Evaluation of Slope Greening Performance in Promoting the Urban Ecology of Hong Kong

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Abstract
Groundcovers of Hong Kong soil slopes were assessed. Plant coverage of groundcover species was unsatisfactory and mainly occupied by native graminoids and ferns. Plant species composition varied significantly among areas under different intensities of development. Soil slopes have been established on a large scale in Hong Kong owing to its hilly topography and high degree of development. The sophisticated slope upgrading techniques currently available make revegetation of these urban landscapes possible, thus enhancing ecological restoration. Among the plants selected for revegetation, native plants are recently preferred owing to their adaptability to local climates and beneficial ecological roles. Native trees and shrubs are widely studied for their significance to the urban environment whereas groundcovers are usually ignored. The abilities of groundcovers to provide sustainable plant covers and positively influence ecology are occasionally recognized and need to be assessed. Areas with differing degrees of development that have dramatically different environmental conditions may result in alteration of this plant community. Analysis of groundcover vegetation on thirty-five soil slopes was carried out in suburban and urban areas of Hong Kong to assess plant abundance and analyze the substrates for their nutrient status. We also evaluated slope performance to determine any correlation with the groundcover community. Results showed that the plant coverage of groundcovers was generally low, with the initially planted groundcovers replaced by native ferns and graminoids. Significant differences in plant species composition were shown among areas under different intensities of development. Active management of native vegetation on soil slopes is recommended to facilitate the ecological rehabilitation of urban landscapes.

Keywords: groundcover, plant species composition, soil slopes

Introduction

Hong Kong, like other highly developed cities, suffers dramatically from habitat loss and fragmentation. Due to presence of hilly landscapes, the formation of soil slopes is extremely common to allow housing and road development (Dai and Lee, 2002). Works such as topsoil removal and soil compaction further deteriorate our soil environment (Burghardt, 2006). Due to the implementation of advanced slope upgrading works in which soil surface is exposed. The planting opportunities are increased and therefore, revegetation of soil slopes is encouraged to rehabilitate these degraded landscapes. This can promote a sustainable greening effect associated with environmental services to our society (Rosenzweig et al., 2006).

The establishment of vegetation on slopes is constrained by several environmental conditions. Soil temperature and moisture are critical for the survival and growth of vegetation, and slope aspect is significantly correlated with plant diversity as it influences the radiation experienced by plants (Zou et al., 2012). Other environmental factors such as slope elevation or orientation, which show close association to wind speed, also draw much concern of practitioners in greening. As a result, a large variety of plants adaptable to dried locations or alkaline soil in the urban areas have been selected for revegetation (Williams et al., 2015). Among these, the use of native plants for rehabilitation of degraded sites has become more popular owing to the higher adaptability of these plants to local climatic and soil conditions (Hau and Corlett, 2003). They also show higher potential to survive in disturbed areas (Prach and Pyšek, 2001). In addition, urbanization always leads to the substantial decline of native plant species but favors the invasion of exotic ones. Planting natives can restore indigenous plant richness and suppress the abundance of exotic plants growing in degraded landscapes (Forman and Alexander, 1998; Mullaney et al., 2015).

Locally, the effectiveness of focusing on native trees has proved to be successful (Jim and Liu, 2001). Nevertheless, assessments of groundcover species are generally lacking. In fact, the establishment of groundcovers plays a vital role in greening the landscape, especially on steeper slopes on which woody plants are not recommended (GEO, 2011). Up to now, native graminoids such as Bahia grass (*Paspalum notatum*) or Bermuda grass (*Cynodon dactylon*) have been commonly selected and sown on slopes by hydroseeding. However, the fate of these groundcovers after the establishment phase has yet to be assessed. Indeed, some specific site characteristics may not be favorable to the application of hydroseeding and can influence the vegetation growth of groundcovers. Factors such as seasonality or microsite properties also govern the effectiveness of establishing sustainable groundcovers on degraded sites. With time, the groundcovers originally grown in the target sites are outcompeted by other adaptable plants, resulting in the alteration of plant species composition. As a result, the positive influences induced by native groundcovers on urban landscapes may not be guaranteed. We also need to understand the adaptability of such groundcovers in the urban environment and determine any effect on their distributions caused by the degree of development. Any possible correlations between the abiotic factors of slopes and the groundcover community should also be identified to reflect the condition of revegetating the urban landscapes.

This study aimed to (1) take an account of the plant coverage and the diversity of groundcovers on revegetated soil slopes; and (2) examine the effects of development on the plant abundance of groundcovers.

Body

Methodology

We divided Hong Kong into 7 areas based on the intensity of development (Fig. 1). These included urbanized areas (Hong Kong Island & Kowloon Peninsula) and suburban areas (Lantau Island, New Territories East, New Territories North & New Territories West). Among the suburban areas, the areas in New Territories had higher intensities of development pressure than the one on an isolated island, Lantau Island, due to the prolonged establishment of new towns. We also included a suburban area at higher elevation (New Territories Central, NTC) to determine any changes of plant species composition by altitudes. We used an online database, the Slope Information Systems, HKSAR for searching studied slopes in each area. Greening work such as pit-planting or hydroseeding was conducted on these landscapes. No maintenance work was carried out afterwards to allow natural growth of vegetation. We obtained the relevant information such as slope angle, area and elevation of each study site from the system.

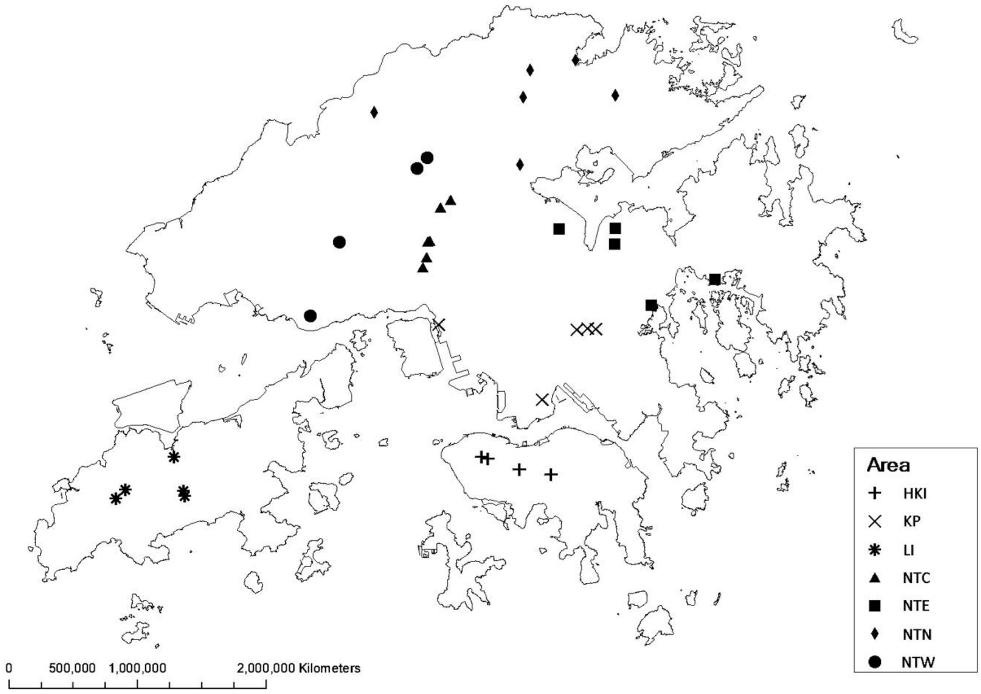

Fig 1. Thirty-five study sites in Hong Kong, southern China.

We totally studied 35 soil slopes in seven areas and each area will consist of 4 to 6 slopes. We randomly set up quadrats to examine the plant abundance of groundcovers. We decided to make 10 quadrats (0.25 m^2) at each site. We identified the herbaceous and woody seedlings of groundcovers and determined plant coverage by visual inspection. We also used a camera equipped by 180° fisheye lens to take images of tree canopy layers on slopes. They were then analyzed by the Image-J program to determine the slope openness.

We used one-way analysis of variance (ANOVA) to compare the plant coverage between different plant types and areas under different intensities of development. We examined the diversity of groundcovers and the relevant formulae are listed below:
H' = -Σ*Pi* ln P*i*, where *Pi* = the relative abundance of each plant species; and
J' = H'/ln *S*, where H' = Shannon-Wiener index and *S* = number of plant species.
The Duncan multiple range test was used for classifying groups (p<0.05). We also examined the effects of erosion control mats on the groundcovers of soil slopes by a *t*-test. The Kolmogorov-Smirnov test and Levene's test were used for the checking of normality and homogeneity of the variance respectively. All the tests were conducted by the use of SPSS (ver. 25). We also examined the plant species composition by PRIMER (ver. 6.0). The mean plant coverage of each species on each slope was transformed and used in this analysis. We performed one-way analysis of similarity by Bray Curtis similarity coefficient (ANOSIM; Clarke and Warwick, 2001) to determine the differences in plant species composition among areas under different levels of development pressure. We showed the results using non-metric multi-dimensional scaling (NMDs) plots. Besides, we determined the contribution of species to the overall dissimilarity of plant species composition among areas by similarity percentage analysis (SIMPLER; Clarke and Warwick, 2001). Those plant species making up to a level of 20% of significant differences are shown.

Results

The average plant coverage of groundcovers was approximately 30% and dramatically varied among plant types. Among them, plant cover made by ferns consisted of around 20% and significantly outweighed other plant types (Fig. 2). *Dicranopteris pedata, Lophatherum gracile, Lygodium japonicum* and *Pteris semipinnata* became the dominant groundcovers (Table 1). Besides, 153 species were encountered and woody species in seedling stage occupied for the majority (91 species). The most commonly found groundcovers were *Blechnum orientale, Cyclosorus parasiticus, Dicranopteris pedata, Logodium japonicum* and *Miscanthus floridulus*. The abundance of exotic plant species was not great that accounted for only about 11% of all groundcover species. Among them, *Parthenocissus dalzielii*, *Acacia confusa*, *Oxalis debilis* subsp. *corymbosa* and *Bidens alba* were commonly found. The application of ECMs caused a significant change in the plant coverage of soil slopes (Table 2). Soil slopes with ECMs had lower plant coverage than those without. Although the application of ECMs on soil slopes did not alter species richness as well as the Shannon-Wiener index of groundcovers, those slopes covered by ECMs consisted of higher evenness index (Table 2). The plant coverage in suburban areas was generally higher than that in urban areas, although no dramatic differences among plant types were found. Regarding to species richness, it differed dramatically among the areas under different intensities of development, with the highest in both urban and suburban areas (Fig. 3). However, no significant differences in biological diversity among these areas were found.

Table 1

Top four groundcover species on soil slopes.

Name	Plant Family	Plant type	Origin
Dicranopteris pedata	Gleicheniaceae	Ferns	Native
Lophatherum gracile	Poaceae	Graminoids	Native
Lygodium japonicum	Lygodiaceae	Ferns	Native
Pteris semipinnata	Pteridaceae	Ferns	Native

Table 2

Plant coverage and diversity of soil slopes with and without erosion control mats (ECM) (**p*<0.05).

	Slope with ECM (n=17)	Slopes with no ECM (n=18)	df	*t*
Plant coverage (%)	26.2±3.45	36.8±3.75	33	-2.08*
Species richness	17.6±7.58	19.7±7.72	33	-0.80
Shannon-Wiener index	2.08±0.51	1.83±0.65	33	1.24
Evenness index	0.75±0.09	0.64±0.15	33	2.62*

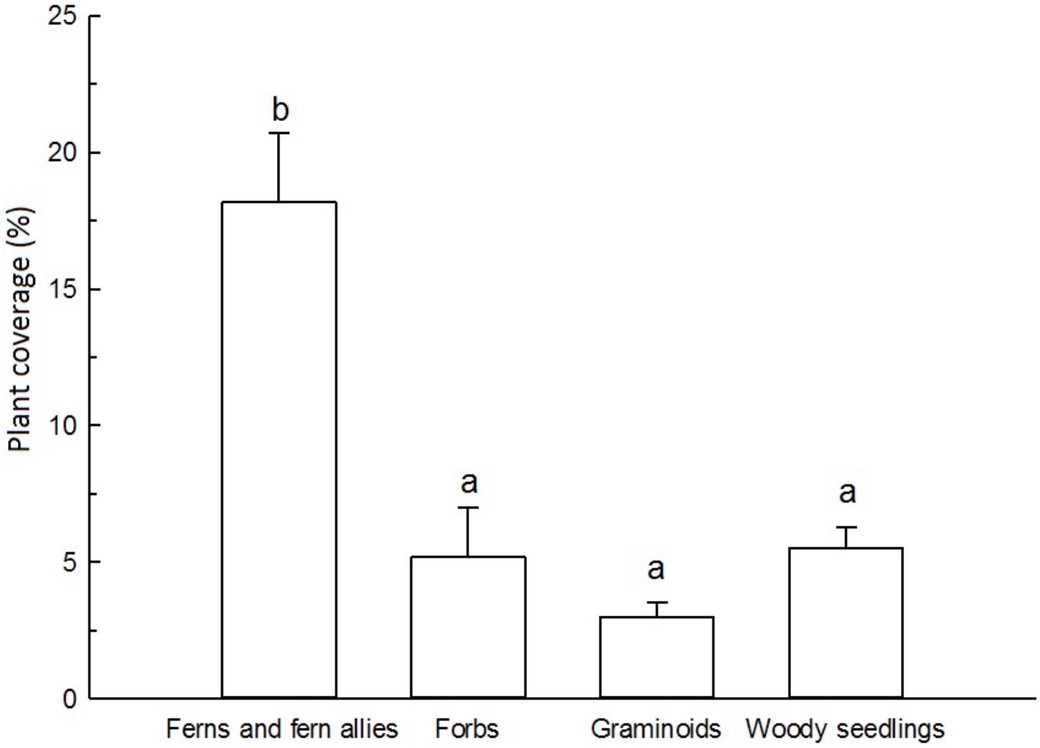

Fig 2. Plant coverage on soil slopes among plant types (mean ± standard error). Bars having different letters denote significant differences.

Fig 3. Plant diversity of groundcovers on soil slopes among different areas (mean ±

standard error). Bars having different letters denote significant differences ($p < 0.05$) between areas.

The two-dimensional multidimensional scaling plot demonstrated significant differences in plant species composition between suburban and urban areas (Fig. 4). LI, a suburban area with a lower degree of development, differed remarkably from the urbanized areas (Table 3). Another suburban area, NTE, also showed a significant difference when compared with the urban area nearby (KP). No significant change in plant community was found in the area at the higher elevation (NTC). There were also no dramatic changes in plant community between the urban areas, but significant differences were found between the suburban areas (Table 3). LI showed a significant difference compared to the two distant suburban areas (NTE and NTN) but showed a similar species abundance to other closer suburban areas (NTC and NTW). The plant species making significant contribution to the overall dissimilarity among areas are shown in Table 4. The dissimilarities were mainly caused by the significant higher abundance of plant species in an area in contrast to their low abundance or absence in other areas. These plant species were native fern species including *Cyclosours parasiticus*, *Dicranopteris pedata* and *Lygodium japonicum, Nephrolepis auriculata*, and an exotic species, *Bidens alba*. Moreover, the average abundance of native species in the suburban areas was significantly higher. In contrast, the urban areas consisted of higher abundance of exotic plants than those found in the suburban areas.

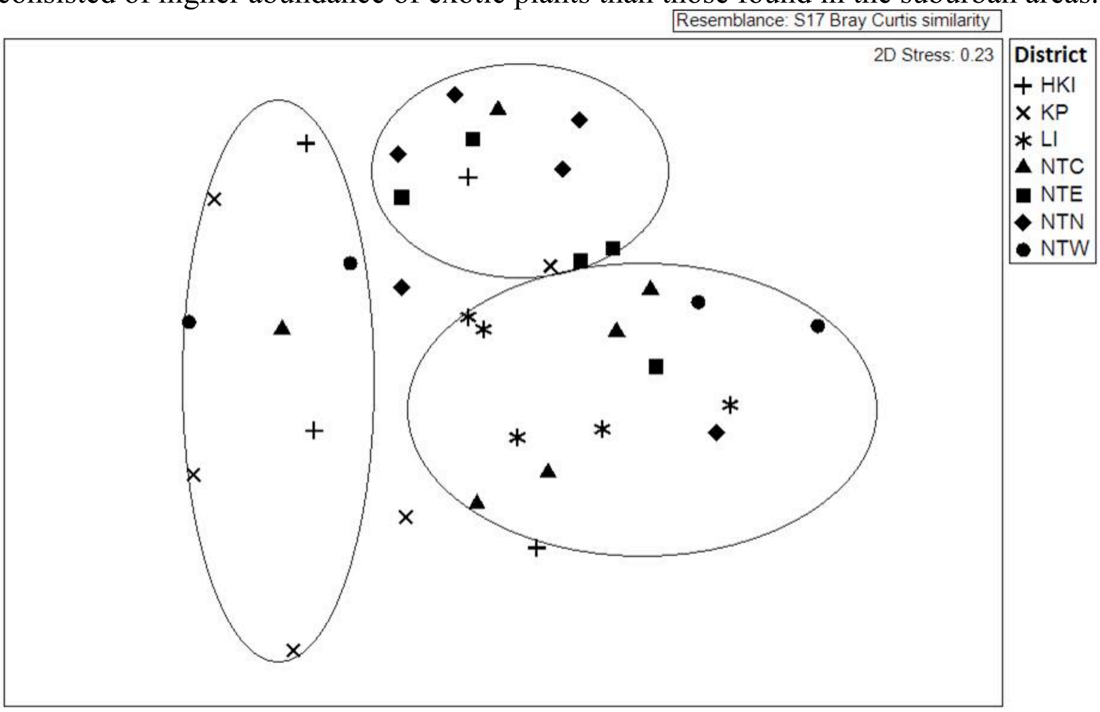

Fig 4. 2D-MDS plots illustrating plant species composition of study sites.

Table 3

Analysis of similarity (ANOSIM) on groundcover of soil slopes among different areas (global $R= 0.154$, $p< 0.05$).

	HKI	KP	LI	NTC	NTE	NTN	NTW
HKI							
KP	0.088						

LI	0.488*	0.330*				
NTC	0.143	0.220	0.168			
NTE	0.200	0.268*	0.396*	0.037		
NTN	0.187	0.160	0.301*	0.102	-0.099	
NTW	0.208	-0.006	0.281	0.091	0.069	0.095

Table 4
Plant species that contribute to the overall dissimilarity among areas.

Species	**Average abundance**		**Cumulative (%)**
Average dissimilarity = 91.83	KP	NTE	
Lygodium japonicum	<0.01	0.06	8.80
Cyclosorus parasiticus	0.01	0.06	17.17
Dicranopteris pedata	<0.01	0.05	25.06
Average dissimilarity = 90.62	LI	HKI	
Dicranopteris pedata	0.07	<0.01	13.80
Nephrolepis auriculata	0.01	0.05	24.69
Average dissimilarity = 91.65	LI	KP	
Dicranopteris pedata	0.07	<0.01	12.13
Bidens alba	<0.01	0.05	20.08
Average dissimilarity = 83.03	LI	NTE	
Dicranopteris pedata	0.07	0.05	13.26
Lygodium japonicum	0.01	0.06	23.33
Average dissimilarity = 86.72	LI	NTN	
Dicranopteris pedata	0.07	0.08	17.20
Cyclosorus parasiticus	0.02	0.10	33.63

Discussion

The revegetation of soil slopes is primarily aimed at providing a full or satisfactory green cover of an artificial environment. In this study, we found that the originally planted groundcover species were dramatically replaced after a certain period of time. The plant coverage of groundcovers was generally low, which might be contributed by the main substrate of soil slopes, completely decomposed granites. This coarse substrate is poor in nutrient and prone to erosion, enhancing the difficulties in plant establishment. The establishment of tree canopies on soil slopes, which provides a shaded environment, further disfavors the growth of groundcovers (De Keersmaeker et al., 2004). For plant richness, the number of species found in this study was consistent to that of other cities. Native plants contributed to the majority of the groundcovers except for some soil slopes that were dominated by the aggressive and invasive groundcover, *Wedelia trilobata*. Among them, ferns consisted of the highest coverage owing to their relatively large frond size. When compared to exotic plants, native plants often show higher adaptability when facing to the limited resources. *W. trilobata*, which originates in tropical Central and South America, either invades the slopes from adjacent areas or is being grown for revegetation. Its aggressive behavior outcompetes other plants, leading to a long-lasting groundcover and lowers the ecological values of urban landscapes. As a result, *W. trilobata* should be minimized by replacing it with other native plants.

Planting native species on soil slopes can improve the plant species composition on soil slopes. However, most of the originally planted native groundcovers no longer existed. Instead, the soil slopes have been dominated by ruderal generalists commonly found in disturbed habitats. This was in line with a previous study showing that some perennial herbs could colonize and gradually replace the original groundcovers in degraded landscapes (Zhang and Chu, 2013). Plant traits such as high specific leaf area and plant height may contribute to their strong adaptations to urban environment (Calfapietra et al., 2015; Williams et al., 2015).

Both the suburban and urban areas showed insignificant differences in vegetation cover, which was caused by slopes with similar substrates and under consistent planting strategies. However, dramatic difference in plant species composition between urban and specific suburban areas was found. The plant community composition of LI, resembled to that of neighboring suburban areas, NTW and NTC. Nevertheless, the plant community of those suburban areas differed significantly to the two neighbouring urban areas, HKI and KP. This indicated the effect of urban development on the plant community. The plant species contributing to the overall dissimilarity of plant community included *Nephrolepis auriculata* and exotic *Bidens alba* (Table 4). Urban areas also promote the growth of exotic plants (DeCandido, 2004; Walker et al., 2009). Factors such as climate and environmental stress differ from those in suburban areas and are closely associated with the invasion of such plants (Cilliers et al., 2008). Locational barriers can also hinder the interactions of plant communities between different areas and therefore may have caused the formation of contrasting plant communities for groundcovers between LI and the two distant suburban areas, NTE and NTN (Bastin and Thomas, 1999; Muñiz-Castro et al., 2006).

Conclusions

In this study, the plant species composition of groundcovers on soil slopes has been changed in the urbanized landscapes of Hong Kong. The plant cover on soil slopes was unsatisfactory and colonized by native plants. Moreover, significant different plant species composition among the studied areas indicated the implications of urban development on groundcovers. Native planting strategies have a role in contributing to the rehabilitation of degraded landscapes and should be actively promoted. Improvement of plant selection, substrate amendment and engineering design should also be considered to facilitate the revegetation of soil slopes.

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