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ARTICLE

Early ecological succession on landslide trails, Hong Kong, China

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ABSTRACT

In Southeast Asia, intensive rainstorms caused by strong monsoon and tropical cyclones can trigger landslides in mountainous or hilly regions, which may significantly impact the natural terrains. This mostly includes the loss of vegetation cover, the emptying of seed banks and degradation of the top soil. The objective of this study was to assess the spontaneous vegetation regeneration on nine landslide trails approximately 2.5 years after disturbance. A systematic vegetation sampling was conducted using 5 × 5 m quadrats. A total of 1,304 individuals from 72 tree and shrub species were recorded across the landslide trails, with a mean density of 1.09 ± 0.71 individual m^{-2}. The woody component of the regeneration was dominated by bird-dispersed species, followed by wind-dispersed species. Ground cover was dominated by two mat-forming ferns *Dicranopteris pedata* and *Blechnum orientale*. In order to facilitate the vegetation restoration and to speed up ecological succession on landslides, it is recommended to establish pioneer trees to improve both the top soil stability and soil-building process. The importance of providing bird perches must be emphasized, as it improves seed rain to the disturbed landscapes, thus promoting the regrowth of trees and shrubs.

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Couloirs de glissement de terrain; régénération; succession écologique; agents de dispersion

RÉSUMÉ

En Asie du Sud-Est, les pluies torrentielles intenses causées par les fortes moussons et les cyclones tropicaux peuvent déclencher des glissements de terrain dans les régions à relief accidenté. Il peut en résulter de impacts significatifs sur les milieux naturels, notamment la perte du couvert végétal et de la banque de graines, ainsi que la dégradation du sol en surface. L'objectif de cette étude était d'évaluer la régénération végétale spontanée dans neuf couloirs de glissement de terrain environ 2,5 ans après la perturbation. Un échantillonnage systématique de la végétation a été effectué dans des quadrats de 5 × 5 m. Un total de 1304 individus appartenant à 72 espèces d'arbres et d'arbustes ont été enregistrés dans les couloirs, pour une densité moyenne de 1,09 ± 0,71 individu m^{-2}. Les espèces avichores dominaient la composante ligneuse de la régénération, suivies des espèces anémochores. Le recouvrement au sol était dominé par deux espèces de fougères formant des tapis: *Dicranopteris pedata* et *Blechnum orientale*. Afin de faciliter la restauration végétale et d'accélérer la succession écologique sur les glissements de terrain, il est recommandé d'établir des espèces d'arbres pionnières pour améliorer les propriétés du sol en surface et le processus de pédogénèse. Les perchoirs à oiseaux jouent un rôle important en promouvant l'ensemencement et, par conséquent, la recolonisation des sites par les arbres et les arbustes.

Introduction

Landslides frequently occur in mountainous regions, particularly in areas with steep terrains and tropical rainstorms (Dai et al. 2001). This natural disaster causes significant loss of human life and has deep socio-economic consequences, impacting the natural environment, including the morphology of subaerial and submarine surfaces, habitat integrity, and native fauna and flora (Schuster and Highland 2003). The death toll and socio-economic impact from landslides has drawn worldwide attention. As a result, landslide risk management has been implemented in most mountainous regions and countries (e.g., Wong and Ho 2006).

From an ecological perspective, landslides not only remove the vegetation by sliding and shearing forces, but also wash the topsoil and its seed bank (Garwood 1985; Guariguata 1990), nutrients (Adams and Sidle 1987; Guariguata 1990) and mycorrhizal inoculum (Dalling and Tanner 1995). Therefore, plant recolonization is largely dependent upon the seeds brought by

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wind and animals (Dosch et al. 2007), while re-sprouting from existing vegetation is difficult since stumps and logs are largely absent.

Hong Kong has a hilly topography and over 60% of its area is steeper than 15° (Choi and Cheung 2013). Hong Kong is also affected by a sub-tropical monsoon climate with severe rainstorm and typhoons that raise the likelihood of landslide events. In fact, over 100,000 landslide events have occurred between 1924 and 2006 based on aerial photos (MFJV, 2007). Although engineering measures have reduced potential hazards (e.g., installation of soil nails; building of concrete blocks as check dams at the bottom of landslide trails), they were mainly restricted to sites close to populated areas and major transportation corridors. Remote landslide trails used to be given lower priority for slope engineering works due to inaccessibility and remoteness (i.e., higher costs). However, with the increasing level of urbanization in Hong Kong, landslides on natural terrains are becoming a major concern. For example, 38 landslides occurred on 7 June 2008 above the North Lantau Highway (NLH) during a severe rainstorm. Four of these landslides developed into channelized debris flows, blocking the NLH for 16 hours and significantly affecting traffic flow to and from the Hong Kong International Airport (AECOM 2012).

In this study, we investigated the species composition and abundance of plants that have established on landslide trails by using species rank abundance curves and non-metric multi-dimensional scaling (NMDS), approximately two and a half years after a severe rainstorm on 7 June 2008.We examined plant communities established by different dispersal modes. Since debris and seed deposition differ along the landslide trails and altitude, we hypothesized that stem density, as well as species richness and evenness, would vary across landslides, altitudes and different parts of the trails. The regeneration pattern was then compared to similar sites elsewhere in Southeast Asia.

Material and methods

Study site

Hong Kong is located to the south of the Guangdong Province in South China, approximately 300 km south of the Tropic of Cancer. Grassland and shrubland are the most extensive vegetation types and constitute more than 40% of the total land area, compared to 16.5% for secondary forests (Dudgeon and Corlett 2004). Hong Kong generally experiences dry (November to February) and wet seasons (May to September), separated by transitional climate (Dudgeon and Corlett 2004; Hong Kong Observatory 2015). Severe weather conditions, usually combined with intense rainfall and typhoons, may trigger landslide events. On 7 June 2008, about 2,400 natural terrain landslides occurred on Lantau Island after a severe rainstorm, recording over 300 millimeters of rainfall in one day (Choi and Cheung 2013; Hong Kong Observatory 2016). Because only 16.8% of the total land area of Hong Kong is urbanized and developed, most landslides have occurred in remote areas and are distributed in natural habitats. We selected nine of these landslide trails for this study based on their accessibility and degree of vegetation destruction (Figure 1).

Natural regeneration survey

Plant succession on the nine landslide trails (A to I) was studied by placing a total of 48 5 × 5 m plots across all trails. Up to six sampling plots were randomly placed within each trail but four were surveyed at Landslide A, three at Landslide D and five at Landslide G, as these landslides were comparatively smaller; and mostly too steep to access.

Woody plants ≥5 cm in height that had grown after the landslide events were identified to species, counted and their height was measured. The percentage ground cover of herbaceous, climbers and fern species was visually estimated. All plant species were identified in the field. In this study, plant nomenclature follows Hong Kong Herbarium & South China Botanical Garden (2007–2011). The dispersal agents of all recorded plant species were inferred from Bodle et al. (1994), Corlett (1996), Lucas and Corlett (1998) and Chen et al. (2016). Species with fleshy fruits and unknown dispersal agents were assigned 'unknown vertebrates' as the potential agent, whereas species with dry dehiscent fruits were considered wind- or mechanically dispersed (van der Pijl, 1982; Sorensen, 1986; Eriksson and Bremer 1992). Similarly, all fern species were considered wind-dispersed. All surveys were completed between September 2010 and March 2011, approximately two and a half years after the landslides occurred. As all the landslides occurred on the same day, they therefore have the same age.

Environmental parameters

Landslide trail zones were categorized according to Franks (1999) and Walker et al. (2009). The trails were divided into three distinct zones: initiation, transportation and deposition. The initiation zone is identified as the surface of the ruptures near the crest of the

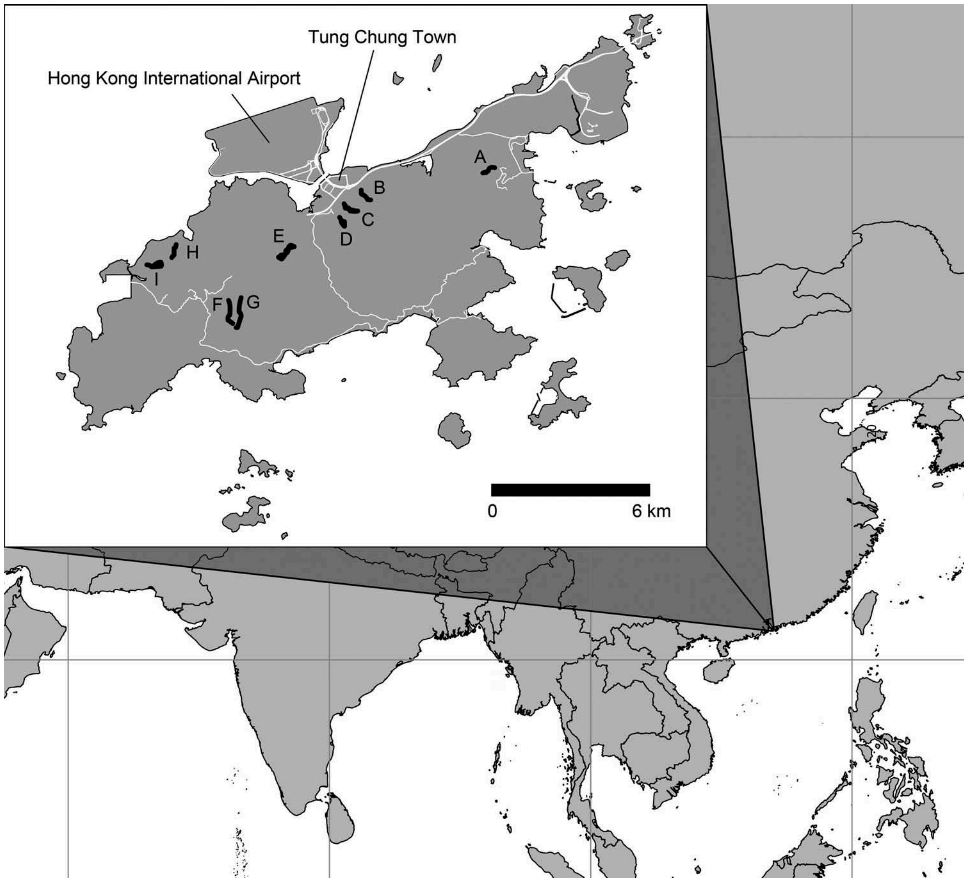

Figure 1. Location of the nine landslide trails (A-I) selected for this study on Lantau Island, Hong Kong. All landslides occurred on 7 June 2008.

trail; the transportation zone is defined as the trail downslope of the initiation zone where debris transport predominates; while the deposition zone is where the majority of the debris are deposited (Franks, 1999; Walker et al. 2009). All sampling plots were evenly placed in the transportation and deposition zones in each landslide trail, but not near the initiation zone as it is often too steep and unstable to access. We identified deposition zones by the presence of large boulders and large wood logs, which were often at the bottom of the trail. Sampling plot elevation was initially determined with a handheld GPS device (GPSMAP® 60CSx, Garmin Ltd.) and then verified using 1:20,000 topographic maps produced by the Survey and Mapping Office of the HKSAR Government.

Data analysis

A species rank abundance curve was constructed to demonstrate relative abundance of all tree and shrub species recorded on the landslide trails. Species with <1% of the total number of individual woody plants were considered as rare (Blackham et al. 2014). The effects of landslide trail and zonation on stem density, species diversity and evenness of the established vegetation were tested using two-way ANOVAs. We used Pearson correlations to measure the dependence of stem density, species richness and evenness on elevation. Patterns of species composition were analyzed by non-metric multi-dimensional scaling (NMDS) based on the absolute abundance of plant individuals. Only trees and shrubs were included in the analysis as abundance data for herbaceous, climbing and fern species were impractical to obtain in the field. These data were square-root transformed and then normalized by Wisconsin double standardization in order to down-weight the effect of the most abundant plant species. The Bray-Curtis coefficient was used for similarity measure among sampling plots. Differences in plant community composition among landslide trails and zones were tested for significance using analysis of similarity (ANOSIM), with 1000 random reassignments of species to groups to determine whether the dissimilarity matrix was significantly different from random (Warwick et al. 1990). Similarity Percentages (SIMPER) was used to identify the major contributors to the dissimilarity of plant communities among landslide trails (Seaby and Henderson 2014). All analyses were performed using R 3.3.3 (R Development

Core Team 2011). The vegan library (Oksanen et al. 2017) was used for the NMDS analysis.

Results

A total of 182 morphospecies was recorded in the 48 sampling plots, including 72 trees and shrubs, 93 herbaceous and climbing species, and 17 ferns. For trees and shrubs, 1,304 individuals were recorded with a mean density of 1.09 ± 0.71 individual m^{-2}, ranging from 0.16 to 2.84 individuals m^{-2} (Table 1). The species rank abundance curve suggests that landslide trails were dominated by a few species (Figure 2). Among the 72 trees and shrubs, 51 are rare species (70.8%), indicating low evenness. The shrub species *Melastoma sanquineum* (Melastomaceae) is the most abundant woody species recorded, constituting 20.7% of all woody individuals across all plots surveyed. This species was 2.35 times more abundant than the second most abundant species *Mallotus paniculatus* (Euphorbiaceae) and 2.81 times more abundant than the third one, *Sapium discolor* (Euphorbiaceae). *Melastoma sanquineum* is also the most frequent species in the survey (present in 81.63% of all plots), followed by *Mallotus paniculatus* (63.27%) and *Sapium discolor* (61.22%) (Table 2). The mean height of trees and shrubs across all plots was 52.40 ± 39.14 cm (mean ± SD). Among the 10 most abundant woody species, three were 2 m or taller in height, namely *Mallotus paniculatus, Sterculia lanceolata* and *Melastoma sanguineum* (Figure 3).

The ground cover was dominated by two ferns, *Dicranopteris pedata* (16.86 ± 13.27%) and *Blechnum orientale* (15.37 ± 13.66%), which were also the two most frequent species across the landslide trails (Table 3). Although a total of 110 herbaceous, climbing and fern species were recorded, most covered less than 5% of the plot area, suggesting unevenness as in the woody component.

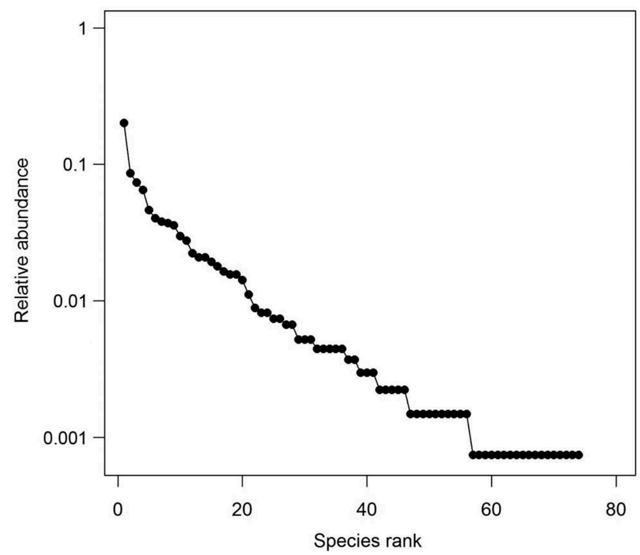

Figure 2. Rank abundance curve of trees and shrubs recorded by quadrat surveys in the landslide trails after 2.5 years of natural ecological succession.

The similarity of vegetation composition among plots is illustrated by the two-dimensional NMDS plot (Figure 4). The ordination has a stress of 0.19, which provides a reasonable representation of the similarities between the samples. A significant difference was found between landslide trails in terms of plant community compositions (ANOSIM $R = 0.47$, $p = 0.001$). Common species (species with relative abundance ≥1%) contributed at least 40% to plant composition dissimilarities in all the comparisons among landslide trails. No compositional differences were detected among landslide zones (ANOSIM $R = 0.03$, $p = 0.87$).

Table 1. Natural regeneration diversity and structure on the nine landslide trails.

		Landslide Trails									
		A	B	C	D	E	F	G	H	I	Pooled
Number of plots		4	6	6	3	6	6	5	6	6	48
Species diversity											
Shannon-Weiner index	Mean	1.92	1.94	1.88	1.8	1.39	2.03	1.96	1.68	1.76	3.22
	SD	0.27	0.49	0.3	0.17	0.36	0.38	0.26	0.56	0.52	
Species richness											
No. of species per trail		43	67	57	51	48	65	62	50	51	182
No. of species per 25 m^2 plot	Mean	20.5	24	21.5	25	15.67	22.5	23.4	22.67	16.17	21.02
	SD	4.8	6.23	3.45	6.08	3.88	8.6	5.86	7.79	7.83	6.63
Plant regeneration											
Stem density (individual m^{-2})	Mean	1.47	1.77	0.93	1.01	0.35	0.72	1.49	1.11	0.79	1.07
	SD	0.81	0.80	0.23	0.46	0.31	0.41	0.88	0.82	0.39	0.71
Vegetation height (cm)	Mean	65.82	60.14	45.49	15.03	64.59	54.43	52.27	44.14	53.13	52.40
	SD	52.21	34.47	30.76	10.69	49.66	41.37	41.94	23.44	35.97	39.14
Percentage ground cover											
Dicranopteris pedata	Mean	11.25	23.33	19.17	8.33	20.00	18.75	14.00	19.17	10.00	16.86
	SD	6.29	16.33	20.60	2.89	14.14	15.48	10.84	12.01	7.07	13.27
Blechnum orientale	Mean	16.25	7.20	15.00	25.00	24.17	20.00	21.00	10.83	5.00	15.37
	SD	11.09	4.09	5.48	21.21	21.31	21.21	14.32	9.70	0.00	13.66

Table 2. The ten most abundant tree and shrub species and their respective frequency of occurrence in the landslide trails.

Family	Species	% of Abundance	% Quadrats	Dispersal agents
Melastomaceae	*Melastoma sanguineum*	20.1	81.63	Bird
Euphorbiaceae	*Mallotus paniculatus*	8.6	63.27	Bird
Euphorbiaceae	*Sapium discolor*	7.4	61.22	Bird
Clusiaceae	*Cratoxylum cochinchinense*	6.5	34.69	Wind
Ulmaceae	*Trema tomentosa*	4.6	40.82	Uncertain
Euphorbiaceae	*Phyllanthus cochinchinensis*	4.0	30.61	Unknown vertebrates
Sterculiaceae	*Sterculia lanceolata*	3.8	34.69	Bird
Rosaceae	*Rhaphiolepis indica*	3.7	30.61	Bird
Grossulariaceae	*Itea chinensis*	3.6	32.65	Wind
Melastomaceae	*Melastoma candidum*	3.0	35.42	Bird

The dispersal mode of each plant species was deduced by combining inferences based on fruit morphology and literature review. The biotic dispersal agents of the plants established on the landslide trails include birds, macaques, civets, fruit bats, rodents and hornets. The abiotic modes include wind and mechanical dispersal (Figure 5). In terms of individual plants, birds are the most important dispersal agent (52.1%), followed by wind (21.7%). Other dispersal modes accounted for less than 5% of all plant individuals (excluding the unknown agents). In terms of woody species, 46.6% of the species recorded are bird-dispersed, followed by wind (8.2%) and birds and civets (4.1%). Within all the plant species, bird-dispersed and wind-dispersed modes are equally important, accounting for 54.5% of the species. Other modes explain 7.5% of the total plant species in total.

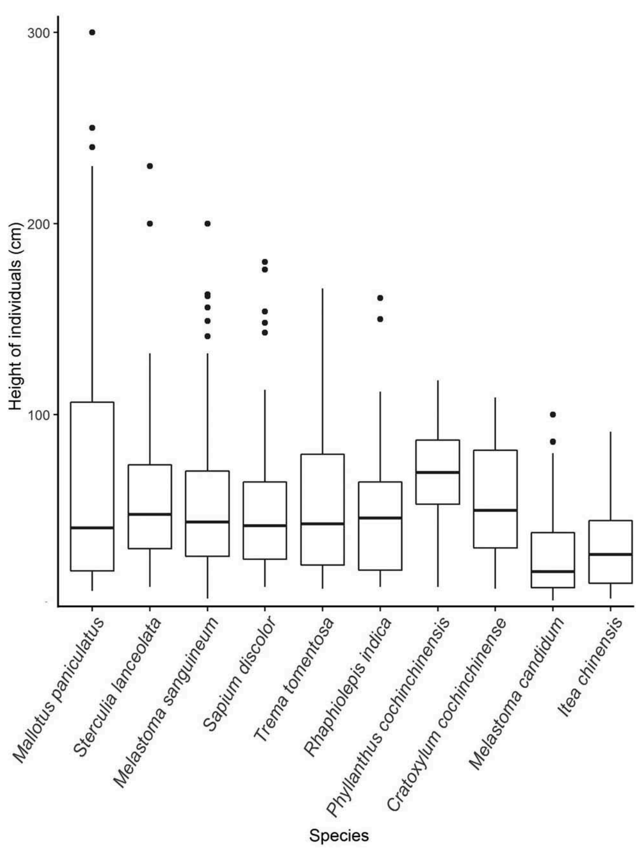

Figure 3. Individual height distribution of the ten most abundant woody species on the landslide trails.

The two-way ANOVA of nine landslide trails and two zones (transportation and deposition) is presented in Table 4. No statistical difference was found for species diversity, evenness and stem density across zonation of trails (two-way ANOVA, species diversity: $p = 0.97$; stem density: $p = 0.28$; Shannon-Weiner index: $p = 0.89$). Stem density varied among landslide trails, but not species richness and evenness. Trail B showed a higher stem density than the rest of the trails while trail E had the lowest density (two-way ANOVA, Tukey Honestly Significant Difference post hoc comparison, $p < 0.05$). The mean (± SD) altitude of all the plots surveyed was 123.5 ± 56.4 m, ranging from 47 m to 238 m above sea level. There was no significant correlation between elevation and stem density (r = 0.11, $p = 0.44$), as well as species diversity (r = 0.03, $p = 0.83$), and Shannon-Weiner index (r = 0.09, $p = 0.55$).

Discussion

This study documented the plant community established on 2.5 year-old landslide trails in Hong Kong. Woody regeneration in the study sites consisted largely of pioneer species that are common in other disturbed habitats in Southeast Asia, including light-demanding *Cratoxylum cochinchinense, Melastoma* spp. and

Table 3. The ten most widespread herb and fern species in the landslide trails.

Family	Species	% Quadrats	Dispersal agents
Blechnaceae	*Blechnum orientale*	93.88	Wind
Gleicheniaceae	*Dicranopteris pedata*	87.76	Wind
Poaceae	*Miscanthus sinensis*	53.06	Wind
Poaceae	*Thysanolaena agrostis*	46.94	Wind
Cyperaceae	*Scleria ciliaris*	40.82	Uncertain
Lycopodiaceae	*Palhinhaea cernua*	36.73	Wind
Lindsaeaceae	*Sphenomeris chinensis*	36.73	Wind
Asteraceae	*Ageratum conyzoides*	28.57	Wind
Liliaceae	*Dianella ensifolia*	24.49	Bird
Rubiaceae	*Hedyotis acutangula*	24.49	Uncertain

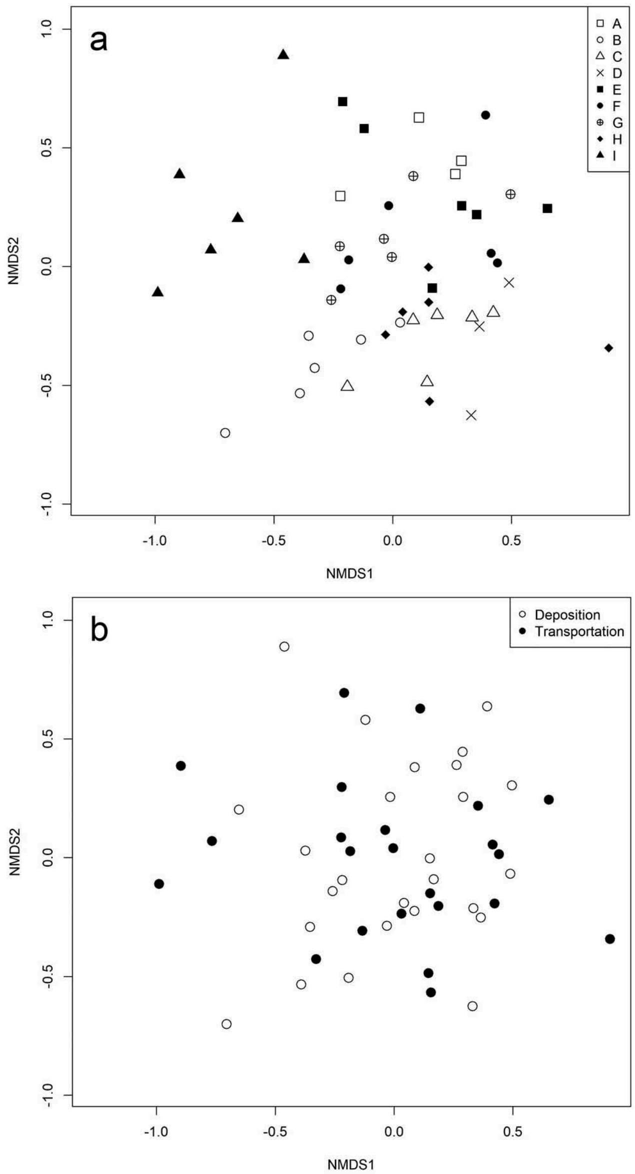

Figure 4. Non-metric multidimensional scaling (NMDS) plots of woody species composition for the surveyed quadrats in the landslide. The community data was square-root transformed and then submitted to Wisconsin double standardization. The plot has a stress of 0.19 which provides a reasonable representation of the similarities between samples. Compositional difference was detected across landslide trails (A) but not among zones (B) using ANOSIM (analysis of similarity).

Mallotus paniculatus (Au et al. 2006; Slik et al. 2008). Plant community composition and stem density were shown to be site-specific and differed across landslide trails. We found no difference in stem density, species diversity and community composition among different zones on the landslide trails. This suggests that most regenerated plant species did not have strict habitat requirements.

The ground cover of the landslide trails was mainly dominated by two ferns: *Blechnum orientale* and *Dicranopteris pedata*. These species are very common locally and often quickly colonize disturbed areas to form dense fern thickets (Corlett et al. 2000; Lai and Wong 2005; Wang et al. 2008). *Dicranopteris* spp. and *Blechnum* spp. have repeatedly been shown to form dense thickets 1–2 meters in height after disturbance (Cohen et al. 1995; Dudgeon and Corlett 2004; Yan et al. 2004; Shono et al. 2006). Although their presence could improve soil fertility by increasing soil moisture, soil nitrogen levels and organic litter thickness, they can also suppress woody regeneration by occupying both above- and below-ground growing space in the early stages of ecological succession (Cleary and Priadjati 2005; Shono et al. 2006; Velázquez and Gómez-Sal, 2009; Walker et al. 2010; Blackham et al. 2014).

Woody species established on the landslide trails are generally classified as pioneer light-demanding species which are able to colonize thin, infertile soils. Among them, *Mallotus panicultus, Sterculia lanceolata* and *Melastoma sanguineum* were the only species that reached over 2 m within 2.5 years. Species with rapid growth are particularly advantageous, especially when competing with fern thickets which shade out the shorter, young tree seedlings. Rapid growing trees may have created patchy shelters along the landslide trails, given that the density of tall individuals (>2 meters in height) was sparse. This may have created less favorable habitats for the light-demanding ferns and promoted the growth of more shade-tolerant late-successional species. They also serve as perches to attract bird dispersers to promote seed rain upon the landslides (Shiels and Walker 2003; Walker et al. 2009). However, no typical late-successional species, such as *Machilus* spp., *Syzygium* spp. and Fagaceae, was observed (Zhuang and Corlett 1997; Zhang et al. 2013).

Woody regeneration on the landslide trails was dominated by species dispersed by wind and birds. Species that are common on landslide trails have been reported to be frequently consumed by bulbuls (*Pycnonotus* spp.) and Japanese white-eye (*Zosterops japonicas*), which are abundant in the study area (Corlett 1998; Carey et al. 2001). The domination of bird-dispersed species in early successional stages in Hong Kong is explained by the loss of large frugivores, especially mammals, due to intensive deforestation and hunting in the pre-colonial period (Dudgeon and Corlett 2004). Similar observations were reported in Singapore (Corlett 1991; Shono et al. 2006), Indonesia (Blackham et al. 2014) and South China (Ren et al. 2007) where bird-dispersed plants dominate in novel and newly disturbed areas in the absence of mammals. Mammal-dispersed species are sparse on landslide

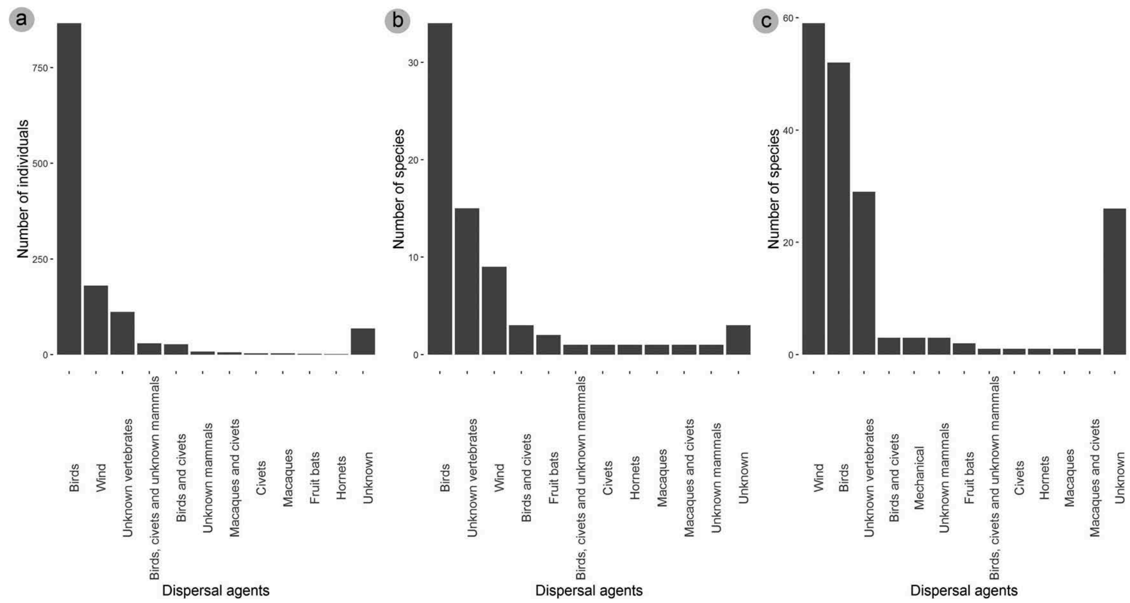

Figure 5. Number of tree and shrub individuals (A), number of tree and shrub species (B) and number of all plant species (C) by their dispersal agents in the landslide trails.

Table 4. Two-way ANOVA of the effects of landslide trails and zonation on stem density, species richness and Shannon-Weiner index in the samplings plots.

Source of variations	d.f.	SS	MS	*F*-ratio	*p*
Stem density					
Trail	8	4,268	533.5	2.40	0.03*
Zonation	1	268	267.8	1.21	0.28
Species richness					
Trail	8	166	20.7	1.78	0.11
Zonation	1	0.00	0.02	0.00	0.97
Shannon-Weiner index					
Trail	8	1.59	0.20	1.20	0.33
Zonation	1	0.00	0.00	0.02	0.89

trails, though this does not necessarily reflect seed deposition by mammals such as civets or fruit bats. Seeds may reach the trails directly from parent plants next to the landslide trails. Wind-dispersed species appeared to be more important in colonizing the ground cover of the degraded landslide trails. Wind-dispersed species often have a long seed shadow, which is particularly advantageous for opportunistic herbaceous plants to colonize disturbed areas, which would later be dominated by trees and shrubs (Willson 1993). The airborne nature of seeds or spores allows the plants to reach areas shortly after disturbance, where animals seldom visit, which explains the biased dispersal mode of plant assemblages on landslide trails.

Early successional stages on landslide trails in Hong Kong are dominated by similar species as observed in other disturbed areas in Southeast Asia (Corlett 1991; Shono et al. 2006; Ren et al. 2007; Wang et al. 2008; Blackham et al. 2014), but the process of vegetation recovery varied across studies. In Malaysia and Singapore, areas disturbed by intensive agriculture required more than two decades to accumulate 50 woody species (Kochummen and Ng 1977; Corlett 1991). In this study, we recorded an even higher richness (72 woody species in 1,200 m^2 of degraded area) less than three years after disturbance, which is comparable to another study in Singapore (Shono et al. 2006). This rapid recovery is probably due to higher availability of nearby natural seed sources, compared to larger deforested areas (Velázquez and Gómez-Sal 2008).

As most natural terrains in Hong Kong have been intensively degraded by logging and fire in the past, the current vegetation species pool is considered well-adapted to disturbances such as landslide, while many late-successional and climax species have probably been lost (Dudgeon and Corlett 2004). Despite the unfavorable soil conditions, landslides are likely to be within the effective dispersal range of most woody species (i.e., ≦30 m) (Martínez -Garza & Gonzalez-Montagut, 1999, 2002; Dosch et al. 2007). Therefore, although with a limited sample size, it is reasonable to expect a similar successional pattern on most landslides in Hong Kong. This study revealed that the recruitment of woody species on landslides in Hong Kong is high in the early successional stage, but further monitoring of the impact of dense fern thickets on tree growth is necessary. This potential barrier to restoration may be overcome by promoting rapid-growing trees and removal of aggressive fern thickets, although this needs to be documented by empirical studies (Walker 1994; Negishi et al. 2006; Walker et al. 2009). While traditional tree planting is difficult on remote and steep terrains, technological advances in aerial seeding using unmanned vehicles could possibly become a more economical and effective option to sow seeds in those areas in order to speed up tree regeneration and control soil erosion.

Conclusion

This study documented a fast-regenerating vegetation community on young landslide trails in Hong Kong. Spontaneous regeneration was shown to yield a diverse pioneer community on disturbed sites when compared to other studies in Southeast Asia. Close proximity to natural seed sources is considered crucial in explaining this high plant diversity. Fast growing pioneer tree species were identified, and were able to reach over 2 m in height within 2.5 years after disturbance, hence providing bird perches for further seed rain to the landslide trails. Although invasive species were rare, two native mat-forming ferns were found to be abundant along the landslide trails and could potentially suppress subsequent woody regeneration. To restore landslide-disturbed areas, direct seeding or pit planting of selected pioneer woody species immediately after disturbance should be promoted. This could potentially quicken the speed of vegetation regeneration and overcome the suppressive effect of fern thickets on the regrowth of woody components.

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Disclosure statement

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