Ecological Inventory of Restored Quarries in Hong Kong

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Abstract

Ecological inventory can provide critical data for conservation planning. In this research, different phases of three operating quarries (Anderson Road Quarry, Shek O Quarry and Lam Tei Quarry) and one completed old quarry (Turret Hill Quarry) were studied for their soil quality, vegetation community and faunal assemblages.

The soil in these quarries were acidic (pH 5-6) and contained only trace amount of organic carbon (< 1%) and major plant nutrients. Vegetation study was also conducted on these sites. More than 140 plant species were identified on the four quarries. Gramineae and Papilionaceae were the two most common families. Faunal inventories including surveys on two insect orders, viz Lepidoptera and Odonata, were carried out on these sites. They have often been suggested as surrogate measures of species richness or ecosystem attributes. Butterflies and odonates were investigated by Pollard-walk method and visual encounter method, while light-traps were used to study moth communities. About 50 species of butterflies, over 60 species of moths and 10 species of odonates were recorded on the restored quarries. Some uncommon lepidopteran species were found, such as *Spindasis syama, Graphium doson, Nausinoe geometralis* and *Scirpophaga novella*.

In general, the flora and fauna species abundance and diversity index in older sites (e.g. Turret Hill Quarry) were higher when compared with newly restored sites (e.g. Anderson Road Quarry). Vegetation diversity was highly correlated with soil total nitrogen content since nitrogen is the most essential macronutrient which affects plant growth. Correlations between species diversity of different faunal groups suggested that butterfly diversity could reflect moth diversity on restored quarries at a local scale as their ecological role were similar. Dragonfly diversity was correlated with vegetation diversity on restored quarries. As dragonfly feeds on small insects, and diversified vegetation supports more species and higher population of insects. Soil and vegetation development of the restored quarries could then be estimated by fauna diversity. The information obtained from the project can help achieve succession management for quarry restoration.

摘要

這份研究報告，會探討三個分別在香港正在開發中的礦場，包括安達臣道礦場，石澳礦場及藍地礦場, 和一個已駿工的女婆山礦場，並分析各地點的土質及生物多樣性。

研究結果顯示其土質屬酸性（pH5-6），且含有少量的有機碳(少於 1%)，而其他植物所需之營養成份亦偏低。於各礦場進行的植被調查發現多於 140 種植物種類在各礦場中生長，當中以禾本科（Gramineae）和蝶形花科（Papilionaceae）之植物最爲普遍。另外，此項研究亦對兩類昆蟲進行考察，包括鱗翅目（Lepidoptera）和蜻蛉目（Odonata），它們常被視爲生物指示者（Biological Indicator）。至於研究蝴蝶和蜻蜓的方法是採用多種目測法（包括 Pollard-walk 和 visual encounter 的方法），而使用電光管則可捕捉飛蛾。在這些礦場中記錄到大約 50 種蝴蝶，超過 60 種飛蛾及 10 種蜻蜓，至於一些在香港較罕見的鱗翅目品種，亦可在修復中的礦場找到，例如豆粒銀線灰蝶（*Spindasis syama*），青斑鳳蝶（*Graphium doson*）和茉莉葉野螟蛾（*Nausinoe geometralis*）等。

舊礦場（如女婆山礦場）擁有的動植物品種數量比新修復的礦場（如安達臣道礦場）豐富及有較高的生物多樣性。研究發現不同生物群落之間的多樣性持有相互的關係。氮作爲植物的主要營養之一，泥土中氮的含量會影響植被的發展。基於生態相似性，蝴蝶的多樣性能有效地反映蛾類於修復中的礦場的生物多樣性。蜻蜓多捕食其他昆蟲，而昆蟲跟植物多樣性亦十分有關連，故此植物的多樣

性會影響蜻蜓的數量和多樣性。此外，植物多樣化跟泥土中總氮量的關係亦十分密切。因此，在修復中的礦場中，土質與植物的發展可從動物的多樣性中預測出來。這些資料能幫助荒地的演替管理，使礦場修復成功。

Declaration

I declare that the assignment here submitted is original except for source material explicitly acknowledged. I also acknowledge that I am aware of University policy and regulations on honesty in academic work, and of the disciplinary guidelines and procedures applicable to breaches of such policy and regulations, as contained in the website http://www.cuhk.edu.hk/policy/plagiarism/

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I also thank the Mines and Quarries Section of Civil Engineering Department for their permission to enter the quarries, and in particular Quarry Managers and Officers in Anderson Road Quarry, Lam Tei Quarry and Shek O Quarry for their arrangement in accessing the study sites.

Thanks for the support from fellow postgraduates and research assistants who also gave freely of their time for discussion and participation on my field works: Mr. Chiky Wong, Mr. Raymond Wong, Mr. Martin Tsui, Mr. John Chong, Ms. S.M. Ho, Mr. Michael Cheng, Mr. Ben Yeung and Ms. Mimi Cheung. Last but not least, I must thank Dr. Kendrick Roger for giving me advice on many practical aspects of materials, methods and insect identification, without whom this project and thesis could not becompleted

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Contents

List of Figures

List of Tables

List of Plates

Chapter 1 Introduction

Hong Kong as a world city and has a continuous demand for high quality aggregates for the construction industry. The demand is about 15 million tonnes per year which is largely supplied by quarrying. Quarries operation started in the 1960s. At that time, the quarries were small in scale and no restoration work after was included. Little consideration was also given to the environmental aspects. As a result, many near vertical rock faces were formed and were left as huge permanent unsightly scars in the landscapes.

Owing to the rise in public awareness of environmental conservation, government has become more concerned about restoration of degraded lands and put more effort in aspect of environmental conservation from the 1980s. The Government's Metroplan Landscape Strategy for the Urban Fringe and Coastal Areas, which was published by the Civil Engineering Department in 1989, identified quarries as areas of degraded landscape requiring improvement and restoration. Quarrying will lead to habitat destruction where the vegetation is completely removed and the soil profile will be destroyed. It will lead to degradation on ecosystem in terms of both structural and functional means. As a result, restoration works are required to bring the ecological status back to or close to the original form. Otherwise, quarries will remain barren rocky surface which can only support very little wildlife.

1.1 About Hong Kong

1.1.1 Geography

Hong Kong is a Special Administrative Region (SAR) of China with its own constitution. Plate 1.1 is a satellite image of Hong Kong. It is situated on the southeastern coast of China (22°09'N, 113°58'E to 22°37'N, 114°26'E), comprising mainland areas which consist of Kowloon (47 km^2) and the New Territories (747 km^2), Hong Kong Island (80 km^2) and over 200 outlying islands (227 km^2). The population size is about 6.8 millions, living in a small terrestrial size of about 1100

Plate 1.1 Satellite image of Hong Kong Special Administrative Region (CED, 1997).

km^2 including 62 km^2 reclaimed area (HKSAR Census and Statistics Department, 2001). Hong Kong now is one of the densest populations in the world (6182 per km^2). Because of extensive volcanic activity in the early Jurassic period, the topology of territory is mainly hilly with steep slopes. Hills are typically around 500 m in height. They occupy about 3/4 of the total area (800 km^2). The highest point is Tai Mo Shan at 957m, located in the centre of the New Territories, which is then followed by Lantau Peak (934 m) and Sunset Peak (869 m).

Volcanic rock, granite and sedimentary rock are the three main types of rock in Hong Kong. Volcanic rock is formed by eruption of now extinct volcanoes as ash and lava flows. Granite is coarse-grained, light-colored, hard igneous rock consisting chiefly of quartz, orthoclase or microcline, and mica. It is formed from molten rock underneath. Sedimentary rock is formed by the deposition of sediment that originally accumulated in seas, lakes and river deltas. The distribution of different rock types is shown on the geological map of Hong Kong in Figure 1.1. About half of the territory is covered by volcanic rock and one third is covered by granite. Volcanic rock and granite are similar in chemical composition but differ in granular size due to the difference in cooling time. Granite is susceptible to erosion and nutrient leaching. The resulting plant communities were affected by the variation in quartz grain size (Dudgeon and Corlett, 1994). Furthermore, granitic soils are mostly acidic, and it ranges from 4.66 to 4.74 in some granite-based areas in Hong Kong (Chau and Chan, 2000).

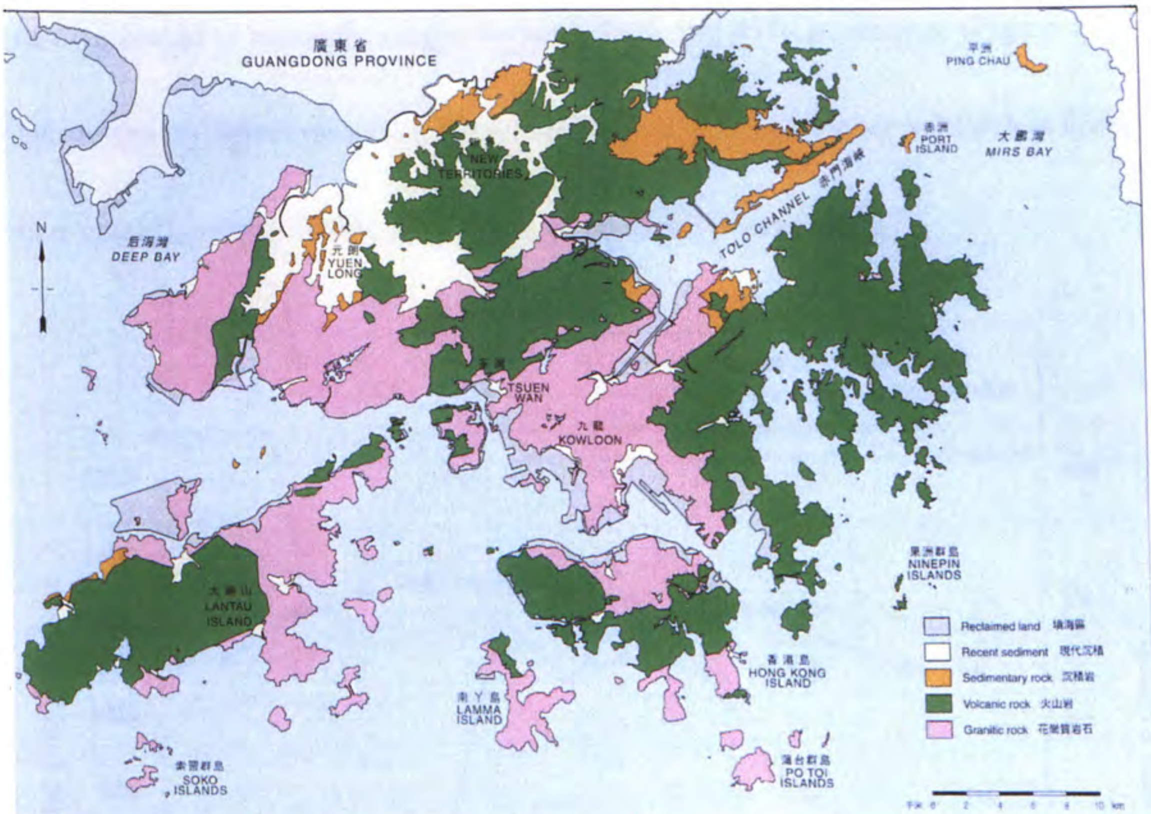

Figure 1.1 Geological map of Hong Kong based on different underlying rocks (CED, 1997).

1.1.2 Climate

Hong Kong is perched on the south-east coast of China, located within the tropic but the climate is widely classified as subtropical. This is because the blasts of maritime airstream that blows from the South China Sea during summer from May to September, bringing hot and humid tropical air. In winter (from December to

February), the seasonal wind reverses and Hong Kong is under the influence of continental air blasts of cold and dry wind generated from the huge land mass of north Asia. Thus, it is quite obvious in seasonality affected by such monsoon winds. The relative humidity normally ranges between 75% and 85% in summer (Figure 1.2). Due to the dry winter monsoon, the relative humidity from October to March is lower in average, normally 40% to 60% (Hong Kong Observatory, 2002).

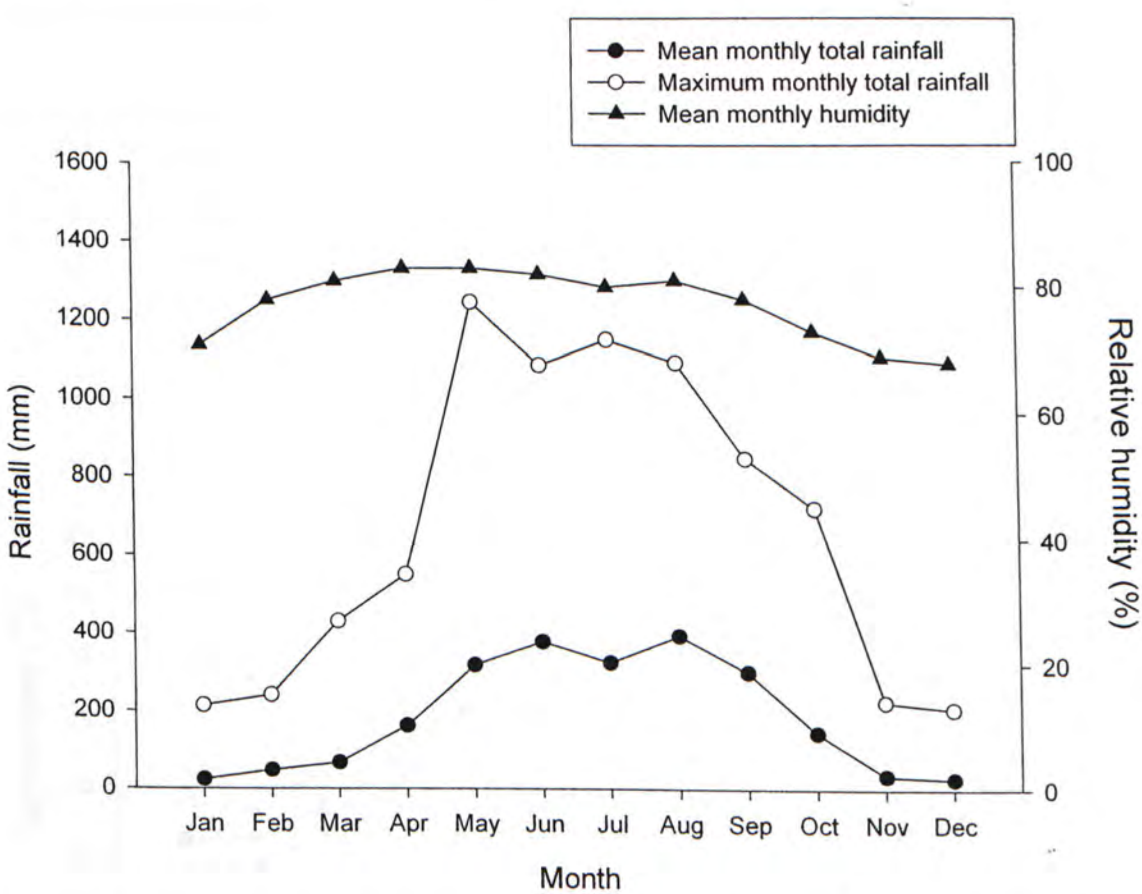

Figure 1.2 Average monthly relative humidity and mean monthly total rainfall for Hong Kong from 1961-1990 (Hong Kong Observatory, 2002).

From 1961 to 1990, the annual mean temperature was 23°C (Hong Kong Observatory, 2002) (Figure 1.3). Temperature can drop below 10°C in winter and exceed 31°C in summer. Summer is dominated by warm, wet southern monsoon winds with temperatures normally above 25°C and sometimes up to 30°C, typical and subtropic temperature. In winter, the average temperatures fluctuated from 15°C to 22°C. Although the average monthly temperatures are generally considered as a subtropic climate, there were some extreme cases. The highest temperature record was 36.1°C, which occurred in 1900 and 1990. And in 1893, temperature at sea level had once dropped to 0°C.

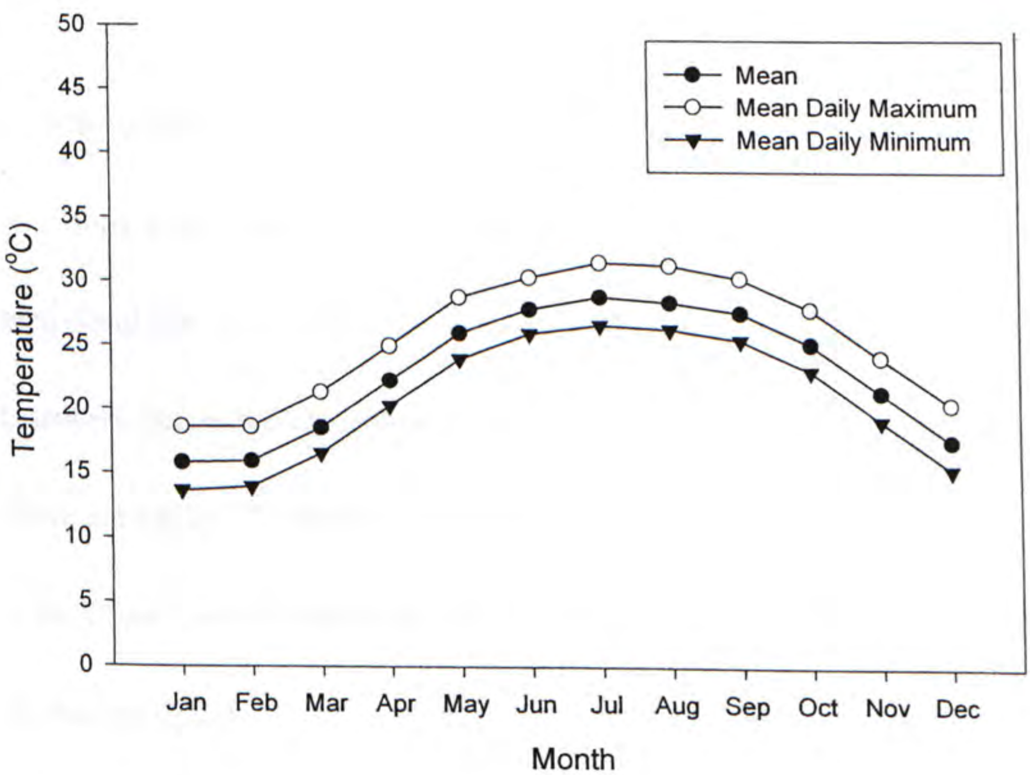

Figure 1.3 Mean temperature for Hong Kong from 1961-1990 (Hong Kong Observatory, 2002).

About 80% of the annual rainfall occurs between May and September (Figure 1.2). Tropical cyclones are vigorous in summer and bring much of the rains. It was called typhoons when they approached Hong Kong with maximum wind speed over 33 m s^{-1}, which can bring damage to vegetation especially some exotic plantation species with shallow root system (e.g. *Acacia mangium*). The average annual rainfall was about 2214 mm from 1961 to 1990 (Hong Kong Observatory, 2002). Rainfall in Hong Kong increases with altitude, for example in Tai Mo Shan, the annual rainfall can reach over 3000 mm (Hong Kong Observatory, 2002). It also decreases towards the Northwest New Territories and the southern islands with mean annual rainfall lesser than 1600 mm (Hong Kong Observatory, 2002).

1.1.3 Vegetation

Hong Kong was originally covered with a mixture of evergreen and subtropical semi-deciduous broadleaved forest which was mainly dominated by Fagaceae and Lauraceae before human settlement (Heppner, 1991; Hong Kong Herbarium, 2002). There are totally 239 families, 1278 genera and 2723 vascular plant species recorded in the Check List of Hong Kong Plants, in which about 70% are natives (Hong Kong Herbarium, 2002).

The slopes of the hills are largely covered with grassland (land covered with grasses and low shrubs generally <0.3 m in height). The occurrence of large grassland area is mainly due to frequent hill fires that are ignited by visitors and spread easily by dry windy from November to March. After the hill fire season, the disturbed slopes are quickly recolonized by native grasses. *Ischaemum* spp., *Arundinella* spp. and *Cymbopogon* spp. dominate these grassy hill slopes. Ferns such as *Dicranopteris linearis* (Gleucheniaceae) are also common because of the acidic soil especially after hill fire. Frequent hill fire would baffle natural succession and restrict development to early successional stage. Moreover, vegetation would become insufficient to control erosion after heavy rain and might result in badland formation (Hodgkiss *et al*., 1981; Thrower and Thrower, 1986). Areas of continuous disturbance are frequently covered with grasses like *Miscanthus sinensis* (Gramineae), *Neyraudia arundinacea* (Gramineae) and weeds such as *Ageratum conyzoides* (Compositae).

In the wet season, numerous small ravines are formed. Such areas are relatively higher in humidity and can escape hill fires and subsequently develop into broad-leaved shrublands (woody vegetation between 0.3 m and 2.4 m in height with fairly dense cover). *Rhaphiolepis indica* (Rosaceae), *Rhodomyrtus tomentosa* (Myrtaceae), *Melastoma sanguineum* (Melastomataceae), *Psychotria rubra* (Rubiaceae) and *Smilax china* (Smilacaceae) are common native shrubs. In addition, nearly half (47.5 %) of Hong Kong are covered by grassland and shrubland (Huwlett, 1996).

Ravines provide a suitable environment that generally remain undisturbed by human impact and form some small fragments of woodland (land with a continuous cover of woody vegetation > 2.4 m in height). Trees like *Litsea glutinosa* (Lauraceae), *Celtis sinensis* (Ulmaceae) and *Bridelia tomentosa* (Euphorbiaceae) are commonly found in such habitat. Also, because of the Chinese tradition of planting and preserving woodland near villages (especially in the New Territories), vegetation is then protected by these "fung shui woods" and hence escape from human impacts. Many economic plant species are planted by the villagers and mixed with other original tree species. As a result, fung shui woods are generally high in flora diversity (Zhuang, 1997). Fruit trees such as *Litchi chinensis* (Sapindaceae), *Dimocarpus longan* (Sapindaceae), *Clausena lansium* (Rutaceae) and *Psidium guajava* (Myrtaceae) are common in fung shui woods. Others like *Aquilaria sinensis* (Aquilariaceae) and many bamboos (*Bambusa* spp. and *Dendrocalamus* spp.) are also common in such habitat.

Owing to heavy timbering, vegetation destruction was vigorous in the 1840s and Hong Kong was described to have 'barren' and 'bare' landscape. In response to this, reforestation was carried out in large scale since 1880. In the beginning, exotics were heavily planted and only a few native species was used due to poor soil quality. According to Dudgeon and Corlett (1994), there were 42 km^2 reforested area on the Hong Kong Island in the late 1930s. However, most woody species were harvested for fuel and timber during Japanese occupation from 1941 to 1945, and plantation restarted after war. *Acacia confusa* (Mimosaceae), *Acacia mangium* (Mimosaceae), *Pinus elliotti* (Pinaceae), *Eucalyptus* spp. (Myrtaceae) and *Casuarina equisetifolia* (Casuarinaceae) are very common plantation species. In recent years, natives are more concerned to be used as plantation species. Not all natives can adapt and are suitable for plantation, among them, *Liquidambar formosana* (Hamamelidaceae) and *Schima superba* (Theaceae) were successful ones (Chong, 1999). Woodland, including plantation areas, covered about 20% of the total land area in Hong Kong.

1.1.4 Wildlife conservation in Hong Kong

Wildlife in Hong Kong can be protected in Country Parks, which covers up to about 37% of the total land area in Hong Kong. There are 23 Country Parks, and 15 Special Areas (11 of which lie inside Country Parks) have been established since 1976, and they make up a total area of 41,582 hectares. Beside Country Parks, other conservation zones, including Sites of Special Scientific Interest (SSSI), Conservation Areas, Coastal Protection Areas and Green Belts, also sustain Hong Kong's biodiversity.

These areas contain a wide variety of vegetation, including native and exotic tree species. Efforts on flora conservation are concentrated on the rare and endangered plant species (e.g. *Iris speculatrix* and *Nepenthes* spp.) and they are protected by registration under the Forests and Countryside Ordinance (Chapter 96). Moreover, habitat protection and active plant propagation help to conserve floral species diversity. *Keteleeria fortunei*, *Camellia crapnelliana* and *Camellia granthamiana* are three successful examples of active propagation. Seeds of these species have been collected in the field and nourished in nursery and then replanted in the wild habitats.

Hong Kong is also rich in diversity of local fauna, especially insects and birds, because of the wide variety of habitats. For insects, there are about 4,000 species recorded in Hong Kong (Agriculture, Fisheries and Conservation Department, 2002). Lepidoptera and Odonata are two most abundant insect groups among them. More than 200 species of butterflies and over 100 species of dragonflies were recorded in the territory (Wilson, 1995; Bascombe, 1999). There are over 450 species of birds recorded in Hong Kong, in which about 100 species are residents, 120 are winter visitors, 120 are passage migrants and 80 are summer visitors (Carey *et al.*, 2001). Some are globally threatened species such as *Platalea minor* and *Otus lempiir*.

Unfortunately, land degradation and urbanization cause loss in habitats and thus reduce the number of wild animals. Government takes action to protect the natural environment by legislation (Wild Animals Protection Ordinance, Cap. 170) and by the activities of its conservation staff.

The complexity of the ecosystem is far beyond our imagination. Species loss will adversely affect ecosystem functioning and stability. Critical natural processes at the ecosystem level, such as weathering and nutrient cycling, lead to the change in plant productivity, soil fertility, water quality, atmospheric chemistry and many environmental factors that ultimately affect human welfare. Thus, the extinction of wildlife will definitely affect the existence of human beings.

1.2 Land Restoration

Restoration is the conservation strategy that allows us to recover damaged ecosystems in both ecological function and structure (Bradshaw, 1980; Clewell, 2000). In strict sense, ecological restoration refers to the conservation of the affected ecosystems back to its original form (Bradshaw, 1980). On the other hand, ecological rehabilitation to accelerate natural successional processes artificially in order to bring the ecosystem closes to the original one. Restoration in quarry is interpreted in a broad sense in this study to include ecological rehabilitation.

Although restoration works are always difficult and expensive, they are important in terms of conservation. Human is a group of animals depending upon nature in order to survive. Many human activities including agriculture and industry are affecting the environment. From such activities, we take part in many natural processes such as nutrient cycling, water cycling, soil preservation, and climate regulation. Restoration of landscapes can retain the natural processes, which in turns conserve the earth.

The main objective of the quarry restoration works is to revegetate the final landform to a stable condition that eventually blends with the surrounding natural environment. It can encourage and provide the opportunity for the development of a self-sustaining ecosystem with a similar biodiversity to the surrounding environment and provide a natural and safe environment for future land use. The visual impact is also reduced, especially the existing barren quarry faces, within the shortest possible timeframe (Yu and Lam, 1998)

1.2.1 General processes of restoration

Restoration works can be divided into two parts. One is engineering rehabilitation, and the other is biological restoration.

Engineering rehabilitation is planned to re-shape the quarry faces and benches to form overall slopes consistent with the adjacent natural slopes, and to reduce soil erosion wherever possible. In Hong Kong quarries, there are two main methods of sloping: bench slope (such as Lam Tei Quarry) and scree slope (like Shek O Quarry). Both methods are similar to each other. They involve grading of the surface and lying of topsoil material with the construction of drainage system. A sufficient depth of topsoil is spread over in order to provide a suitable medium for plant growth. It is then hydroseeded before plantation to assist the establishment of a permanent self-supporting soil-plant system, reduce the risk of soil erosion, moderate extreme microclimates and raise soil organic matter (Dutton *et al.*, 1992). Different types of grass are used to achieve different objectives of plantation. *Cynodon dactylon* and *Paspalum notatum* are commonly used for hydroseeding in both seasons, while *Lolium perenne* is used in cool dry season (Chong, 1999).

After the establishment of grasses, the slope is then planted with shrubs and trees to further stabilize the landscapes, strengthen the ability to resist soil erosion and accelerate soil and ecosystem development. Usually the quarry will be progressively mix-planted with a variety of native and exotic species to produce a vegetated landform compatible with the surrounding natural environment. Fertilizer is usually applied in the early stage of hydroseeding and after tree planting.

1.2.2 Plantation in Hong Kong quarries

Species selection is an important link to the success of plantation because it is meaningless to plant a species that cannot survive. As a result, exotic species is always being placed as the first consideration in the planting list, because of their fast growth rate as well as low nutrient demanding characteristics. As a result, they have a high survivorship on the poor soil environment. They can also adapt to low rainfall and are planted to provide windbreaks, reduce soil erosion to restored quarries.

Exotics such as *Acacia* spp. (Mimosaceae), *Eucalyptus* spp. (Myrtaceae) and *Leucaena leucocephala* (Mimosaceae) are widely used in plantations. Most exotics are native to Australia which has the most infertile soil of all continents (Pimental, 1993; Bauhus *et al.,* 2002). Exotics can adapt and grow well in poor soil. For legumes and nitrogen fixing plants, because of their nitrogen-fixing ability, they can modify soil microclimate and physical, chemical and biological conditions. This can improve soil quality for the establishment of other more nutrient demanding natives. They have high survivorship and rapid growth in nutrient-deficient soil (Lugo, 1988). Some of them can even grow in very acidic soil such as *Pinus* spp. and *Eucalyptus* spp. (Bordeleau and Prevost, 1994; Ashwash *et al.*, 1995).

Native species are also mix-planted in restored quarries in Hong Kong. Some common species are *Sapium sebiferum* (Euphorbiaceae), *S. discolor* (Euphorbiaceae) and *Schefflera octophylla* (Araliaceae). In contrast, the growth performance of native species compared less favorably with exotic pioneers and their survival and growth rate were found to be low (Chong, 1999). Recently, many green groups advocate the use of native species in ecological restoration because of the higher conservation value of natives compared with exotics. The benefits of native species are well documented in the literature, including preservation of the local flora, attractiveness to wildlife, and enhancement of biodiversity.

1.2.3 Ecological succession in Hong Kong

In general, colonization and succession would occur when the condition is suitable for plant growth (Davis, 1986). Colonization is normally a continuous process during natural succession in which certain native species become established in the later stages when suitable conditions of soil, shade, shelter and nutrients developed.

Studies on natural forest succession show that grassland on local degraded lands after fire can develop into closed-canopy secondary forest through natural succession after about 30-40 years in the absence of disturbance. However, the time span required is longer on severely degraded and eroded lands, where the soil profile has been destroyed (Zhuang, 1997). According to Thrower (1970), the predominant soils of Hong Kong are considered to be characteristic of forested warm-temperate and tropical regions. Thus, the expected climax of Hong Kong would be semi-deciduous forest or monsoon forest.

Starting with fast-growing exotic species and adding native species can accelerate natural succession because exotics, especially N-fixing species, can modify soil quality (Yu *et al.*, 1994). Under proper ecological management, there would be an increase in tree density and diversity after restoration (Aweto, 1981). Species diversity would increase due to establishment, colonization and facilitation of species. It was initiated by seed dispersal from the surrounding environment which plays a positive role in revegetation of secondary sites such as the quarries. The invasion of flora is highly related to the adjacent environment, because restored sites recruit seeds from extant plants on their peripheries either by wind or animal dispersal (Burrows, 1975; Cheke *et al.*, 1979; Murray, 1986).

1.2.4 Problems in quarry restoration

In quarry restoration, there are some technical problems which may affect vegetation development on the sites. Such technical problems of establishing vegetation on quarries are mainly due to steep slopes on the quarry faces that may result in soil erosion during heavy rain and wind. Another critical problem is nutrient deficiency because of poor physical and chemical properties of topsoil used (Davis, 1986; Hooper, 1992; Jim, 1997 and 2001). Generally, organic carbon and nutrients like nitrogen and phosphorus are most limited in granite soil commonly used in quarry restoration (Jim, 2001). This will affect the growth of the regenerated vegetation and hence bring about a chain reaction to the recruitment of biota on the quarry sites. During the revegetation process, establishment and development of plant species is greatly affected by the properties of the final cover soil. In many cases, both physical and chemical properties of soil used in the restoration process are not good enough to support vegetation because of poor in accumulation of nutrients. In general, soil organic content is low, which leads to the shortage of nitrogen and phosphorus in soil (Chapter 2). Other problems such as low cation exchange capacity, high stone content, excessively coarse soil texture, compaction and limited available moisture storage are also common in soil quality of some restored quarries (Jim, 2001). The quarries in Hong Kong are mostly free from pollutants.

1.3 Objectives

1.3.1 Study sites

There are four operating quarries in Hong Kong. They are Anderson Road, Shek O, Lam Tei and Lamma. The first three quarries were chosen as the study sites in this project and an early restored quarry, Turret Hill, was also included. The location of the four quarries is shown in Figure 1.4. Turret Hill Quarry is a completed quarry while the other three quarries have different phases of completion. Phases that completed hydroseeding on 1991, 1994, 1996, 1998 and 2001 were studied. Totally eight phases on the four quarry sites were chosen (Table 1.1). The phases that completed in the same year can be used for comparison. The variation in soil properties, as well as flora and fauna community can be estimated.

The aims of this project were:

1. to investigate the status and quality of the soil on restored quarries;
2. to assess the situation of establishment and colonization of vegetation, especially naturally colonized native species, among the sites;
3. to evaluate the conservation value of the restored quarries in Hong Kong;
4. and to investigate the relationship between vegetation development and fauna diversity.

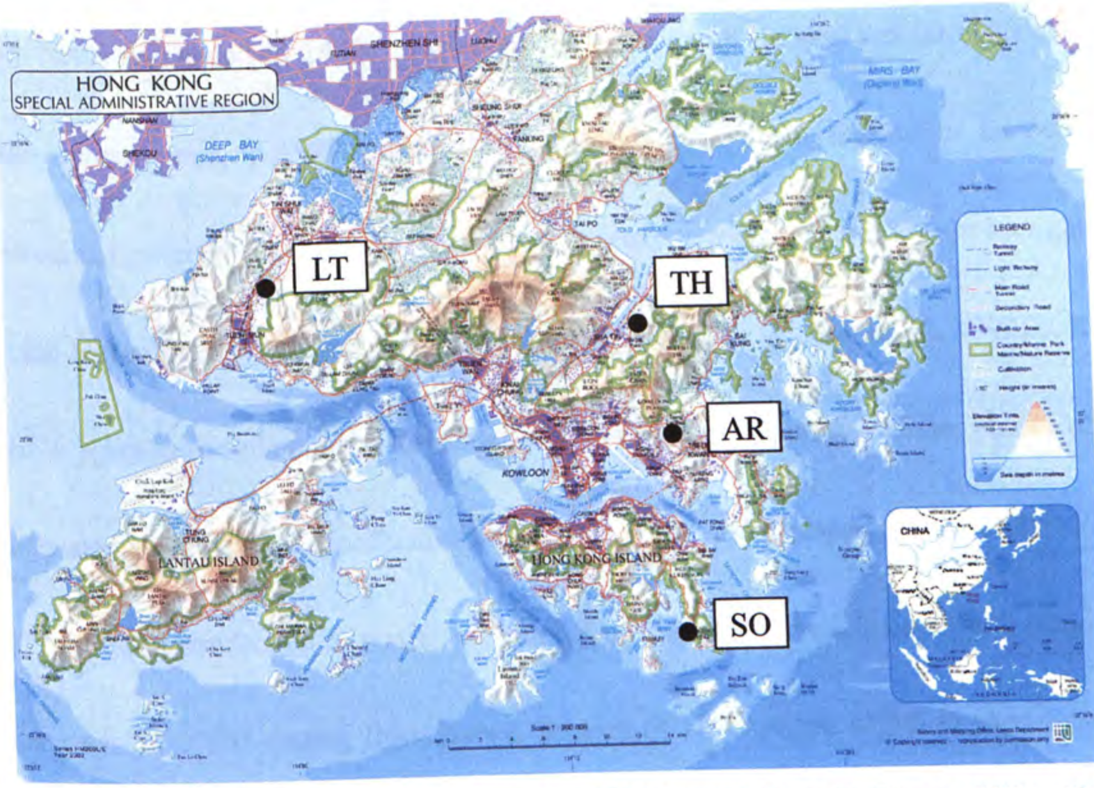

Figure 1.4 Location of the four quarries. LT: Lam Tei; TH: Turret Hill; AR: Anderson Road; SO: Shek O.

Table 1.1. Study sites and their corresponding codes for the various quarries.

Quarry	Phase	Corresponding code
Turret Hill (TH)	1991	TH91
	1994	TH94
Lam Tei (LT)	1996	LT96
	1998	LT98
	2001	LT01
Shek O (SO)	1998	SO98
	2001	SO01
Anderson Road (AR)	2001	AR01

Turret Hill Quarry (TH) is located at the northeast of Shatin, New Territories (Plates 1.2 and 1.3). It covers a plan area of about 25 ha and is one of the early developed quarries in Hong Kong (Dutton *et al.*, 1992). It was operated from the mid 1960s and ended in 1983. However, the quarry was not restored immediately. After several years, in 1989, rapid urban development in Shatin and public concern pushed the government to restore the quarry in order to reduce visual impact brought by the barren quarry face and to provide a stable landscape (Dutton *et al.*, 1992). It took 6 years to complete the restoration (1989 – 1995). The early and late phases of the quarry were studied, i.e. Phases 91 and 94. The rocky slopes are about 40° to 53°, and there are ledges to retain soil to support vegetation (bench slope with rough rock surface). The quarry floor covers an area of about 4 ha, which is used by a refuse transfer station and the Construction Industry Training Authority.

Plate 1.2 Aerial photo of Turret Hill Quarry.

Plate 1.3 Close view of Turret Hill Quarry.

Lam Tei Quarry (LT) is located at about 3 km north of the Tuen Mun New Town at the western side of New Territories (Plates 1.4 and 1.5). It operated since 1982 and is completed in 2003. It covers an area of about 30.5 ha, in which 23.5 ha are restored. The restoration works began from 1995. The final landform involves 9 benches, each of 15 m high cut slope. The overall angles of the slope surface formed ranged from 60° to 70° which is similar to Turret Hill Quarry but with smooth rock surface (bench slope with smooth rock surface). Phases 96, 98 and 01 were chosen for this study.

Plate 1.4 Aerial photo of Lam Tei Quarry.

Plate 1.5 Close view of Lam Tei Quarry.

Shek O Quarry (SO) situates on the west coast of the Cape D' Aguilar Peninsula on the Hong Kong Island (Plates 1.6 and 1.7), covering an area of 45 ha which is about 15 ha larger than Lam Tei Quarry. It has been operated since 1964 and will be completed in 2009. At the end of the quarry operation, 30 ha of area would be restored and the final land-use would be recreational and residential. The rehabilitated landform consists of rock slopes approximately 10 m in height. Scree slope is the major slope form with an overall slope angle of 35°. Compared with LT, construction of different phases for restoration is in patches, not the whole bench. As a result, there is no clear boundary between phases, and the year of completion of the phase was determined by aerial photographs. In this study, Phases 98 and 01 were investigated.

The largest operating quarry, Anderson Road Quarry (AR) is located on the south-western slopes of the Tai Sheung Tok Hill near Sau Mau Ping, East Kowloon (Plates 1.8 and 1.9). The quarry covers an area of 86 ha, which is almost double that of SO. It has been operated since 1956 and will complete in 2013 with 77 ha of restored area. AR was originally a combination of two separate quarries, Tai Sheung Tok Quarry and old Anderson Road Quarry. The quarry rehabilitation contract was signed in 1997, so that the restoration progress is relatively late compared with the other three quarries. The slope form of AR consists of both scree slope and bench slope. There are 7 benches at the central portion and 3 benches on each of the east and west ends of the quarry. The overall slope angle is 55° which is similar to the adjacent natural hillsides. Slopes completed and restored in 2001 were included in this study.

Plate 1.6 Aerial photo of Shek O Quarry.

Plate 1.7 Close view of Shek O Quarry.

Plate 1.8 Aerial photo of Anderson Road Quarry.

Plate 1.9 Close view of Anderson Road Quarry.

1.3.2 Soil-plant ecosystem

Soil and plants are highly inter-related. Soil provides anchorage, nutrients and suitable media for plants to grow. It acts as temporary storage of nutrients from the atmosphere and the weathering of minerals (Trudgill, 1977). On the other hand, plants are also involved in nutrient cycling. Nutrients will return back to the soil profile as a result of decomposition and metabolic waste or dead body of living organism, or by the help of nitrogen-fixing bacteria which fix the atmospheric nitrogen into nitrate (Blow, 1955; Bocock *et al.*, 1960; Gilbert and Bocock, 1960; Dickinson and Pugh, 1974, Jones *et al.*, 1997). Plants prevent soil erosion which is one of the most important causes leading to desertification and losses of soil nutrients.

The changes in soil chemical and physical processes and the responses of vegetation is one of the important studies in ecosystem restoration, so it is useful to understand the soil properties of the quarries (at different phases) and their corresponding botanical composition.

1.3.3 Insect study

Insects are the most abundant group of organism on earth. As mentioned in Section 1.1.4, Hong Kong has over 4,000 species of insects. They are widely distributed across the territory, and have colonized most available habitats. Insects, with a wide variety of feeding strategies, play many important roles within ecosystems. For example, some insects associated with plants may feed on nectars and are responsible for their pollination, while others feed on various plant parts and bring damage to the plants. Some insects are herbivores, as predators or parasites, they help to balance the population and community within the ecosystem. Other insects feed on dung or decay materials; they help in decomposition and enhance nutrient cycling. Insects are also food sources for many other animals such as fishes, birds and mammals, and even plants (e.g. *Nepenthes* spp.).

As a pioneer animal species in quarries, insect diversity is highly related with plants and other animals. They influence the survival and dispersal of plant species, and affect the population and community of birds and mammals immigrated to the restored quarries. Lepidoptera and Odonata are two insect orders investigated in this project.

1.3.3.1 Lepidopteran as a study group

Lepidopterans, including butterflies (suborder Rhopalocera) and moths (suborder Heterocera), is one important insect group. They are relatively easy to observe, especially butterfly, and both of them are closely related with vegetation.

The life cycle of butterfly and moth generally consist of four stages: egg, larva, pupa (chrysalis) and imago (adult). This is called holometabolous life cycle and occurs in the majority of insects. All butterfly and most moths are oviparous. They lay eggs on various parts of their host plants that depend on Lepidoptera species, so that plant act as anchorage substrate for the eggs. It provides protection for eggs against their predator. The most common mechanism for the eggs to hide themselves is procrypsis such that the appearance of the eggs blending into their background.

Plants act as a food for most lepidopterous larvae. The egg is usually laid on or close to appropriate food source which can be vascular plants, lichens, fungi and algae. After the hatching of eggs, the larvae (also called caterpillars) are able to locate their food by plant chemistry, mechanics and innate behavior (Miller and Feeny, 1989; Luo *et al.*, 1995). Lepidopterans often utilize groups of related plants which mean their host plants (food plants) can be more than one species of plant. They usually feed on plants within a similar taxonomic group. For example, Pierinae feed on Cruciferae and Coliadinae on Leguminosae. As a result, these herbivorous insects and their related plants influence each other and are partly responsible for each other's diversity (Brues, 1920).

Nectar is the commonest food source of lepidopterans. Sucrose content in the nectar seems to be an important factor that influences on foraging behavior (May, 1988; Erhardt, 1991; Erhardt, 1992; Rusterholz and Erhardt, 1997). In this way, nectar-feeders play an important role in pollination of nectar-producing flowering plants.

Because plants and lepidopterans evolved in parallel, their relationship however is not always mutually beneficial. From the life cycle of lepidopterans, imagoes are generally beneficial to the plant in terms of pollination. However, not all imagoes are nectar feeders. There are some butterfly and moth species that the imagoes do not feed on nectar or even do not feed for the entire life stage. These species do not help in pollination. Flowering plant is only a portion in flora diversity in restored quarries in Hong Kong. Furthermore, since most lepidopterans feed on plant body (including leaves, stems, buds and pollens), this brings certain damage to the plant. Hence, some lepidopterans species are regarded as pest to vegetation when they are in large population.

Since the relationship between plants and lepidopterans is so close, it is important to obtain a more complete inventory of lepidopterans species recorded in the restored quarries with reference to the vegetation on different restored quarries. The population community of lepidopterans can generally reflect the vegetation diversity of a site because plants are the major food source of lepidopterans. The presence of certain lepidopterans species may indicate that their host-plants are very likely to be present or located near to the site. Nectar feeding lepidopterans can also reflect the community of flowering plant in the sites.

1.3.3.2 Odonata as a study group

Order Odonata is divided into two sub-orders, i.e. Anisoptera (dragonflies) and Zygoptera (damselflies). They can be found almost everywhere, but their life cycle is ineludibly linked to aquatic environments. The life cycle of odonates is holometabolous. After mating the female dragonflies lay eggs on water surface, plants, in mud, or even on objects which are close to the water source which is species specific. The larvae hatch out from the eggs and return to water. Larval stage may last for as long as 4 or 5 years and they go through a series of stages (instars). There are about 8 to 15 instars in larval development, and when they are fully developed, the larvae crawl out of the water and emergence on plant stems or rock surface.

Odonates are carnivorous insect that feed on their prey in every life stage. As a result, they are one of the major consumers in terrestrial and aquatic ecosystem. The larvae feed on mosquito larvae, tadpoles and even small fish. The adults with large compound eyes and independent wings have excellent vision and amazing flight ability, making them unbeatable hunters of other insects like grasshoppers, butterflies, moths and even other small vertebrates. In this sense, they can generally reflect the insect population in the habitat. Because of their high availability and high in trophic level, they are a good indicator in terrestrial and aquatic ecosystem (Watson *et al.*, 1982; Brown, 1991).

1.4 Project Significance

Site conditions such as soil quality, invasion of native species and engineering design are key factors to the success of vegetation succession. Soil quality directly influences the survivorship and growth of plants. As a result, the basic soil properties of the quarries have to be investigated.

Vegetation succession would occur on quarries when there is no disturbance and restored quarries will support local flora and wildlife. Wildlife would gradually migrate into the quarries when suitable environment prevails. Higher vegetation diversity (especially native species) would lead to increase in animal diversity. Plant diversity and density are related to those of insects and other wildlife.

Recently, many quarries in Hong Kong are under restoration. An environmental inventory is the first step to assess the success of environmental restoration. This ecological assessment included the review of soil properties, vegetation and insect study in the different restored quarries. The results of this study could provide a foundation for ecological planning and restoration project initiatives. With the help of ecological inventory, we can collect evidence of areas of conservation priority, identify landscapes, assess the status of wildlife habitat and determine the presence of special species, such as endangered species.

Quarries have different engineering design, age, geographical condition, microclimate, seed sources and wildlife sources. These lead to difference in soil, vegetation, fauna and ecological development in restored quarries in Hong Kong. Quarries are of low vandalism and low pollution. Native plant species are able to invade these quarries by natural processes, and can regenerate on quarries after restoration. At the same time, fauna will establish together with vegetation on quarries after restoration. It is hoped that we can have a clearer picture on the ecological status and conservation value of quarries. For conservation planning, such information can be used to strengthen the case for habitat conservation by documenting the distribution of species. Results obtained can help create a more general and useful information for the development of restored quarries within Hong Kong. Such information can aid in formulating the successional management and hence the future restoration program for quarries in Hong Kong as well as the nearby Southeast Asia countries.

Chapter 2 Soil Status in Restored Quarries of Hong Kong

2.1 Introduction

Soil quality is fundamental to the success of sustainable restoration, and soil improvement is one important factor in habitat reconstruction of quarries and related disturbed lands. The blended rocky surface formed after quarry blasting cannot support vegetation development. In order to provide a suitable condition for plant growth, quarry restoration must start with reducing the slope gradient by blasting and installation of topsoil layer. The reconstitution and management of soil layer are therefore crucial phases of landscape restoration because it influences the stability and quality of the soil, and hence the key to restoration (Roberts and Roberts, 1986).

One major role of soil is the storage of nutrient and organic matter. Nutrients mainly come from geological, biological and atmospheric sources, and are also released by decomposition of organic matter through either soil fauna or microorganisms. Minerals are released from soil slowly by weathering. In addition, microbial biomass is also important organic and nutrient sources with high turnover rate, especially organic carbon, nitrogen, phosphorus and sulphur (Singh *et al.*, 1989 and 1991; Banerjee *et al.*, 1993).

Decomposed granite (DG), a cheap and easily available material in Hong Kong, is commonly used as the topsoil material in many restoration projects in the quarries of Hong Kong. In practice, it may mix with volcanic soil in some instances, while the fertility of the soil depends on the sources and nature of the parent rock, and the soil genesis processes. However, such highly weathered soil has little capacity to release nutrients for plant use. There are some common problems found in the usage of DG such as the poor soil structure, texture, stability, water holding capacity. Such properties will result of poor water retention ability, poor soil nutrient contents, so that it may not be a very good substratum for plants to growth. Most granitic soils are acidic in nature. In Hong Kong, the pH ranged from 4.66 to 4.74 in some granite-based areas (Chau and Chan, 2000). In some cases, the soil properties of restored quarry were still unsatisfactory after several years (Jim, 2001). Besides, the high proportion of unweathered quartz results in low nutrient content. Critically, nitrogen and phosphorus, which are two most limiting nutrients required in large amount by plants, are lacking in DG (Claassen and Marler, 1998). These lead to other problems such as poor plant growth and fauna development. However, information of soil quality change in restored quarries in Hong Kong is scarce.

This chapter aimed to examine the soil status and quality among the restored quarries, and hence soil development in different phases of quarries can be estimated. It provides some background information of the soil quality which affects plant establishment in the quarries of Hong Kong.

2.2 Materials and Methods

2.2.1 Soil sampling

Soil samples were collected from late January to early June 2002. Ten sampling points were randomly selected on each of the different phases of the four quarries: two from Turret Hill (TH91 and TH94), three from Lam Tei (LT96, LT98 and LT01), two from Shek O (SO98 and SO01) and one from Anderson Road (AR01). Soil samples were taken from the surface 15 cm using 4 cm diameter stainless steel soil core. Three cores of soil were collected from each sampling point which were then transferred to the laboratory. The three samples from a sampling point were pooled together to form a bulk sample which were air-dried for 2 weeks at room temperature. The air-dried samples were then sieved through a 2 mm mesh sieve.

2.2.2 Soil analysis

In the measurement of reaction pH, soil was suspended in distilled water in the ratio of 1:2.5 (w/v). Soil pH and electrical conductivity were measured by a glass electrode connected to a pH and conductivity meter (Jenway, Essex, England). Soil texture was determined by Bouyoucos hydrometer method (Allen, 1974) which determined the proportion of soil particles. The percentage of sand, silt and clay was calculated according to the International Scale (International Society of Soil Science). Water holding capacity was measured by saturating 10 g soil and allowing the soil to drain by gravity for 24 hours. The soil was then oven dried and the amount of water that held in the soil was measured. It is highly related to the physical soil texture because the ability of the soil to hold water is affected by the soil particle size and porosity (Foth and Turk, 1972). Organic carbon (OC) content was determined by the Walkley-Black method, and the total organic matter (OM) content was calculated by multiplying the OC value by 1.724 (Nelson and Sommers, 1996). Total nitrogen was determined by using an SAN^{plus} segmented flow analyzer (Skalar Analytical BV, De Breda, the Netherlands) after Kjeldahl digestion at 360°C. Extractable ammonium-nitrogen and nitrate-nitrite-nitrogen were determined by the modified Berthelot reaction and cadmium reduction method respectively after extraction in 1 M potassium chloride at 150 rpm for an hour. Total and available phosphorus was extracted by mixed acid digestion (concentrated nitric acid: concentrated sulphuric acid = 5:1) at 120°C and Truog's extraction (diluted and buffered sulphuric acid) respectively, and they were determined by molybdenum blue method with segmented flow analyzer.

2.3 Statistical Analysis

One-way ANOVA was used to determine the differences of soil properties among different phases of quarries. Means were determined by the Tukey's Honestly Significant Difference (HSD) test at $p = 0.05$ level. Data were analyzed by Statistical Package for Social Science (SPSS) for Windows Release 10.0.1.

2.4 Results and Discussion

2.4.1 General properties of soil in the restored quarries

Table 2.1 shows the soil properties of the different phases of the four quarries. In general, the percentage of sand in soil were high (about 70 - 80%), and such soil texture belonged to sandy loam which was coarse-textured soil. On the other hand, the water holding capacity of the soil ranged from 21.6 – 35.9%, which reflects the poor water retention ability of the soils. Coarse soils were good in drainage and aeration, but the ability of retaining plant nutrients and water were worse than fine and medium soils. This means the rate of infiltration and percolation of water in coarse soils was high because of the high proportion of large pore spaces. Such high proportion of sandy soil particles would lower the water holding capacity of water in the soil, making it more susceptible to drought. Water will drain and soluble nutrients will leach out easily during heavy rains. Poor texture would also lead to soil erosion,

Table 2.1 Physical and chemical properties of soils from the different phases of the four quarries.

	Sites							
Parameters	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Sand (%)	71.3	71.3	81.0	78.9	74.3	77.3	77.8	65.8
Silt (%)	10.2	12.9	9.12	9.03	12.3	8.57	9.02	22.1
Clay (%)	18.5	15.7	9.88	12.1	13.4	14.0	13.2	12.1
Textural class	Sandy loam	Sandy loam	Loamy sand	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Water holding capacity (%)	32.1 ± 5.60bc	33.8 ± 6.70c	23.0 ± 4.40a	26.9 ± 7.00ab	25.5 ± 7.00ab	31.6 ± 7.50bc	23.4 ± 4.80a	35.8 ± 9.30c
pH	5.23 ± 0.35a	5.50 ± 0.50ab	5.90 ± 0.19bc	6.12 ± 0.30c	6.91 ± 1.19d	6.77 ± 0.60d	5.86 ± 0.80bc	5.52 ± 0.38ab
Conductivity (μS cm^{-1})	108 ± 38.5bc	86.6 ± 27.5ab	66.8 ± 10.6a	68.0 ± 13.4a	118 ± 43.0c	83.8 ± 43.1ab	70.3 ± 22.6a	58.5 ± 33.8a
Organic carbon (%)	0.82 ± 0.32d	0.68 ± 0.30bcd	0.75 ± 0.10cd	0.61 ± 0.21abc	0.50 ± 0.18ab	0.66 ± 0.19bcd	0.48 ± 0.16ab	0.43 ± 0.20a
Soil organic matter (%)	1.41 ± 0.55d	1.17 ± 0.52bcd	1.29 ± 0.17cd	1.05 ± 0.36abc	0.86 ± 0.31ab	1.14 ± 0.33bcd	0.83 ± 0.28ab	0.74 ± 0.34a
TKN (mg kg^{-1})	307 ± 78.3d	265 ± 86.3d	60.4 ± 27.1a	50.4 ± 24.4a	57.4 ± 13.8a	152 ± 54.2c	116 ± 40.8b	60.6 ± 10.8a
Extractable NO_x-N (mg kg^{-1})	16.2 ± 12.6b	16.0 ± 12.6b	2.30 ± 0.65a	2.19 ± 0.61a	1.93 ± 0.45a	4.18 ± 1.22a	3.75 ± 0.66a	13.2 ± 18.7b
Extractable NH_4-N (mg kg^{-1})	59.2 ± 40.5bc	56.5 ± 41.4bc	26.0 ± 5.34ab	21.4 ± 2.45a	14.8 ± 4.82a	17.0 ± 2.44a	16.3 ± 2.20a	65.5 ± 79.2c
Total P (mg kg^{-1})	78.0 ± 20.9d	73.5 ± 22.3d	67.2 ± 22.8cd	69.4 ± 26.6cd	50.1 ± 21.1bc	35.3 ± 23.6ab	28.4 ± 24.3ab	24.1 ± 10.3a
Extractable PO_4-P (mg kg^{-1})	29.6 ± 2.29e	20.5 ± 2.20d	22.8 ± 3.80d	23.2 ± 1.20)d	9.73 ± 2.36a	23.1 ± 2.45d	16.6 ± 2.16c	12.2 ± 4.48b

Mean values sharing the same letters on the same row are not significantly different in $p<0.05$ level by Tukey's Honestly Significant Difference (HSD) test.

temperature fluxes and eventually will affect plant growth because of the insufficient supply of water and nutrients (Birkeland, 1984; Poesen and Lavee, 1994).

Soil pH ranged from 5.2 - 6.9, which were slightly to moderately acidic. Acidic soils are usually considered to be unsuitable for woodland establishment since the essential elements such as phosphorus, calcium, magnesium and potassium become less available when the soil is very acidic. Such acidity may be due to the acidic parental soil (DG) and the acidification of soil. There were various reasons for soil acidification, such as the increases in carbon, nitrogen and sulphur input (Haynes, 1983; Bolan and Hedley, 2003), imbalance cation or anion uptake of plants (Tang and Rengel, 2003) and acid rains (Howells, 1995). Soil conductivity ranged from 58.5 to 107.9 $\mu S\ cm^{-1}$, which were below the threshold level of most plants (Landon, 1991).

Organic carbon contents were generally lower than 1% (from 0.43 – 0.82%), while the soil OM ranged from 0.74 – 1.41%. Organic carbon below 4% is considered as a low concentration (Landon, 1991). Organic matter is the major carbon and nitrogen source for plants via decomposition by soil microbes. Levels of organic matter affect soil aggregation and determine soil erodibility. At high organic matter level, it will increase the water retention of soil, especially in sandy and silty soils (Lavelle and Spain, 2001). In contrast, at low organic matter level, the soil will become loosened which leads to increased runoff and nutrient loss. Moreover, soil organic matter aids the retention of cations especially in acid soil (Lavelle and Spain, 2001). As the soils were low in organic contents, this would limit the availability of nitrogen and phosphorus. In addition to the loss of some valuable soil nutrients, soil particles will be easily blown away by wind or washed away by heavy rains especially for fine particle soils. As a result, the proportion of fine soil was low in the restored quarries (Table 2.1). These can impact air quality, and water erosion can result in gullies or "washed out" channels and sedimentation to down-slope areas, and this happened in Anderson Road Quarry.

The range of total Kjeldahl nitrogen (TKN) was wide in the four quarries, from 50.4 to 307 mg kg^{-1}. Since they were much lower than 2 g kg^{-1}, they were rated as low TKN level for tropical soils (Landon, 1991). The extractable NO_x-N contents ranged from 1.93 – 16.2 mg kg^{-1}, while those of NH_4-N ranged from 14.8 – 65.5 mg kg^{-1}. These show that the soils were deficient in available nitrogen. Total phosphorus ranged from 24.1 to 85.4 mg kg^{-1}, which was far below 200 mg kg^{-1} and considered as low concentration (Landon, 1991). Available phosphorus ranged from 9.97 to 29.8 mg kg^{-1}, which also belonged to low to medium level (Landon, 1991).

In some practices in quarry restoration, the initial organic content of soil was 15 – 20% in the top-soil. After 30 years, the soil organic content gradually fall back to 2 – 15% depending on the soil textures, and then become stable (Abakumov, 2005).

Extreme high organic level may indicate slow mineralization in soil, but too low in organic level could lead to the low nutrient and water retention ability of the site. For long-term and sustainable ecological development in a natural way, revegetation would help to accumulate organic matter, which would then support and attract a variety of soil organisms active in the decomposition of organic matter, permitting nutrient turnover. In fact, plant residues are one major source of organic matter which act as long term supply of nitrogen and phosphorus for plants (Schoenholtz *et al.*, 1992; Zhang *et al.*, 2002). Maintaining good organic layer on top provides good protection to erosion and prevents rapid loss of moisture from the soil. Revegetation will also be essential in improving near-surface microclimate.

2.4.2 Soil description on different phases among the sites

Among the quarries, Phases 91 and 94 of Turret Hill Quarry were in the highest ranking in terms of many chemical contents such as organic carbon, nitrogen and phosphorus (Table 2.1). They were very similar in general soil properties except extractable PO_4-P. Many studies on forest development showed that there was conductivity enhancement and soil acidification along time (Chau and Marafa, 1999; Tang and Rengel, 2003), but such phenomena were not obvious in Turret Hill Quarry. Although the average conductivity and organic carbon contents were higher in TH91 (the older phase), the changes were not marked enough to distinguish the conductivity and organic carbon content among phases. The extractable PO_4-P was higher in TH91, showing that extractable phosphorus accumulated in soil along time.

Soils from various phases of different ages at Lam Tei Quarry can also be compared (Table 2.1). Acidification can be observed along time as soil pH decreased from 6.91 to 5.90 (from LT01 to LT96). Soil conductivity in Phase 01 was significantly higher and near to neutral, and this may be related to the original physical and chemical properties of DG soil which was used in restoration. Moreover, there was significant accumulation of organic matter content along time (rise from 0.86% in LT01 to 1.29% in LT96). This is attributed due to the accumulation of litter, animal faeces and excretions, and even dead insect and animal bodies, which was common in woodland development (Chau and Marafa, 1999; Lavelle; 2001; Keersmaeker *et al.*, 2004). OC content was related to the total nitrogen and total phosphorus contents since organic matter is an important storehouse of these major elements. In Lam Tei Quarry, there were corresponding increases in total phosphorus and extractable PO_4-P content along time. There was significant enhancement of ammonium nitrogen, but the change in total nitrogen content was not significant.

On the other hand, the soil properties of Phase 01 of Shek O Quarry (SO01) were generally poorer than those of Phase 98 (SO98) (Table 2.1). The water holding capacity of the soil was significantly lower in SO01. This was related to the sandy soil structure and also the correspondingly lower OM content in SO01. Soil of SO01 was even more acidic than that of SO98, which may be due to the original DG properties. Organic carbon accumulated slowly along time, and led to enrichment in total nitrogen content in SO98. The increase of OM seems not to take much effect on total phosphorus, which suggested that the OM might be low in phosphorus content.

2.4.3 Soil comparison on different phases with the same age

Soils of the quarries which had been restored in the same year were compared to detect any possible difference in soil properties between different sites.

When soils at Phase 98 of Lam Tei Quarry and Shek O Quarry were compared (Table 2.1), water holding capacity, acidity, total nitrogen contents, extractable NO_x-N and NH_4-N levels, and total phosphorus contents were significantly different between the two sites.

The water holding capacity of soil in SO98 was higher than that in LT98 as the former was slightly higher in the clay fraction. SO98 had also higher pH and contents of total nitrogen, NO_x-N and NH_4-N. This is probably due to the heavy planting of legumes in Shek O Quarry (Chapter 3). The top three most common tree species in SO98 were *Desmodium heterocarpon*, *Acacia auriculiformis* and *Leucaena leucocephala*, which were all nitrogen-fixers. Lam Tei Quarry was dominated instead by Compositae such as *Bidens pilosa* and *Ageratum conyzoides*.

Phase 01 of Lam Tei Quarry, Shek O Quarry and Anderson Road Quarry were also compared. Although they were restored at the same year, they differed in water holding capacity, pH, conductivity, and the contents of various forms of nitrogen and phosphorus (Table 2.1). Soils on AR01 were higher in water holding capacity, probably due to the higher fraction of silt. They had higher NO_x-N and NH_4-N levels when compared with LT01 and SO01. The total nitrogen content in SO01 was the highest among the quarries, which again is related to the large area of fast growing legume plantation in the Shek O Quarry.

Soil fertility plays a major role in the success of quarry restoration. The quarry grounds of Hong Kong are mainly sandy substrates with poor water retention ability and low nutrient content. The results of soil analysis indicate that soil development in the four restored quarries was not in parallel, though many soil properties were in relation to the age of the various phases. The earliest restored quarry – Turret Hill Quarry was the highest in most soil nutrients compared with other quarries. Soils in most phases of the quarry were slightly acidic, this may help in assisting the establishment of some plants. Liming was a possible solution to improve soil acidity, and it can effectively neutralize topsoil acidity. As a result, it can only act as a short-term conditioner. Landscape and soil rehabilitation are the first and the key steps in environmental restoration, and help return the quarries into beneficial uses afterward. A "healthy soil" can sustain plant and animal productivity, maintain or even enhance water quality and promote ecosystem health (Doran *et al.*, 1996).

2.5 Conclusion

In general, the amount of organic matter accumulation was in proportion to the age of the restored quarries. Organic matter is significantly important to soil sustainability. It increases soil aggregation and affects water holding capacity. It also increases the availability of water to plants and plays a key role in soil water supply. At the beginning of the restoration, manure could be added as organic soil conditioner (Dutton *et al.*, 1992; Jim, 2001). This makes the soil more resistant to erosion and prevents degradation after restoration. Also, plantation is necessary for the sustainable development of restored quarries. Soil development is closely related to plant productivity and development. The interaction between soil and plant is one of the most important processes in natural ecosystems. Nutrients in soil also influence plant production and quality.

Soils in Shek O Quarry were generally higher in total nitrogen content when compared with those in Lam Tei Quarry of the same age. This shows a significant soil-plant interaction in which the large scale of legume plantation in Shek O Quarry increased the nitrogen input. Carbon and nitrogen accumulation have been regarded as indicators of soil fertility and productivity (Jenny, 1958).

Chapter 3 Vegetation Study of Restored Quarries

3.1 Introduction

Quarry restoration requires both physical and biological interventions. Physical intervention refers to engineering rehabilitation including reducing slope grading, soil preparation, and installation of topsoil and drainage systems. Biological rehabilitation shares an important role in the restoration programs of quarry. This includes hydroseeding to reduce soil erosion, planting of nitrogen-fixing trees to increase the nitrogen content of soils, and growing natives to enhance biodiversity. The primary goal of quarry restoration is to restore critical ecological services, in which exotic species are commonly used because of their high survival rate and growth rate in rather poor quality soil.

All animals rely, directly or indirectly, on plants. Vegetation development is closely related to soil condition, as soil provides physical anchorage, support, water and most nutrients required for plant growth. Revegetation in quarries is generally hydroseeding and tree planting. The quick establishment of a herbaceous ground vegetation cover would induce a less drying soil and near-surface microclimate and hence a suitable condition for plant growth. Fertilizers or soil conditioners are usually applied to enhance plants growth performance.

The major function of revegetation 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 (Zhuang and Yau, 1999). These somehow bring positive effect on biodiversity enrichment, vegetation development, slope stabilization and erosion control. So the initial works for revegetation are based on suitable selection of plant species which can adapt successfully to the harsh environment, and provide the necessities for subsequent colonization by natives.

Plantations in restored quarries in Hong Kong are mainly mixed culture. Exotics such as *Acacia confusa* which are less nutrient demanding are extensively used. Legumes are one of a favourite plant group because of their nitrogen-fixing ability which improves soil nitrogen content by the nitrogen-fixing bacteria inside the root nodules of nitrogen-fixing plants (Quispel, 1974; Stacey *et al.*, 1992).

The successional development may be different among various restored quarries at different phases since revegetation projects on different quarries are carried out by different contractors, and different types of plant are used on different sites. Failure or success of plant establishment would affect the quarry sites not only in terms of flora diversity but also the diversity and activity of other organisms. Site diversity would then affect the stability of the community (Kimmins, 1997). The final land use of the various quarries will be different; some would be residential (e.g. Anderson Road Quarry) and other recreational (e.g. Shek O Quarry). Regardless of the afteruse, maintaining high community stability is very important for a successful restoration project. High stability helps the development of self-sustainable ecosystem which does not require continued input or expense to maintain productivity.

This part examined plant coverage and community diversity of the various phases of the quarries. It characterized vegetation performance by assessing the status of vegetation establishment, colonization and the successional development among various sites. Changes in vegetation structure and species composition that occur during revegetation may have important consequences for wildlife populations. As the vegetation succession was at the early stage, lower in flora diversity was a common situation. It was hoped that through natural succession and regeneration of native flora, the diversity of the restored quarries can support more animal species. Many animals rely on forest resources as sites for food, foraging, nesting and protection. As a result, it may vary in abundance in quarries of different ages. It is important for plants to act as a resource for other animals and to provide recommendations for management of key species in restoration programme. Through the study of vegetation, it is hoped that such data can correlate with the soil quality (Chapter 2) and insect assemblages (Chapter 4) on the restored quarries of Hong Kong.

3.2 Materials and Methods

3.2.1 Vegetation survey

Vegetation coverage on the various sites was examined from May to September 2002. Each phase was divided into several 10 m long strips. The coverage of trees and shrubs (plants higher than 1.3 m), understorey vegetation (grasses, herbs and short shrubs lower than 1.3 m) and bare ground were recorded.

3.2.2 Quadrat analysis

The vegetation analysis was carried out from July 2002 to November 2002. The coverage, density and frequency of individual plant species were studied by the frame quadrat method. Four strings were used to setup a quadrat and its size was 5 m x 5 m. The plots of study were the same as those for soil analysis in Chapter 2 (i.e. 10 random sampling plots for each phase). The coverage of individual plants was recorded according to their basal area within the quadrats.

3.2.3 Vegetation description

3.2.3.1 Similarity index

Similarity index, S_c, was used to determine the similarity between two sites based on the coverage of the species (Czekanowski 1913):

$$S_c = 2\sum_{i=1}^{m}\min(Xi,Yi)/(\sum_{i=1}^{m}Xi+\sum_{i=1}^{m}Yi)$$

where Xi and Yi = Coverage of species i

$\sum_{i=1}^{m}\min(Xi,Yi)$ = Sum of the lesser coverage of species i which was found on both sites

m = Number of species

3.2.3.2 Species richness index

The abundant of species in the quarries was estimated by species richness index, R:

$$R = \frac{S}{\sqrt{n}}$$

where S = Total number of species

n = Total vegetation coverage

3.2.3.3 Diversity index

Shannon-Wiener diversity index, H, was used to estimate the diversity of plants on the quarries:

$$H = -\sum_{i=1}^{S}(pi \ln pi)$$

where S = Number of species

pi = Relative coverage of the species i

3.2.3.4 Evenness index

Evenness index was calculated according to Pielou (1969):

$$E = H / \ln(S)$$

where S = Total number of species

H = Shannon-Wiener diversity index

3.2.3.5 Effective number of species

The effective number of species was calculated according to Hill (1973), which helps weighing out the most important species on various phases of the quarries.

The effective number N0, N1 and N2 represent the number of species, number of abundant species and number of very abundant species accordingly:

$$N0 = S$$

$$N1 = e^{H}$$

$$N2 = (\sum_{i=1}^{S} pi^{2})^{-1}$$

where S = Total number of species

H = Shannon-Wiener diversity index

pi = Relative coverage of the species i

3.3 Results and Discussion

3.3.1 Vegetation coverage on restored quarries

The coverage of trees and shrubs (plants higher than 1.3 m) and understorey vegetation (grasses, herbs and short shrubs lower than 1.3 m) are shown in Table 3.1.

In general, the coverage of trees and shrubs was positively correlated to the age of the sites. At Shek O Quarry, for example, the coverage of trees and shrubs greatly increased from 5.1% to 59.4% at Phases 01 and 98 respectively. Similarly in LT01, the coverage of trees and shrubs was below 6%, but the coverage reached 42.3% and 49.7% at Phases 96 and 98 respectively.

Table 3.1 Vegetation coverage on the side slope of different phases of the four restored quarries.

	Coverage (%)		
	Trees and shrubs (>1.3 m)	Grasses and herbs (<1.3 m)	Bare ground
TH91	57.1	75.3	10.5
TH94	68.0	62.9	13.2
LT96	49.7	69.5	19.8
LT98	42.3	71.9	16.4
LT01	5.90	82.7	5.90
SO98	59.4	74.1	7.60
SO01	5.10	80.6	10.5
AR01	1.70	61.8	21.1

The vegetation coverage of Anderson Road Quarry (AR01) was significantly lower when compared with the other sites of the same age, e.g. SO01 and LT01. The coverage of trees and shrubs in AR01 was less than 2% while that of understorey vegetation was about 60% (Plate 3.1). This is due to the low vegetation coverage in Area B of the quarry. There was not enough topsoil for plants to grow and the rocky surface was exposed (Plate 3.2). Beside, since the quarry is in a relatively high attitude, the windy micro-climate limited plant growth on the exposed side slopes of the quarry. The growth rate of *Acacia* spp. for example was low in windy environment.

Plate 3.1 Tree and shrub species were young on Anderson Road Quarry. Grasses were the dominant species.

Plate 3.2 Bare rocky surface with low vegetation coverage on Anderson Road Quarry. Common in Area B.

TH94 had highest tree coverage of 68% (Plate 3.3). The vegetation of LT96, LT98 (Plate 3.4) and SO98 (Plate 3.5) were grassland and woodland. SO98 was higher in the coverage of trees and shrubs (59.4%) than that of LT98 (42.3%). This could be explained by the shading effect in Lam Tei Quarry (Wong, 2001). The sunlight duration in Lam Tei Quarry was shorter than that in Shek O Quarry, and this limited the growth of many plants, especially light-demanding species such as *Desmodium heterocarpon*, which was commonly found on these quarries (Table 3.1). The situation of LT01 and SO01 (Plate 3.6) were similar that they were mainly grassland with high coverage of understorey species.

3.3.2 Vegetation structure and diversity on restored quarries

The results of the vegetation quadrat study on the four quarries are shown in Tables 3.2 to 3.5, in which plant density, coverage and occurrence frequency of each species are recorded. A summary of the species description and gross coverage of the vegetation survey is shown in Table 3.6. The number of plant species was highest in Turrest Hill Quarry while it was the lowest in Anderson Road Quarry.

Plate 3.3 Turret Hill Quarry with high vegetation coverage.

Plate 3.4 Phase 98 of Lam Tei Quarry was developed into woodland habitat.

Plate 3.5 Phase 98 of Shek O Quarry was developed into a shrubland and woodland habitat.

Plate 3.6 Phase 01 of Shek O Quarry was mainly grassland habitat with low coverage of tree and shrub.

Table 3.2 Plant density, coverage and frequency in various phases of Turret Hill Quarry.

Species	Chinese name	**Family**	Density (100 m^{-2})		Coverage (%)		Frequency (%)	
			91	94	91	94	91	94
Trees								
Acacia auriculiformis	耳果相思	Mimosaceae	0.4	0.2	5.18	2.01	10	5
Acacia confusa	台灣相思	Mimosaceae	1.2	1.4	4.76	4.33	30	30
Aleurites montana	木油樹	Euphorbiaceae	0.4	0.6	0.91	1.07	10	15
Bauhinia sp.	羊蹄甲(屬)	Caesalpiniaceae		0.4		7.49		10
Bridelia tomentosa	逼迫仔	Euphorbiaceae	1.2		2.33		30	
Castanopsis fissa	裂斗錐栗	Fagaceae	0.4	0.4	1.16	1.18	10	10
Eucalyptus citriodora	檸檬桉	Myrtaceae	2.8	2.6	6.30	6.80	50	45
Ficus elastica	印度橡樹	Moraceae	1.2		4.01		20	
Ficus hispida	對葉榕	Moraceae	0.8	0.4	3.27	1.36	20	5
Leucaena leucocephala	銀合歡	Mimosaceae	3.2	4.6	2.29	4.84	40	55
Liquidambar formosana	楓香	Hamamelidaceae		0.2		1.21		5
Litsea glutinosa	潺槁	Lauraceae	0.4	0.2	3.12	0.93	10	5
Macaranga tanarius	血桐	Euphorbiaceae	1.2	0.4	3.87	1.02	30	10
Melodinus suaveolens	山橙	Apocynaceae	0.4		2.02		10	
Pinus elliotti	愛氏松	Pinaceae	1.2		6.19		30	
Pinus massoniana	馬尾松	Pinaceae	0.8		4.23		20	
Rhus chinensis	鹽膚木	Anacardiaceae	0.8	0.2	2.66	0.77	20	5
Rhus succedanea	野漆樹	Anacardiaceae	0.8		1.88		20	
Sterculia lanceolata	假蘋婆	Sterculiaceae	0.4		4.04		10	
Trema orientalis	山黃麻	Ulmaceae	0.4		2.15		10	
Shrubs								
Desmodium heterocarpon	假地豆	Papilionaceae	2.0	2.2	2.83	3.10	30	40
Hibiscus rosa-sinensis	大紅花	Malvaceae		0.4		1.77		10
Ilex asprella	梅葉冬青	Aquifoliaceae	0.4		0.45		10	
Lantana camera	馬纓丹	Verbenaceae	1.6	1.2	2.49	1.85	40	25
Melastoma candidum	野牡丹	Melastomataceae	2.0		0.77		30	
Melastoma sanguineum	毛棯	Melastomataceae	1.2	0.8	0.62	0.47	20	10
Mimosa pudica	含羞草	Mimosaceae		0.6		0.43		15
Ormosia emarginata	凹葉紅豆	Papilionaceae	0.4		1.85		10	
Phyllodium pulchellum	排錢草	Papilionaceae		0.2		0.19		5
Pteroloma triquetrum	胡蘆茶	Papilionaceae		0.2		0.20		5

Table 3.2 (cont'd)

Species	Chinese name	**Family**	Density (100 m^{-2})		Coverage (%)		Frequency (%)	
			91	94	91	94	91	94
Raphiolepis indica	車輪梅	Rosaceae	0.8	0.6	0.54	0.47	20	10
Rhodomyrtus tomentosa	桃金孃	Myrtaceae	2.0	0.2	1.58	0.94	30	5
Saplum discolor	山烏桕	Euphorbiaceae	0.4	0.4	0.21	0.15	10	10
Schefflera octophylla	鴨腳木	Araliaceae		0.8		0.25		10
Thyllanthus emblica	餘甘子	Euphorbiaceae	1.2	0.6	1.22	0.33	20	10
Herbs								
Ageratum conyzoides	勝紅薊	Compositae	16.8	14.8	10.4	10.2	50	25
Anisopappus chinensis	山黃菊	Compositae	13.2	20.4	7.83	8.90	20	50
Bidens pilosa	三葉鬼針草	Compositae	6.4	5.6	3.00	2.12	30	15
Blumea clarkei	七里明	Compositae		1.2		0.01		10
Celosia argentea	青葙	Amaranthaceae	1.6		0.35		20	
Centella asiatica	崩大碗	Umbelliferae	15.2	10.8	5.15	2.40	50	30
Christia obcordata	羅藟草	Papilionaceae		1.2		0.18		20
Chrysanthemum indicum	野菊	Compositae	11.2	11.0	3.64	2.82	30	20
Conyza canadensis	小白酒草	Compositae		0.8		0.01		10
Emilia sonchifolia	一點紅	Compositae	12.8	12.8	2.88	3.07	30	20
Euphorbia hirta	飛揚草	Euphorbiaceae	0.8	0.2	0.01	0.01	20	5
Hedyotis corymbosa	傘房花耳草	Rubiaceae	1.2		0.09		10	
Hedyotis diffusa	白花蛇舌草	Rubiaceae	2.4		0.09		20	
Justicia procumbens	爵牀	Acanthaceae	0.4	0.2	0.01	0.01	10	5
Lactuca indica	山萵苣	Compositae	1.2	1.6	0.21	0.15	10	15
Lindernia crustacea	母草	Scrophulariaceae		1.2		0.03		10
Oxalis corniculata	酢醬草	Oxalidaceae	16.4	7.6	0.39	0.24	40	25
Sesbania sp.	田菁(屬)	Papilionaceae	2.0		0.27		20	
Solanum nigrum	龍葵	Solanaceae	0.4	0.2	0.05	0.02	10	5
Solidago virgo-aurea	一枝黃花	Compositae		0.2		0.01		5
Urena lobata	地桃花	Malvaceae	0.8		0.20		20	
Vernonia cinerea	夜香牛	Compositae	2.4	2.2	1.04	1.03	10	10
Wedelia trilobata	南美蟛蜞菊	Compositae	10.4	15.2	13.7	17.1	40	75
Lianas								
Abrus mollis	毛相思子	Papilionaceae		0.2		0.01		5
Cassytha filiformis	無根藤	Lauraceae	1.2	0.8	0.04	0.03	30	20
Dunbaria rotundifolia	圓葉野扁豆	Papilionaceae	0.8		0.01		20	
Ficus pumila	薜荔	Moraceae	0.8	0.2	0.01	0.01	20	5

Table 3.2 (cont'd)

Species	Chinese name	**Family**	Density (100 m^{-2})		Coverage (%)		Frequency (%)	
			91	94	91	94	91	94
Ipomoea cairica	五爪金龍	Convolvonaceae	0.8	1.8	3.79	7.37	20	25
Mikania micrantha	薇甘菊	Compositae	1.2	0.8	1.26	0.76	30	15
Paederia scandens	雞矢藤	Rubiaceae	0.8		0.15		20	
Parthenocissus himalayana	爬牆虎	Vitaceae		0.2		0.01		5
Smilax china	金剛藤	Smilacaceae	0.4		0.01		10	
Smilax glabra	光葉菝葜	Smilacaceae	0.4		0.03		10	
Toxocarpus wightianus	弓果藤	Asclepiadaceae		0.2		0.05		5
Grasses								
Apluda mutica	水蔗草	Gramineae	n.c.	n.c.	2.00	2.29	10	10
Arundinella sinensis	華野古草	Gramineae		n.c.		0.05		5
Cyrtococcum patens	弓果黍	Gramineae	n.c.	n.c.	0.50	0.21	10	5
Eleusine indica	蟋蟀草	Gramineae	n.c.	n.c.	0.04	0.03	10	5
Eragrostis curvule	彎葉畫眉草	Gramineae	n.c.		0.20		20	
Eremochloa ciliaris	蜈蚣草	Gramineae	n.c.	n.c.	0.02	0.01	10	10
Ischaemum aristatum	鴨咀草	Gramineae	n.c.	n.c.	0.66	0.23	30	10
Miscanthus floridulus	五節芒	Gramineae		n.c.		0.16		10
Neyraudia reynaudiana	石珍茅	Gramineae	n.c.	n.c.	4.15	1.19	20	10
Panicum maximum	大黍	Gramineae	n.c.	n.c.	1.58	1.37	30	20
Paspalum conjugatum	兩耳草	Gramineae	n.c.	n.c.	9.81	8.60	50	30
Paspalum scrobiculatum	雀稗	Gramineae	n.c.	n.c.	8.33	6.14	50	55
Pennisetum alopecuroides	狼尾草	Gramineae	n.c.	n.c.	1.17	0.88	20	10
Pogonatherum critinum	金髮草	Gramineae	n.c.	n.c.	5.59	3.42	30	15
Rhynchelytrum repens	紅毛草	Gramineae	n.c.	n.c.	2.12	0.35	30	5
Saccharum spontaneum	割手密	Gramineae		n.c.		0.16		5
Setaria sp.	狗尾草(屬)	Gramineae	n.c.	n.c.	1.70	0.30	30	20
Sporobolus fertilis	鼠尾粟	Gramineae	n.c.	n.c.	0.01	0.03	10	15
Thysanolaena maxima	大棕葉蘆	Gramineae		n.c.		0.19		5
Sedges								
Cyperus alternifolius	風車草	Cyperaceae		1.6		0.02		10
Cyperus distans	疏穎莎草	Cyperaceae	2.0	1.4	0.08	0.05	20	10
Cyperus haspan	畦畔莎草	Cyperaceae	3.2	1.6	0.12	0.03	30	10

Table 3.2 (cont'd)

Species	Chinese name	**Family**	Density (100 m^{-2})		Coverage (%)		Frequency (%)	
			91	94	91	94	91	94
Fimbristylis dichotoma	稜穗飄拂草	Cyperaceae	0.4		0.02		10	
Fimbristylis spathacea	佛焰苞飄拂草	Cyperaceae		0.2		0.01		5
Mariscus umbellatus	磚子苗	Cyperaceae	2.0	0.6	0.11	0.03	20	5
Pycreus polystachyus	多枝莎草	Cyperaceae	2.4	2.6	0.19	0.19	20	20
Ferns								
Adiantum flabellulatum	扇葉鐵線蕨	Pteridaceae	3.2	2.8	0.02	0.01	20	15
Blechnum orientale	烏毛蕨	Blechnaceae	4.8	0.8	0.10	0.02	50	10
Dicranopteris linearis	鐵芒萁	Gleicheniaceae	2.8	1.4	0.06	0.01	30	10
Humata repens	陰石蕨	Davalliaceae	1.2	2.0	0.03	0.03	30	35
Lycopodium cernuum	鋪地蜈蚣	Lycopodiaceae	2.4	1.4	0.04	0.02	40	25
Lygodium flexuosum	曲軸海金沙	Schizaeaeae	3.6	4.2	0.32	0.47	30	40
Lygodium japonicum	羅網藤	Schizaeaeae	0.8	0.6	0.15	0.10	20	15
Nephrolepis biserrata	長葉腎蕨	Davalliaceae	1.4	2.2	0.08	0.09	20	30
Pityrogramma calomelanos	粉葉蕨	Pteridaceae	1.2		0.06		10	
Pteridium aquilnum	蕨	Pteridaceae	3.6	0.4	0.04	0.01	30	5
Pteris semipinnata	半邊旗	Pteridaceae	2.4	0.4	0.25	0.07	40	10
Pteris vittata	長葉甘草蕨	Pteridaceae	6.4	1.0	0.39	0.10	50	15

"n.c." means "not count" in grass species.

Table 3.3 Plant density, coverage and frequency in various phases of Lam Tei Quarry.

Species	Chinese name	Family	Density ($100\ m^{-2}$)			Coverage (%)			Frequency (%)		
			96	98	01	96	98	01	96	98	01
Trees											
Acacia confusa	台灣相思	Mimosaceae	2.4	2.8	3.2	10.3	12.6	10.4	40	60	70
Bridelia tomentosa	逼迫仔	Euphorbiaceae	0.4	0.8		0.49	0.61		10	20	
Casuarina equisetifolia	木麻黃	Casuarinaceae	1.2	1.2	6.4	6.21	6.47	13.8	30	30	90
Eucalyptus robusta	大葉桉	Myrtaceae	0.4	0.4	0.4	1.25	1.93	0.50	10	10	10
Eucalyptus torelliana	毛葉桉	Myrtaceae	0.4	0.4	0.4	1.03	1.05	0.40	10	10	10
Ficus hispida	對葉榕	Moraceae	0.4			0.10			10		
Litsea glutinosa	潺槁	Lauraceae	0.4			0.07			10		
Lophostemon confertus	紅膠木	Myrtaceae	1.2	1.6	0.8	4.02	6.91	1.55	20	30	10
Macaranga tanarius	血桐	Euphorbiaceae	1.2	0.4		0.38	0.10		30	10	
Pinus elliotti	愛氏松	Pinaceae	0.8			4.64			20		
Rhus chinensis	鹽膚木	Anacardiaceae	0.4	0.4		0.10	0.06		10	10	
Rhus succedanea	野漆樹	Anacardiaceae	0.4	0.4		0.09	0.10		10	10	
Schima superba	木荷	Theaceae			1.6			1.25			20
Shrubs											
Bougainvillea glabra	簕杜鵑	Nyctaginaceae	0.4	0.4	0.8	0.18	0.27	0.13	10	10	20
Desmodium heterocarpon	假地豆	Papilionaceae	10.0	6.4	2.4	8.88	2.73	0.24	50	30	10

Table 3.3 (cont'd)

Species	Chinese name	Family	Density (100 m^{-2})			Coverage (%)			Frequency (%)		
			96	98	01	96	98	01	96	98	01
Cassia bicapsularis	雙莢槐	Caesalpiniaceae			1.2			1.05			20
Duranta repens	假連翹	Verbenaceae	1.6	0.8		0.50	0.32		20	20	
Ilex asprella	梅葉冬青	Aquifoliaceae	0.4	0.4		0.02	0.02		10	10	
Indigofera hirsuta	剛毛木藍	Papilionaceae	0.4			0.03			10		
Lantana camera	馬纓丹	Verbenaceae	0.4	0.8	0.4	0.31	0.53	0.13	10	20	10
Melastoma candidum	野牡丹	Melastomataceae	2.0	1.6		0.37	0.18		40	30	
Melastoma sanguineum	毛棯	Melastomataceae	1.6	0.8		0.20	0.09		30	10	
Raphiolepis indica	車輪梅	Rosaceae	1.2	0.8	0.4	0.08	0.05	0.01	20	10	10
Sapium sebiferum	烏桕	Euphorbiaceae			1.2			0.85			20
Herbs											
Ageratum conyzoides	勝紅薊	Compositae	32.4	27.2	13.6	10.3	15.2	4.90	100	100	70
Alternanthera nodiflora	節節花	Amaranthaceae		0.8			0.45			20	
Alysicarpus vaginalis	鍊莢豆	Papilionaceae	0.8	1.6		0.24	0.55		10	20	
Bidens pilosa	三葉鬼針草	Compositae	20.4	20.8	9.6	19.0	20.4	8.94	100	100	50
Centella asiatica	崩大碗	Umbelliferae	2.4	1.6	0.8	0.21	0.10	0.02	40	30	20
Chrysanthemum indicum	野菊	Compositae	4.4	1.6		1.17	0.25		20	10	
Conyza bonariensis	香絲草	Compositae	11.6	2.4		0.09	0.01		40	10	
Conyza canadensis	小白酒草	Compositae	2.0	1.6		0.01	0.01		20	20	

Table 3.3 (cont'd)

Species	Chinese name	Family	Density (100 m^{-2})			Coverage (%)			Frequency (%)		
			96	98	01	96	98	01	96	98	01
Eclipta prostrata	鱧腸	Compositae	0.4			0.01			10		
Emilia sonchifolia	一點紅	Compositae	7.2	14.8	11.2	0.34	0.49	0.44	30	40	40
Euphorbia hirta var typica	飛揚草	Euphorbiaceae	0.8	0.8		0.01	0.01		10	20	
Hedyotis diffusa	白花蛇舌草	Rubiaceae			1.2			0.01			10
Lindernia crustacea	母草	Scrophulariaceae	4.4	5.6	1.6	1.17	3.11	0.84	40	70	10
Mazus pumilus	通泉草	Scrophulariaceae	0.8			0.01			10		
Oxalis corniculata	酢醬草	Oxalidaceae	2.0	4.4	1.6	0.09	0.18	0.05	20	50	10
Phyllanthus urinaria	葉下珠	Euphorbiaceae		3.6	0.8		0.05	0.01		20	10
Pterocypsela indica	野生菜	Compositae	11.6	8.0		0.05	0.01		80	50	
Scoparia dulcis	野甘草	Scrophulariaceae	9.6	4.0		0.02	0.01		40	20	
Sonchus arvensis	苣蕒菜	Compositae	1.6	2.8		0.01	0.05		30	50	
Lianas											
Bauhinia glauca	羊蹄甲藤	Caesalpiniaceae			0.4			0.30			10
Cassytha filiformis	無根藤	Lauraceae	0.8			0.01			20		
Lonicera reticulata	顯脈忍冬	Caprifoliaceae	0.4	0.4		0.01	0.01		10	10	
Mikania micrantha	薇甘菊	Compositae	3.2	2.0	1.6	0.54	0.19	0.10	40	40	20
Paederia scandens	雞矢藤	Rubiaceae	0.8	0.4		0.02	0.01		20	10	
Smilax china	金剛藤	Smilacaceae	0.8			0.03			10		

Table 3.3 (cont'd)

Species	Chinese name	Family	Density ($100\ m^{-2}$)			Coverage (%)			Frequency (%)		
			96	98	01	96	98	01	96	98	01
Grasses											
Apluda mutica	水蔗草	Gramineae	n.c.	n.c.		2.54	2.61		30	40	
Cynodon dactylon	狗牙根	Gramineae			n.c.			43.2			90
Digitaria radicosa	華馬唐	Gramineae	n.c.	n.c.	n.c.	20.3	12.1	6.76	50	30	20
Neyraudia reynaudiana	石珍茅	Gramineae	n.c.	n.c.		1.19	1.04		20	20	
Panicum maximum	大黍	Gramineae	n.c.			0.20			10		
Paspalum dilatatum	毛花雀稗	Gramineae		n.c.			0.29			30	
Paspalum notatum	百喜草	Gramineae			n.c.			28.1			40
Paspalum scrobiculatum	雀稗	Gramineae	n.c.			1.88			20		
Pogonatherum critinum	金髮草	Gramineae	n.c.	n.c.	n.c.	0.25	0.25	0.10	30	20	10
Rhynchelytrum repens	紅毛草	Gramineae	n.c.	n.c.	n.c.	13.9	10.0	1.25	50	40	10
Sporobolus fertilis	鼠尾粟	Gramineae		n.c.	n.c.		0.02	0.01		20	20
Sedges											
Cyperus brevifolis	水蜈蚣	Cyperaceae		1.2	0.8		0.55	0.23		20	10
Cyperus haspan	畦畔莎草	Cyperaceae	1.2			0.03			20		
Fimbristylis dichotoma	稜穗飄拂草	Cyperaceae	5.6	1.6		0.07	0.02		80	30	
Mariscus umbellatus	磚子苗	Cyperaceae	0.4			0.05			10		
Pycreus polystachyus	多枝莎草	Cyperaceae	3.2	0.8	1.2	1.92	1.05	0.81	30	20	20

Table 3.3 (cont'd)

Species	Chinese name	Family	Density (100 m^{-2})			Coverage (%)			Frequency (%)		
			96	98	01	96	98	01	96	98	01
Ferns											
Blechnum orientale	烏毛蕨	Blechnaceae	1.2			0.02			20		
Brainea insignis	蘇鐵蕨	Blechnaceae		0.8			0.01			10	
Cyclosorus parasiticus	金星草	Aspidiaceae	3.2	0.4		0.03	0.01		30	10	
Dicranopteris linearis	鐵芒萁	Gleicheniaceae	4.0	3.6		0.23	0.18		30	20	
Lycopodium cernuum	鋪地蜈蚣	Lycopodiaceae	0.4			0.01			10		
Lygodium flexuosum	曲軸海金沙	Schizaeaeae	2.8	2.0	0.4	1.09	0.44	0.01	70	50	10
Lygodium japonicum	羅網藤	Schizaeaeae	0.4	0.4		0.02	0.04		10	20	
Lygodium scandens	石韋藤	Schizaeaeae	0.4			0.03			20		
Pityrogramma calomelanos	粉葉蕨	Pteridaceae		3.2			0.42			20	
Pteridium aquilnum	蕨	Pteridaceae	1.6			0.20			20		
Pteris semipinnata	半邊旗	Pteridaceae	0.8	0.4		0.09	0.12		10	10	
Pteris vittata	長葉甘草蕨	Pteridaceae	12.4	11.2	5.6	4.28	5.81	0.37	80	70	30

"n.c." means "not count" in grass species.

Table 3.4 Plant density, coverage and frequency in various phases of Shek O Quarry.

Species	Chinese name	**Family**	Density (100 m^{-2}) 98	01	Coverage (%) 98	01	Frequency (%) 98	01
Trees								
Acacia auriculiformis	耳果相思	Mimosaceae	1.6		14.8		40	
Acacia confusa	台灣相思	Mimosaceae	1.2	2.0	10.8	18.2	30	50
Acacia mangium	大葉相思	Mimosaceae	0.8		5.23		20	
Leucaena leucocephala	銀合歡	Mimosaceae	3.2	0.4	13.2	0.20	70	10
Lophostemon confertus	紅膠木	Myrtaceae	1.6		1.40		30	
Macaranga tanarius	血桐	Euphorbiaceae	0.4		0.29		10	
Shrubs								
Desmodium heterocarpon	假地豆	Papilionaceae	16.4	0.8	28.4	1.99	80	10
Hibiscus rosa-sinensis	大紅花	Malvaceae	0.4		1.00		10	
Lantana camera	馬纓丹	Verbenaceae	0.4	0.4	0.23	0.08	10	10
Melastoma candidum	野牡丹	Melastomataceae	0.4		0.16		10	
Melastoma sanguineum	毛棯	Melastomataceae	0.8	0.4	0.27	0.08	10	10
Mimosa pudica	含羞草	Mimosaceae	1.6		1.04		20	
Phyllodium pulchellum	排錢草	Papilionaceae	0.4		0.29		10	
Raphiolepis indica	車輪梅	Rosaceae	0.8	0.4	0.27	0.11	10	10
Triumfetta pilosa	長毛刺蒴麻	Tiliaceae	0.4		0.10		10	
Herbs								
Achyranthes aspera	土牛膝	Amaranthaceae	1.2		0.13		30	
Ageratum conyzoides	勝紅薊	Compositae	24.8	4.8	10.6	2.72	100	60
Alysicarpus vaginalis	鍊莢豆	Papilionaceae	0.8		0.11		20	
Bidens pilosa	三葉鬼針草	Compositae	9.6	3.2	2.66	1.61	40	20
Centella asiatica	崩大碗	Umbelliferae	2.4	3.2	0.65	0.47	20	20
Chrysanthemum indicum	野菊	Compositae	0.8		0.19		10	
Conyza bonariensis	香絲草	Compositae	0.4		0.26		10	
Conyza canadensis	小白酒草	Compositae	0.4		0.01		10	
Desmodium tortuosum	扭莢山綠豆	Papilionaceae	0.8		0.14		20	
Emilia sonchifolia	一點紅	Compositae	5.2	3.6	0.45	0.20	30	20
Hedyotis acutangula	方骨草	Rubiaceae	0.8		0.13		20	
Oxalis corniculata	酢醬草	Oxalidaceae	4.8	2.8	0.53	0.12	20	20
Phyllanthus urinaria	葉下珠	Euphorbiaceae		0.4		0.07		10

Table 3.4 (cont'd)

Species	Chinese name	**Family**	Density (100 m^{-2})		Coverage (%)		Frequency (%)	
			98	01	98	01	98	01
Pterocypsela indica	野生菜	Compositae	0.4		0.05		10	
Scoparia dulcis	野甘草	Scrophulariaceae	0.4		0.02		10	
Lianas								
Dunbaria rotundifolia	圓葉野扁豆	Papilionaceae	1.2		0.12		20	
Ipomoea cairica	五爪金龍	Convolvonaceae	0.4		0.10		10	
Mikania micrantha	薇甘菊	Compositae	0.8	0.4	0.19	0.09	20	10
Paederia scandens	雞矢藤	Rubiaceae	0.4		0.07		10	
Pueraria phaseoloides	三裂葉野葛	Papilionaceae	0.8	0.4	0.14	0.10	20	10
Grasses								
Apluda mutica	水蔗草	Gramineae	n.c.	n.c.	0.25	0.17	10	10
Cynodon dactylon	狗牙根	Gramineae		n.c.		43.7		70
Neyraudia reynaudiana	石珍茅	Gramineae	n.c.		0.91		10	
Panicum maximum	大黍	Gramineae	n.c.	n.c.	0.88	0.23	10	10
Paspalum notatum	百喜草	Gramineae		n.c.		20.2		40
Paspalum orbiculare	圓果雀稗	Gramineae	n.c.	n.c.	0.10	0.36	10	20
Pogonatherum critinum	金髮草	Gramineae	n.c.		0.65		20	
Rhynchelytrum repens	紅毛草	Gramineae	n.c.	n.c.	1.19	0.60	30	10
Sporobolus fertilis	鼠尾粟	Gramineae	n.c.		0.05		10	
Sedges								
Cyperus distans	疏穎莎草	Cyperaceae	0.8	0.4	0.41	0.22	20	10
Mariscus umbellatus	磚子苗	Cyperaceae	1.6		0.68		20	
Pycreus polystachyos	多枝莎草	Cyperaceae	0.8	1.2	0.08	0.15	10	10
Ferns								
Blechnum orientale	烏毛蕨	Blechnaceae	1.2		0.31		30	
Dicranopteris linearis	鐵芒萁	Gleicheniaceae	0.8	0.8	0.15	0.15	10	20
Lycopodium cernuum	鋪地蜈蚣	Lycopodiaceae	2.0	1.6	0.20	0.15	30	30
Pteridium aquilnum	蕨	Pteridaceae	1.2		0.25		20	
Pteris semipinnata	半邊旗	Pteridaceae	1.6	0.4	0.45	0.25	40	10

Table 3.5 Plant density, coverage and frequency in phase 01 of Anderson Road Quarry.

Species	Chinese name	Family	Density (100 m^{-2})	Coverage (%)	Frequency (%)
Trees					
Acacia confusa	台灣相思	Mimosaceae	2.0	0.83	50
Aleurites montana	木油樹	Euphorbiaceae	0.4	0.15	10
Castanopsis fissa	裂斗錐栗	Fagaceae	0.8	0.14	20
Lophostemon confertus	紅膠木	Myrtaceae	0.4	0.10	10
Macaranga tanarius	血桐	Euphorbiaceae	0.4	0.10	10
Shrubs					
Lantana camera	馬纓丹	Verbenaceae	0.8	0.22	10
Melastoma candidum	野牡丹	Melastomataceae	1.6	0.45	30
Melastoma sanguineum	毛棯	Melastomataceae	2.0	0.42	30
Raphiolepis indica	車輪梅	Rosaceae	1.6	0.75	40
Rhodomyrtus tomentosa	桃金孃	Myrtaceae	0.8	0.15	20
Thyllanthus emblica	餘甘子	Euphorbiaceae	1.2	0.30	30
Herbs					
Ageratum conyzoides	勝紅薊	Compositae	17.6	12.4	80
Bidens pilosa	三葉鬼針草	Compositae	7.2	2.82	30
Chrysanthemum indicum	野菊	Compositae	1.2	0.73	10
Emilia sonchifolia	一點紅	Compositae	11.6	9.39	60
Helicteres angustifolia	山芝麻	Sterculiaceae	0.4	0.01	10
Lactuca indica	山萵苣	Compositae	0.4	0.02	10
Oxalis corniculata	酢醬草	Oxalidaceae	4.0	0.47	20
Solanum nigrum	龍葵	Solanaceae	0.4	0.02	10
Lianas					
Mikania micrantha	薇甘菊	Compositae	0.8	0.13	20
Parthenocissus himalayana	爬牆虎	Vitaceae	0.4	0.10	10
Grasses					
Cynodon dactylon	狗牙根	Gramineae	n.c.	30.5	60
Paspalum dilatatum	毛花雀稗	Gramineae	n.c.	0.12	20
Paspalum notatum	百喜草	Gramineae	n.c.	29.2	70
Pennisetum alopecuroides	狼尾草	Gramineae	n.c.	0.37	30
Pogonatherum critinum	金髮草	Gramineae	n.c.	0.82	30
Rhynchelytrum repens	紅毛草	Gramineae	n.c.	2.75	10
Setaria pallide-fusca	褐毛狗尾草	Gramineae	n.c.	1.16	20

Table 3.5 (cont'd)

Species	Chinese name	Family	Density (100 m^{-2})	Coverage (%)	Frequency (%)
Sedges					
Cyperus rotundus	香附子	Cyperaceae	1.6	0.04	20
Pycreus polystachyos	多枝莎草	Cyperaceae	2.0	0.09	20
Ferns					
Blechnum orientale	烏毛蕨	Blechnaceae	2.4	0.07	20
Dicranopteris linearis	鐵芒萁	Gleicheniaceae	2.4	0.09	30
Humata repens	陰石蕨	Davalliaceae	0.4	0.03	10
Lycopodium cernuum	鋪地蜈蚣	Lycopodiaceae	1.6	0.01	20
Nephrolepis biserrata	長葉腎蕨	Davalliaceae	2.0	0.08	20
Pteridium aquilnum	蕨	Pteridaceae	0.8	0.05	10
Pteris semipinnata	半邊旗	Pteridaceae	0.4	0.09	10

"n.c." means "not count" in grass species.

Table 3.6 Distribution of species on different phases of the four quarries.

	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Trees	18	12	11	9	6	6	2	5
Shrubs	10	12	9	8	6	9	4	6
Herbs	18	18	16	16	8	14	6	8
Lianas	8	7	5	3	2	5	2	2
Grasses	16	19	7	8	6	7	6	7
Sedges	5	6	4	3	2	3	2	2
Ferns.	12	11	10	8	2	5	3	7
Total species no.	87	85	62	55	32	49	25	37
Gross coverage (%)	168	127	121	110	127	101	92.3	95.2

Table 3.7 is a comparison of the largest plant families in Hong Kong and the four quarries. Gramineae was the largest family present in both Hong Kong and the four

quarries. There were 26 species of Gramineae found on the quarries and they were dominant especially in young restored quarries. The second largest plant family was Compositae, in which 16 species were found on the four quarries. They can establish on the sites efficiently and sometimes they were considered as weeds. Some common Compositae which include *Bidens pilosa* (Plate 3.7), *Ageratum conyzoides* (Plate 3.8), *Emilia sonchifolia* (Plate 3.9) and *Mikania micrantha* (Plate 3.10) had already invaded the sites. The third largest family was Papilionaceae, typical N-fixing plants. Legumes were planted in large number in order to enhance soil quality.

Table 3.7 The largest plant families in Hong Kong and on the four quarries.

Hong Kong	The four quarries studied
Gramineae	Gramineae (26)*
Compositae	Compositae (16)
Leguminosae	Papilionaceae (12)
Cyperaceae	Cyperaceae (9)
Orchidaceae	Euphorbiaceae (7)
Euphorbiaceae	Mimosaceae (5)
Rubiaceae	Pteridaceae (5)
Fagaceae	Rubiaceae (4)
Scrophulariaceae	
Lauraceae	

* Number of species in parentheses.

Plate 3.7 A common Compositae, *Bidens pilosa,* found on Lam Tei Quarry.

Plate 3.8 *Ageratum conyzoides* was commonly found on Anderson Road Quarry.

Plate 3.9 *Emilia sonchifolia* found on Turret Hill Quarry.

Plate 3.10 *Mikania micrantha* was invading onto the Anderson Road Quarry.

There were 9 plant species common to all sites (Table 3.8). They were *Rhynchelytrum repens* (Gramineae), *Ageratum conyzoides* (Compositae), *Bidens pilosa* (Compositae), *Emilia sonchifolia* (Compositae), *Mikania micrantha* (Compositae), *Oxalis corniculata* (Oxalidaceae), *Raphiolepis indica* (Rosaceae), *Lantana camera* (Verbenaceae) and *Acacia confusa* (Mimosaceae). Some of them were planted by the contractors, e.g. *A. confusa* and *R. indica*, but the others were invaded species from neighboring ecosystems. Four Compositae were dominant on the sites. The coverage of *A. conyzoides* and *B. pilosa* were high in the four quarries (especially in Lam Tei Quarry).

Table 3.8 Common plant species found on all sites.

Species	Family	Coverage (%)							
		TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Rhynchelytrum repens	Gramineae	2.12	0.35	13.9	10.0	1.25	1.19	0.60	2.75
Ageratum conyzoides	Compositae	10.4	10.2	10.3	15.2	4.90	10.6	2.72	12.4
Bidens pilosa	Compositae	3.00	2.12	19.0	20.4	8.94	2.66	1.61	2.82
Emilia sonchifolia	Compositae	2.88	3.07	0.34	0.49	0.44	0.45	0.20	9.39
Mikania micrantha	Compositae	1.26	0.76	0.54	0.19	0.10	0.19	0.09	0.13
Oxalis corniculata	Oxalidaceae	0.39	0.24	0.09	0.18	0.05	0.53	0.12	0.47
Raphiolepis indica	Rosaceae	0.54	0.47	0.08	0.05	0.01	0.27	0.11	0.75
Lantana camera	Verbenaceae	2.49	1.85	0.31	0.53	0.13	0.23	0.08	0.22
Acacia confusa	Mimosaceae	4.76	4.33	10.3	12.6	10.4	10.8	18.2	0.83

3.3.3 Ecological indices on various sites

Vegetation coverage and composition affect many ecological indices of the vegetation among the sites and phases (Table 3.9).

Table 3.9 Ecological indices of the vegetation on the various phases of the four quarries.

Indices	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Diversity index (H)	3.71	3.32	2.73	2.64	2.04	3.00	2.90	1.88
Richness index (R)	6.71	7.55	5.56	5.24	2.84	4.89	2.60	3.79
Evenness index (E)	0.83	0.75	0.66	0.66	0.59	0.77	0.90	0.52
No. of species (N0)	87	85	61	54	31	49	25	37
No. of abundant species (N1)	40.6	27.7	15.3	14.1	7.71	20.1	18.2	6.58
No. of very abundant species (N2)	30.4	18.5	10.6	9.98	5.15	5.71	0.35	4.43

The richness index, R, describes a more general picture in species diversity among various sites. It is correlated with the number of species and total coverage of vegetation. In general, site with the higher species number would also have higher richness score. As a result, older phase on the same site had a higher R. One exception was Turret Hill Quarry, the richness index in TH91 was smaller than that in TH94. This might be due to the total vegetation coverage of TH91 was higher than that of TH94 while the species number was more or less similar, so that R score would be smaller. The R score in LT98 was higher (R = 5.24) than that in SO98 (R = 4.89). However at Phases 01, Anderson Road Quarry was the highest (R = 3.79) followed by Lam Tei Quarry (R = 2.84) and Shek O Quarry (R = 2.60). These were mainly affected by the number of species on the sites.

Species diversity and richness of a vegetation community are indicated by Shannon-Wienner diversity index (H') and species richness index (R) respectively. In general, the diversity indices of Turret Hill Quarry were the highest, followed by Shek O Quarry and Lam Tei Quarry, while Anderson Road Quarry was the lowest. TH91 had the highest Shannon-Wienner diversity index (H' = 3.71) while AR01 had the lowest (H' = 1.88) (Table 3.9). There was a trend that plant diversity was related to the age of the site. As we compared different phases of each quarry, older phase on the same site would have higher diversity score. Time is needed for soil improvement as well as plant establishment and colonization. Also, since Turret Hill Quarry was a closed quarry, human disturbance would be minimized and natural succession was facilitated.

Among sites restored in the same year, say in 1998, the diversity in Shek O Quarry was higher than that in Lam Tei Quarry (H' = 3.00 and 2.64 respectively). Similarly for sites restored in 2001, the Shannon-Wienner diversity index was also higher in Shek O Quarry (H' = 2.90) than Lam Tei Quarry (H' = 2.04) and Anderson Road Quarry (H' = 1.88). This could be attributed to the higher concentration of soil nutrient especially nitrogen, in SO01 which supported a more diverse flora community.

Regarding the evenness index (E), SO01 was the highest (E = 0.90) followed by TH91 (E = 0.83), TH94 (E = 0.75), LT96 (E = 0.66), LT98 (E = 0.66), LT01 (E = 0.59) and AR01 (E = 0.52). The higher the score of evenness index, the more even was the distribution of plants on the site. It would be smaller when only few plant species were dominated in the plant community.

Table 3.10 Similarity index of vegetation between different phases comparison.

	Similarity index (Sc)%
TH91-TH94	81
LT96-LT98	82
LT98-LT01	58
LT96-LT01	56
SO98-SO01	41
LT98-SO98	48
LT01-SO01	84
SO01-AR01	64
LT01-AR01	73

3.3.4 Successful plant species at various phases of different quarries

The number of species (N0), number of abundant species (N1) and number of very abundant species (N2) in various phases of the sites are shown in Table 3.9.

Totally 108 species were recorded at the two phases of the Turret Hill Quarry. The total species number was also the largest at the oldest phase among all sites (TH91); there were 87 species, of which 36 species were trees and herbs. It was followed by TH94 with 84 recorded plant species. Tables 3.11 to 3.14 show the top three species present at each phase of the four quarries. At both phases, *Wedelia trilobata* (Plate 3.11) and *Ageratum conyzoides* were the two most dominant species (Table 3.11). The coverage of *W. trilobata* was 13.7% and 17.1% while that of *A. conyzoides* was 10.4% and 10.2% at TH91 and TH94. *W. trilobata* is a creeping evergreen perennial herb and was introduced to Turret Hill Quarry as a ground cover plant. *A. conyzoides* was a common weed on all sites and was dominant at some phases. It was pollinated by insects but seed is an achene with an aristate pappus and is easily dispersed by wind, so it can be dispersed throughout the site quickly.

Plate 3.11 *Wedelia trilobata* found on Turret Hill Quarry. The coverage of the species was very high (13.7% on TH91 and 17.1% on TH94).

Table 3.11 Top three ranked plant species on the two phases of Turret Hill Quarry.

Phase	Species	Family	Coverage
91	*Wedelia trilobata*	Compositae	13.7
	Ageratum conyzoides	Compositae	10.4
	Paspalum conjugatum	Gramineae	9.81
94	*Wedelia trilobata*	Compositae	17.1
	Ageratum conyzoides	Compositae	10.2
	Anisopappus chinensis	Compositae	8.90

Since the soil quality of Turret Hill Quarry was better compared with other sites (Chapter 2), it could support more late-successional native species (e.g. *Sterculia lanceolata*, *Rhus chinensis*, *R. succedanea* and *Melodinus suaveolens*) which are more nutrient demanding. *Ficus elastica* was only found in TH91. It requires a specific wasp for pollination and the seeds are spread by birds. However, the specific warp was not introduced in Hong Kong, so *F. elastica* in Hong Kong do not form fruit and they were planted during restoration. Fruit plants such as *Melodinus suaveolens* and *Sterculia lanceolata* provided fruits for the wildlife. The presence of exotic Mimosaceae, such as *Acacia* spp. and *Leucaena leucocephala*, and native Papilionaceae such as *Ormosia emarginata*, are nitrogen-fixing plants which are a source of nitrogen inputs to the ecosystems.

There were 77 species recorded at the three phases of Lam Tei Quarry (Table 3.3). Species number increased with age of the restored community; there were 62, 55 and 32 species recorded on LT96, LT98 and LT01 accordingly (Table 3.9). At Phases 96 and 98, *Bidens pilosa* and *Ageratum conyzoides* were the top two dominant species (Table 3.12). *B. pilosa* is pollinated by insects and its seeds are spread from clothing or animal's fur or feathers. It is light-demanding species and suitable to grow on relatively dry and infertile soil (Swarbrick 1997). However, it may form a dense ground cover that prevents regeneration of other species. *Desmodium heterocarpon* and *Acacia confusa* were the third abundant species in LT96 and LT98 respectively. They are widely used in restoration projects and they are nitrogen-fixing. In LT01, hydroseeding species *Cynodon dactylon* and *Paspalum notatum* were the two dominant species in terms of coverage. *Casuarina equisetifolia* was the third common species in LT01, and since it is also a nitrogen-fixing plant, it increase the nitrogen contents of the soil (Aspiras 1981).

Table 3.12 Top three ranked plant species on the two phases of Lam Tei Quarry.

Phase	Species	Family	Coverage
96	*Bidens pilosa*	Compositae	19.0
	Ageratum conyzoides	Compositae	14.3
	Desmodium heterocarpon	Papilionaceae	13.9
98	*Bidens pilosa*	Compositae	20.4
	Ageratum conyzoides	Compositae	19.2
	Acacia confusa	Mimosaceae	12.6
01	*Cynodon dactylon*	Gramineae	43.2
	Paspalum notatum	Gramineae	28.1
	Casuarina equisetifolia	Casuarinaceae	13.8

Similarly on the Shek O Quarry, the plant species number in SO98 was larger than that in SO01 (Table 3.9). There were 25 species found in SO01, while 49 species were recorded in SO98, nearly twice that of the 01 phase. The top three common species in SO98 were all legumes (Table 3.13). This shows the adaptation of legumes on quarries. *D. heterocarpon* was the most dominant species in SO98 followed by two Mimosaceae, *A. auriculiformis* (Plate 3.12) and *L. leucocephala* (Table 3.13). They are all planted species that grow well in relatively infertile soil. Beside these three species, the coverage of *A. conyzoides* was about 10% which occupied relatively large area. Hydroseeded grass species *C. dactylon* and *P. notatum* covered most area of SO01. *A. confusa* was also widely planted on SO01.

Plate 3.9 *Acacia auriculiformis* was one of the commonest trees found on SO98.

Table 3.13 Top three ranking of plant in each phase of Shek O Quarry.

Phase	Species	Family	Coverage
98	*Desmodium heterocarpon*	Papilionaceae	28.4
	Acacia auriculiformis	Mimosaceae	14.8
	Leucaena leucocephala	Mimosaceae	13.2
01	*Cynodon dactylon*	Gramineae	43.7
	Paspalum notatum	Gramineae	21.2
	Acacia confusa	Mimosaceae	18.2

There were 37 species recorded in the Anderson Road Quarry, on which *C. dactylon* and *P. notatum* were the two dominant species (Table 3.14). The plant species colonized was mainly herbs, grasses and ferns. *A. conyzoides* colonized the site and increase its coverage to more than 10% in only a year. This species is considered a weed, and control is often difficult (Lam *et al.*, 1993; Waterhouse, 1993).

Table 3.14 Top three ranking of plant in AR01.

Species	Family	Coverage
Cynodon dactylon	Gramineae	30.5
Paspalum notatum	Gramineae	29.2
Ageratum conyzoides	Compositae	12.4

3.3.5 Trees vs shrubs, native vs exotic

The conventional practice of quarry restoration programmes started with hydroseeding and then tree planting. In Hong Kong, turf grass species such as *Paspalum* spp. and *Cynodon* spp. are the most popular grass species being used for hydroseeding, depending on the season and the engineering purpose (Kirkbride and Forbes, 1994; Chong, 1996). Local grasses are rarely used. Tree plantation is the next step after hydroseeding. Saplings planted are mainly several common exotic species, such as *Acacia* spp., *Leucaena leucocephala* and *Casuarina equisetifolia*. However, because of the awareness of native flora conservation, natives are also being planted in restoration works in recent years. Trees rather than shrubs are widely used in revegetation. Many researchers have raised doubt on the immediate need of planting trees as they required more nutrients than shrubs to grow upward in order to obtain more sunlight. Shrubs can be considered as the pioneer species to establish and improve the soil quality (Su and Zhao, 2003). In fact, there are shrub legumes such as *Myrica pensylvanica*, *Cytisus scoparius* and *Acacia salicina*, which are well studied and could improve soil condition efficiently and attract wildlife (Schlesinger *et al.*, 1990, 1996; Shumway, 2000; Wambolt *et al.*, 2001; Yu, 2002). Evidence have shown that the establishment of not only trees, but also herbs and shrubs are responsible for maintaining vegetative cover and is conducive to improved soil quality (Yu *et al.*, 2002).

The colonization of herbaceous and shrub species initiates a vegetation cover on the site. Soil temperatures are lower in the shade of trees, and hence reduce the evaporation of water from the soil. As a result, soil will be less vulnerable to drought. Moreover, for example in the Anderson Road Quarry, trees such as *A. confusa* and *Castanopsis fissa*, are not suitable to grow because of the windy situation. Their leaves would crash with each other and would easily be damaged, thus inhibiting the growth rate of trees. Soil covered with grasses, herbs and shrubs can help to resist windy and sandy environment, by shielding wind-dispersed seeds of invading species and increasing the possibility of seed recruitment and establishment (Shumway, 2000). Therefore, from another point of view, revegetation with shrub species could be considered as shrubs could facilitate the growth of invaded plant species and vegetation development by creating a benign micro-climatic condition as well as soil improvement.

3.4 Conclusion

After restoration processes, some indigenous grasses, herbs and shrubs gradually invaded to the sites. With increasing restoration time, species diversity and plant coverage increased. Differences were found on species diversity and richness among various phases. Because of the restoration age within a site was not long, the increase in diversity and coverage were not so obvious for intra-site comparison. However, the high diversity and coverage in Turret Hill Quarry (restored for about 10 years) which showed a positive influence of restoration. Species diversity and richness as well as coverage of trees and shrubs were the highest on Turret Hill Quarry. The invasion, establishment and development of herbaceous species also help transforming the simple, artificial ecosystem to a more natural one.

Anderson Road Quarry had the lowest tree and shrub coverage. In fact, most areas in the restored phases of Anderson Road Quarry were grasslands. Windy environment hindered plant growth and it hinder the seed establishment even there are seed sources nearby the site. In addition, lack of dense shrub cover also lead to difficulty in seed establishment. This can be reflected by the species diversity index, which were lowest in Anderson Road Quarry even when compared with other quarries of the same age (i.e. SO01 and LT01).

The use of fast growing nitrogen-fixing legumes resulted in the accumulation of carbon and nitrogen in soil and has been shown to increase soil nitrogen levels (Chapter 2) and to facilitate seedling growth in nutrient-poor environments (Shumway, 2000). With increasing plantation age, the vegetation community on the restored quarries would be more diverse. Although legumes can improve the soil properties, they were not dominant in the quarries. Grass and herbaceous species showed their greater reproductive potential. In fact, many species of Compositae and Gramineae families dominated on various quarries. They were the pioneer species which explored the site and helped altering the environment in such a way to permit new communities to occupy the site.

Chapter 4: Butterfly Communities on Restored Quarries

4.1 Introduction

Lepidopterans can be divided into suborder Rhopalocera (butterflies) and Heterocera (moths). In Hong Kong, there are about 230 recorded butterfly species and more than 2,200 known species of moths. New species are continuously discovered every year. Especially moths, the actual species number may exceed 4,000.

There are 10 families of butterfly found in Hong Kong, including Papilionidae, Pieridae, Nymphalidae, Satyridae, Danaidae, Lycaenidae, Hesperiidae, Riodinidae and Amathusiidae. Hong Kong with its subtropical climate has a predominantly Indo-Australian butterfly fauna. About 92% Hong Kong's butterfly species can be found in India and 80% in Malay Peninsula. About 65% butterfly species are also recorded in Taiwan (Bascombe *et al.*, 1999).

Butterflies are widely discussed within the conservation community, not only because of their beauty, but also their capability to serve as good indicator of environmental changes (Armstrong and van Hensbergen, 1995; Blair and Launer, 1997; Dover, 1997; Oostermeijer and van Swaay, 1998; Smallidge and Leopold, 1997). However, a number of recent studies about insects in restored sites showed that butterflies and moths cannot fully reflect the vegetation status on the degraded sites such as coal mines (Holl, 1995; Holl, 1996). In general, lepidopterans respond directly or indirectly to vegetation development within restored landscape as they are sensitive to the microclimate of habitats and are highly dependent on plants in their life cycle (Bascombe *et. al.*, 1999; Meyer and Sisk, 2001). Richness of butterfly species depends on the supply of food plants and other environmental factors.

Most studies on restored land focused on soil quality, vegetation development and general ecology. Insect fauna, especially vegetation-based insects such as lepidopterans, are scarcely studied. This experiment aimed to investigate the population structures of Lepidoptera on the different phases of restored quarries. Management plans must accommodate the constraints of the regional landscape and the spatial and temporal dynamics of the restoration management regime. They often have been suggested as surrogate measures of species richness or ecosystem attributes.

4.2 Materials and Methods

4.2.1 Pollard-walk method

Butterfly communities in the four quarries were recorded by Pollard-walk method (Pollard, 1977; Gall, 1985) during May 2002 to May 2003. This recording method is more formal and was done weekly which involved counting numbers of butterflies as well as recording the existence of different species. A transect route was planned on each phase of the four quarries, i.e., Turret Hill Quarry (Figure 4.1), Lam Tei Quarry (Figure 4.2), Shek O Quarry (Figures 4.3a and 4.3b) and Anderson Road Quarry (Plates 4.1a and 4.1b). The transect routes covered all major habitat types at the restoration site. The transect was monitored once a week on sunny days and totally 40 days of survey for each site and phase. All butterflies seen within an imaginary box (about 5 m^3) of the transect route are identified and counted. The number of counts represents an index of abundance (Pollard, 1991).

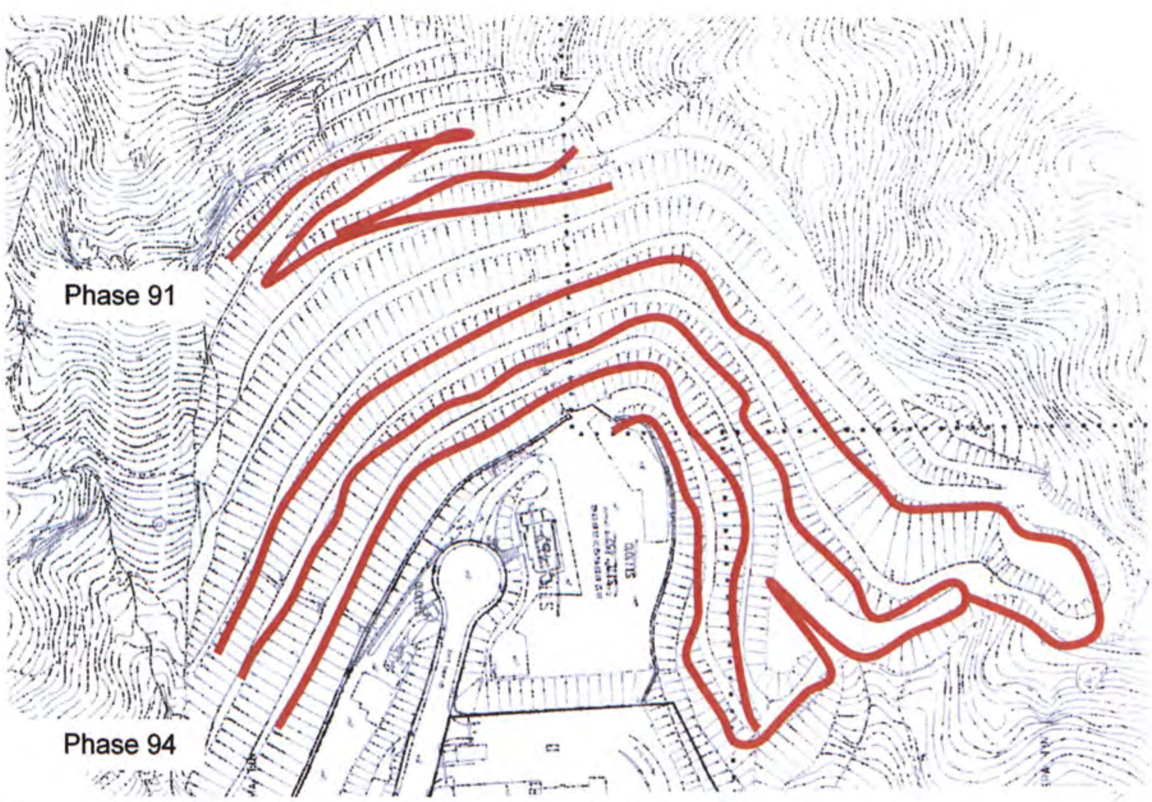

Figure 4.1 Red lines represent the routes for Pollard-walk on Turret Hill Quarry (TH).

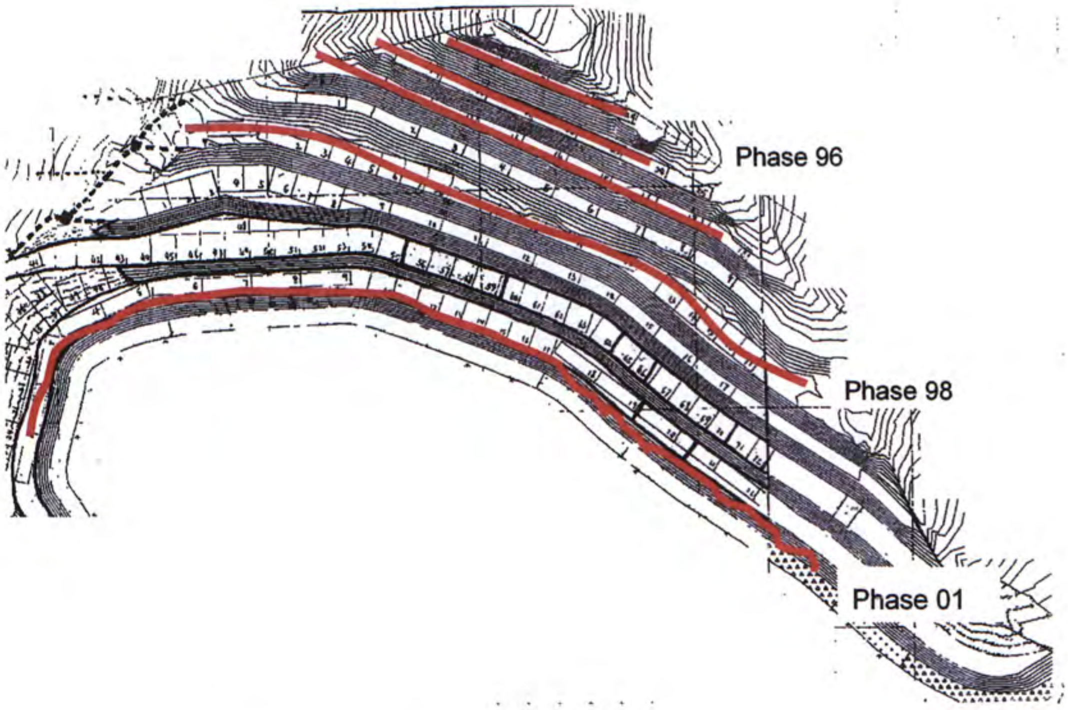

Figure 4.2 Red lines represent the route for Pollard-walk on Lam Tei Quarry (LT).

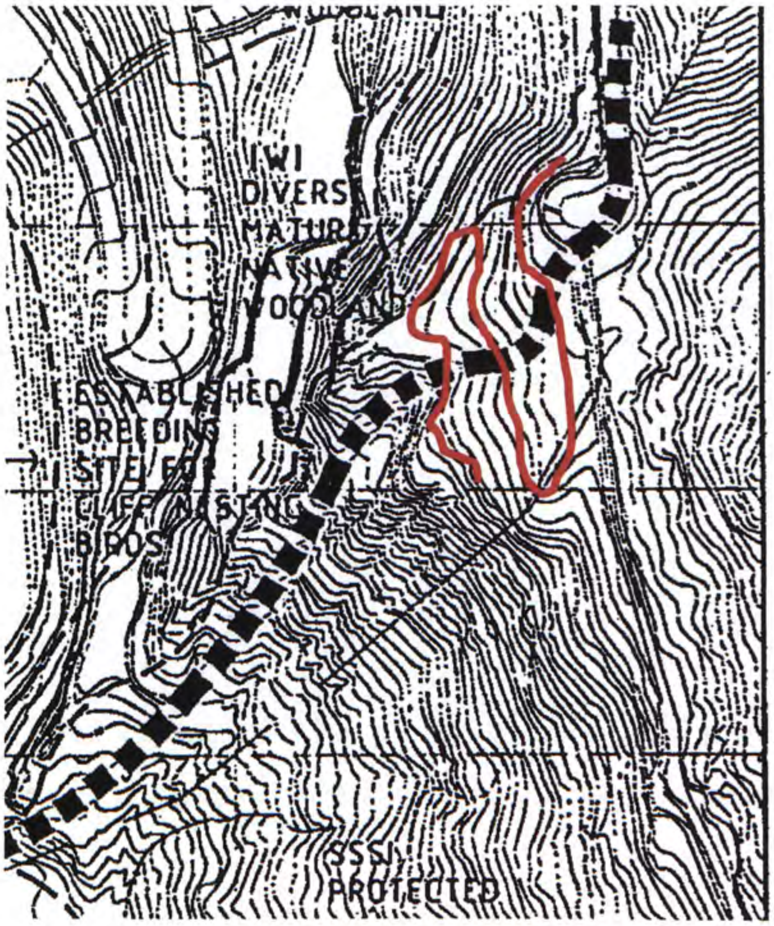

Figure 4.3a Red lines represent the route for Pollard-walk on SO98.

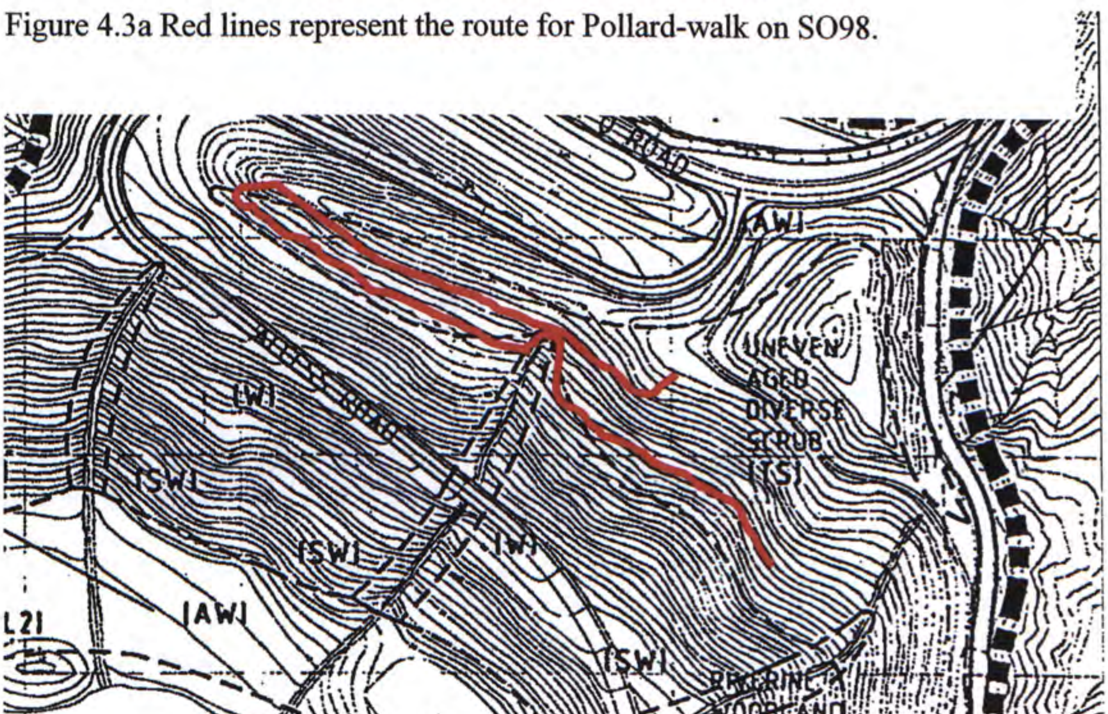

Figure 4.3b Red lines represent the route for Pollard-walk SO01.

Plate 4.1a Route for Pollard-walk on Anderson Road Quarry (AR) Site A.

Plate 4.1b Route for Pollard-walk on Anderson Road Quarry (AR) Site B.

Pollard-walk is particularly useful because the weekly data, when looked at over a period of time, give clear indications of success or failure of the various butterfly species and changes to the way that habitat management can be planned.

4.2.3 Statistical analysis

Shannon-Wiener diversity index (H'), evenness index (E) and similarity index (Sc) were estimated as described in Chapter 3.

4.3 Results and Discussion

4.3.1 General description of the butterfly communities

Species composition at different phases of the four quarries is shown in Table 4.1. Totally 52 butterfly species were found in the four quarries (Table 4.2). This comprised about 23% recorded butterfly species number in Hong Kong (232 species). It was high when the area of the sites relative to that of Hong Kong is considered. The number of butterfly species recorded in Turret Hill, Lam Tei, Shek O and Anderson Road quarries were 39, 25, 21 and 11 respectively. More species were found on sites that were closed for longer times. In Turret Hill Quarry, the number of butterfly species was almost 4 times that in Anderson Road Quarry. Besides Riodinidae and Amathusiidae, other 6 families of butterfly could be found among these quarries. Only one species of Riodinidae (*Abisara echerius*) was recorded in Turret Hill Quarry and Lam Tei Quarry.

Table 4.1 Butterfly species composition at different phases of the four quarries.

Species	Chinese name	Family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01	Status
Danaus genutia	虎斑蝶	Danaidae	+	+	+	+	+				VC
Euploea mulciber	異型紫斑蝶	Danaidae	+	+				+			UC
Parantica aglea	絹斑蝶	Danaidae	+	+	+	+	+				VC
Tirumala limniace	青斑蝶	Danaidae								+	C
Astictopterus jama	腌翅弄蝶	Hesperiidae	+	+	+	+					C
Bibasis gomata	白傘弄蝶	Hesperiidae	+	+							C
Borbo cinnara	秈弄蝶	Hesperiidae	+	+				+		+	C
Parnara bada	么紋稻弄蝶	Hesperiidae	+	+				+	+		C
Parnara guttata	直紋稻弄蝶	Hesperiidae			+	+	+	+	+		C
Potanthus trachala	斷紋黃室弄蝶	Hesperiidae	+	+							C
Suastus gremius	素弄蝶	Hesperiidae			+	+	+	+			C
Tagiades litigiosus	沾邊裙弄蝶	Hesperiidae	+	+							C
Acytolepis puspa	鈕灰蝶	Lycaenidae	+		+	+					C
Chilades lajus	紫灰蝶	Lycaenidae						+	+		VC
Everes lacturnus	長尾藍灰蝶	Lycaenidae	+	+	+	+	+	+		+	C
Lampides boeticus	亮灰蝶	Lycaenidae			+	+					C
Pratapa deva	珀灰蝶	Lycaenidae	+	+							UC
Spindasis syama	豆粒銀線灰蝶	Lycaenidae	+	+							UC
Udara albocaerulea	白斑嫵灰蝶	Lycaenidae	+	+	+	+		+			UC
Zizeeria karsandra	吉灰蝶	Lycaenidae		+							UC
Zizina otis	毛眼灰蝶	Lycaenidae	+	+	+	+	+	+	+		C
Argyreus hyperbius	斐豹蛺蝶	Nymphalidae	+	+	+	+		+			C
Cupha erymanthis	黃襟蛺蝶	Nymphalidae						+	+		VC
Dichorragia nesimachus	電蛺蝶	Nymphalidae			+						UC
Hestina assimilis	黑脈蛺蝶	Nymphalidae	+	+	+	+					C
Hypolimnas bolina	幻紫斑蛺蝶	Nymphalidae			+	+	+				VC
Junonia lemonias	蛇眼蛺蝶	Nymphalidae	+	+							UC

Table 4.1 (cont'd)

Species	Chinese name	Family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01	Status
Limenitis sulpitia	殘鍔線蛺蝶	Nymphalidae			+	+					C
Neptis sp.	環蛺蝶	Nymphalidae	+	+							-
Parasarpa dudu	Y 紋俳蛺蝶	Nymphalidae	+	+							UC
Phaedyma columella	柱菲蛺蝶	Nymphalidae	+		+						UC
Vanessa cardui	小紅蛺蝶	Nymphalidae								+	UC
Chilasa clytia	斑鳳蝶	Papilionidae	+	+							C
Graphium doson	木蘭青鳳蝶	Papilionidae	+	+							UC
Papilio bianor	碧鳳蝶	Papilionidae	+	+	+	+					C
Papilio demoleus	達摩鳳蝶	Papilionidae						+			C
Papilio helenus	玉斑鳳蝶	Papilionidae	+	+	+	+	+	+	+		VC
Papilio memnon	美鳳蝶	Papilionidae	+	+						+	VC
Papilio paris	巴黎翠鳳蝶	Papilionidae	+	+	+	+	+	+	+	+	VC
Papilio polytes	玉帶鳳蝶	Papilionidae			+	+	+	+	+		VC
Catopsilia pomona	遷粉蝶	Pieridae	+	+						+	C
Delias pasithoe	報喜班粉蝶	Pieridae	+	+				+	+		VC
Eurema hecabe	寬邊黃粉蝶	Pieridae	+	+	+	+	+	+	+	+	VC
Pieris canidia	東方菜粉蝶	Pieridae	+	+						+	VC
Abisara echerius	蛇目褐蜆蝶	Riodinidae	+	+	+	+					VC
Lethe confusa	白帶黛眼蝶	Satyridae	+	+				+	+		VC
Melanitis leda	暮眼蝶	Satyridae	+	+							VC
Melanitis phedima	睇暮眼蝶	Satyridae	+	+				+	+	+	C
Mycalesis mineus	小眉眼蝶	Satyridae			+	+	+	+	+		VC
Mycalesis panthaka	平頂眉眼蝶	Satyridae	+	+							C
Ypthima baldus	矍眼蝶	Satyridae	+	+	+	+	+	+	+	+	VC
Ypthima lisandra	黎桑矍眼蝶	Satyridae	+	+	+	+	+				C

"+" denotes the presence of a species at a specific phase

According to Young and Yiu (2002), about 90% of the butterfly species found in the quarries were nectar feeders (Table 4.3). This indicates that they play a very important role in the pollination of the flowering plants in the quarries (Ehrlich and Raven, 1964). Compositae were the second largest plant family in the four quarries (Chapter 3), and most of them required insects for pollination. Many plants on the restored quarries, such as *Lantana camera*, *Melastoma* spp., *Raphiolepis indica* and *Rhodomyrthus tomentosa*, are flowering plants, and they were mainly pollinated by nectar feeding insects such as butterflies. Fruit juice, tree sap, excreta and decaying fluid are other food sources for butterflies. Among the butterfly species, only *Dichorragia nesimachus*, *Melanitis phedima*, *Mycalesis panthaka*, *Mycalesis mineus* and *Melanitis leda* do not feed on nectar, but on water in the drainage system.

Table 4.2 Number of butterfly species found on the four quarries (up to Oct 2002).

Family	TH	LT	SO	AR	All sites	Total in HK
Hesperiidae	6	3	4	1	8	54
Lycaenidae	7	5	4	1	9	51
Nymphalidae	6	6	2	1	11	50
Pieridae	4	1	2	3	4	22
Papilionidae	6	4	4	2	8	21
Satyridae	6	3	4	2	7	17
Danaidae	3	2	1	1	4	12
Riodinidae	1	1	0	0	1	3
Amathusiidae	0	0	0	0	0	2
Total number of species	39	25	21	11	52	232

Table 4.3 Food source and occurrence status of butterflies on the four quarries according to Young and Yiu (2002).

		TH	LT	SO	AR	All sites
Food source (%)	Nectar	92	92	90	91	90
	Fruit juice, tree sap, excreta and decaying fluid	28	44	38	36	31
	Water	38	40	24	55	33
Status	Uncommon	9	3	2	1	11
	Common	17	12	9	5	23
	Very common	12	9	10	5	17

4.3.2 Uncommon species found on the quarries

Butterfly species are rated for their rarities according to Young and Yiu (2002) (Table 4.4). The butterfly species recorded on the quarries can be divided into three categories: very common, common and uncommon species.

Table 4.4 Status of butterfly in Hong Kong with reference to their percentage of occurrence (Walthew, 1997; Young and Yiu, 2002).

Percentage of occurrence (%)	Status
<1	Very rare
1-4	Rare
4-11	Uncommon
11-33	Common
> 33	Very Common

Most of them (23 species) belonged to common species in Hong Kong (Table 4.1). Seventeen species were very common species in Hong Kong; 11 of them were defined as uncommon in Hong Kong, including *Pratapa deva*, *Parasarpa dudu*, *Phaedyma columella*, *Dichorragia nesimachus*, *Graphium doson*, *Junonia lemonias*, *Vanessa cardui*, *Euploea mulciber*, *Udara albocaerulea*, *Zizeeria karsandra* and *Spindasis syama* (Plate 4.3). The status of butterfly is based on the frequency of occurrence in Hong Kong which divided the landmass of Hong Kong into 170 one-kilometer grid squares (Walthew, 1997; Young and Yiu, 2002).

There were 9 uncommon species recorded in the oldest Turret Hill Quarry (Table 4.1). *Pratapa deva*, *Parasarpa dudu*, *Graphium doson*, *Junonia lemonias*, *Euploea mulciber*, *Udara albocaerulea* and *Spindasis syama* were recorded at Phases 91 and 94, while *Phaedyma columella* was found on TH91 and *Zizeeria karsandra* on TH94 (Table 4.1). *P. deva*, was always in close association to its host plant - *Scurrula parasitica*, so *S. parasitica* was very likely to be present in the quarry. Regarding Lam Tei Quarry, *U. albocaerulea* was recorded at Phases 96 and 98; *Phaedyma columella* and *Dichorragia nesimachus* were only found on LT96. In Shek O Quarry, *E. mulciber* and *U. albocaerulea* only visited Phase 98. In Anderson Road Quarry, uncommon species - *Vanessa cardui*, was recorded. The number of *V. cardui* increased in recent years and could be recorded at hill like Anderson Road Quarry (Young and Yiu, 2002). However, since the relative abundance of *V. cardui* was very low, the quarry may not be a good nursery site for the species.

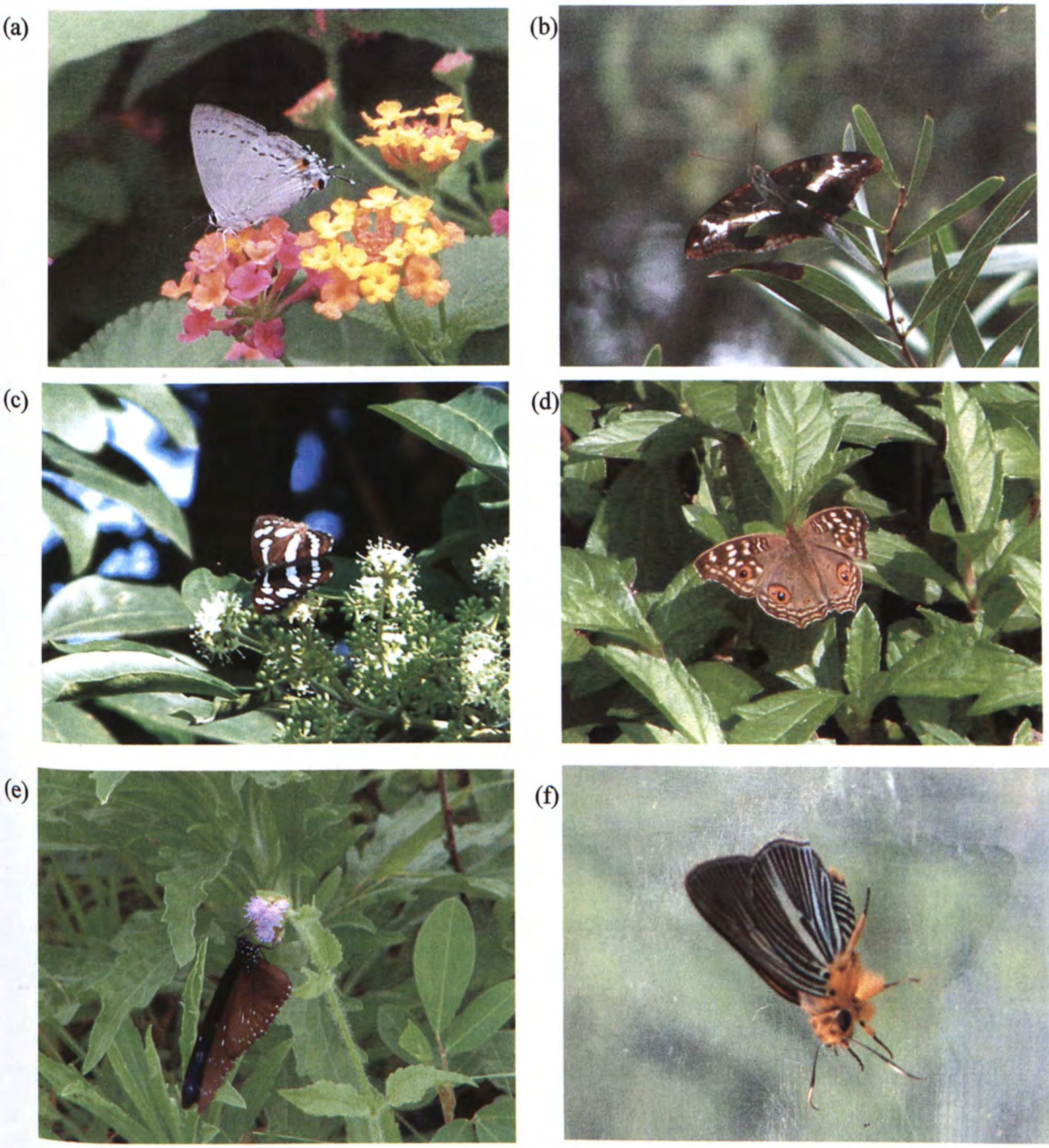

Plate 4.2 Various butterfly species found on Turret Hill Quarry, including (a) *Pratapa deva,* (b) *Parasarpa dudu,* (c) *Phaedyma columella,* (d) *Junonia lemonias,* (e) *Euploea mulciber and* (f) *Spindasis syama.*

Some Lepidoptera conservationists proposed that by conserving one or two dominant and charismatic species on the site, the other species on the same site will also be preserved (Thomas, 1999; Fleishman *et al.*, 2000). However, they ignore the conservation need of some rare species for proper habitat management, and may exclude habitats that contain rare species (Prendergast *et al.*, 1993; Ricketts *et al.*, 2001). The presence of such uncommon species on site increases the conservation value of the restored quarries.

4.3.3 Butterfly species found on various phases of quarry

The presence of butterfly was very likely correlated with the age of the sites and vegetation coverage and density of the sites (Chapter 3). The index of abundance and relative abundance for butterfly species among different quarries were shown in Tables 4.5 and 4.6 respectively. Older sites supported more butterflies in terms of both number of species and population size (Table 4.7).

In Turret Hill Quarry, Phase 91 has only one species more than Phase 94. However, the total number of individuals was higher at TH94 than that at TH91. This was because TH94 was larger in area than TH91, so there was more resources and shelter to support more individuals. The soil and vegetation status of the two phases of Turret Hill Quarry were very similar (Chapters 2 and 3), and the boundary

Table 4.5 Index of abundance for butterfly species among phases of the four quarries. Figures represent total number of individuals recorded on each area over the entire study period.

Species	Chinese name	Family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01	Total
Danaus genutia	虎班蝶	Danaidae	60	72	31	34	5				202
Euploea mulciber	異型紫班蝶	Danaidae	21	23				18			62
Parantica aglea	絹班蝶	Danaidae	76	84	36	32	19				247
Tirumala limniace	青班蝶	Danaidae								4	4
Astictopterus jama	腌翅弄蝶	Hesperiidae	15	20	9	11					55
Bibasis gomata	白傘弄蝶	Hesperiidae	5	7							12
Borbo cinnara	秈弄蝶	Hesperiidae	24	35				16		3	78
Parnara bada	幺紋稻弄蝶	Hesperiidae	5	8				10	4		27
Parnara guttata	直紋稻弄蝶	Hesperiidae			13	17	6	14	7		57
Potanthus trachala	斷紋黃室弄蝶	Hesperiidae	24	34							58
Suastus gremius	素弄蝶	Hesperiidae			17	22	8	23			70
Tagiades litigiosus	沾邊裙弄蝶	Hesperiidae	20	29							49
Acytolepis puspa	鈕灰蝶	Lycaenidae	73		83	71					227
Chilades lajus	紫灰蝶	Lycaenidae						172	29		201
Everes lacturnus	長尾藍灰蝶	Lycaenidae	181	196	86	58	30	27		19	597
Lampides boeticus	亮灰蝶	Lycaenidae			28	29					57
Pratapa deva	珀灰蝶	Lycaenidae	5	5							10
Spindasis syama	豆粒銀線灰蝶	Lycaenidae	5	7							12
Udara albocaerulea	白斑嫵灰蝶	Lycaenidae	12	17	15	11		7			62
Zizeeria karsandra	吉灰蝶	Lycaenidae		28							28
Zizina otis	毛眼灰蝶	Lycaenidae	144	162	60	56	35	135	33		625
Argyreus hyperbius	斐豹蛺蝶	Nymphalidae	50	29	28	20		30			157
Cupha erymanthis	黃襟蛺蝶	Nymphalidae						23	8		31
Dichorragia nesimachus	電蛺蝶	Nymphalidae			3						3
Hestina assimilis	黑脈蛺蝶	Nymphalidae	32	24	16	15					87
Hypolimnas bolina	幻紫班蛺蝶	Nymphalidae			36	21	5				62
Junonia lemonias	蛇眼蛺蝶	Nymphalidae	12	29							41

Table 4.5 (cont'd)

Species	Chinese name	Family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01	Total
Limenitis sulpitia	殘鍔線蛺蝶	Nymphalidae			15	17					32
Neptis sp.	環蛺蝶	Nymphalidae	45	28							73
Parasarpa dudu	Y 紋俳蛺蝶	Nymphalidae	8	6							14
Phaedyma columella	柱菲蛺蝶	Nymphalidae	5		7						12
Vanessa cardui	小紅蛺蝶	Nymphalidae								2	2
Chilasa clytia	班鳳蝶	Papilionidae	46	39							85
Graphium doson	木蘭青鳳蝶	Papilionidae	25	30							55
Papilio bianor	碧鳳蝶	Papilionidae	43	32	35	27					137
Papilio demoleus	達摩鳳蝶	Papilionidae						26			26
Papilio helenus	玉班鳳蝶	Papilionidae	53	72	36	39	5	16	3		224
Papilio memnon	美鳳蝶	Papilionidae	65	59						3	127
Papilio paris	巴黎翠鳳蝶	Papilionidae	105	89	62	68	16	71	16	13	440
Papilio polytes	玉帶鳳蝶	Papilionidae			24	31	4	40	5		104
Catopsilia pomona	遷粉蝶	Pieridae	121	137						32	290
Delias pasithoe	報喜班粉蝶	Pieridae	176	144				46	10		376
Eurema hecabe	寬邊黃粉蝶	Pieridae	118	152	61	42	40	82	58	37	590
Pieris canidia	東方菜粉蝶	Pieridae	89	102						189	380
Abisara echerius	蛇目褐蜆蝶	Riodinidae	87	135	23	57					302
Lethe confusa	白帶黛眼蝶	Satyridae	112	152				38	2		304
Melanitis leda	暮眼蝶	Satyridae	99	117							216
Melanitis phedima	睇暮眼蝶	Satyridae	123	120				30	4	3	280
Mycalesis mineus	小眉眼蝶	Satyridae			126	132	41	109	32		440
Mycalesis panthaka	平頂眉眼蝶	Satyridae	39	33							72
Ypthima baldus	矍眼蝶	Satyridae	96	120	63	45	27	40	25	14	430
Ypthima lisandra	黎桑矍眼蝶	Satyridae	26	40	18	24	3				111

Table 4.6 Relative abundance of butterfly species among phases of the four quarries.

Species	Chinese name	Family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Danaus genutia	虎斑蝶	Danaidae	2.67	2.98	3.33	3.87	2.05			
Euploea mulciber	異型紫斑蝶	Danaidae	0.94	0.95				1.85		
Parantica aglea	絹斑蝶	Danaidae	3.39	3.48	3.87	3.64	7.79			
Tirumala limniace	青斑蝶	Danaidae								1.25
Astictopterus jama	腌翅弄蝶	Hesperiidae	0.67	0.83	0.97	1.25				
Bibasis gomata	白傘弄蝶	Hesperiidae	0.22	0.29						
Borbo cinnara	秈弄蝶	Hesperiidae	1.07	1.45				1.64		0.94
Parnara bada	么紋稻弄蝶	Hesperiidae	0.22	0.33				1.03	1.69	
Parnara guttata	直紋稻弄蝶	Hesperiidae			1.40	1.93	2.46	1.44	2.97	
Potanthus trachala	斷紋黃室弄蝶	Hesperiidae	1.07	1.41						
Suastus gremius	素弄蝶	Hesperiidae			1.83	2.50	3.28	2.36		
Tagiades litigiosus	沾邊裙弄蝶	Hesperiidae	0.89	1.20						
Acytolepis puspa	鈕灰蝶	Lycaenidae	3.25		8.92	8.08				
Chilades lajus	紫灰蝶	Lycaenidae						17.7	12.3	
Everes lacturnus	長尾藍灰蝶	Lycaenidae	8.06	8.11	9.24	6.60	12.3	2.77		5.96
Lampides boeticus	亮灰蝶	Lycaenidae			3.01	3.30				
Pratapa deva	珀灰蝶	Lycaenidae	0.22	0.21						
Spindasis syama	豆粒銀線灰蝶	Lycaenidae	0.22	0.29						
Udara albocaerulea	白斑嫵灰蝶	Lycaenidae	0.53	0.70	1.61	1.25		0.72		
Zizeeria karsandra	吉灰蝶	Lycaenidae		1.16						
Zizina otis	毛眼灰蝶	Lycaenidae	6.41	6.71	6.44	6.37	14.3	13.9	14.0	
Argyreus hyperbius	斐豹蛺蝶	Nymphalidae	2.23	1.20	3.01	2.28		3.08		
Cupha erymanthis	黃襟蛺蝶	Nymphalidae						2.36	3.39	
Dichorragia nesimachus	電蛺蝶	Nymphalidae			0.32					
Hestina assimilis	黑脈蛺蝶	Nymphalidae	1.43	0.99	1.72	1.71				
Hypolimnas bolina	幻紫班蛺蝶	Nymphalidae			3.87	2.39	2.05			
Junonia lemonias	蛇眼蛺蝶	Nymphalidae	0.53	1.20						
Limenitis sulpitia	殘鍔線蛺蝶	Nymphalidae			1.61	1.93				

Table 4.6 (cont'd)

Species	Chinese name	Family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Neptis sp.	環蛺蝶	Nymphalidae	2.00	1.16						
Parasarpa dudu	Y 紋俳蛺蝶	Nymphalidae	0.36	0.25						
Phaedyma columella	柱菲蛺蝶	Nymphalidae	0.22		0.75					
Vanessa cardui	小紅蛺蝶	Nymphalidae								0.63
Chilasa clytia	斑鳳蝶	Papilionidae	2.05	1.61						
Graphium doson	木蘭青鳳蝶	Papilionidae	1.11	1.24						
Papilio bianor	碧鳳蝶	Papilionidae	1.92	1.32	3.76	3.07				
Papilio demoleus	達摩鳳蝶	Papilionidae						2.67		
Papilio helenus	玉斑鳳蝶	Papilionidae	2.36	2.98	3.87	4.44	2.05	1.64	1.27	
Papilio memnon	美鳳蝶	Papilionidae	2.90	2.44						0.94
Papilio paris	巴黎翠鳳蝶	Papilionidae	4.68	3.68	6.66	7.74	6.56	7.30	6.78	4.08
Papilio polytes	玉帶鳳蝶	Papilionidae			2.58	3.53	1.64	4.11	2.12	
Catopsilia pomona	遷粉蝶	Pieridae	5.39	5.67						10.0
Delias pasithoe	報喜班粉蝶	Pieridae	7.84	5.96				4.73	4.24	
Eurema hecabe	寬邊黃粉蝶	Pieridae	5.26	6.29	6.55	4.78	16.4	8.43	24.6	11.6
Pieris canidia	東方菜粉蝶	Pieridae	3.96	4.22						59.3
Abisara echerius	蛇目褐蜆蝶	Riodinidae	3.88	5.59	2.47	6.48				
Lethe confusa	白帶黛眼蝶	Satyridae	4.99	6.29				3.91	0.85	
Melanitis leda	暮眼蝶	Satyridae	4.41	4.84						
Melanitis phedima	睇暮眼蝶	Satyridae	5.48	4.97				3.08	1.69	0.94
Mycalesis mineus	小眉眼蝶	Satyridae			13.5	15.0	16.8	11.2	13.6	
Mycalesis panthaka	平頂眉眼蝶	Satyridae	1.74	1.37						
Ypthima baldus	矍眼蝶	Satyridae	4.28	4.97	6.77	5.12	11.1	4.11	10.6	4.39
Ypthima lisandra	黎桑矍眼蝶	Satyridae	1.16	1.66	1.93	2.73	1.23			

between the two phases was not clear. As a result, the territorial boundary of several species might cross both phases, and large and strong flight butterflies (such as Papilionidae) would find their nectar sources at both phases.

Table 4.7 Number of butterfly species and their total index of abundance recorded in the different phases of the four quarries.

	No. of species	Index of abundance
TH91	38	2245
TH94	37	2416
LT96	25	931
LT98	23	879
LT01	14	244
SO98	21	973
SO01	14	236
AR01	11	319

The ranking of butterfly species on Turret Hill Quarry was shown in Table 4.8. The species composition of the two phases were very similar (Table 4.1). Most species were found at both phases. *Everes lacturnus* (Lycaenidae) was the most dominant species at both phases. It is a common species often found in open area such as abundant fields and roadsides. *Desmodium heterocarpon* was the host plant of *E. lacturnus* and it was found on all sites and phases; this helped the wide spread of *E. lacturnus*. *Zizina otis* (Lycaenidae) was another common species found in Turret Hill Quarry. It was common and abundant in Hong Kong throughout the year.

Table 4.8 The ten most abundant butterfly species in each phase of Turret Hill Quarry according to their abundance.

Phase	Species	Family	Index of abundance
91	*Everes lacturnus*	Lycaenidae	181
	Delias pasithoe	Pieridae	176
	Zizina otis	Lycaenidae	144
	Melanitis phedima	Satyridae	123
	Catopsilia pomona	Pieridae	121
	Eurema hecabe	Pieridae	118
	Lethe confusa	Satyridae	112
	Papilio paris	Papilionidae	105
	Melanitis leda	Satyridae	99
	Ypthima baldus	Satyridae	96
94	*Everes lacturnus*	Lycaenidae	196
	Zizina otis	Lycaenidae	162
	Eurema hecabe	Pieridae	152
	Lethe confusa	Satyridae	152
	Delias pasithoe	Pieridae	144
	Catopsilia pomona	Pieridae	137
	Abisara echerius	Riodinidae	135
	Melanitis phedima	Satyridae	120
	Ypthima baldus	Satyridae	120
	Melanitis leda	Satyridae	117

Lam Tei Quarry showed a typical gradient of number of species and individuals among phases. More species and individuals were recorded at the older phase. At Phases 96 and 98, there were 25 and 23 butterfly species recorded respectively. In terms of index of abundance, LT96 was slightly higher than LT98, while LT01 had the lowest. Species number and abundance also dropped in LT01 because the diversity and coverage of plant species greatly declined in LT01, especially because of the low occurrence of flowering plants to provide nectar. The low coverage of shrub and tree species also affected the occurrence of butterflies as the exposed area is not a good visiting site for some large butterflies such as some species of Papilionidae and Danaidae.

Plate 4.3 *Papilio paris* recorded on Lam Tei Quarry was also very common on other quarries.

Mycalesis mineus (Satyridae) was the most abundant species among the three phases in Lam Tei Quarry (Table 4.9). However, since it does not visit flower and only feed on tree sap, animal excretion and rooting fruits, it may not help in pollination of plants. Two Lycaenidae, *Everes lacturnus* and *Acytolepis puspa*, were the second and third most abundant species in LT96; *A. puspa* was second most abundant species in LT98. It was common throughout Hong Kong and was found in sheltered secondary woodland as the case in LT96 and LT98. *Papilio paris* (Plate 4.4) was the most common Papilionidae found in LT especially in the phase 98. The abundance of *A. puspa* and *P. paris* help the reproduction of flowering plants as they frequently feed on nectors throughout the sites. Since the flying ability of *P. paris* is so strong that it can help in pollination of plants in a wide area. This helps to increase the genetic diversity of the flowering plants as they will also feed in nearby landscape. In the case of LT01, restoration and vegetation development was still in early stage so it may not support and attract many nectar feeders. *Eurema hecabe* (Pieridae) (Plate 4.5) was the second common species in LT01. It is the most common species in Hong Kong and can be found in most open areas (Bascombe *et al.*, 1999). It feeds on nectars of a variety of flowers.

Plate 4.4 *Eurema hecabe* recorded on Lam Tei Quarry.

Table 4.9 Top ten ranking of butterfly species in each phase of Lam Tei Quarry according to their index of abundance.

Phase	Species	Family	Index of abundance
96	*Mycalesis mineus*	Satyridae	126
	Everes lacturnus	Lycaenidae	86
	Acytolepis puspa	Lycaenidae	83
	Ypthima baldus	Satyridae	63
	Papilio paris	Papilionidae	62
	Eurema hecabe	Pieridae	61
	Zizina otis	Lycaenidae	60
	Papilio helenus	Papilionidae	36
	Hypolimnas bolina	Nymphalidae	36
	Parantica aglea	Danaidae	36
98	*Mycalesis mineus*	Satyridae	132
	Acytolepis puspa	Lycaenidae	71
	Papilio paris	Papilionidae	68
	Everes lacturnus	Lycaenidae	58
	Abisara echerius	Riodinidae	57
	Zizina otis	Lycaenidae	56
	Ypthima baldus	Satyridae	45
	Eurema hecabe	Pieridae	42
	Papilio helenus	Papilionidae	39
	Danaus genutia	Danaidae	34
01	*Mycalesis mineus*	Satyridae	41
	Eurema hecabe	Pieridae	40
	Zizina otis	Lycaenidae	35
	Everes lacturnus	Lycaenidae	30
	Ypthima baldus	Satyridae	27
	Danaus genutia	Danaidae	19
	Papilio paris	Papilionidae	16
	Suastus gremius	Hesperiidae	8
	Parnara guttata	Hesperiidae	6
	Papilio helenus	Papilionidae	5

In SO, there were 21 butterfly species recorded at Phase 98 but only 14 at SO01 (Table 4.7). The abundance of individual in SO98 was much greater than that in SO01. This clearly shows that older phase could attract more butterfly than newly restored one. By comparing the coverage of trees and shrubs (Chapter 3) with the abundance of butterfly, the correlation between plant and butterfly community becomes clearer. Higher trees and shrubs coverage could support more individual with enough food and shelter.

Table 4.10 shows the ranking of butterfly species in Shek O Quarry. *Chilades lajus* (Lycaenidae) was the most dominant species in SO98. Its appearance was usually not far from its larval host plant, *Atalantia buxifolia.* Although *A. buxifolia* was not found on site, it is common low shrub that grows in secondary woodland and near beach; it is very likely that the host plant was present near the quarry. It occurs widely in Hong Kong; it flies close to the ground and frequently visits flowering plants. *Zizina otis* (Lycaenidae) and *Mycalesis mineus* (Satyridae) (Plate 4.7) were also very common in Shek O Quarry. *Z. otis* is a ubiquitous grassland species and is found in low-level open habitats like Shek O Quarry.

Plate 4.5 *Mycalesis mineus* recorded on Shek O Quarry.

Table 4.10 Top ten ranking of butterfly species in each phase of Shek O Quarry according to their index of abundance.

Phase	Species	Family	Index of abundance
98	*Chilades lajus*	Lycaenidae	172
	Zizina otis	Lycaenidae	135
	Mycalesis mineus	Satyridae	109
	Eurema hecabe	Pieridae	82
	Papilio paris	Papilionidae	71
	Delias pasithoe	Pieridae	46
	Ypthima baldus	Satyridae	40
	Papilio polytes	Papilionidae	40
	Lethe confusa	Satyridae	38
	Melanitis phedima	Satyridae	30
01	*Eurema hecabe*	Pieridae	58
	Zizina otis	Lycaenidae	33
	Mycalesis mineus	Satyridae	32
	Chilades lajus	Lycaenidae	29
	Ypthima baldus	Satyridae	25
	Papilio paris	Papilionidae	16
	Delias pasithoe	Pieridae	10
	Cupha erymanthis	Nymphalidae	8
	Parnara guttata	Hesperiidae	7
	Papilio polytes	Papilionidae	5

The number of species recorded in Anderson Road Quarry was the lowest among the quarries; only 11 species was discovered and the index of abundance was 319. Pieridae was the most dominant family on the site (Table 4.11). *Pieris canidia* comprised more than half of the abundance. It was found in large number and readily feed on nectar of many low-growing herbs and shrubs such as *Ageratum conyzoides*, *Bidens pilosa*, *Lantana camera* and *Melastoma candidum*. The caterpillars of *M. candidum* are common pest because they feed on many vegetables. *Eurema hecabe* and *Catopsilia pomona* were the second and third most common species in Anderson Road Quarry. *C. pomona* occurs in most rural areas and other man-made environment.

Pieridae species were common on all sites, and they mainly feed on nectars of low-growing herbs. Compositae was dominant on the four sites, and it is believed that the widespread of butterflies would assist the pollination of such plants.

Table 4.11 Top ten ranking of butterfly species of Anderson Road Quarry according to their index of abundance.

Phase	Species	Family	Index of abundance
01	*Pieris canidia*	Pieridae	189
	Eurema hecabe	Pieridae	37
	Catopsilia pomona	Pieridae	32
	Everes lacturnus	Lycaenidae	19
	Ypthima baldus	Satyridae	14
	Papilio paris	Papilionidae	13
	Tirumala limniace	Danaidae	4
	Papilio memnon	Papilionidae	3
	Melanitis phedima	Satyridae	3
	Borbo cinnara	Hesperiidae	3

4.3.4 Ecological indices on various sites

Table 4.12 shows some common ecological indices of the butterfly communities among the various phases of the four quarries. The Shannon-Wiener diversity index increased with increased age of restoration. This trend could be observed on all sites except Anderson Road Quarry where only one phase had been investigated. The diversity index was highest (H'=3.29 for TH91; 3.28 for TH94) in Turret Hill Quarry.

On the contrary, Anderson Road Quarry had the lowest index (H'=1.45). Within the same quarry, the diversity index was higher at the older phase. Earlier restored phase or site could support more diverse fauna, and therefore higher diversity index, which result in greater stability of the ecosystem. The diversity of butterfly was related to the abundance and diversity of plants. The richness index, R, also indicates that R increased as the year of restoration increased. The pattern of the richness index is similar to that of the diversity index. The evenness indices on all sites were high except Anderson Road Quarry (AR01). This indicates that the butterfly community in Anderson Road Quarry was dominated by a few species (e.g. *P. canidia*). The grassland habitat in AR01 with low shrubs and trees coverage did not attract larger butterflies such as Papilionidae and Danaidae, which avoided the predation by birds and other animals, but facilitated the widespread of Pieridae.

Table 4.12 Ecological indices of the butterflies on the various phases of the four quarries.

	Diversity index (H')	Evenness index (E)
TH91	3.29	0.91
TH94	3.28	0.91
LT96	2.95	0.92
LT98	2.94	0.94
LT01	2.32	0.88
SO98	2.70	0.89
SO01	2.24	0.85
AR01	1.45	0.60

The similarity indices, Sc, of different phases within the same quarry were high (Table 4.13). For Turret Hill Quarry, the similarity index between Phases 91 and 94 was as high as 90.2%. This indicates that the ecological situation and development of the two phases were convergent, not only in butterfly community but also in vegetation structures (see Chapter 3). For Lam Tei Quarry, the similarity indices among the three phases were more than 70% (Sc = 72.1% between LT98 and LT01; Sc = 75.9% between LT96 and LT98; Sc = 88.8% between LT96 and LT98). The similarity index between two phases of Shek O Quarry was 77.5%. The similarity indices among the different quarries with same restored year were also high especially between LT01 and SO01. The butterfly species composition was also related to the altitude of the site. As the Anderson Road Quarry is at higher altitude (about 380 m) than the other quarries, its species composition was different from LT01 and SO01 even they were restored in same year.

Table 4.13 Similarity index of the butterflies between different phases comparison.

	Similarity index (Sc) (%)
TH91-TH94	90.2
LT96-LT98	88.8
LT98-LT01	72.1
LT96-LT01	75.9
SO98-SO01	77.5
LT98-SO98	79.1
LT01-SO01	90.3
SO01-AR01	65.0
LT01-AR01	72.0

4.4 Conclusions

There existed strong correlation between fauna diversity and the age of quarry development. With the increasing age of restored quarry, the diversity of butterfly increased. The Shannon-Wiener diversity index in the older quarries were generally higher than the younger phases. Woodland vegetation attracted more butterfly species than grassland. Vegetation, geological factors and altitude of the site would influence the diversity and abundance of butterfly. Human disturbance such as frequent blasting would also interrupt the occurrence of lepidopterans (especially butterflies).

In recent study of restoration of degraded land, the butterfly community was not so strongly related or even unrelated with the vegetation community (Holl, 1995; Holl 1996). In restored quarries of Hong Kong, although it was not very strong, there was a correlation between these two factors (see Chapter 6). Vegetation diversity can be reflected by butterfly diversity.

Chapter 5: Moth Communities on Restored Quarries

5.1 Introduction

Although butterflies are attractive and well known, they are only a small group in lepidopterans. In fact, about 90% lepidopterans ever recorded in Hong Kong are moths (Kendrick, 2002). There are 32 families in Heterocera. Since both moth and butterfly belong to the same order, they are similar in several characteristics. Even though they are so similar to each other, butterflies are unlikely to be useful indicators of moth diversity at a local scale. Moths are able to adapt urbanized environment more than butterfly (Leverton, 2001). Moths can survive at a lower density and in more fragmented habit because moths use pheromones to find their mates, but this is not commonly applied to butterflies (Ford, 1945). Moths employ scent to locate the food plants for egg-laying. Moreover, moths are relatively smaller in size, so less energy is required for them, so that within the same area can support more moths than butterflies. Moth diversity also very much depends on diversity and richness of understorey plants (Chey *et al.*, 1997). Unfortunately, diversity patterns in moths are poorly understood in many areas including Hong Kong.

Moths and butterflies belong to the same order (Lepidoptera). They have similar characteristics and share a similar life cycle. Though there exists ecological similarities between them, the relationship between moth and butterfly communities is not imaginably high and the diversity of moth cannot be predicted by butterfly community (Ricketts *et al.*, 2000).

5.2 Materials and Methods

5.2.1 Light trapping method

Light traps were used to sample moths on various sites (Muirhead-Thomson, 1991). Light traps mainly consisted of five components: a light source, baffles around the light source, a funnel, a holding container and a portable 12V power supply (Plate 5.1). Blacklight lamps were used as the light source, the major peaks of which are in the ultraviolet region at around 365 nm, with additional peaks in the visible range at around 410 to 450 nm. The lamps were fitted with three baffles arranged at 120° to each other. The light traps were operated once a week from 9 pm to 5 am in the next morning. Moths attracted by the light and struck the lamps or the baffles around the lamps, fell into the funnel and the holding container. One trap was put at each phase of the quarries. Moths were collected from the containers every week from May 2002 to April 2003. They were placed in labeled plastic bags, then transferred to the laboratory, oven dried and stored for identification.

Plate 5.1 A light trap consisted of five components: a blacklight lamp, three baffles around the lamp, a funnel, a holding container and a portable power supply.

5.3 Results and Discussion

5.3.1 General description of moth community

The community structure of moths varied among the quarries. Totally 68 moth species were captured and 2768 individuals were recorded at different phases of the quarries from May 2002 to April 2003 (Table 5.1). The species number in the four quarries only occupied a very small proportion when compared with the total number of species recorded in Hong Kong. Fifty eight moth species were recorded in Turret Hill Quarry; most of them were found at Phase 94 (54 species), and many species appeared at TH91 and TH94. Table 5.2 represented the species composition of moth and their ecological status in Hong Kong. The moth status is according to the information provided by Kendrick (2002), which is based on the relative abundance recorded in Hong Kong. Forty species were found at the three phases of Lam Tei Quarry; 34, 36 and 14 species were recorded at LT96, LT98 and LT01 respectively. In Shek O Quarry, there were 36 and 12 species recorded at phases 98 and 01 respectively, and the total number of species found on Shek O Quarry was 37. Ten species were recorded on the Anderson Road Quarry and was the lowest among quarries.

Table 5.1 Number of moth species and their total index of abundance recorded at the different phases of the four quarries.

	No. of species	Total index of abundance
TH91	45	599
TH94	54	815
LT96	34	384
LT98	36	395
LT01	13	86
SO98	36	381
SO01	12	81
AR01	10	27

Most recorded species were common in Hong Kong, but there were still some newly recorded species: 7 new species were found for the first time in Hong Kong. For the known species, there were 3 species recognized as scarce species and 2 species were rarely found in Hong Kong (Kendrick, 2001). Together with 6 uncommon species, 11 species had high conservation value in Hong Kong. *Nola* sp. nr. *tornotis* (Nolidae) (Plate 5.2), *Nausinoe geometralis* (Crambidae) and *Macaria abydata* (Geometridae) (Plate 5.3) are scarcely found in Hong Kong, while *Scirpophaga novella* (Crambidae) and *Problepsis eucircota* (Geometridae) (Plate 5.4) are rare species. On the other hand, 5 species were captured on all sites, including *Cnaphalocrocis medinalis* (Crambidae), *Metoeca foedalis* (Crambidae), *Nothomiza flavicosta* (Geometridae), *Orthonama obstipata* (Geometridae) and *Euthrix isocyma* (Lasiocampidae).

Plate 5.2 *Nola* sp. nr. *tornotis* found on Turret Hill Quarry.

Plate 5.3 *Macaria abydata* found on Turret Hill Quarry.

Plate 5.4 *Problepsis eucircota* found on Turret Hill Quarry.

5.3.2 Ecological indices of moth on various sites

Moth composition and diversity varied among the sites (Tables 5.2 and 5.3). The Shannon-Wiener diversity index, H', of moths on the older phases (H' = 3.21 and

Table 5.2 Species composition and status of moth species at different phases of the four quarries. "+" denotes the presence of a species at a specific phase

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01	Status*
Amsactoides solitarius	Arctiidae	Arctiinae	+	+				+			UC
Creatonotus gangis	Arctiidae	Arctiinae			+	+				+	C(W)
Creatonotus transiens	Arctiidae	Arctiinae	+	+	+	+		+			C
Nyctemera mulleri	Arctiidae	Arctiinae	+	+	+	+		+			C(W)
Syntomoides imaon	Arctiidae	Arctiinae	+	+		+		+		+	C
Asura alikangiae	Arctiidae	Lithosiinae	+	+	+	+	+	+			C(W)
Eilema antica	Arctiidae	Lithosiinae			+	+	+				C(W)
Eilema fuscodorsalis	Arctiidae	Lithosiinae	+	+	+	+		+			C(W)
Neasura hypophaeola	Arctiidae	Lithosiinae	+	+	+	+		+	+	+	UC
Schistophleps bipuncta	Arctiidae	Lithosiinae	+	+	+	+					C(W)
Antigastra sp. A	Crambidae	Pyraustinae			+	+	+				-
Cangetta hartoghialis	Crambidae	Pyraustinae	+	+				+	+		UC
Cnaphalocrocis medinalis	Crambidae	Pyraustinae			+	+	+	+	+	+	C
Herpetogramma sp. C	Crambidae	Pyraustinae						+			-
Herpetogramma sp. D	Crambidae	Pyraustinae		+		+					-
Herpetogramma submarginalis	Crambidae	Pyraustinae	+	+	+	+	+	+			C(W)
Isocentris filalis	Crambidae	Pyraustinae						+			C(W)
Metoeca foedalis	Crambidae	Pyraustinae	+	+	+	+	+	+	+	+	C(W)
Nausinoe geometralis	Crambidae	Pyraustinae		+							S
Spoladea recurvalis	Crambidae	Pyraustinae	+	+			+		+	+	C
Scirpophaga nivella	Crambidae	Scheonobiinae	+	+	+	+					R
Chiasmia emersaria	Geometridae	Ennominae	+	+				+			C(W)
Chiasmia ozariaria	Geometridae	Ennominae	+	+		+					C(W)
Cleora alienaria	Geometridae	Ennominae	+	+	+	+		+			C
Hyposidra talaca	Geometridae	Ennominae		+							VC
Kranandra oliveomarginata	Geometridae	Ennominae	+		+	+					C
Macaria abydata	Geometridae	Ennominae	+	+							S
Nothomiza flavicosta	Geometridae	Ennominae	+	+	+	+		+			C
Ourapteryx clara	Geometridae	Ennominae		+							C

Table 5.2 (cont'd)

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01	Status*
Plutodes costatus	Geometridae	Ennominae	+	+	+	+		+			VC
Comostola pyrrhogona	Geometridae	Geometrinae	+	+							C
Pingasa chloroides	Geometridae	Geometrinae			+	+		+			UC
Orthonama obstipata	Geometridae	Larentiinae	+	+	+	+		+			C
Sigilliclystis kendricki	Geometridae	Larentiinae	+	+	+	+		+			C(W)
Anisodes minorata	Geometridae	Sterrhinae	+	+					+		C
Idaea costigutatta	Geometridae	Sterrhinae	+	+							C
Idaea impexa	Geometridae	Sterrhinae		+	+	+	+	+	+		UC
Perixera illepidaria	Geometridae	Sterrhinae	+	+					+		C
Problepsis eucircota	Geometridae	Sterrhinae	+	+							R
Somatina obscuriciliata	Geometridae	Sterrhinae		+	+	+	+	+	+		C
Euthrix isocyma	Lasiocampidae		+	+	+	+	+	+	+	+	VC
Arctornis sp.	Lymantriidae		+	+							-
Dasychira chekiangensis	Lymantriidae		+	+	+	+	+	+			C(W)
Euproctis quadrangularis	Lymantriidae		+	+	+			+	+	+	C
Euproctis sp. H	Lymantriidae		+								-
Euproctis sp. I	Lymantriidae					+		+			-
Euproctis subnotata	Lymantriidae			+							C
Perina nuda	Lymantriidae			+							C
Cerynea ustula	Noctuidae	Acontiinae	+	+							C
Lophonycta confusa	Noctuidae	Acronictinae		+	+	+		+			F
Condica conducta	Noctuidae	Amphipyrinae	+	+	+	+		+		+	C
Spodoptera litura	Noctuidae	Amphipyrinae		+	+	+					C
Erygia apicalis	Noctuidae	Catocalinae	+								C
Gesonia obeiditalis	Noctuidae	Catocalinae	+	+				+			C
Lacera procellosa	Noctuidae	Catocalinae		+							F
Mocis frugalis	Noctuidae	Catocalinae	+	+	+			+			C
Mocis undata	Noctuidae	Catocalinae	+	+							C
Plecoptera luteiceps	Noctuidae	Catocalinae	+	+							C

Table 5.2 (cont'd)

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01	Status*
Mythimna separata	Noctuidae	Hadeninae		+		+	+	+			C
Hypena ophiusoides	Noctuidae	Hypeninae			+	+					F
Giaura robusta	Nolidae	Chloephorinae	+	+	+	+					C(W)
Earias flavida	Nolidae	Earidinae	+	+				+	+		C
Nola brunella	Nolidae	Nolinae	+	+	+	+	+	+	+		C(W)
Nola maginata	Nolidae	Nolinae						+			UC
Nola sp. F	Nolidae			+							-
Nola sp. G	Nolidae		+		+						-
Nola sp. nr. *tornotis*	Nolidae		+	+				+			S
Herculia nigrivitta	Pyralidae		+	+	+	+		+		+	F
	Total number of species		45	54	34	36	13	36	12	10	

* The status of moth is described according to the information by Kendrick (2002), where "UC" stand for "uncommon"; "C" stand for "common"; "C(W)" stand for "common in woodland"; "UC" stand for "uncommon"; "F" stand for "frequent"; "S" stand for "scarce "; and "R" stand for "rare".

3.40 in TH91 and TH94 respectively) were much higher than the younger phases (H' = 2.19, 1.27 and 1.35 in LT01, SO01 and AR01 respectively). The diversity index indicates a high relation between flora and moth (Chapter 3). Besides plant diversity, there were other factors affecting moth diversity such as climate, size of habitat, number of predators and human disturbance. Phase 01 in Shek O Quarry and Lam Tei Quarry were exposed grassland habitat. Low in shrub and tree coverage, and plant diversity at early development phases cannot provide larval host plants, adult nectar sources and shelter. As a result, moths and butterflies will retreat into nearby woodland on windy days, and this inhibited their diversity and population size. In Turret Hill Quarry, Phase 94 had a higher diversity index than Phase 91. The vegetation area in TH94 was much bigger than that in TH91, so that there were more resources to support moth population.

Table 5.3 Ecological indices of moth on the various phases of the four quarries.

Indices	Diversity index (H')	Evenness index (E)
TH91	3.21	0.50
TH94	3.40	0.50
LT96	3.07	0.52
LT98	3.12	0.52
LT01	2.19	0.49
SO98	3.11	0.52
SO01	1.27	0.29
AR01	1.35	0.41

The evenness index (E) was around 0.5 at various sites (E = 0.50 in TH91 and TH94; E = 0.52 in LT96, LT98 and SO98; E = 0.49 and 0.52 in LT01 and SO98 respectively) (Table 5.3). In SO01, the evenness index was the lowest among all sites (E = 0.29). On the other hand, the similarity index, Sc, of moth community at different phases within the same quarry was quite high in Turret Hill Quarry and Lam Tei Quarry (Table 5.4). The similarity index between Phases 96 and 98 of Lam Tei Quarry was the highest (Sc = 84.3% between LT96 and LT98). In contrast, the moth community in LT01 was different from the other two phases, and the similarity index were only about 50% (Sc = 50.6% between LT98 and LT01; Sc = 48.9% between LT96 and LT01). This indicates that an exposed grassland habitat could support fewer moths. The similarity index between the two phases of Shek O Quarry was also relatively low (Sc = 62.2% between SO98 and SO01). This shows that the spatial distribution of the moth community in Shek O Quarry was uneven, and it was dominated by only few species. The similarity indices among the different quarries with same restored year were ranged from 30.0% (Sc between LT01 and AR01) to 75.0% (Sc between LT98 and SO98). This indicates that the moth species in Anderson Road Quarry were different from other quarries, and this is probably due to the high altitude and different flora composition of the quarry.

In general, moths are highly mobilized which can easily more from one area to another, and for some moth species, even larger scale migration will occur. The dispersion is affected by weather conditions; the need to find a mate, food and water can initiate the dispersal of moths (Taylor, 1963). As a result, the population size of moth community depends on the availability of resources on the site. Within the same quarry, the similarity indices of moth species (and also butterfly species) are very high. Some species with strong flying ability are able to search for food throughout the site, but many other species are restricted to certain area.

Table 5.4 Similarity index of moth between different phases comparison.

	Similarity index (Sc)%
TH91-TH94	82.4
LT96-LT98	84.3
LT98-LT01	50.6
LT96-LT01	48.9
SO98-SO01	62.2
LT98-SO98	75.0
LT01-SO01	71.2
SO01-AR01	56.0
LT01-AR01	30.0

5.3.3 Moth species found on various phases of the sites

The index of abundance and relative abundance for moth species among different quarries are shown in Tables 5.5 and 5.6, while the ranking of the species at

Table 5.5 Index of abundance for moth species among phases of the four quarries. Figures represent total number of individuals recorded on each area over the entire study period.

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Amsactoides solitarius	Arctiidae	Arctiinae	22	30				10		
Creatonotus gangis	Arctiidae	Arctiinae			12	8				11
Creatonotus transiens	Arctiidae	Arctiinae	19	22	5	9		7		
Nyctemera mulleri	Arctiidae	Arctiinae	11	14	7	7		2		
Syntomoides imaon	Arctiidae	Arctiinae	2	4		2		2		2
Asura alikangiae	Arctiidae	Lithosiinae	27	40	17	13	5	14		
Eilema antica	Arctiidae	Lithosiinae			19	24	5			
Eilema fuscodorsalis	Arctiidae	Lithosiinae	14	9	4	7		11		
Neasura hypophaeola	Arctiidae	Lithosiinae	21	27	18	16		21	2	1
Schistophleps bipuncta	Arctiidae	Lithosiinae	5	7	1	4				
Antigastra sp. A	Crambidae	Pyraustinae			8	15	1			
Cangetta hartoghialis	Crambidae	Pyraustinae	21	14				5	7	
Cnaphalocrocis medinalis	Crambidae	Pyraustinae			62	70	27	14	17	2
Herpetogramma sp. C	Crambidae	Pyraustinae						4		
Herpetogramma sp. D	Crambidae	Pyraustinae		7		2				
Herpetogramma submarginalis	Crambidae	Pyraustinae	14	17	44	39	7	51		
Isocentris filalis	Crambidae	Pyraustinae						17		
Metoeca foedalis	Crambidae	Pyraustinae	29	31	16	17	3	12	5	1
Nausinoe geometralis	Crambidae	Pyraustinae		8						
Spoladea recurvalis	Crambidae	Pyraustinae	11	6			6		4	2
Scirpophaga nivella	Crambidae	Scheonobiinae	5	7	2	4				
Chiasmia emersaria	Geometridae	Ennominae	18	8				2		
Chiasmia ozariaria	Geometridae	Ennominae	2	2		1				
Cleora alienaria	Geometridae	Ennominae	12	26	17	10		50		
Hyposidra talaca	Geometridae	Ennominae		7						
Kranandra oliveomarginata	Geometridae	Ennominae	1		2	1				
Macaria abydata	Geometridae	Ennominae	10	15						
Nothomiza flavicosta	Geometridae	Ennominae	7	6	21	28		17		
Ourapteryx clara	Geometridae	Ennominae		9						

Table 5.5 (cont'd)

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Plutodes costatus	Geometridae	Ennominae	11	15	3	8		10		
Comostola pyrrhogona	Geometridae	Geometrinae	4	10						
Pingasa chloroides	Geometridae	Geometrinae			5	7		4		
Orthonama obstipata	Geometridae	Larentiinae	14	17	7	12		19		
Sigilliclystis kendricki	Geometridae	Larentiinae	15	9	11	7		5		
Anisodes minorata	Geometridae	Sterrhinae	5	13					18	
Idaea costigutatta	Geometridae	Sterrhinae	13	20						
Idaea impexa	Geometridae	Sterrhinae		11	10	7	9	7	3	
Perixera illepidaria	Geometridae	Sterrhinae	12	8					6	
Problepsis eucircota	Geometridae	Sterrhinae	5	8						
Somatina obscuriciliata	Geometridae	Sterrhinae		24	20	9	2	16	5	
Euthrix isocyma	Lasiocampidae		16	13	26	21	15	7	8	4
Arctornis sp.	Lymantriidae		2	7						
Dasychira chekiangensis	Lymantriidae		45	59	5	8	3	7		
Euproctis quadrangularis	Lymantriidae		5	3	2			1	2	2
Euproctis sp. H	Lymantriidae		2							
Euproctis sp. I	Lymantriidae					2		3		
Euproctis subnotata	Lymantriidae			7						
Perina nuda	Lymantriidae			5						
Cerynea ustula	Noctuidae	Acontiinae	10	12						
Lophonycta confusa	Noctuidae	Acronictinae		4	1	1		3		
Condica conducta	Noctuidae	Amphipyrinae	16	14	7	5		8		1
Spodoptera litura	Noctuidae	Amphipyrinae		2	2	5				
Erygia apicalis	Noctuidae	Catocalinae	5							
Gesonia obeiditalis	Noctuidae	Catocalinae	12	17				2		
Lacera procellosa	Noctuidae	Catocalinae		4						
Mocis frugalis	Noctuidae	Catocalinae	34	58	3			7		
Mocis undata	Noctuidae	Catocalinae	4	10						
Plecoptera luteiceps	Noctuidae	Catocalinae	7	9						

Table 5.5 (cont'd)

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Mythimna separata	Noctuidae	Hadeninae		6		5	1	1		
Hypena ophiusoides	Noctuidae	Hypeninae			6	4				
Giaura robusta	Nolidae	Chloephorinae	68	82	4	1				
Earias flavida	Nolidae	Earidinae	1	6				12	4	
Nola brunella	Nolidae	Nolinae	18	24	6	11	2	15		
Nola maginata	Nolidae	Nolinae						7		
Nola sp. F	Nolidae			7						
Nola sp. G	Nolidae		2		3					
Nola sp. nr. *tornotis*	Nolidae		5	3				5		
Herculia nigrivitta	Pyralidae		17	12	8	5		3		1
	Total number of individuals		599	815	384	395	86	381	81	27

Table 5.6 Relative abundance of moth species among the phases of the four quarries.

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Amsactoides solitarius	Arctiidae	Arctiinae	3.67	3.68				2.62		
Creatonotus gangis	Arctiidae	Arctiinae			3.13	2.03				40.7
Creatonotus transiens	Arctiidae	Arctiinae	3.17	2.70	1.30	2.28		1.84		
Nyctemera mulleri	Arctiidae	Arctiinae	1.84	1.72	1.82	1.77		0.52		
Syntomoides imaon	Arctiidae	Arctiinae	0.33	0.49		0.51		0.52		7.41
Asura alikangiae	Arctiidae	Lithosiinae	4.51	4.91	4.43	3.29	5.81	3.67		
Eilema antica	Arctiidae	Lithosiinae			4.95	6.08	5.81			
Eilema fuscodorsalis	Arctiidae	Lithosiinae	2.34	1.10	1.04	1.77		2.89		
Neasura hypophaeola	Arctiidae	Lithosiinae	3.51	3.31	4.69	4.05		5.51	2.47	3.70
Schistophleps bipuncta	Arctiidae	Lithosiinae	0.83	0.86	0.26	1.01				
Antigastra sp. A	Crambidae	Pyraustinae			2.08	3.80	1.16			
Cangetta hartoghialis	Crambidae	Pyraustinae	3.51	1.72				1.31	8.64	
Cnaphalocrocis medinalis	Crambidae	Pyraustinae			16.2	17.7	31.4	13.1	22.2	7.41
Herpetogramma sp. C	Crambidae	Pyraustinae						1.05		
Herpetogramma sp. D	Crambidae	Pyraustinae		0.86		0.51				
Herpetogramma submarginalis	Crambidae	Pyraustinae	2.34	2.09	11.5	9.87	8.14	13.4		
Isocentris filalis	Crambidae	Pyraustinae						4.46		
Metoeca foedalis	Crambidae	Pyraustinae	4.84	3.80	4.17	4.30	3.49	3.15	6.17	3.70
Nausinoe geometralis	Crambidae	Pyraustinae		0.98						
Spoladea recurvalis	Crambidae	Pyraustinae	1.84	0.74			6.98		4.94	7.41
Scirpophaga nivella	Crambidae	Scheonobiinae	0.83	0.86	0.52	1.01				
Chiasmia emersaria	Geometridae	Ennominae	3.01	0.98				0.52		
Chiasmia ozariaria	Geometridae	Ennominae	0.33	0.25		0.25				
Cleora alienaria	Geometridae	Ennominae	2.00	3.19	4.43	2.53		3.67	21.0	
Hyposidra talaca	Geometridae	Ennominae		0.86						
Kranandra oliveomarginata	Geometridae	Ennominae	0.17		0.52	0.25				
Macaria abydata	Geometridae	Ennominae	1.67	1.84						
Nothomiza flavicosta	Geometridae	Ennominae	1.17	0.74	5.47	7.09		4.46	3.70	
Ourapteryx clara	Geometridae	Ennominae		1.10						
Plutodes costatus	Geometridae	Ennominae	1.84	1.84	0.78	2.03		2.62	7.41	

Table 5.6 (cont'd)

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Comostola pyrrhogona	Geometridae	Geometrinae	0.67	1.23						
Pingasa chloroides	Geometridae	Geometrinae			1.30	1.77		1.05		
Orthonama obstipata	Geometridae	Larentiinae	2.34	2.09	1.82	3.04		4.99	2.47	
Sigilliclystis kendricki	Geometridae	Larentiinae	2.50	1.10	2.86	1.77		1.31		
Anisodes minorata	Geometridae	Sterrhinae	0.83	1.60						
Idaea costigutatta	Geometridae	Sterrhinae	2.17	2.45						
Idaea impexa	Geometridae	Sterrhinae		1.35	2.60	1.77	10.5	1.84		
Perixera illepidaria	Geometridae	Sterrhinae	2.00	0.98						
Problepsis eucircota	Geometridae	Sterrhinae	0.83	0.98						
Somatina obscuriciliata	Geometridae	Sterrhinae		2.94	5.21	2.28	2.33	4.20	6.17	
Euthrix isocyma	Lasiocampidae		2.67	1.60	6.77	5.32	17.4	1.84	9.88	14.8
Arctornis sp.	Lymantriidae		0.33	0.86						
Dasychira chekiangensis	Lymantriidae		7.51	7.24	1.30	2.03	3.49	1.84		
Euproctis quadrangularis	Lymantriidae		0.83	0.37	0.52			0.26		7.41
Euproctis sp. H	Lymantriidae		0.33							
Euproctis sp. I	Lymantriidae					0.51		0.79		
Euproctis subnotata	Lymantriidae			0.86						
Perina nuda	Lymantriidae			0.61						
Cerynea ustula	Noctuidae	Acontiinae	1.67	1.47						
Lophonycta confusa	Noctuidae	Acronictinae		0.49	0.26	0.25		0.79		
Condica conducta	Noctuidae	Amphipyrinae	2.67	1.72	1.82	1.27		2.10		3.70
Spodoptera litura	Noctuidae	Amphipyrinae		0.25	0.52	1.27				
Erygia apicalis	Noctuidae	Catocalinae	0.83							
Gesonia obeiditalis	Noctuidae	Catocalinae	2.00	2.09				0.52		
Lacera procellosa	Noctuidae	Catocalinae		0.49						
Mocis frugalis	Noctuidae	Catocalinae	5.68	7.12	0.78			1.84		
Mocis undata	Noctuidae	Catocalinae	0.67	1.23						
Plecoptera luteiceps	Noctuidae	Catocalinae	1.17	1.10						

Table 5.6 (cont'd)

Species	Family	Sub-family	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Mythimna separata	Noctuidae	Hadeninae		0.74		1.27	1.16	0.26		
Hypena ophiusoides	Noctuidae	Hypeninae			1.56	1.01				
Giaura robusta	Nolidae	Chloephorinae	11.4	10.1	1.04	0.25				
Earias flavida	Nolidae	Earidinae	0.17	0.74				3.15	4.94	
Nola brunella	Nolidae	Nolinae	3.01	2.94	1.56	2.78	2.33	3.94		
Nola maginata	Nolidae	Nolinae						1.84		
Nola sp. F	Nolidae			0.86						
Nola sp. G	Nolidae		0.33							
Nola sp. nr. *tornotis*	Nolidae		0.83	0.37				1.31		
Herculia nigrivitta	Pyralidae		2.84	1.47	2.08	1.27		0.79		3.70

different phases among the four quarries is presented in Tables 5.7 to 5.10. *Giaura robusta* (Nolidae) (Plate 5.5) was the most dominant species in Turret Hill Quarry. It can be found in secondary woodlands and feng shui woods and could be dispersed at least 500 m from its host plant, as was occasionally recorded outside woodland. The second largest species was *Dasychira chekiangensis* (Lymantriidae) and the third one was *Mocis frugalis* (Noctuidae). The caterpillars of *M. frugalis* were common agricultural pest on various species of Poaceae as they are host plants for *M. frugalis* and can be found on the quarry sites.

Table 5.7 Top five ranked butterfly species in different phases of Turret Hill Quarry according to their relative abundance.

Phase	Species	Family	Relative abundance (%)
91	*Giaura robusta*	Nolidae	11.4
	Dasychira chekiangensis	Lymantriidae	7.51
	Mocis frugalis	Noctuidae	5.68
	Metoeca foedalis	Crambidae	4.84
	Asura alikangiae	Arctiidae	4.51
94	*Giaura robusta*	Nolidae	10.1
	Dasychira chekiangensis	Lymantriidae	7.24
	Mocis frugalis	Noctuidae	7.12
	Asura alikangiae	Arctiidae	4.91
	Metoeca foedalis	Crambidae	3.80

Plate 5.5 *Giaura robusta* found on Turret Hill Quarry.

Rice leaffolder, *Cnaphalocrocis medinalis* (Crambidae) (Plate 5.6), was dominant in three phases of Lam Tei Quarry. The larvae of *C. medinalis* are feed on leaves of rice (such as *Leptochloa chinensis* and *Oryza sativa*) and possibly other Poaceae, so that they are considered as an insect pest of rice. Since rice was not recorded in local habitats (Chapter 3), *C. medinalis* may come from the neighboring landscape. They are able to migrate effectively which leads to the widespread distribution of the species (Ian, 1990). The relative abundance of *C. medinalis* was very high in LT01 (relative abundance = 31.4%), and resulted in a high evenness index for LT01. *Herpetogramma submarginalis* (Crambidae) and *Nothomiza flavicosta* (Geometridae) were also common in Lam Tei Quarry.

Plate 5.6 *Cnaphalocrocis medinalis* found on Lam Tei Quarry.

Table 5.8 Top five ranked butterfly species in different phases of Lam Tei Quarry according to their relative abundance.

	Species	Family	Relative abundance (%)
96	*Cnaphalocrocis medinalis*	Crambidae	16.2
	Herpetogramma submarginalis	Crambidae	11.5
	Euthrix isocyma	Lasiocampidae	6.77
	Nothomiza flavicosta	Geometridae	5.47
	Somatina obscuriciliata	Geometridae	5.21
98	*Cnaphalocrocis medinalis*	Crambidae	17.7
	Herpetogramma submarginalis	Crambidae	9.87
	Nothomiza flavicosta	Geometridae	7.09
	Eilema antica	Arctiidae	6.08
	Euthrix isocyma	Lasiocampidae	5.32
01	*Cnaphalocrocis medinalis*	Crambidae	31.4
	Euthrix isocyma	Lasiocampidae	17.4
	Idaea impexa	Geometridae	10.5
	Herpetogramma submarginalis	Crambidae	8.14
	Spoladea recurvalis	Crambidae	6.89

In Shek O Quarry, *Cleora alienaria* (Geometridae) (Plate 5.7) was common at Phases 98 and 01. This moth species was recorded in abundance from plantations of *Acacia mangium* and *Paraserianthes falcataria* (Leguminosae) in the lowlands of Sabah (Chey *et al.*, 1993). In fact, *A. mangium* was also commonly plant in Shek O Quarry and hence a higher population of *C. alienaria*. Another host-plant for *C. alienaria* is *Cinnamomum* spp. (Lauraceae) (Prout, 1929). *A. mangium* was planted in the quarry to enhance the nutrient content of soil, but there was a risk of pest as *C. alienaria* feed on the flower and leaf part of the plant. *H. submarginalis* and *C.*

medinalis were also common at SO98. The relative abundance of *Anisodes minorata* and *C. medinalis* were 22.2% and 21.0% respectively in SO01, and they comprised a large proportion of the moth population.

Plate 5.7 *Cleora alienaria* recorded on Shek O Quarry.

Table 5.9 Top five ranked butterfly species in different phases of Shek O Quarry according to their relative abundance.

Phase	Species	Family	Relative abundance (%)
98	*Herpetogramma submarginalis*	Crambidae	13.4
	Cleora alienaria	Geometridae	13.1
	Neasura hypophaeola	Arctiidae	5.51
	Orthonama obstipata	Geometridae	4.99
	Nothomiza flavicosta	Geometridae	4.46
01	*Anisodes minorata*	Geometridae	22.2
	Cnaphalocrocis medinalis	Crambidae	21.0
	Euthrix isocyma	Lasiocampidae	9.88
	Cangetta hartoghialis	Crambidae	8.64
	Metoeca foedalis	Crambidae	6.17
	Somantina obscuriciliata	Geometridae	6.17

Moth diversity and population was low at Phase 01 of the quarries. In AR01, the number of capture and the species diversity was low, *Creatonotus gangis* (Arctiidae) dominated with a relative abundance of 23.4%, which was extremely high when compared with other species. It feeds on grasses, sedges and broadleaves such as *Leptochloa chinensis*, *Echinochloa colona*, *Eleusine indica*, *Isachne globosa*, *Paspalum* spp., *Leersia hexandra*, *Brachiaria* spp., *Chloris barbata*, *Imperata cylindrica*, *Cyperus* spp., *Fimbristylis miliacea*, and *Commelina diffusa* (Catindig *et al*., 1993). As *Paspalum* spp. and *Cyperus rotundus* were presented in the quarry, they might be the host plants for *C. gangis*.

Table 5.10 Top five ranked butterfly species of Anderson Road Quarry according to their relative abundance.

Phase	Species	Family	Relative abundance (%)
01	*Creatonotus gangis*	Arctiidae	40.7
	Euthrix isocyma	Lasiocampidae	14.8
	Syntomoides imaon	Arctiidae	7.41
	Cnaphalocrocis medinalis	Crambidae	7.41
	Spoladea recurvalis	Crambidae	7.41

Spatial distribution of moths in Hong Kong has been investigated by some biologists. It was noted that the species diversity of moth on grassland and mangrove was low when compared with forest which was very diverse (Kendrick, 2002).

5.3.4 Ecological importance of lepidopterans

The ecological and environmental importance of lepidopterans is basically related to their insect-plant relationship. Larvae, as a primary consumer, help to break down plant tissue. However in this circumstance, lepidopterans would have pressure on plants if their predators were removed, and would become serious pests. In revegetation area, such as plantation in restored quarries, there are still risks in mass planting if only a few plant species were involved. For example in Shek O Quarry, *C. alienaria* was so dominant that might affect the growth of *A. mangium* because it is one of the major host plants of *C. alienaria*. As a result, pest control should also be considered as an important precaution in restoration. Diverse plant populations through mixed plantation can withstand insects, diseases and many other environmental problems. Moreover, mixed plantation is also more attractive in view.

Another plant-associated role of lepidopterans is pollination. Flowers considered as typically adapted to pollination by lepidopterans are long with large corolla, and strong fragrances. Moths are attracted by white flowers, while butterflies are attracted by colorful flowers. By observation, shrubs such as *Lantana camera*, *Raphiolepis indica* and *Hibiscus rosa-sinensis*, and herbaceous plants of Compositae like *Ageratum conyzoides* and *Bidens pilosa* were frequently visited by butterflies. This explains the fast colonization of such understory vegetation was related to their insect pollinator - Lepidoptera.

In addition, all stages of lepidopterans are preys of many insectivorous predators or parasitoids. The population of Lepidoptera plays a role in regulating the population of their predators (Dempster, 1983). The main predators are birds, bats, parasitoids, carnivorous insects such as dragonflies, and small mammals (Malcolm, 1992; Howell *et al.*, 1998). They mainly feed on older larvae, pupae and adults, while some small arthropods are predators of eggs. As a food source for other animals, lepidopterans have an important ecological role as to support the upper trophic level.

5.4 Conclusions

The lepidopterans species (especially moths) declined sharply in open habitats such as Phases 01 of Lam Tei Quarry, Shek O Quarry and Anderson Road Quarry. Woodland vegetation attracted more moth species than grassland. Diversity of moths varies according to vegetation and altitude. Primary forest have the highest diversity and forest sites in general were more diverse than restoring secondary forest, grassland and agricultural sites in other Indo-Australian tropics (Kitching *et al.*, 1993; Robinson and Tuck, 1993; Intachat *et al.*, 1999). Species favouring open or disturbed habitats were often found to be widespread (Kendrick, 2002), but within

Geometridae, subfamilies including Ennominae, Cassymini, Trichopterygini and Larentiinae were not recorded in exposed grassland such as AR01, SO01 and LT01.

Vegetation provided satisfactory shelter and food source for lepidopterans. On the other hand, lepidopterans are food source for animals in higher trophic levels, such as carnivorous insects, birds, and other mammals. This attracts their predators to migrate to the restored quarries and enhance and facilitate the sustainable development in the rehabilitated ecosystem of restored quarries.

Chapter 6 General Conclusion

6.1 Soil Development and Species Diversity

Organic carbon (OC), nitrogen and phosphorus contents were correlated with woodland age which in turn affect coverage of trees and shrubs and flora diversity (Table 6.1). Organic matter content improves the water- and nutrient-holding capacities and hence soil quality (Spaccini *et al.*, 2002; Lal, 2003; McDowell, 2003), while phosphorus affects plant growth in many ways, especially in root growth and water uptake ability (Plaster, 1997). Better soil quality increased the coverage and diversity of vegetation on the older sites such as Turret Hill Quarry and Phases 96 and 98 of Lam Tei Quarry and also Phase 98 of Shek O Quarry. Nitrate is one major nitrogen source for plants, which can easily diffuse through soil to plant roots (Plaster, 1997), though vegetation coverage and diversity has a less correlation with nitrate concentration. As nitrate is readily absorbed by plants, increase in the coverage and amount of vegetation will lower the nitrate nitrogen content of soil. On the other hand, total nitrogen content was strongly correlated with flora diversity. The results show that the higher the total nitrogen content, the higher was the vegetation diversity. Since flora diversity can indicate the maturity of vegetation development, soil total nitrogen content can act as a good indicator of vegetation development of restored quarries.

Table 6.1 Pairwise correlation coefficients between the vegetation coverage, flora butterfly, moth and dragonfly diversity and various soil properties at different phases of restored quarries.

	Tree and shrub coverage	Vegetation diversity	Butterfly diversity	Moth diversity
OC	0.88**	0.79	0.89**	0.86**
TKN	0.62	0.86**	0.61	0.47
NO_x-N	0.29	0.42	0.15	0.14
NH_4-N	0.17	0.19	-0.01	0.05
Total P	0.70	0.57	0.88**	0.82*
PO_4-P	0.82*	0.85**	0.80*	0.74

*p<0.05; **p<0.01.

Lepidopterans including butterflies and moths showed their strong correlation with the soil OC, total and extractable phosphorus contents. This is because sites with higher OC and phosphorus content were generally higher in shrubland and woodland which can support more diverse lepidopterans.

Butterfly and moth diversity was highly correlated with tree and shrub coverageon restored quarries (Table 6.2). High correlation also existed between butterfly diversity and vegetation diversity. Abundance of nectar-producing plants was the most important factor in increasing butterfly population and diversity, while moths were mostly favoured by shelter provided by vegetation such as shrubs and trees (Saarinen *et al.*, 2004). Newly restored sites, such as Phases 01 of Anderson Road Quarry, Lam

Tei Quarry and Shek O Quarry, surrounded by bare ground or low in coverage and diversity of vegetation were generally related to low population and diversity of both Lepidoptera groups. When plant species diversity is reduced, butterfly populations would also be affected. This is because of the reduction in direct sunlight which unfavoured several butterfly species, and the decline in both quantity and quality their larval hostplants (Sparks *et al.*, 1996).

Butterflies are likely to be useful indicators of moth diversity on restored quarries at a local scale as their correlation was high (Table 6.2). This result is different from those research in other terrestrial habitats such as meadows, aspen forests, and coniferous forest (Ricketts *et al.*, 2001), which may be due to the diverse vegetation with both natives and exotics in local restored quarries.

Table 6.2 Pairwise correlation coefficients for the species diversity among the different taxonomic group at different phases of restored quarries.

	Tree and shrub coverage	Vegetation diversity	Butterfly diversity	Moth diversity
Tree and shrub coverage	-	0.77	0.88**	0.93***
Vegetation diversity		-	0.82*	0.62
Butterfly diversity			-	0.90**
Moth diversity				-

*p<0.05; **p<0.01;***p<0.001

6.2 Current Status of Restored Quarries in Hong Kong

The success of degraded land restoration is influenced by climatic factors and the ecological conditions of the site (Bradshaw and Chadwick, 1980; Su and Zhao, 2003). In the present study, the restoration age was not long enough to detect any obvious change in soil improvement within each quarry. However, the difference can be observed between the oldest restored quarry (Turret Hill Quarry) and the others. Refer to other study on degraded land, the recovery rate of a degraded site is faster during the early establishment stage (0–13 years) and a slower during the late successional stage (13–28 years) in terms of soil's physicochemical properties and microbial biomass (Singh *et al.*, 2001). The results also indicate that soil development differed on different sites, but organic matter accumulated slowly with time. With the help of vegetation development, carbon and nitrogen can be accumulated due to the organic matter supply from plant litter, dead animals and soil microorganisms. The soil improvement induced in restoration by revegetation is a complicated ecological process that is simultaneously affected by many biotic and abiotic factors (Liu *et al.*, 1998). It should be noted that carbon and nitrogen contents were still relatively low even after 10 years of restoration in Turret Hill Quarry. This shows that the recovery of soil quality will require very long period of time.

Plantation can enhance secondary succession in terms of species richness and diversity in restored quarries. Vegetation development on restored quarries can be coordinated to provide a landscape with habitats suitable for numerous species. Revegetated quarries could recruit lepidopteran species in terms of abundance and diversity. Lepidopterans respond to the environmental conditions and show their correlation with the vegetation development of the restored quarry. By measuring the population and diversity of lepidopterans, the succession status of the restored quarries could be assessed referring to the biodiversity and richness of the site.

Vegetation diversity was generally related to lepidopteran and odonate diversity, so that by investigating lepidopterans and odonates, the vegetation development stage of the site can be determined. And within Lepidoptera group, although in other cases butterfly diversity was unrelated with moth, butterfly diversity can act as an indicator of moth diversity in restored quarries in Hong Kong as their correlation was high

6.3 Conservation Value of Restored Quarries

Conservation value of a habitat can determine the conservation priority of the sites, which is referred to environmental, socio-economic, biodiversity or landscape values. Proper management and monitoring of a restored site are critical to ensuring balance biodiversity and maintaining the overall health of ecosystems (Spellerberg and Hardes, 1992). One purpose of quarry restoration is to restore the degraded area into natural habitat which can benefit wildlife. As a result, the environmental and landscape value of the restored quarries can be intrinsically high which can derive value from benefits to both the ecosystem and human.

For quarries in Hong Kong, planting with exotics and natives is a common practice in restoration projects, which has been managed to maintain vegetation development. Artificial planting and subsequent natural succession helps to recruit plant community on restored quarries. Species richness and diversity of vegetation was low at the younger sites (e.g. Phase 01 of the quarries) and high at older sites (e.g. TH91, TH94 and LT96) (Chapter 3). Vegetation diversity in Turret Hill Quarry and Shek O Quarry were higher than those in other plantation areas and even higher than some lowland secondary forests and montane forests in Hong Kong (Zhuang, 1997). The types of habitat in restored quarries were not diverse enough. However, recent plantation practice of mix-planting with fast-growing exotics and natives can accelerate forest succession. This shows a trend of vegetation development on the restored quarries, which potentially increases the conservation value of the sites. Coverage and diversity of vegetation affect the lepidopterans community (Table 6.2). Overall, the result indicates that quarry restoration benefits lepidopteran population and diversity. Some uncommon Lepidoptera species were recorded on the restored quarries (Chapter 4), and this greatly increases the conservation value of the sites. Restored quarries become a breeding and feeding sites for such uncommon Lepidoptera species, which should be conserved. On the other hand, restored quarries may not be a suitable habitat for odonates; the species richness and diversity of odonates were low which is probably because of the limitation of breeding sites for Odonata species on the restored quarries (Chapter 5), and the correlation between odonate and vegetation diversity was low (Table 6.2). Odonates may be a good indicator for small insect, but may not be a good indicator for the vegetation development of the sites. All species found on the quarries were widespread in Hong Kong, and conservation value is low in such aspect.

6.4 Limitation of the study

6.4.1 Light-trap

Light trapping is commonly used as the primary method of collecting nocturnal adult moths (Waring, 1994; Young, 1997; Leverton, 2001; Kendrick, 2002). UV emitting light sources, such as mercury vapour lamp, are used to attract nocturnal adult moths. It is an applicable method to collect data on the relative abundance and distribution of moths. Critically, it is not a perfect method and has its limitations. Firstly, not all moth species are nocturnal, UV light of mercury lamp are not consistently attractive to all nocturnal moths (Hsiao, 1972; Mikkola, 1972; Baker and Mather, 1982; Waring, 1994; Kendrick, 2002). To minimize this problem and be more inclusive, mercury lamp with UV-B and UV-C bands was used in this experiment because it can attract most species (Belton and Kempster, 1963; Taylor and Brown, 1972; Walker and Galbraith, 1979). Secondly, the response distance for the light-trap varies among different moth families (Muirhead-Thompson, 1991), and the phase of the moon brings a very significant effect on the response distance. This is because the light source of moon will also attract moths and will compete with the light-trap, and this is why the number of catch would be high on moonless nights (Siddorn and Brown, 1971; Bowden, 1973; Bowden and Church, 1973; Bowden and Morris, 1975; Persson, 1976; Vaishampayan and Verma, 1982; Dent and Pawar, 1988; Kendrick, 2002). The response distance may vary from 3 m up to 736 m depending on weather and geological conditions (Baker and Sadovy, 1978; Bowden, 1982; McGeachie, 1988). The more powerful mercury vapour lamps can sample more moths per night. However, for the ease of handling of the trap, portable style was used and hence the response distance of the lamps were further limited in this experiment. Thirdly, trap placement is critical because the habitat structure can affect the response distance of a light trap. When the trap was placed in an open area, the mercury lamp could easily be seen and was very attractive to moths. As a result, the catchment radius is longer and will include more species than placement in enclosed habitats (Kendrick, 2002).

It is a weakness for light trapping which cannot sample all nocturnal moth species.

But on the other hand, it is not desirable if all (or even, most) of the moths was being captured. In order to minimize the human impact to the moth community, a weekly sampling was preferred. Bait trapping and pheromone traps are alternative methods in studying moth community (Waring, 1994). Light traps were seldom used in studying rare species because many of the rare species cannot be captured by light traps because of the above reasons (Kendrick, 2002).

In fact, many moth species appeared in Hong Kong are widespread because of the diverse ecosystem in Hong Kong. The moth fauna in Hong Kong forests is comparable in richness to that in Indonesia and Malaysia (Kendrick, 2001). However, data on the other habitats in Hong Kong were lacking. To get a clearer picture of the moth community composition within each habitat, further sampling should be performed.

6.4.2 Correlation vs causation

The correlation between different groups of organism and soil properties were compared in previous and recent chapters. However, this only showed that there is a correlation between two factors, and cannot imply the causation between them. Causation can be shown by experiments to manipulate different factors, so that changes in a factor would cause changes in another factor. The study can be improved by changing the vegetation status of a single phase and assemblage the insect groups again and find out the changes of other factors. Unfortunately, there was also a limitation of time and site selection, because only 4 quarries in Hong Kong which were available for the study.

6.5 Area for Further Investigation

6.5.1 Seed bank analysis

The process of succession varies with and depends on the seed bank and seed rain input (Brown and Lugo, 1994; Yu *et al.*, 1994). After hydroseeding and plantation, there will be colonization of both native and exotic seedlings species. Several studies have shown that native species seedling recruitment is poor on some degraded lands (Buschbacher, 1986; Aide *et al.*, 1995; Cubina & Aide, 2001). Many factors lead to the shortage of seeds, such as isolation of the habitat, seedling predation, drought, competition with established grasses and poor soil fertility. By studying the seed bank composition and comparing the seed bank with existing vegetation composition, vegetation development on restored quarries could be predicted.

6.5.2 Other inventories

An important goal of ecological restoration is to accelerate natural successional processes in order to increase biological productivity, soil fertility and biotic control over biogeochemical fluxes within the recovering ecosystems, and to reduce rates of soil erosion. Analysis of different natural successions on natural and artificial sites can be done to obtain more information on the difference of immigration rate of fauna between these sites. Study on the feeding preference of pollinator insects such as bees can be performed to see whether they prefer native plants or exotic plants, and this will affect the vegetation composition of the sites. Moreover, other fauna such as herpetofauna, and insects such as ants and beetles could also be studied in order to get a more conclusive picture of the ecological status on the restored quarries. Since light traps only account for about 60% of the total moth species (Kendrick, 2002), other trapping method can be done in order to obtain a more conclusive picture of moth richness and diversity in restored quarries.

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Appendix: Odonate Communities on Restored Quarries

Introduction

Order Odonata can be divided into three suborders i.e. Anisoptera, Zygoptera and Anisozygoptera. The latter suborder has only two species which are not recorded in Hong Kong. Dragonflies have strongly biting mouthparts and are active and aggressive carnivores in both adult and larval stages. Adults mainly feed on other insects while in their larvae feed on other insect larvae, crustaceans, tadpoles and even small fishes. They are considered as beneficial insects because they consume many other insect pests.

There are totally 111 species of odonates recorded in Hong Kong. The humid subtropical climate of Hong Kong with high annual rainfall is suitable for the growth of odonates. Humid habitats with rich water supply are particularly important for odonates. They lay their eggs in freshwater where the larvae grow, and their larvae need fairly clean water resources as they are sensitive to many water pollutants and human disturbance. As a result, they are also considered as sensitive environmental indicator for water pollution (Samways and Steytler, 1996; Bulankova, 1997). Most of the adult odonates can be found during the early spring and summer months (Wilson, 2003). They inhabit the edges of water bodies, such as ponds, forest streams and rivers and freshwater marshes. In Hong Kong, natural forest and mountain ravines contain many native plants and mountain streams which can support many odonates (Wilson, 1995). Because of the dependence of water, odonates can lay eggs in catchwater channel and even drainage system on the quarries where sand and silt are allowed to accumulate. Emergent and floating vegetation and the slow water current are important for egg and larval development of many species of odonates. In the restored quarries studied, the drainage system provided a suitable oviposit habitat for odonates. Since the newly restored phases of the quarries would be irrigated, this created wet habitats and small water bodies for odonates.

Odonates are insects that seldom receive the attention that deserve from biologists and resource managers, but they are ecologically important for many reasons. Since they are carnivorous insect, they take an important role in the food web as secondary consumers. They are upper-level predators in aquatic and semi-aquatic habitats. Many species are habitat-specific and their presence can be used to characterize healthy wetlands (Wilson, 1995; Bulankova, 1997). Furthermore, similar to Lepidoptera, as being large, colourful, diurnal creatures, odonates are identifiable organisms in the field and hence their suitability for long-term monitoring programs.

The objective of this study was to examine the distribution and species composition of odonates on the restored quarries. It helps to obtain a clearer picture in the restoration progress of Hong Kong, and gather information for better restoration management and conservation planning.

Materials and Methods

Visual encounter survey

The odonate survey was done weekly from May 2002 to April 2003. Visual encounter survey (VES), which is a common technique used for odonate inventory, was used to estimate the odonates biodiversity of the quarries. It was similar with the Pollard-walk method in Chapter 4. VES was done by walking through an area for a prescribed time period in a systematic way within a particular route (Sutherland, 1996). As a result, it was carried at the same time of the butterfly survey with the same route on the quarry (Chapter 4). Through VES, a species list was compiled. The species richness of a site and its relative abundance of species were estimated.

Statistical analysis

Shannon-Wiener diversity index (H'), evenness index (E) and similarity index (S_c) was estimated using the same calculation method as mentioned on Chapter 3.

Results and Discussion

General description of odonate community

Totally 10 species were recorded in the four restored quarries in Hong Kong (Table 7.1). The number of dragonfly species found on the four restored quarries was lower than other sites such as wetland, lagoon, river ponds and woodland in Hong Kong (Wilson, 1995). Seven species were found in Shek O Quarry, and 6 species in Lam Tei Quarry. Generally, only 2 to 4 species were recorded at each phase among the restored quarries (Table 7.2), and the total index of abundance (total recorded number) ranged from 244 to1186 at AR01 and SO98 respectively (Tables 7.2 and 7.3).

All 10 recorded species were of the suborder Anisoptera (dragonflies), and no Zygoptera (damselflies). All belonged to the family Libellulidae, which was dominant and widespread throughout Southeast Asia and Indo-China and was accounted for nearly one third of the species recorded in Hong Kong (Wilson, 2003). Most species of this family prefer to lay eggs in static water such as ponds, tanks, slow flowing reaches of streams and irrigation ditches (Wilson, 1995; Wilson, 2003). As a result, the drainage system and the small water ponds on the restored quarries provided a good nursery places for the dragonfly larvae, and hence dominance of the family Libellulidae. The status of all species found on the four restored quarries was

Table 7.1 Species composition of Odonata in different phases of the four quarries

Species	Family	中文名稱	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01	Status*
Crocothemis servilia	Libellulidae	紅蜻	+	+						+	A
Orthetrum glaucum	Libellulidae	黑尾灰蜻							+		A
Orthetrum luzonicum	Libellulidae	呂宋灰蜻	+	+	+				+		A
Orthetrum pruinosum	Libellulidae	赤褐灰蜻									A
Orthetrum sabina	Libellulidae	狹腹灰蜻				+	+	+			C
Orthetrum triangulare	Libellulidae	鼎異色蜻	+	+					+		C
Pantala flavescens	Libellulidae	黃蜻	+	+	+	+	+	+	+	+	A
Rhyothemis variegata	Libellulidae	彩裳蜻蜓			+			+			C
Tramea virginia	Libellulidae	華斜痣蜻					+			+	C
Trithemis aurora	Libellulidae	曉褐蜻蜓					+	+			A

* The status of odonates is according to the information by Wilson (2003), where "A" means "abundant"; "C" means "common"

"common" or "abundant" (Table 7.1).

Table 7.2 Number of Odonata species and their total index of abundance recorded in the different phases of the four quarries.

	No. of species	Total index of abundance
TH91	4	881
TH94	4	1004
LT96	3	520
LT98	2	834
LT01	4	342
SO98	4	1186
SO01	4	528
AR01	3	244

Ecological indices of odonate on various sites

The Shannon-Wiener diversity index, H', of odonates on the four restored quarries were low (Table 7.4). The diversity indices of all phases except TH91 were lower than one. The Shannon-Wiener diversity index of TH91 was the highest (H' = 1.17), followed by SO98 and SO01 (H' = 0.96 and 0.95 respectively). On the contrary, the Shannon-Wiener diversity index of AR01 was the lowest (H' = 0.26). Such low in diversity index indicates that the restored quarries support only a few odonates. There were several reasons for such low in species diversity on the restored quarries. Firstly, the presence of odonates was limited by the availability of water sources. Although the drainage system of the restored quarries serves as a breeding site for odonates, the catchment channel is not extensive enough to support

Table 7.3 Index of abundance among the phases of the four quarries. Sums represent total number of dragonfly individuals recorded in each area over the entire study.

Species	Family	中文名稱	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Crocothemis servilia	Libellulidae	紅蜻	107	183						17
Orthetrum glaucum	Libellulidae	黑尾灰蜻							45	
Orthetrum luzonicum	Libellulidae	呂宋灰蜻	110	47	157				48	
Orthetrum pruinosum	Libellulidae	赤褐灰蜻								
Orthetrum sabina	Libellulidae	狹腹灰蜻				251	55	177		
Orthetrum triangulare	Libellulidae	鼎異色蜻	178	258					68	
Pantala flavescens	Libellulidae	黃蜻	486	516	347	583	206	717	367	215
Rhyothemis variegata	Libellulidae	彩裳蜻蜓			16			8		
Tramea virginia	Libellulidae	華斜痣蜻					12			12
Trithemis aurora	Libellulidae	曉褐蜻蜓					69	284		
Total number of individuals			881	1004	520	834	342	1186	528	244

more diverse fauna. In this case, breeding sites becomes a limiting factor for the occurrence of odonates. Secondly, the dragonfly diversity was also affected by the availability of their food sources. Odonates are predators, which mainly consume aquatic insects at larval stage, but feed on many other insects at adult stage. As a result, greater prey number and diversity would support a higher odonate number and diversity. In this circumstance, the diversity and number of odonates reflected the diversity and abundance of other small animals (especially small insects). Lepidopterans are one of the food sources for odonates. If the abundance and diversity of odonates varied with that of lepidopterans on the restored quarries, this indicates that the predator-prey relationship between odonates and lepidopterans is highly correlated, and this will be discussed in the next chapter.

Table 7.4 Ecological indices of Odonata on the various phases of the four quarries.

Indices	Diversity index (H')	Evenness index (E)
TH91	1.17	0.17
TH94	0.80	0.12
LT96	0.74	0.67
LT98	0.61	0.88
LT01	0.75	0.54
SO98	0.96	0.70
SO01	0.95	0.68
AR01	0.26	0.05

The evenness index, E, in LT98 was relatively high when compared with other restored quarries in Hong Kong (E = 0.88 in LT98), which indicates a more even distribution on the site. In Turret Hill Quarry and Anderson Road Quarry, the evenness indices at different phases were statistically low. In Turret Hill Quarry, the evenness indices in Phases 91 and 94 were 0.17 and 0.12 respectively, while it was 0.05 in AR01. Such low evenness index in Anderson Road Quarry was due to the dominance of a particular species, *Pantala flavescens*.

Table 7.5 Similarity index of Odonata between different phases comparison.

	Similarity index (Sc)%
TH91-TH94	86.8
LT96-LT98	74.6
LT98-LT01	47.7
LT96-LT01	74.5
SO98-SO01	67.7
LT98-SO98	88.0
LT01-SO01	71.9
SO01-AR01	73.9
LT01-AR01	98.0

For Turret Hill Quarry, a high similarity index, Sc, was obtained (Sc = 86.8%, Table 7.5). This further suggests that the environmental conditions between the two phases were very similar to each other. The similarity indices were also similar with those of the lepidopterans community of the restored quarries (Chapter 4). On the other hand, the similarity indices of odonata between different quarries of the same age were very high. This shows the species composition between different restored quarries was very close with each other within the same age of phases, and the restored quarries were dominant by several species only, such as *P. flavescens* (Plate 7.1).

Plate 7.1 *Pantala flavescens* found on Anderson Road Quarry.

Odonates species on various phases of the sites

Among the different restored quarries, *P. flavescens* was the species that could be found on all sites. Compared with other species, the index of abundance was the highest for *P. flavescens*, so that they were the most abundant species recorded in the quarries (Table 7.6). This shows that they were one of the pioneer species in quarries, and was the commonest dragonfly species occurring in Hong Kong. They

Table 7.6 Relative abundance (%) among the phases of the four quarries. Sums represent total number of dragonfly individuals recorded in each area over the entire study.

Species	Family	中文名稱	TH91	TH94	LT96	LT98	LT01	SO98	SO01	AR01
Crocothemis servilia	Libellulidae	紅蜻	12.2	18.2						6.97
Orthetrum glaucum	Libellulidae	黑尾灰蜻							8.52	
Orthetrum luzonicum	Libellulidae	呂宋灰蜻	12.5	4.68	30.2				9.09	
Orthetrum pruinosum	Libellulidae	赤褐灰蜻								
Orthetrum sabina	Libellulidae	狹腹灰蜻				30.1	16.1	14.9		
Orthetrum triangulare	Libellulidae	鼎異色蜻	20.2	25.7					12.9	
Pantala flavescens	Libellulidae	黃蜻	55.2	51.4	66.7	69.9	60.2	60.5	69.5	88.1
Rhyothemis variegata	Libellulidae	彩裳蜻蜓			3.08			0.67		
Tramea virginia	Libellulidae	華斜痣蜻					3.51			4.92
Trithemis aurora	Libellulidae	曉褐蜻蜓					20.2	23.9		

occur in huge aggregations of many individuals and can be found all year round. They occur in small groups even in winter. It is a pond species, which uses water pond in restored quarries for breeding, and a migratory species that would seek out moisture-laden air. They are quick in larval development (Wilson, 1995; Wilson 2003). This brings an advantage, so that they can occupy and establish the site quickly. The relative abundance (Tables 5.7 – 5.10) of *P. flavescens* was over 50% in the restored quarries. It reached 88% in Anderson Road Quarry and was the most dominant species on all sites.

Table 7.7 Top 3 ranked dragonfly species at different phases of Turret Hill Quarry according to their relative abundance.

Phase	Species	Family	Relative abundance (%)
91	*Pantala flavescens*	Libellulidae	55
	Orthetrum triangulare	Libellulidae	20
	Orthetrum luzonicum	Libellulidae	13
94	*Pantala flavescens*	Libellulidae	51
	Orthetrum triangulare	Libellulidae	26
	Crocothemis servilia	Libellulidae	18

Table 7.8 Top 3 ranked dragonfly species at different phases of Lam Tei Quarry according to their relative abundance.

Phase	Species	Family	Relative abundance (%)
96	*Pantala flavescens*	Libellulidae	67
	Orthetrum luzonicum	Libellulidae	30
	Rhyothemis variegata	Libellulidae	3.1
98*	*Pantala flavescens*	Libellulidae	70
	Orthetrum sabina	Libellulidae	30
01	*Pantala flavescens*	Libellulidae	60
	Trithemis aurora	Libellulidae	20
	Orthetrum sabina	Libellulidae	16

*only two species recorded at LT98.

Table 7.9 Top 3 ranked dragonfly species at different phases of Shek O Quarry according to their relative abundance.

Phase	Species	Family	Relative abundance (%)
98	*Pantala flavescens*	Libellulidae	61
	Trithemis aurora	Libellulidae	24
	Orthetrum sabina	Libellulidae	15
01	*Pantala flavescens*	Libellulidae	70
	Orthetrum triangulare	Libellulidae	13
	Orthetrum luzonicum	Libellulidae	9.1

Table 7.10 Top 3 ranked dragonfly species at AR01 according to their relative abundance.

Species	Family	Relative abundance (%)
Pantala flavescens	Libellulidae	88
Crocothemis servilia	Libellulidae	7.0
Tramea virginia	Libellulidae	4.9

Besides *P. flavescens*, there were 5 *Orthetrum* spp. recorded in restored quarries, viz. *O. glaucum*, *O. luzonicum*, *O. pruinosum*, *O. sabina* and *O. triangulare*.

Restored woodlands such as Turret Hill Quarry and Phases 98 of Lam Tei Quarry and Shek O Quarry were important for many species in providing the sheltered habitats. As a result, the numbers of odonates recorded in these phases were more abundant than Phases 01 as there were mainly grasslands (Chapter 3). Although woodland can support more individuals, but the number of species was still limited in only 2 to 4 species among quarries. This shows that the colonization of odonates was just initiated in many early restored quarry phases.

Conclusions

Ten species of the Family Libellulidae was recorded in the restored quarries in Hong Kong. The species richness and evenness were low, which were reflected by the low in Shannon-Wiener diversity index, H', and the evenness index, E. Low macroinvertebrate diversity of the newly restored quarries was one reason leading to such low in odonate diversity. Older restored sites and phases had more diverse and evenly distributed species composition. The dominance of pond species, such as *P. flavescens*, is due to the abundance of catchment channel which is suitable for the breeding of the species, and also fast growing rate of the larvae is one factor leading to the dominance of *P. flavescens*. As a result, this species colonized the site quickly even in the initial stage of restoration (i.e. Phases 01). As the vegetation development in older phases of restored quarries was quite successful, this provided satisfactory shelter for the odonates. Amongst the four restored quarries, the species composition was very similar between quarries as the similarity index, were mostly very high.

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