their activities were directly influenced by soil temperature, moisture and nutrient availability. Compared with newly rehabilitated sites, older sites had more complex community structure and abundant litter which could provide better growth conditions for soil microbes, thereby accelerating N mineralization. The results also show that net N mineralization was significantly correlated with rainfall, air temperature, soil moisture, pH, C:N ratio, litter cover, ground cover, woody species richness, grass richness and native species richness. N flux fluctuated with the ecological development of vegetation and soil. This study shows that net N mineralization increased with increasing restoration ages, notably in SO. However, LT01 and LT04 had higher N mineralization than LT98 and TH94 in the wet season, because LT and TH which adopted similar bench slope had lower fluxes of soil nutrients and poorer recruitment of soil microbes and may lead to the

development of a specific microbial community in older phases. N deficiency was a potential problem in rehabilitated quarries as a consequence of excessive leaching loss, especially in summer. The use of leguminous species, especially native species, which could effectively assist in the buildup of N capital in quarries, should be recommended.

Chapter 7 Soil Microbial Characteristics in Rehabilitated Quarries

7.1 Introduction

Efforts to revegetate degraded lands in Hong Kong aim to control erosion and provide a greening effect. Exotic plant species such as *Eucalyptus* spp., *Acacia* spp. and *Casuarina equisetifolia* that are fast growing and hardy are heavily used in southern China to produce rapid stands. However, exotic plantation is likely to maintain low community complexity and diversity (Blakesley et al., 2002), because of their low soil fanual recruitment, relatively slower decomposition of litter and poor association of decomposing microbes (Mahakur and Behera, 1999; Mboukou-Kimbatsa and Bernhard-Reversat, 2001; Zahn et al., 2009). The plantation of *Eucalyptus* spp. may have a deleterious impact on soil fertility and microbial community (Kilian, 1998; Behera and Sahani, 2003). Therefore, it may be difficult or impossible to establish a fully functional forest community in most plantations with exotic species (Zhuang, 1997).

The relationship between species diversity and ecosystem functioning has emerged in recent years as a major scientific issue in ecological engineering (Grime, 1997; Loreau, 2000). However, most studies have only taken into account the diversity, structure and productivity of the aboveground vegetation of terrestrial

ecosystems and little attention has been paid to the belowground soil microbial communities, which is a small but vital component of soil biota. They play an important role in ecosystems and influence a number of important ecosystem processes, including nutrient cycling, carbon cycling and soil formation (Bardgett, 2005). After planting exotic species on degraded lands, some native species are naturally recruited through seed dispersal, producing changes in plant diversity, composition and structure (Guariguata and Ostertag, 2001). These changes may affect the structure and composition of soil microbial communities which play a key role in maintaining soil quality and ecosystem health due to their involvement in organic matter dynamics, nutrient cycling and decomposition (Mummey et al., 2002). They can also be sensitive biological markers for assessing disturbed soils (Anderson, 2003; Hartley et al., 2008).

Traditionally, studies of soil microbial properties mainly focused on the biomass, respiration rate and enzyme activity. However, less attention has been given to community level response to changes in soil properties (Hill et al., 2003), which may serve as important and sensitive indicators of both short- and long-term changes in soil quality resulting from changed management strategies (Pankhurst et al., 1997). Over the past 20 years, the approach to analyzing soil microbial communities has changed dramatically and many new methods allow for better assessment of soil

microbial diversity and function. These approaches could be divided into two categories: one is the traditional culture-dependent methods and another one is the recent culture-independent methods (Ranjard et al., 2000; Hill et al., 2000), in which the former includes dilution plating and culturing method and community-level physiological profiler, and the latter includes phospholipid fatty acid analysis and DNA-based techniques (Giraffa and Neviani, 2001). Community-level physiological profiles have been facilitated by the use of a commercial taxonomic system, known as the Biolog system, which has been used to assess the functional diversity of soil microbial community (Mummey et al., 2002; Graham and Haynes, 2004; Machulla et al., 2005). Biolog test can potentially provide information on the functional abilities of the microbial community and can reflect on the effects of vegetation and forest management techniques on soil microbial community (Grayston et al., 1998; Pietikainen et al., 2000; Chodak et al., 2009). Phopholipid fatty acids are components of the membranes of all organisms and each species has a characteristic fatty acid pattern (Jandl et al., 2005). In soil microbial ecology, fatty acid pattern has been used to assess the composition and structure of soil microbial community and determinate gross community changes that accompany soil disturbances (White et al., 1996; Petersen et al., 1998; Zelles, 1999; Gagliardi et al., 2001; Marschner et al., 2005; Sullivan et al., 2006).

The present study aims to characterize soil microbial biomass, community metabolic profiles and community composition and structure in quarries rehabilitated in different periods of time and also assess the effects of plant community structure on soil microbial characteristics in revegetated quarries. Findings obtained could shed light on the ecological functioning of rehabilitated ecosystems and management strategies for the restoration of rock quarries.

7.2 Materials and methods

7.2.1 Sample collection

Soil sampling was carried out on TH, LT and SO in June-August 2007. On each phase of the three quarries, six 30 m transects were randomly set. The sampling points were respectively set in 0 m, 10 m, 20 m and 30 m along the transect. 2.5 cm diameter soil cores were taken from 0-5 and 5-10 cm depths at each sampling point, and then were mixed into a composite sample respectively for two depths. There are total 6 soil samples for each depth taken from each site. Soil samples were transported in aseptic sealed plastic bags. Each soil sample were ground and sifted through a 2 mm sieve to remove gravels and litter. Half of the samples were air-dried for chemical analysis and the others were stored in polythene bags at 4°C and -20°C prior to soil microbial analysis. For the analysis of soil chemical properties, please refer to Section 5.2 in Chapter 2. The refrigerated samples kept at 4°C were used for microbial parameter

(microbial abundance, biomass and community level physiological profiles) analyses within a week after sampling, and then samples kept at -20°C were used to analyze the fatty acid methylester (FAME) profiles.

7.2.2 Soil microbial abundance

Total bacteria, fungi and actinomycetes were enumerated by the spread plate method (Wollum, 1982). Ten grams of fresh soil sample were shaken with sterilized physiological saline (0.85% NaCl). Serial dilutions were carried out and 0.1 ml of aliquot from a range of four dilutions was spread onto triplicated agar plantes with a sterilized glass spreader. Bacteria were enumerated on tryptic soy agar. Actinomycetes were cultured on starch-casein agar, while fungal abundance were obtained using Martin's rose Bengal medium. All the agar plates were incubated in darkness at 25 ± 1°C. Agar plates for bacteria, actinomycetes and fungi were examined after 3-, 7- and 14-day incubation respectively. The dilutions that yielded from 30 to 300 colonies per plate were selected for inspection.

7.2.3 Soil microbial biomass

Microbial biomass C and N were determined by the fumigation-extraction method (Vance et al., 1987). Three subsamples of fresh soil were extracted with 0.5 M K_2SO_4, shaken and filtered. Simultaneously, three other subsamples were fumigated with ethanol-free chloroform for 24 h and then extracted, shaken and filtered similarly.

C and N in the extracts were determined by an automated TOC and TN Analyzer (TOC-500 and TN-500, Shimazu, Japan). Microbial biomass $C=E_C/Kec$, where E_C = (organic C extracted from fumigated soils) – (organic C extracted from nonfumigated soils) and Kec=0.45 (Wu et al., 1990). Microbial biomass $N=E_N/Kn$, where E_N = (N extracted from fumigated soils) – (N extracted from nonfumigated soils) and Kn=0.54 (He et al., 1997).

7.2.4 Community level physiological profiles

The Biolog system was used to test community level physiological profiles of microorganisms from soil dilutions (Garland and Mills, 1991). Briefly, 10 g of fresh soil was added to 90 ml physiological saline (0.9%) which was sterilized in a 250 ml flask and shaken on a rotary shaker at 150 rpm for 10 min. The 10^{-3} dilution was used to inoculate the Ecoplates (Biolog, Hayward, CA) which were incubated at 25°C for 7 days. Colour development was measured as absorbance using an automated plate reader at 590 nm and the data were collected using Microlog 4.01 software (Biolog, Hayward, CA). The average well colour development (AWCD) was calculated as follows: $AWCD=\Sigma(C-R)/n$, where C is the absorbance value within each well except the control well, R is the value of the control well, and n is the number of substrates.

7.2.5 Fatty acid methylester (FAME) profiles

Fatty acids were extracted from the soils using the MIDI's protocol (Microbial

ID, Inc.). Briefly, the method consisted of four steps: 1) Saponification of fatty acids at 100°C with 3 ml 3.75 M NaOH in aqueous methanol (methanol:water ratio = 1:1) for 30 min; 2) Methylation at 80°C in 6 ml of 6 M HCl in aqueous methanol (methanol:water ratio = 1:0.85) for 10 min; 3) Extraction of the FAMEs with 3 ml of 1:1 (v/v) methyl-tert-butyl ether/hexane; 4) Washing of the solvent extract with 1.2% (w/v) NaOH. The FAMEs were analyzed in a 6890 GC Series II equipped with a flame ionization detector and a fused silica capillary column (25 m × 0.2 mm) using H_2 (ultra high purity) as the carrier gas. Peaks in a sample were compared to standard fatty acids (Microbial ID, Inc.) and their relative peak areas (percentages calculated against total detected areas) were determined with respect to the other fatty acids in a sample using the Aerobe method of the MIDI system.

Within the FAME profiles, individual FAME markers were investigated to compare the relative abundance of specific microbial groups. The groups such as gram-positive bacteria, gram-negative bacteria, actinomycetes, fungi and other soil organisms could be estimated by so-called signature fatty acids (Table 7.1) (White et al., 1996; Olsson et al., 1997; Zak et al., 2000). FAMEs were described by the number of C atoms, followed by a colon, the number of double bonds and then by the position of the first double bond form the methyl (*w*) end of molecules. Isomers *cis* and *trans* were indicated by *c* and *t*, respectively. Prefixes *i* and *a* indicated *iso* and *anteiso*

branching, respectively. Other abbreviated notations were *Me* for methyl and *cy* for cyclopropane (Frostegard et al., 1993).

7.2.6 Statistical analysis

One-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) test at $p<0.05$ was used to determine any significant difference between means of different phases. Pearson correlation coefficients at $p<0.05$ between microbial parameters and soil properties were also calculated. The patterns of metabolic profiles and FAME profiles were summarized using principal component analysis (PCA).

Average well colour development (AWCD) data at 96 h of incubation in the Biolog ecoplates were used as the rate of substrate utilization was typically most rapid after 96 h of incubation (Garland, 1997). To minimize the effects of differential rates of colour development (due to inoculum density) on the classification of samples, Biolog data were transformed by dividing the raw differences (substrate well value – control well value) of each well by the AWCD of the plate, which could give greater indication of the sole-carbon-source utilization patterns among samples (Preston-Mafham et al., 2002).

Table 7.1 Specific microbial groups and their signature fatty acids

Specific microbial groups	Signature fatty acid	Specific microbial groups	Signature fatty acid
G^+ bacteria	10me16:0	Bacteria	14:0
	i15:0		15:0
	a15:0		17:0
	i16:0		a17:0/17:1w8c
	i17:0		
G^- bacteria	16:1w7c	Actinomycetes	10me18:0
	16:1w5c		
	cy17:0	Fungi	18:1w9c
	18:1w7c		18:2w6
	18:1w7t		18:3w3
	18:1w5c		
	cy19:0	AM fungi*	16:1w5

*AM fungi: arbuscular mycorrhizal fungi

The relationships between plant parameters and microbial parameters were determined using redundancy analysis (RDA) (van den Wollenberg, 1977; Ramette, 2007). Soil microbial parameters were used as 'species' and plant richness and coverage were used as environmental variables, which allowed the relationships between the plant variables as well as soil microbial parameters to be directly compared. The scaling of the ordination focused on inter-species correlations, and species scores were log-transformed to reduce the effects of extreme values. The

significance of the plant variables which accounted for the variance of soil microbial parameters was calculated using Monte Carlo permutation test (Leps and Smilauer, 2003). Regarding substrate utilization, 31 carbon sources were subdivided into six substrate groups, amino acids (AA), amines (AM), carboxylic acids (CA), carbohydrates (CHO), miscellaneous (MI) and polymers (PO), for use as microbial community metabolic parameters (Zak et al., 1994). The average absorbance of all carbon sources within each group was determined. All except RDA data were analyzed by Statistical Package for the Social Science (SPSS) for Windows Release 12.0, while RDA data were run using the Canoco 4.5 Software (Centre for Biometry, Wageningen, Netherlands) (Leps and Smilauer, 2003).

7.3 Results

7.3.1 Soil microbial population number

The total microbial number was higher in soils from 0-5 cm than those from 5-10 cm at different phases (Table 7.2). In the 0-5 cm soils, SO98 and LT01 had the highest total microbial number ($p<0.05$), while LT04 had the lowest ($p<0.05$). The total microbial numbers were in the descending order of SO98 ≥ LT01 ≥ SO01 ≥ TH94 ≥ SO04 ≥ LT98 ≥ SO06 ≥ LT04 at 0-5 cm, but those at 5-10 cm were in a slightly different order of SO98 ≥ SO01 ≥ SO04 ≥ SO06 ≥ TH94 ≥ LT01 ≥ LT98 ≥ LT04. Total microbial number increased with increasing age at the two depths only in SO

but not in LT. As usual, the bacterial population dominated (65.7-91.2%), while fungi were scarce (0.35% to 1.23%).

Bacterial abundance was positively correlated ($p<0.05$) with organic C, TKN and extractable NO_3-N (Table 7.3). The fungal population had significant correlations ($p<0.05$) with organic C, TKN and TP. Microbial biomass C and N had similar significant correlations with organic C, TKN and NO_3-N ($p<0.05$) (Table 7.3).

7.3.2 Soil microbial biomass

Total microbial biomass was higher in soils from 0-5 cm than those from 5-10 cm at different phases (Table 7.4). Microbial biomass C (Cmic) ranged from 102 to 378 mg/kg in 0-5 cm soils and 49 to 196 mg/kg in 5-10 cm soils at the different phases of the three quarries. SO98 had the highest Cmic while SO06 had the lowest at the two depths, but Cmic was not significantly different ($p>0.05$) at the other quarry sites. Microbial biomass N (Nmic) ranged from 19 to 52 mg/kg in 0-5 cm soils and 2 to 14 mg/kg in 5-10 cm soils. LT01 and SO98 had the highest Nmic while SO06 was the lowest at 0-5 cm; LT98 and SO04 had the highest Nmic while SO06 was the lowest at 5-10 cm. Microbial biomass C and N had similar significant correlations with organic C, TKN and NO_3-N ($p<0.05$) (Table 7.5).

Table 7.2 Microbial population number in soils at different phases in the three quarries

Sites	0-5 cm							5-10 cm						
	Total ($\times10^4$ g^{-1})	Bacteria ($\times10^4$ g^{-1})		Fungi ($\times10^4$ g^{-1})		Actinomycetes ($\times10^4$ g^{-1})		Total ($\times10^4$ g^{-1})	Bacteria ($\times10^4$ g^{-1})		Fungi ($\times10^4$ g^{-1})		Actinomycetes ($\times10^4$ g^{-1})	
		Number	(%)	Number	(%)	Number	(%)		Number	(%)	Number	(%)	Number	(%)
TH94	51.2ab	47.3a	91.2	0.24de	0.45	4.30d	8.30	28.2b	22.5ab	79.8	0.11c	0.40	5.57cd	19.8
LT98	37.9bc	32.1ab	84.8	0.15de	0.39	5.61cd	14.8	24.1b	19.1ab	79.2	0.13c	0.53	4.87d	20.2
LT01	72.6a	65.0a	89.6	0.26cde	0.35	7.28cd	10.0	26.4b	23.0ab	87.3	0.12c	0.47	3.21d	12.2
LT04	19.6c	15.1b	77.0	0.09e	0.43	4.42d	22.6	16.1b	12.6b	78.5	0.06c	0.41	3.40d	21.1
SO98	75.2a	53.0a	70.5	0.92a	1.23	21.3a	28.3	69.6a	52.6a	75.6	0.37ab	0.53	17.0a	23.9
SO01	60.8ab	43.3ab	69.6	0.69b	1.13	17.8ab	29.3	38.5ab	26.5ab	68.9	0.41a	1.08	11.6ab	30.0
SO04	50.9ab	36.9ab	72.4	0.52bc	1.01	13.5abc	26.6	29.5b	19.4ab	65.7	0.23bc	0.76	9.86abc	33.5
SO06	34.0bc	22.2b	65.4	0.37cd	1.10	11.4bc	33.5	29.0b	21.7ab	75.0	0.15c	0.50	7.10bcd	24.5

Mean values followed by the same letter within a column are not significantly different at p=0.05 level according to the Tukey's HSD test

Table 7.3 Pearson correlation coefficients among microbial parameters and soil properties

	Bacteria number	Fungi number	Actinomycetes number
Organic C	0.726*	0.645*	0.479
TKN	0.688*	0.693*	0.523*
Ext. NH_4-N	-0.011	0.185	0.176
Ext. NO_3-N	0.703*	0.447	0.256
TP	0.334	0.645*	0.580*
Ext. P	-0.500*	-0.154	-0.078

* $p<0.05$

Table 7.4 Microbial biomass C and N (mg kg^{-1}) in soils at different phases in the three quarries

Sites	0-5 cm			5-10 cm		
	Microbial biomass C (mg kg^{-1})	Microbial biomass N (mg kg^{-1})	C_{mic}/N_{mic} ratio	Microbial biomass C (mg kg^{-1})	Microbial biomass N (mg kg^{-1})	C_{mic}/N_{mic} ratio
TH94	192bc	24.2b	7.93	130ab	3.48c	37.4
LT98	204bc	34.3b	5.94	90.1bc	13.8a	6.52
LT01	314ab	52.0a	6.04	108bc	12.1ab	8.91
LT04	226bc	19.0b	11.9	84.2bc	8.25abc	10.2
SO98	378a	49.8a	7.59	196a	7.36bc	26.7
SO01	231bc	37.2b	6.22	140ab	13.3ab	10.5
SO04	209bc	19.3b	10.8	112bc	13.8a	8.12
SO06	102d	2.78c	36.8	49.9c	2.47c	20.2

Mean values followed by the same letter are not significantly different at p=0.05 level according to the Tukey's HSD test.

Table 7.5 Pearson correlation coefficients among microbial parameters and soil properties

	Microbial biomass C	Microbial biomass N	C_{mic}/N_{mic} ratio
Organic C	0.805*	0.654*	-0.276
TKN	0.811*	0.643*	-0.249
Ext. NH_4-N	-0.052	-0.134	0.064
Ext. NO_3-N	0.706*	0.603*	-0.296
TP	0.421	0.242	0.202
Ext. P	-0.064	-0.169	0.092

* $p<0.05$

7.3.3 Microbial community level physiological profiles

The rate of substrate utilization for each sample was typically most rapid after 96 h of incubation. In the top 5 cm soils, AWCD at 96 h had a similar trend with soil microbial biomass. LT01 had the highest AWCD, and LT04 and SO98 followed, while SO04 and SO06 had low AWCD (Figure 7.1). In 5-10 cm soils, AWCD was the highest in SO98, TH94 and LT98, but lowest in SO04 and SO06 (Figure 7.1).

Shannon index and evenness calculated using the 96 h incubation data are listed in Table 7.6. In 0-5 cm soils, Shannon index had no significant ($p>0.05$) difference among TH and LT. However, Shannon index was the highest in SO98, but lowest in SO06 ($p<0.05$). In 5-10 cm soils, SO04 and SO06 had the lowest Shannon index ($p<0.05$), while the differences among other phases were not significant. Shannon

evenness was not significantly different among all phases except SO04 and SO06 in the two soil depths.

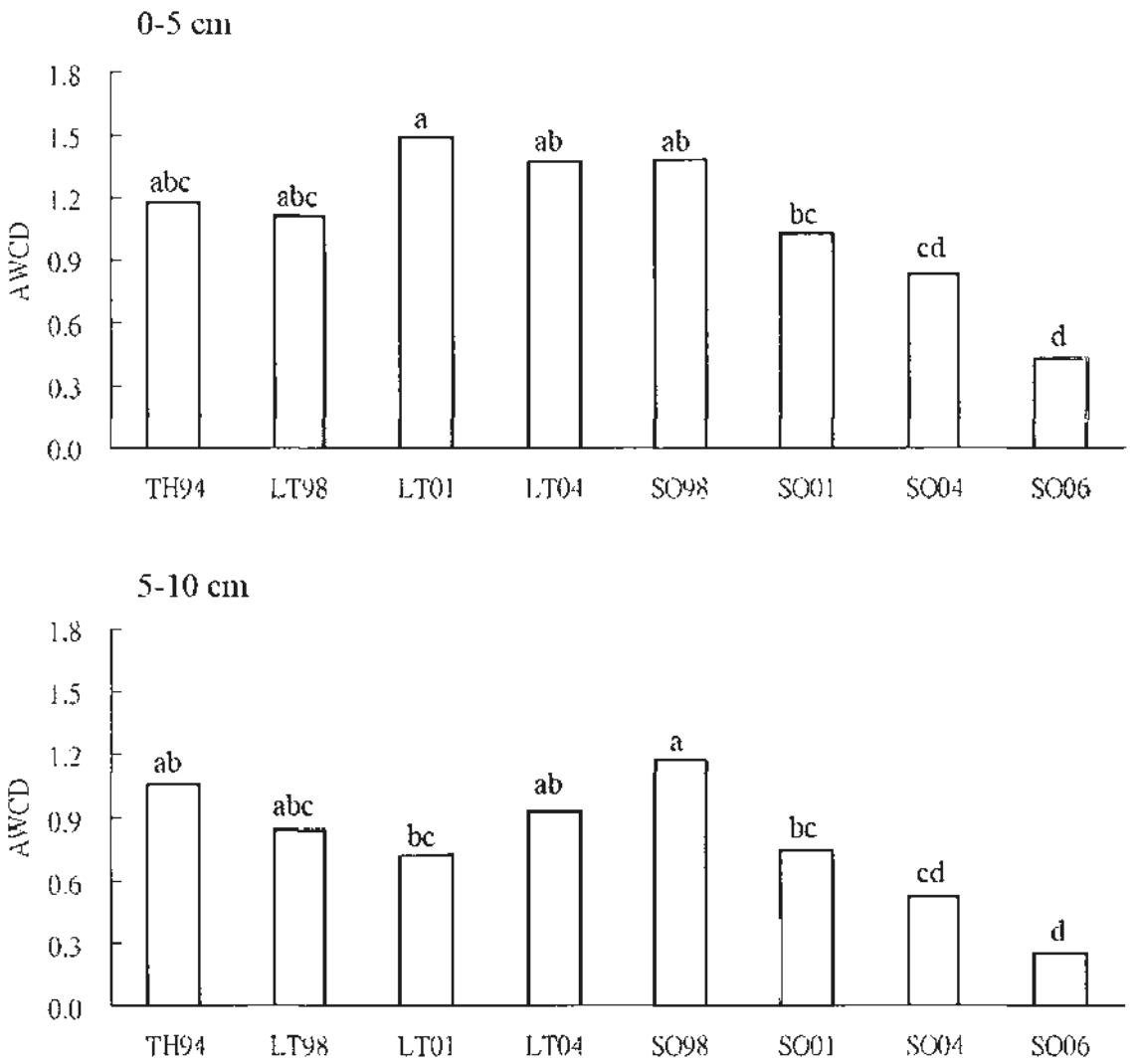


Figure 7.1 Average well colour development (AWCD) for microorganisms at 96h of incubation in soils on the different phases in the three quarries

Mean values followed by the same letter are not significantly different at p=0.05 level according to the Tukey's HSD test

Table 7.6 Diversity of utilized substrates at 96 h of incubation for microorganisms in soils at different phases in the three quarries

Sites	0-5 cm		5-10 cm	
	Shannon index (H')	Evenness (E)	Shannon index (H')	Evenness (E)
TH94	3.12a	0.909a	3.08a	0.898a
LT98	3.14a	0.913a	3.05a	0.889a
LT01	3.23a	0.941a	3.04a	0.886a
LT04	3.16a	0.919ab	2.92ab	0.850ab
SO98	3.19a	0.931a	3.05a	0.889a
SO01	3.09ab	0.889ab	3.03a	0.882a
SO04	2.92b	0.849b	2.76b	0.805bc
SO06	2.69c	0.785c	2.54c	0.739c

Mean values followed by the same letter are not significantly different at p=0.05 level according to the Tukey's HSD test

Principal component analysis of the 31 carbon substrates at 96 h of incubation reveals a scattered distribution for all sites, indicating that they had different microbial communities in terms of potential C utilization pattern (Figures 7.2). The first principal component (PC1) accounted for more than 49% of the variance, and the second accounted for about 20% at the two depths for all soil samples. For the two depths, principal component analysis of C utilization clearly separated soils from different phases in SO based on the distribution in PC1 and PC2. However the patterns of C utilization are similar among soils in TH and LT.

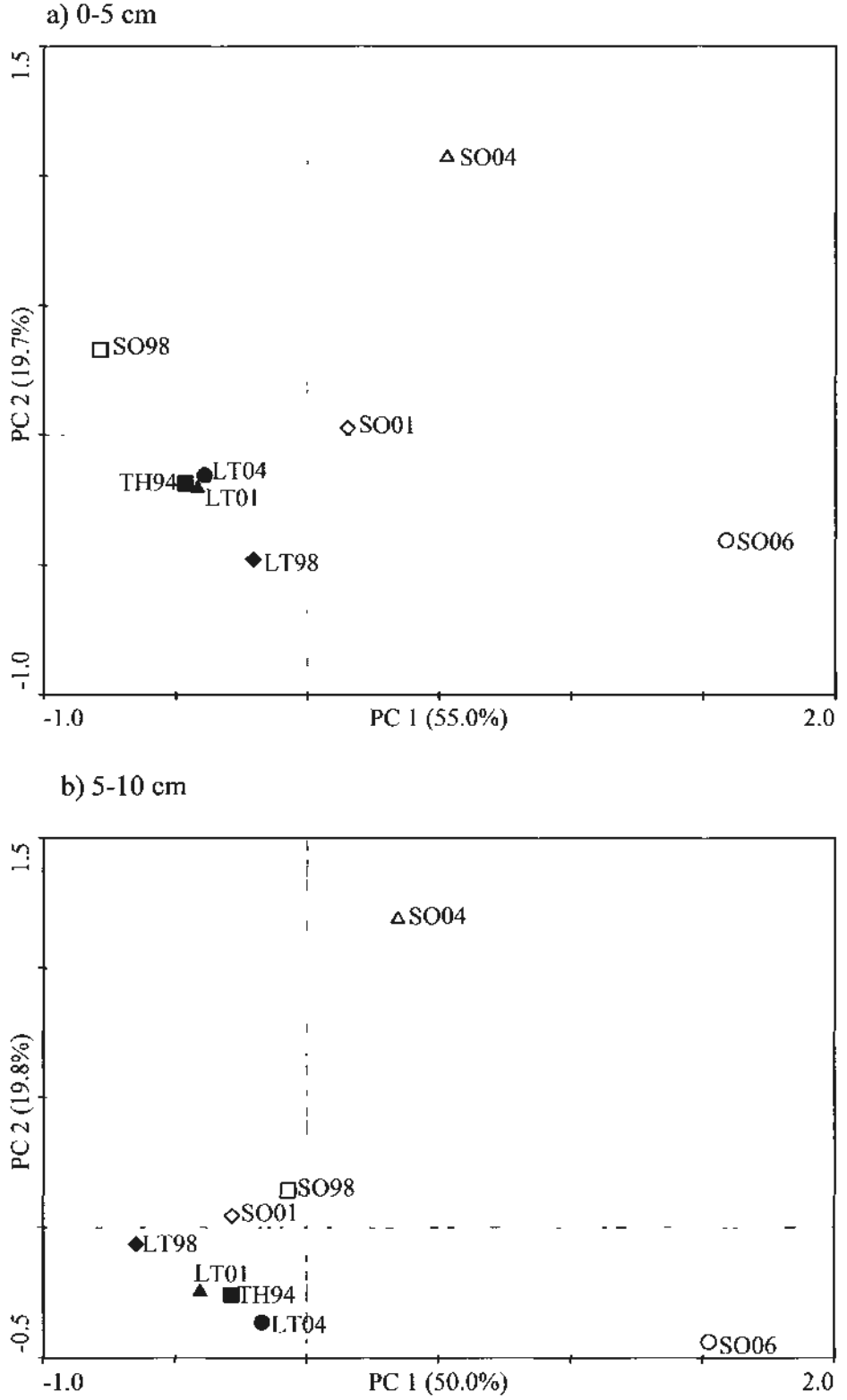


Figure 7.2 Principal component analysis of carbon utilization at 96 h of incubation for microorganisms in 0-5 cm (a) and 5-10 cm (b) soils at different phases in the three quarries

7.3.4 Fatty acid methylester (FAME) profiles

The average number of FAMEs in soils at 0-5 cm depth was higher than those of at 5-10 cm depth (Table 7.7). At 0-5 cm depth, LT01 had the highest number of FAMEs, and SO98 followed. The new rehabilitated sites (LT04, SO04 and SO06) had the low number of FAMEs. At 5-10 cm depth, there was a similar trend for the number of FAMEs. With a few exceptions, similar trends were shown by FAME peak areas that indicated microbial abundance. LT01 and SO98 had higher peak areas at two depths, while LT04, SO04 and SO06 had the low peak areas at two depths.

Using individual FAMEs as biomarkers, the relative abundance of specific microbial groups was compared among the soils (Table 7.8). The relative abundances of G^+ bacteria, G^- bacteria, fungi, actinomycetes and AM fungi were higher in 0-5 cm depth than in 5-10 cm depth. The group of G^- bacteria dominated in all sites, in which cy19:0 represented more than 15% of the total extracted FAMEs in all soils tested, except the soils of SO06 at 5-10 cm depth. The group of bacteria (including 14:0 and 17:0) occurred at TH and LT quarries, however, were absent in SO. It was also found that the group of AM fungi decreased with the increasing ages in SO and LT.

Table 7.7 Total number and peak area of FAME detected in soils at different phases in the three quarries

Sites	0-5 cm		5-10 cm	
	Number	Area	Number	Area
TH94	26b	79176b	18ab	41369ab
LT98	24bc	65616b	16ab	32568bc
LT01	36a	196309a	21a	61893a
LT04	18cd	47223b	15ab	25041bc
SO98	32a	90594ab	21a	58955ab
SO01	20bcd	41152b	15ab	28397bc
SO04	15d	30129b	13b	25585bc
SO06	17d	33307b	12b	9533c

Mean values followed by the same letter are not significantly different at p=0.05 level according to the Tukey's HSD test

Table 7.8 Percentage of microbial indicator FAMEs in total tetected FAMEs in soils at different phases in the three quarries

Organisms	0-5 cm								5-10 cm							
	TH94	LT98	LT01	LT04	SO98	SO01	SO04	SO06	TH94	LT98	LT01	LT04	SO98	SO01	SO04	SO06
G^+ bacteria																
10me16:0	3.84a	ND	ND	ND	2.42a	1.29b	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
i15:0	5.24ab	4.10bc	4.44abc	2.96c	5.32ab	4.26bc	4.37bc	6.24a	3.74ab	2.90ab	3.65ab	2.23b	4.32a	3.69ab	2.54ab	3.30ab
a15:0	1.79b	1.66b	1.86b	1.18b	2.39ab	1.56b	1.19b	3.71a	1.17a	1.18a	1.58a	0.90a	1.68a	1.42a	ND	2.00a
i16:0	1.80b	2.42ab	1.64b	1.40b	2.42ab	2.24ab	3.07a	1.82b	1.31a	1.66a	1.27a	0.97a	1.72a	1.31a	1.12a	1.67a
i17:0	ND	0.79b	ND	0.34b	2.74a	0.70b	ND	ND	ND	ND	ND	ND	0.88a	ND	ND	ND
G^- bacteria																
16:1w7c	4.31c	9.83b	4.32c	4.20c	5.52bc	10.0ab	14.3a	10.5ab	3.10bc	1.34c	3.65bc	3.21bc	4.25b	2.99bc	6.58a	6.21a
cy17:0	11.54a	ND	ND	1.80b	1.72b	ND	ND	ND	ND	ND	ND	0.43a	ND	ND	ND	ND
18:1w7c	1.74c	2.42b	2.74b	2.70b	2.68b	3.59b	3.58b	7.92a	1.71b	2.89b	2.73b	2.12b	1.73b	2.77b	0.00	4.61a
cy19:0	30.1a	27.7b	33.47a	21.1b	35.0a	30.6a	30.5a	30.2a	22.8ab	20.0ab	26.5a	17.3b	19.6b	21.8ab	22.8ab	8.98c

Table 7.8 (continued)

Bacteria																
14:0	4.76a	5.82a	5.36a	3.02b	ND	ND	ND	ND	3.93ab	4.13a	3.21ab	2.29b	ND	ND	ND	ND
17:0	ND	ND	ND	0.25a	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fungi																
18:1w9c	4.65c	9.07bc	12.1ab	10.5ab	5.43c	9.04bc	14.4a	15.7a	3.53c	6.77b	7.88ab	8.91a	4.17bc	6.47b	8.03a	8.08a
18:2w6	4.99c	5.91bc	11.3a	8.85ab	6.33b	6.55b	9.46ab	7.44b	2.89d	5.06bc	6.23ab	7.47a	3.80cd	4.06cd	4.71bc	6.15ab
18:3w6	9.25a	9.28a	ND	1.64c	6.43b	7.34b	ND	2.11c	7.25a	1.70b	ND	0.89b	2.85b	3.07b	ND	1.16b
AM fungi																
16:1w5c	3.36d	7.45bc	8.00bc	16.8a	4.64cd	7.97bc	13.9ab	10.9b	1.13c	3.91bc	4.79bc	11.7a	3.08bc	5.54bc	5.03bc	7.51b
Cy19:0/18:1w7c	17.3a	11.5b	12.2b	7.81bc	13.1ab	8.52c	8.52c	3.81c	13.3a	6.92bc	9.70b	8.16b	11.3ab	7.87bc	0.00d	1.95c

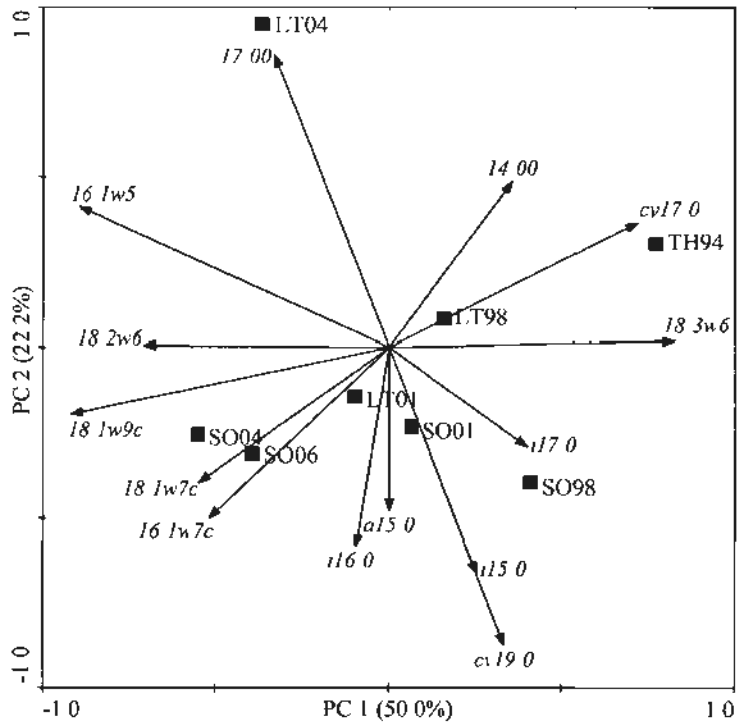
ND: not detected

Mean values followed by the same letter in the same row for each depth soil are not significantly different at p=0.05 level according to the Tukey's HSD test

Principal component analysis, using the whole FAME profiles of two depth soils, revealed a scattered distribution for all sites (Figures 7.3). For the soils of 0-5 cm depth, the first principal component (PC1) accounted for 50% of the variance, and the second accounted for more than 20% for all soil samples. PC1 was accounted mostly by 18:3w6, cy17:0, 18:1w9c and 16:1w5, while PC2 was by 17:0 and cy19:0. PC1 clearly separated soils from the old rehabilitated sites and the new sites. PC2 mainly separated soils from SO and both quarries of TH and LT, except LT01.

For the soils of 5-10 cm depth, the first and second principal components (PC1 and PC2) accounted for more than 80% of the variance. PC1 was accounted mostly by 16:1w5, 18:1w7c, 18:2w6 and cy19:0, while PC2 was by 18:3w6, i16:0 and i15:0. The biplot of PCA clearly separated soils from different phases based on the distribution in PC1 and PC2, except LT98 and SO01.

a) 0-5 cm



b) 5-10 cm

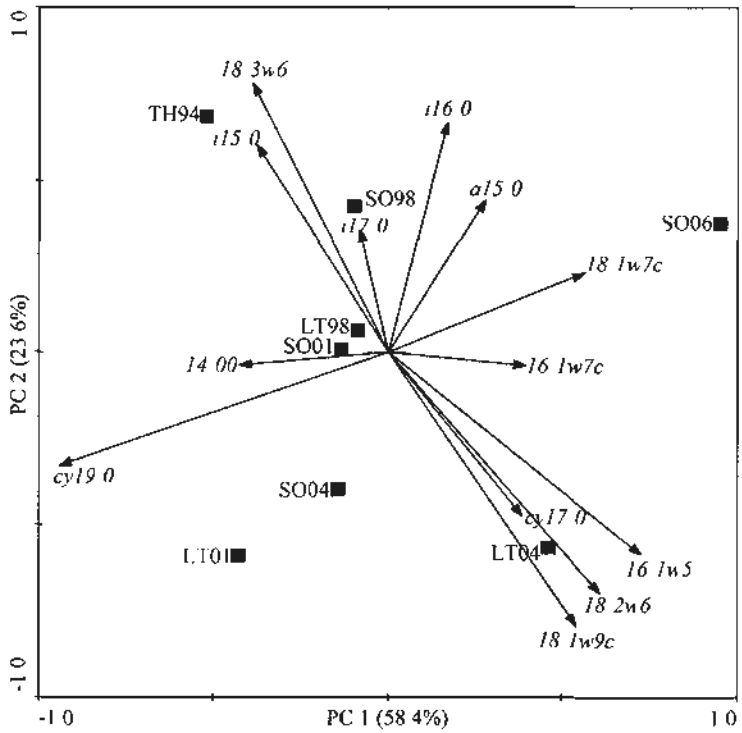


Figure 7.3 Principal component analysis (PCA) of whole FAME profiles at 5-10 cm (a) and 5-10 cm (b) depth for soils at different phases in the three quarries

7.3.5 RDA of plant community and microbial parameters

The results of RDA show that a total 45.7% of the variance of soil microbial parameters could be explained by the plant structure variables (from the canonical sum of the eigenvalues). The first and second canonical axes accounted for 25.9% and 10.4% of the total variance, respectively (Figure 7.4). The percentage of the species-environment variation was 56.7% and 22.7% for the first and second axes, respectively. Monte Carlo permutation test shows that significant plant parameters included grass coverage (P=0.002, F-value=11.98), woody richness (P=0.002, F-value=6.91), native species richness (P=0.002, F-value=6.22), grass richness (P=0.010, F-value=2.69) and woody coverage (P=0.042, F-value=1.87). MBC, MBN, utilization of six carbon substrate groups (AA, AM, CA, CHO, MI and PO) and functional diversity (H) were positively correlated with woody species coverage and grass richness. G^+ bacteria (10me16:0, a15:0, i16:0 and i17:0) and G^- bacteria (cy17:0, cy19:0) were positively correlated with woody richness and native species richness, while G^- bacteria (16:1w7c and 18:1w7c) were negatively correlated with woody richness. The groups of fungi (18:1w9c and 18:2w6) and AM fungi (16:1w5) were positively correlated with grass coverage.

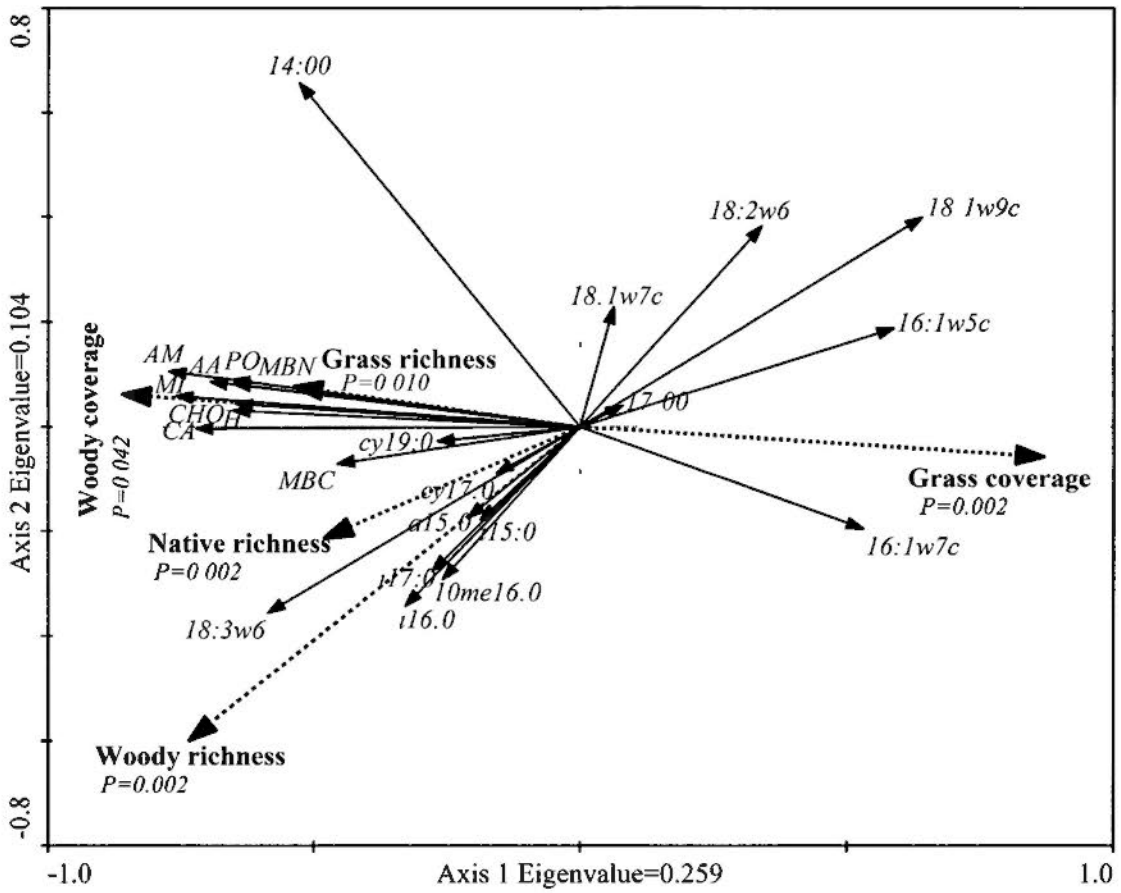


Figure 7.4 Biplot of the first two RDA axes of plant community structure and soil microbial parameters. The soil microbial parameters (expressed as response variables in the RDA analysis) were presented as solid line vectors, and the plant parameters (explanatory variables) were presented as dotted line vectors

Abbreviations: AA: amino acids, AM: amines/amides, CA: carboxylic acids, CHO: carbohydrates, H: diversity of utilized substrates, MI: miscellaneous, MBC: microbial biomass carbon, MBN: microbial biomass nitrogen, PO: polymers.

7.4 Discussion

7.4.1 Effects of soil properties on microbial abundance

There was a highly significant correlation ($p<0.05$) between the bacteria and fungi abundance with organic C and TKN. At the same time, the bacteria abundance had a significant correlation with extractable NO_3-N and extractable P, and the fungal abundance was significantly correlated with TP. The results demonstrate that a linear increase in the abundance of bacteria occurred as organic C, TKN and extractable NO_3-N increased. The growth and development of the fungal population was largely influenced by organic C, TKN and TP. In rehabilitated quarries, with the processes of secondary succession after planting, accumulated organic matter can improve the development of bacteria and fungi. There was less significant correlation ($p>0.05$) between the actinomycetes abundance and soil chemical properties. Actinomycetes exist mostly as spores in soil, and they often remain dormant if the physical condition of the soil is unfavorable (Lacey, 1973). On the other hand, the development of actinomycetes was largely independent of soil nutrient contents in rehabilitated quarries.

7.4.2 Effects of plant community structure on microbial biomass

Soil microbial biomass is a measure of the total microbial community in soil. Mineralization of organic substrates releases nutrients as a result of the heterotrophic

activity of the microbial biomass (Anderson, 2003). In this study, there was a significant correlation ($p<0.05$) between the microbial biomass C and N with organic C, TKN and extractable NO_3-N. This is consistent with the results of a study conducted for brown coal mining, in which microbial biomass correlated well with organic C and total N (Frouz and Novakova, 2005). In addition, soil microbial biomass correlated closely with the changes in vegetation coverage (Frouz et al., 2008) and species richness (Zak et al., 2003; Zhang et al., 2010), which could affect the development of soil microorganisms. A 12-year old restored mine site had a higher soil microbial biomass than younger sites, because of increasing plant species richness (Baldrian et al., 2008). Similarly, the pattern of RDA shows that microbial biomass C and N were significantly positively correlated with woody species coverage and native species richness (Figure 7.4). Increasing plant community coverage could enhance stand microhabitat (e.g. temperature, moisture, light intensity), and greater plant richness could positively affect root morphological characteristics (e.g. root densities and structures) and root chemical properties (e.g. root exudates and tissue qualities) (Wardle and van der Putten, 2002; Wardle, 2005; Baldrian et al., 2008). These may result in greater diversity of food resources and habitat heterogeneity, creating available niches that support diverse microbial community (Bardgett and Shine, 1999; Bardgett and Walker, 2004). Soil microbial biomass increased with

increasing age in SO, as increasing vegetation coverage and species richness (Chapter 2), especially native species richness, may lead to an increase of microbial biomass. However, LT01 had higher microbial biomass C and N instead, which could be explained by its higher vegetation coverage (Chapter 2), because of the leguminous *Calliandra haemaocephala* which has wide crown layer.

7.4.3 Effects of plant community structure on microbial community functional diversity

Sole C source utilization tests using Biolog method is well proven for characterizing microbial communities based on their metabolic profiles (Garland and Mills, 1991). These indices of substrate richness and diversity reflect functional diversity (Garland, 1996 and 1997). Variations in potential substrate utilization had similar pattern as the microbial biomass in the quarries, which indicated a positive relationship between microbial biomass and functional diversity (Lynch et al., 2004). Different patterns of potential C utilization were developed by different microbial communities, indicating that the heterogeneity of catabolic substrates in soil is an important determinant of soil microbial community (Wardle et al., 1999; Gros et al., 2002).

At SO, the metabolic abilities of microbial communities developed gradually with the age of rehabilitation. The results from PCA show that the recently

rehabilitated SO04 and SO06 sites were well separated from the others and were far away from the origin (Figure 7.2). In the early period of revegetation in quarries, there is a lower accumulation of organic matter and nutrients, resulting in a simple composition and functional diversity of the soil microbial community. This result is consistent with the finding that low C availability can act as a stress factor, because heterotrophic organisms rely on carbonaceous compounds for their energy requirements (Othonen et al., 1999). With the process of secondary succession, changes in plant coverage and richness, especially native species richness (Figure 7.4), affect microbial community as different plant species add different C substrates in the forms of litter or root exudates to soil (Grayston et al., 1996; Wardle, 2005). Therefore, the composition and structure of the soil microbial community are becoming more diverse, doubtless due to the presence of more abundant and diverse substrates. Degens et al. (2000) have suggested that land uses causing decreases in organic C may also decrease the catabolic diversity of the microbial community, probably due to the reduced quality and quantity of organic matter in soils. In LT, soil organic C at different phases was lower than in the corresponding phases in SO (Chapter 5). They had similar functional diversity of soil microbial community as shown by PCA of the patterns of C utilization (Figure 7.2). This is perhaps attributable to the different exotic species and engineering construction adopted in the quarries. *Eucalyptus*

tereticornis and *Casuarina equisetifolia* were planted in TH and LT, while *Acacia confusa* and *A. auriculiformis* which are leguminous were planted in SO. It is well documented in agroforestry systems that N availability would be increased by planting legumes (Kahindi et al., 1997; Wardle and van der Putten, 2002; Crews and Peoples, 2005). *Eucalyptus* spp. and *Casuarina equisetifolia* often produce litter with low nutrient concentrations, which breaks down slowly during the early stages of decomposition (Guo and Sims, 1999; Parrotta, 1999). According to observation, both *Eucalyptus* spp. and *C. equisetifolia* had shallow root systems and growth decline was serious in TH and LT. In addition, bench slopes were used for recontouring in TH and LT. Compared with scree slopes in SO, bench slopes had shallower soil and discontinuous soil covers at different rehabilitated phases, which resulted in lower fluxes of soil nutrients and poorer recruitment of soil microbes. Therefore, the plantations in TH and LT may lead to the development of a specific microbial community dominated by the specific r-strategists, which are able to tolerate adverse soil conditions (Rasmussen and Sorensen, 2001), thereby restricting the soil microbial community to healthy development and recovery.

7.4.4 Patterns of soil microbial community composition and structure

As shown in Table 7.7, different rehabilitated sites had different fatty acid composition in their soils, with the old rehabilitated sites showing higher number and

peak area of fatty acids than the young sites. The differences in the proportion of different FAMEs within different sites gave a possible indication of the diverse composition and structure of microorganisms occupying in the old rehabilitated sites. The higher abundance of some FAME indicators in 0-5 cm depth than in 5-10 cm depth was consistent with studies that their abundance decreased with increasing soil depth (Song et al., 2008).

The presence of a large proportion of cyclopropane fatty acids, markers of G^- bacteria (especially for cy19:0), suggested high population of this group of bacteria in the three quarries. Some studies reported that G^+ bacteria were associated with high clay content while G^- bacteria were associated with sandy sediments (Sinclair and Ghiorse, 1989). Our soil study shows that all soils in the three quarries were classified as sand loam, with a very high content of sand and relatively low clay contents (Chapter 5), which could explain the higher abundance of G^- bacteria in the three quarries. Vestal and White (1989) had suggested that the cyclopropane fatty acids could be indicative of anaerobic conditions, which implied that soils lacked aeration space in the three quarries, even ten years after rehabilitation (Chapter 5). The cyclopropane fatty acids were usually produced by a number of bacteria such as *Cromatium*, *Legionella*, *Rhodospirillium* and *Campylobacter* (Wilkinson, 1988). The FAME ratio, cy19/18:1w7c, had used to assess the nutritional stress in

microorganisms, in which higher ratio had been associated with a decrease in bacterial growth rates and an increase in carbon limitation (Kieft et al., 1997; Bossio and Scow, 1998). In our study, the cy19/18:1w7c ratio increased with the age of the rehabilitated quarries (Table 7.8), which implied that the C substrate availability may be more limiting in the young rehabilitated sites. RDA results show that G^- bacteria (cy17:0, cy19:0, 16:1w7c and 18:1w7c) were significantly correlated with woody richness and native species richness, which demonstrates that the increase in plant richness could result in the increase of organic matter, and indirectly resulting in the improvement of soil microbial community (Bonari et al., 1993; Cabrera et al., 1996; Paredes et al., 1999; Mekki et al., 2006; Mechri et al., 2007). Therefore, our study indicated that oxygen and C availability played a dominant role in driving the changes in the structure and composition of G^- bacteria (Kieft et al., 1994; Sahm et al., 1999; Fierer et al., 2003; Song et al., 2008).

The low abundance of branched fatty acids, especially the terminally branched saturated fatty acid (a15:0, i15:0, i17:0) and mid-chain branched saturated fatty acid 10me16:0, suggested that the low concentration of G^+ bacteria in the three quarries, which was different the result of dominance of G^+ bacteria in the whole microbial community (England et al., 1993; Fierer et al., 2003; DeGrood et al., 2005). Our study found that the abundance of G^+ bacteria increased with the increasing rehabilitated

ages in the three quarries (Table 7.8) and were positively correlated with woody richness and native species richness. The results indicated that the C substrate availability also played an important role in the G^+ bacteria communities. Compared with G^- bacteria, growth and maintenance of G^+ bacteria were apparently not as sensitive to oxygen condition in soils (Song et al., 2008). FAME method had been found the limiting of the low bacteria extraction efficiency (Macalady et al., 1998; Drenovsky et al., 2004). In our study, groups of bacteria included 14:0 and 17:0 and only occurred at TH and LT, however, the pattern did not give some implications.

The FAMEs, 18:1w9c, 18:2w6, 18:3w6 and 16:1w5c, were of ecological significance because these FAMEs had been suggested as the indicators of fungi and AM fungi in soils (Olsson, 1999; Stromberger et al., 2007). Madan et al. (2002) reported that 16:1w5c was the dominant fatty acid present in several fungal species of endomycorrhizal associations, including *Glomus coronatum*, *Glomus mosseae*, *Gigaspora margarita* and *Scutellospora calospora*. Our study found that the abundance of fungi (18:1w9c, 18:2w6, 18:3w6) and AM fungi (16:1w5c) decreased with the increasing rehabilitated ages in the three quarries (Table 7.8) and were positively correlated with grass coverage (Figure 7.4). Some studies showed that its relative abundance was correlated with the activities of phosphatases (Acosta-Martinez et al., 2007; Song et al., 2008). Our soil study shows that the new

rehabilitated phases had higher available orthophosphate than the old phases (Chapter 5), which could be explained the higher concentration of fungi and AM fungi in young phases. Therefore, our study demonstrates that available P was the limiting factor regulating the fungi and AM fungi communities and suggested that artificial planting leguminous species and adding phosphate fertilizer in our local quarries plays an important role for the ecosystem rehabilitation.

7.5 Conclusions

Plant species richness and coverage increased with ecological development after planting of exotic species in the closed quarries, which leads to changes in plant community structural complexity and understorey microclimatic conditions. These result in a greater diversity of substrate sources and habitat heterogeneity for the development of soil microbial communities, which could likely enhance both organic decomposition and nutrient mineralization. Soil microbial biomass and community metabolic abilities developed as the site aged in SO, and there was a close relationship between plant community structure and soil microbial parameters in the quarries. As native species richness correlated positively with soil microbial community, the use of natives in enrichment planting after the initial revegetation phase should be recommended for quarry rehabilitation.

There was a decline in the plantations of *Eucalyptus* spp. and *Casuarina*

equisetifolia in TH and LT that were rehabilitated using bench slopes, leading to similar patterns of microbial biomass and community metabolic abilities among different phases in the two quarries. The use of these exotic trees and bench slopes should be cautious for further adoption in quarry rehabilitation.

The diverse composition and structure of microorganisms occurred in older sites. The group of G^- bacteria was dominant in the three quarries and oxygen and C availability in soils played a dominant role in driving the changes in the structure and composition of G^- bacteria. C substrate availability also played an important role in the G^+ bacteria community. Higher concentration of fungi and AM fungi was found in younger sites, which implied that available P was the limiting factor for regulating the fungi and AM fungi communities in our local quarries. Artificial planting of leguminous species and adding phosphate fertilizer should be strongly recommended during the early period of rehabilitation.

Chapter 8 General Conclusions

8.1 Summary of findings

In our study, the planted exotic species were becoming dominant in the plantation and their species number, density and mean height generally increased with the ecological development in the three quarries (Chapter 2). On the other hand, some native species (for example *Bridelia tomentosa*, *Ligustrum sinense*, *Macaranga tanarius*, *Celtis sinensis*, *Rhus succedanea*, *Mallotus apelta* and *Cinnamomum camphora*) which naturally invaded the sites had become mature trees in the plantation. Therefore, reforestation in the early period of rehabilitation is a common and efficient approach used to accelerate forest formation in the rehabilitated quarries. Many woody species occurred in the understorey of the three quarries, and were often more abundant and dominant in older sites than in younger sites, which indicated that exotic plantations would catalyze the regeneration of native flora in their understories. The Shannon indices of understories in the three quarries were relatively low compared with other old plantations and secondary forests in Hong Kong, which implied that simply reforestation with exotic species is not sufficient to restore natural forest diversity. With ecological development in quarries, some light-demanding early succession species naturally invaded in younger plantations and some common secondary forest species and mid- to late- successional species naturally occurred in

older plantations.

A number of factors may impede forest succession on degraded sites. These include low rates of seed recruitment, seed and seedling predation, poor germination conditions, seasonal drought and poor soil conditions. Our seed rain study shows that the abundance and richness of woody species collected was lower in the three quarries than in other degraded hillsides and secondary forests in Hong Kong, which indicated that lack of seed dispersal was a major factor limiting vegetation regeneration in our local quarries (Chapter 3). Birds were the main seed dispersers in the three quarries and wind- and civet- dispersed taxa became very important components on the sites which were far away from the nearby secondary forests. Therefore, efforts on facilitating vegetation recovery must focus on strategies to elevate seed dispersal, such as planting trees that rapidly mature and fruit, thereby attracting seed dispersers. If barriers to seed dispersal are overcome, some interrelated factors may influence seed germination and seedling survival and growth. In our study, most seeds from twelve woody species could germinate in SO quarry, which suggested that lack of seed germination was not a major limiting factor for vegetation regeneration. However, our study found that most emerging seedlings for all twelve species had a low survival rate under field conditions. Air temperature and soil temperature increased and soil moisture decreased during seedling survival period, and seedling

survival had significant correlations with them. Therefore, the adverse microclimate was a limiting factor for seedling establishment in our local quarries.

The dynamics of a soil seed bank include recruitment into the dormant seed bank population through seed dispersal, loss from the dormant seed bank through seed predation or death, and formation of young seedlings through germination. Seed bank analysis is a good method for examining the self-sustainability of species in quarries by studying the regeneration potentials of species. Our results show that the newly rehabilitated sites mainly consisted of seeds from grasses and sedges, which are ruderal plants and are specialized for invading most open areas and wastelands (Chapter 4). With ecological development, some annual ruderal plants were gradually excluded from the ecosystem, and some perennial herbs and woody species were dominated. At the same time, species richness of seed bank increased with increasing ages at the three quarries. Therefore, ecological development favors the increase in species richness and seed density of the seed banks, as seeds from both on-site and off-site species continuously accumulated in the soil. There was no close relationship between the relative proportion of species in the seed bank and vegetation in the three quarries. Twenty two woody species were recorded in the seed bank of the three quarries and they were better represented at the older rehabilitated sites. Although these woody species did not predominate in the quarry during the past ten years, they

still could provide some hints in selecting species for quarry revegetation. Artificial planting of some fast growing native species which have fruits to attract birds should be recommended in the early rehabilitation years and artificial seeding some late successional species to accelerate vegetation succession should also be recommended in older plantations in our local quarries.

Vegetation development plays an important role in the process of soil development. Soil development involves the accumulation of soil organic matter, soil nitrogen capital and available nutrient capital, the enhancement of nutrient cycling processes as well as the development of soil microbial community. Overall, the quarry soils were strongly to moderately acidic in reaction. The contents of organic C, total N and extractable P were all considered low for all eight quarry sites (Chapter 5), and the soils were also deficient in extractable K and Ca. With ecological development, organic C, total N and P and four extractable cation contents increased with age in the three quarries, which were significantly correlated with woody species and grass species richness as well as woody species coverage. However, the availability of extractable NH_4^+, NO_3^- and P decreased with increasing age in three quarries, which was more pH-dependent.

Cover soils of rehabilitated quarries are considered to be poor in nutrient and organic matter contents even more than ten years after exotic tree planting. N may be

the most limiting nutrient in the ecological development in rehabilitated quarries. In our N mineralization study, it was found that the newly rehabilitated sites had net ammonification in the wet season, while immobilization of NH_4^+ occurred at the older sites (Chapter 6). In the dry season, mineralization of NH_4^+ was detected at all sites in the three quarries. The relative demand by microbes for N and C is the main factor to influence ammonification. In the three quarries, those newly rehabilitated phases had relatively low organic C which led to net ammonification, while older sites had lower proportion of N which led to net immobilization. The process of nitrification was mainly influenced by the availability of NH_4^+ and the availability of oxygen. In the wet season, the availability of NH_4^+ was high and net nitrification occurred in most phases. In the dry season, most phases had immobilization of NO_3^-, which indicated the provision of NH_4^+ and low oxygen condition in most phases. Overall, net N mineralization increased with age, especially in SO. N deficiency was a potential problem in rehabilitated quarries as a consequence of excessive leaching loss, especially in summer. The use of leguminous species, especially native species, which could effectively assist in the buildup of N capital in quarries, should be recommended.

Soil microorganisms are a vital component of soil biota. After planting exotic species in rehabilitated quarries, plant species richness and coverage increased with

ecological development in the rehabilitated quarries, which result in a greater diversity of substrate sources and habitat heterogeneity for the development of soil microbial communities, and may lead to changes in the structure and composition of soil microbial communities (Chapter 7). Soil microbial abundance, biomass and community metabolic abilities developed as the site aged in SO, and there was a significant relationship between plant community structure and soil microbial parameters in the quarries. With the process of secondary succession in the rehabilitated quarries, changes in plant coverage and richness, especially native species richness, affected microbial community as different plant species added different C substrates in the form of litter or root exudates to soil. There was a decline in the plantations of *Eucalyptus* spp. and *Casuarina equisetifolia* in TH and LT that were rehabilitated using bench slopes, leading to similar patterns of microbial biomass and community metabolic abilities among different phases in the two quarries. The use of these exotic trees and bench slopes should be cautious for further adoption in quarry rehabilitation. The group of G^- bacteria was dominant in the three quarries and oxygen and C availability in soils played a dominant role driving the changes in the structure and composition of G^- bacteria. C substrate availability also played an important role in the G^+ bacteria community. Higher concentration of fungi and AM fungi was found in young phases, which implied that available P was the limiting

factor for regulating the fungi and AM fungi communities in our local quarries. Therefore, artificial planting leguminous species and native species and adding phosphate fertilizer should be strongly recommended during the early period of rehabilitation.

8.2 Limitations of the study

This study adopts a retrospective approach to assess the vegetation and soil development in three quarries in Hong Kong. It is difficult to truly describe the successional dynamics of vegetation and development of soil properties, because of the absence of zero-time approach, in which changes in permanent plots can be assessed continuously. It is also difficult to choose study sites due to the different rehabilitation years within each of the three quarries. The major consideration in site selection is the age of rehabilitation, but the sites vary in their ecological construction, planting composition and density, soil type, geology, topography and aspect. Therefore, ecological variability occurs in all study sites. In soil assessment, the findings only represent the characteristics of summer sampling, but the seasonal and yearly fluctuations are not investigated. Because of the constraints of time and manpower, four plots for vegetation study and six sampling sites for soil study were used on each site. The plantations are relatively heterogeneous and the increased number of sampling points should improve the precision of the results.

8.3 Implications of the study

Quarry is the main type of degraded sites in southern China and quarrying always leaves the site barren due to the destruction of the soil profile. Successful restoration of a disturbed ecosystem is the acid test of our understanding of that ecosystem (Bradshaw, 1987). Therefore, ecological study in quarries plays an important role in the development of the theory and practice of restoration ecology.

Efforts to revegetate degraded quarries in Hong Kong aim at giving a greening effect and controlling erosion. Species that are tolerant to drought and poor soil quality may be of great advantages and some fast growing and N-fixing species such as *Acacia* spp., *Eucalyptus* spp. and *Casuarina equisetifloia* were widely used to rehabilitate quarries in Hong Kong. With the ecological development in quarries, however, several problems of these exotic plantations are observed, for example stunted growth and forking of the branches, soil infertility and crusting, and low diversity of the understorey vegetation. These problems are especially serious for the plantations of *Eucalyptus* spp. and *Casuarina equisetifloia.* The plantations of *Acacia* spp. exhibited appreciable performance in their understorey diversity. Hence, *Acacia* plantation had a better nursing effect on promoting the recruitment for native species. It is more practical to keep planting *Acacia* spp. instead of eliminating all exotics just because of prevailing trends of promoting the use of natives. The ultimate goal of

quarry rehabilitation should be the enhancement of functions and sustainability of its ecosystem in a cost-effective way. Therefore, the use of some pioneer native species with *Acacia* species in the early stages of revegetation should be recommended as an efficient reforestation approach for quarries. Although planted exotic species dominated the overstorey in the three quarries; some native tree species, e.g. *Bridelia tomentosa*, *Ligustrum sinense*, *Macaranga tanarius*, *Celtis sinensis*, *Rhus succedanea*, *Mallotus apelta* and *Cinnamomum camphora* were becoming dominant species in older sites. These native species could be potential candidates for mixed planting with *Acacia* spp.

Vegetation regeneration in rehabilitated quarries is limited at the early colonization stages. Low richness and abundance of woody species were found in the seed rain and seed bank in the three quarries. Birds were the main seed dispersers in the three quarries, but the three quarries were all far away from the nearby vegetation, which limited the dispersal of woody species by birds. If the disturbed site was small, surrounded by natural vegetation, spontaneous succession was especially advantageous (Prach et al., 2001). Therefore, adding native species with fleshy fruits to attract birds by enrichment planting should be useful to increase biodiversity of plantations and accelerate natural succession. Bird dispersed species, such as *Melastoma sanguineum*, *M. candidum*, *Ficus hispida*, *Ficus variolosa*, *Rhaphiolepis*

indica, *Celtis sinensis*, *Embelia laeta*, *Callicarpa longissima*, *Mallotus apelta* and *Psychotria asiatica*, occurred in the soil seed banks in the three quarries, which could give some hints in selecting species for enrichment planting.

Ecological restoration is often constrained by low nutrient content, strong acidity and poor physical structure of the soils. In our rehabilitated quarries, the exotic plantations were capable of improving the organic matter and N levels, but the magnitude of improvement was small even after 10 years rehabilitation. Physical problems of cover soils were still serious. Therefore, application of organic composts should be considered by quarry contractors and managers during the early rehabilitaiton period to improve soil structure and raise nutrient and moisture storage capacities as well as improve the activities of soil microbial communities. On the other hand, liming of the soil at the time of planting which could reduce aluminium toxicity and enhance the bioavailability of phosphorus should also be considered in our local practice. N deficiency was a potential problem in rehabilitated quarries as a consequence of excessive leaching loss. The use of leguminous species could effectively assist in the buildup of nitrogen capital. Therefore, planting some native leguminous species in enrichment planting should be strongly recommended.

Besides the selection of native species and amendment of the soil, post-planting care is essential to quality development of the rehabilitated vegetation. Silviculture

practice in Hong Kong is limited to planting of the species and their thinning, pruning and fertilizing during the first 3 years (Kong, 2003). Thereafter, the plantations are left unattended except the removal of dead trees blown over by typhoons. In order to increase the ecological functions of plantations, an appropriate management should be chosen. For example, thinning and low pruning of the pioneer species should be carried out in the early stages to provide room for the understorey to develop. Periodic weeding and fertilization should also be paid with much attention by contractors and managers.

8.4 Suggestions for future study

The present study showed that mixed planting using native species and *Acacia* spp. would be an efficient approach in revegetating these quarries. Further studies should be done on the screening of native species, the interaction of species in mixed planting and the ratio of exotics to natives for revegetation. In addition, special consideration should be given to the roles of different plant groups in enhancing understorey diversity and improving the structure and function of soil microbial communities.

With a capacity to fix atmospheric nitrogen, the use of native leguminous species in enrichment planting is strongly recommended in future. The nitrogenase activity of different leguminous species and their seasonal fluctuations and changes with age of

the species should be studied to determine their nitrogen-fixing capacity.

The application of organic composts could be a potential way to improve soil properites. Further research could be conducted to optimize the dosage and frequency of application. In addition, its effects on soil physical and chemical as well as biological improvement should be studied.

Litter quantity (e.g. standing litter and current year litter production) and litter quality (e.g. nitrogen content and C:N ratio) play an important role in providing food resources to soil microbial communities in the rehabilitated quarries. Due to limited time and manpower, none of these were investigated in the present study. Therefore, changes in litter accumulation and decomposition rate, as well as nutrient uptake, storage and use efficiency in plantations should be further studied to broaden our understanding of ecosystem function.

Post-planting measures, such as thinning, pruning and fertilizer replenishment, are essential to accelerate forest recovery. However, there is a lack of these measures in our local environment. A revamped quarry rehabilitation strategy should be applicable to Hong Kong and southern China., Guidelines on quarry rehabilitation should be prepared for the aftercare of closed quarries as man-made ecosystems.

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