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Original Research Article

Vegetation succession on landslides in Hong Kong: Plant regeneration, survivorship and constraints to restoration

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ABSTRACT

Landslides often lead to a unique successional direction because the existing vegetation, seed bank and top soil including nutrient and mycorrhizal inoculum have been lost. This type of disturbance has attracted more attention in recent decades especially in mountainous regions experiencing regular severe rainstorm. In Hong Kong, urban development has been recently extended towards the natural terrain, which consequentially increased the social-economic impact brought by natural terrain landslides. In order to facilitate ecological restoration in such habitats, we studied the establishment and change of vegetation composition on eight landslide trails over the first 8.5 years after the disturbance. We conducted three censuses to measure the survivorship and height of woody individuals at these sites over the study period. We found that the woody composition did not vary across the censuses in terms of stem density, species richness, Shannon-Weiner's index and assemblage similarity. Most of the early-established individuals died in early succession which out-numbered the recruited individuals. Landslides became dominated by fern thickets formed by *Dicranopteris pedata* and *Blechnum orientale* which probably accounts for the suppressed colonization of woody plants. We identified fast-growing trees and species with highest survival rate which could potentially be used for future ecological restoration. They may serve as bird perches and facilitators of seed rain, while suppressing the expansion of fern thickets. Since fern clearance was practically difficult on landslide sites which are steep and remote, we recommended repeated sowing with woody pioneer seeds soon after the disturbance before the establishment of fern thickets. Using UAV for direct seeding could be tested on such remote and difficult terrain.

1. Introduction

Ecological succession is a fundamental concept in plant community and restoration ecology (Johnson, 1979; Johnson and Miyanishi, 2008; Turner et al., 1998). Succession describes the change of vegetation community after disturbances over time, reflecting the spatial and temporal sequences of colonisation and extinction of plants, and the dynamics of the species diversity and the plant community structures (Cook et al., 2005; Li et al., 2017). Different types of disturbances were shown to

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have deterministic impact on the rate and direction of succession. Frequency, size, intensity and severity of disturbances gave shape to the successional pattern (Turner et al., 1998). Vegetation regeneration from forest gaps, abandoned croplands or deforestation was mostly influenced by the residual vegetation and the surrounding seed sources (Aide et al., 1995; Blackham et al., 2014; Kochummen and Ng, 1977; Kou et al., 2016; Tognetti et al., 2010; Zhang, 2005). Succession followed by large, infrequent disturbance was reported to be less predictable, which yielded highly heterogeneous community structures than the small-gap paradigm (Turner et al., 1998).

Among many natural and human-induced disturbances, landslides often create unique successional patterns due to their very different geological and ecological profile. Landslides generally remove all existing vegetation together with the topsoil including seedbank, nutrient and mycorrhizal inoculum (Adams and Sidle, 1987; Dalling and Tanner, 1995; Garwood, 1985; Guariguata, 1990). Re-sprouting from existing vegetation is difficult since stumps and logs are largely absent on landslides. This natural disturbance is particularly frequent in mountainous regions experiencing severe rainstorm (Dai et al., 2001). Such a unique but poorly studied successional pattern had attracted more studies in recent decades (e.g. Guariguata, 1990; Li et al., 2017; Řehounková et al., 2018; Velázquez and Gómez-Sal, 2008; Walker, 1994; Walker et al., 2010; Walker et al., 1996).

Hong Kong's landscape is rugged with 63% of the total land area steeper than 15° and 30% steeper than 30° (Choi and Cheung, 2013). Hong Kong is also affected by a sub-tropical monsoon climate which experiences severe rainstorm and typhoons each year. As a result, landslides are common and over 100,000 landslide events have been recorded between 1924 and 2006 (MFJV, 2007). In addition, large-scale degradation has occurred throughout the history of Hong Kong including logging in pre-colonial period and human-induced hill fires each year (Dudgeon and Corlett, 2004; Zhuang and Corlett, 1997). The combined natural and human disturbance has led to a novel, yet poorly studied, successional pattern in the natural terrain of Hong Kong.

Interestingly, previous studies in ecological succession in Hong Kong focused mainly on secondary forests, plantations and upland habitat with little focus on landslides (Au et al., 2006; Hau and So, 2002; Lee et al., 2005; Zhuang and Corlett, 1997). Since urban development has been extended towards rural areas in Hong Kong in recent decades (Development Bureau, 2017), landslides on natural terrains have become a concern because of their social-economic consequences. For instance, the North Lantau Expressway, a major transportation corridor connecting urban Hong Kong and Hong Kong International Airport, was blocked for 16 h by channelized debris flows caused by a severe rainstorm on 7th June 2008 (AECOM, 2012). On landslide trails that are determined as unstable, reinforced concrete barriers will be built on the tail of the landslide trails to mitigate the impact of further debris flows (Choi and Cheung, 2013). For landslides on remote natural terrains that are not affecting human life and properties, no mitigation measures will be carried out. In both cases, no restoration of the landslide surface is provided. Natural succession is allowed to take its course which is often very slow due to the lack of top soil and seeds. A study on the succession pattern on these landslide surfaces is needed to inform appropriate methods to speed up natural succession.

In this study, we investigated the change of plant establishment, growth and composition on landslides over the first eight and a half years after the disturbance. We hypothesized that the pioneer herbaceous ground cover would be gradually replaced by woody component over time. We further examined the pioneer species by their survivorship and growth, which could provide insight on future restoration strategies in Hong Kong and South China with similar vegetation composition and disturbance history.

2. Material and methods

2.1. Study area

This study was conducted on eight landslides on Lantau Island, Hong Kong, China (22° 16′ 8″ N 113° 57′ 6″ E) which were triggered by a severe rainfall event (300 mm in 24 h) on 7th June 2008. Lantau Island is the largest outlying island in Hong Kong. Frequent landslides occur on Lantau partly due to its rugged terrain where 44% of the land has a slope gradient larger than 25° (Dai et al., 2001) and severe rainstorms. In addition, Lantau has experienced intensive anthropogenic disturbance since the pre-colonial period over a century ago, such as timber harvesting and human-induced hill fire (Dudgeon and Corlett, 2004). These activities had shaped the vegetation cover of the island. Over 50% of the land area of Lantau Island is covered with shrubland and grassland; 26.9% in bareland while secondary woodland represents only 20.5% (Zhou et al., 2002). At present, the island remains largely undeveloped and uninhabited. Major development on the island is restricted to the eastern half of the north coast of the island while low-density villages are scattered on the coastline of the rest of the island (Zhou et al., 2002).

2.2. Sampling design

Vegetation succession was studied in $5 \times 5\ m^2$ permanent quadrats on eight landslide trails (A to H on Fig. 1). The permanent quadrats were randomly fixed in each landslide trail. Three quadrats were fixed at site A and D; five at site B and C; and six at the rest of the sites with a total of 40 quadrats. This is a result of site constraints such as size and steepness of the landslides.

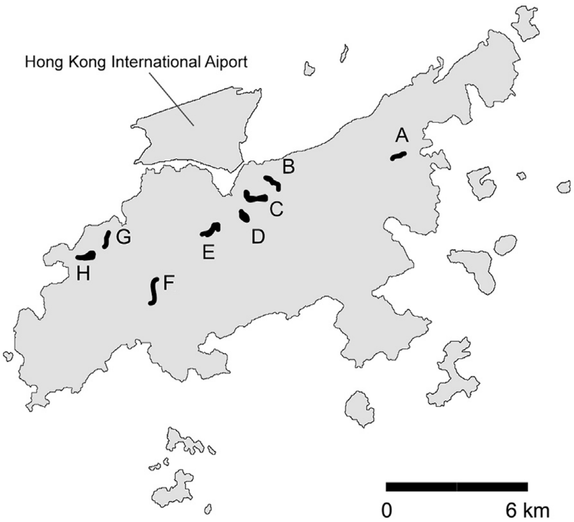

Fig. 1. Location of the eight landslide trails (A–H) on Lantau Island, Hong Kong. All landslides occurred on 7th June 2008 during a severe rainfall.

Woody plants taller than 5 cm within the quadrats were identified to species, counted and measured in height. They were also number-tagged for examination of their growth and survivorship in subsequent surveys. Percentage ground cover of herbaceous species, climbers and ferns was visually estimated. In this study plant nomenclature follows Hong Kong Herbarium & South China Botanical Garden (2007–11). Each quadrat was surveyed three times: the first survey was completed between September 2010 and March 2011 (census 1); the second one was done between December 2011 and March 2012 (census 2); and the third one between August 2016 and February 2017 (census 3). In other words, the sampling plots were surveyed approximately two and a half years, three and a half years and eight and a half years after the landslides were triggered, respectively.

2.3. Data analysis

We investigated the pattern of vegetation succession on the landslides by inspecting the change of mean stem density, species richness and Shannon-Weiner's index across the three surveys. We calculated the Shannon-Weiner's index by: $H' = \sum_{i=1}^{n} p_i \ln p_i$ where p_i is the relative abundance of woody species i in a particular sampling plot and survey year. Importance Value Index (IVI) was calculated for each species by: IVI = relative frequency + relative abundance + relative density (Bhadra and Pattanayak, 2016). One-way Repeated Measures ANOVA was performed to test the statistical significance of change of each variable. A similar approach was used to test the change of the percentage ground cover of two dominating ferns, *Dicranopteris pedata* and *Blechnum orientale*, in the successional process. Patterns of species composition were analysed by non-metric multi-dimensional scaling (NMDS) based on the absolute abundance of plant individuals. Only trees and shrubs were included in the analysis since abundance data for herbaceous, climbing and fern species were impractical to obtain. The data was 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. The significant difference in plant community composition among censuses was obtained using analysis of similarity (ANOSIM). The analysis uses 1000 random reassignments of species to groups to determine whether the dissimilarity matrix is significantly different from random (Warwick and Clarke, 1990).

We divided all woody individuals into seedlings (≥50 cm and <1 m in height), small saplings (≥1 m and <3 m in height) and large sapling (≥3 m in height). Their density was tested for the effect of time allowed for regeneration using One-way Repeated Measures ANOVA. Landslide and quadrat were treated as the error terms. We also pooled all the woody individuals and assigned them into three categories "recruited", "survived" and "died". "Recruited" is defined as the individuals recorded only in census 3; "Survived" are represented by the individuals that persisted in census 3 since census 1 and/or 2. "Died" are those individuals that died and/or disappeared in census 3. The proportion of individuals within each category was calculated per sampling plots and was compared.

We investigated the growth and survivorship of the tagged individuals since our first census, i.e. 2.5 years after the landslide event. The height increment and survival of each tagged individual within the sampling plots were measured and noted. The mean cumulative height increment and survival were compared between species, using One-way ANOVA. All analyses were performed using R 3.3.3 (R Development Core Team, 2014). The vegan library (Oksanen et al., 2017) was used for the NMDS analysis and the agricolae library (De Mendiburu, 2014) for Tukey Honestly Significant Difference post hoc comparison.

3. Results

We sampled all 40 permanent quadrats in 2.5 years (census 1) and 3.5 years (census 2) after the landslide (Table 1). A total of 88 species of tree and shrub species and 118 herbaceous and climbing species were cumulatively recorded on the eight landslides. The mean stem density (±standard error) varied from 1.066 ± 0.110 individual m^{-2} in the first census, to 1.061 ± 0.109 in the second census, and to 0.937 ± 0.09 in the third census. The mean species richness in the three censuses was 9.08 ± 0.62, 9.00 ± 0.60 and 9.23 ± 0.64 respectively. We detected no significant difference of mean stem density and species richness between censuses (Fig. 2A—C). Similarly, no difference was found in the Shannon-Weiner's index of sampling plots between censuses (census 1: 1.77 ± 0.07, census 2: 1.77 ± 0.07 and census 3: 1.79 ± 0.08). Such results suggest that no clear successional trend was observed in the first decade after disturbance.

Importance Value Index gives an indication of the dominance of a species across all sampling plots (Bhadra and Pattanayak, 2016). Over 90% of the species in all censuses had an IVI lower than 10, indicating that the landslides are dominated by a few species at any one time in the first 8.5 years after disturbance. *Melastoma sanguineum* was the species with highest IVI throughout the study period (IVI: 33.29 ± 1.01), followed by *Mallotus paniculatus* (IVI: 15.78 ± 0.19) and then *Sapium discolor* (IVI: 12.75 ± 2.06) (Table 2).

Two ferns, *Dicranopteris pedata* and *Blechnum orientale*, dominated the ground cover since the first census. We found that their coverage increased over time (One-way repeated measures ANOVA, *D. pedata*: $p < 0.001$; *B. orientale*: $p < 0.01$) (Fig. 2D and E). *D. pedata* covered $28.15 \pm 4.38\%$ of the area of the sampling plots in census 3 while *B. orientale* covered $23.45 \pm 3.81\%$.

The vegetation compositions on the landslides were highly similar between the first and second censuses. We excluded the second census from the NMDS analysis. The similarity of vegetation composition among plots is illustrated by the two-dimensional NMDS plot (Fig. 3). The ordination has a stress of 0.21, which provides a reasonable representation of the similarities between the samples. However, only a marginal compositional difference was detected between census 1 and 3 (ANOSIM $R = 0.03$, $p = 0.07$).

Mean density of tree seedlings, small saplings and large saplings in the sampling plots varied between census (One-way ANOVA, $p < 0.001$) (Fig. 4A). Density of seedlings decreased over time while small saplings increased in density from census 1 to 3 (Table 3). Density of large sapling was extremely low in the first two censuses (census 1: 0.002 ± 0.001 m^{-2}; census 2: 0.011 ± 0.004 m^{-2}) and it increased significantly in census 3 (0.05 ± 0.01 m^{-2}). Among all established woody individuals recorded in the three censuses, majority ($53.7 \pm 3.0\%$) had disappeared or died. Only $13.3 \pm 2.4\%$ survived, at least, since the second census (One-way ANOVA, $p < 0.001$) (Fig. 4B). $33.0 \pm 3.1\%$ of them was recruited since the second census.

Examination of the height increment and survivorship of different species on the landslides suggested that both parameters varied with species (One-way repeated measures ANOVA, Tukey Honestly Significant Difference post hoc comparison, height increment: $p < 0.001$; survivorship: $p < 0.001$) (Fig. 5). For height increment, an average height increment of 114.4 ± 7.72 cm was recorded for all woody individuals between the first and third censuses. *Pinus massoniana* demonstrated the quickest growth rate, with a mean increment of 392.0 ± 32.3 cm. *Litsea cubeba* was the second most fast-growing species, with a mean increment of 317.3 ± 83.0 cm. For survivorship, $15.3 \pm 4.3\%$ of the tagged individuals survived since the first census. *Gardenia jasminoides* showed the highest survival rate (0.86 ± 0.14 individual survived), followed by *Reevesia thyrsoidea* (0.55 ± 0.22) and then *Adina piluifera* (0.50 ± 0.08).

4. Discussion

4.1. Patterns of plant regeneration in succession

Spontaneous plant succession occurred for over eight years on the landslide trails after disturbance. There was no clear trend of stem density on the landslides in this period. Density of small and large saplings increased over time as expected.

Table 1
Summary of the natural regeneration on the landslides across the three censuses (Mean ± S.E.).

	Census 1	Census 2	Census 3
Number of sampling plots	40	40	40
Years after landslide	2.5	3.5	8.5
Woody regeneration (individual m^{-2})			
Total stem density	1.07 ± 0.11	1.06 ± 0.11	0.94 ± 0.09
Density of seedlings	0.94 ± 0.09	0.63 ± 0.08	0.35 ± 0.05
Density of small saplings	0.11 ± 0.02	0.25 ± 0.03	0.40 ± 0.05
Density of large saplings	0.00 ± 0.00	0.01 ± 0.00	0.05 ± 0.01
Species diversity (per 25 m^2 plot)			
Shannon-weiner's index	1.77 ± 0.07	1.77 ± 0.07	1.79 ± 0.08
Species richness (per 25 m^2 plot)			
No. of species	9.08 ± 0.61	9.00 ± 0.60	9.23 ± 0.64
Percentage ground cover (%)			
Dicranopteris pedata	15.00 ± 2.28	16.33 ± 3.04	28.15 ± 4.38
Blechnum orientale	12.87 ± 2.23	12.93 ± 1.92	23.45 ± 3.81

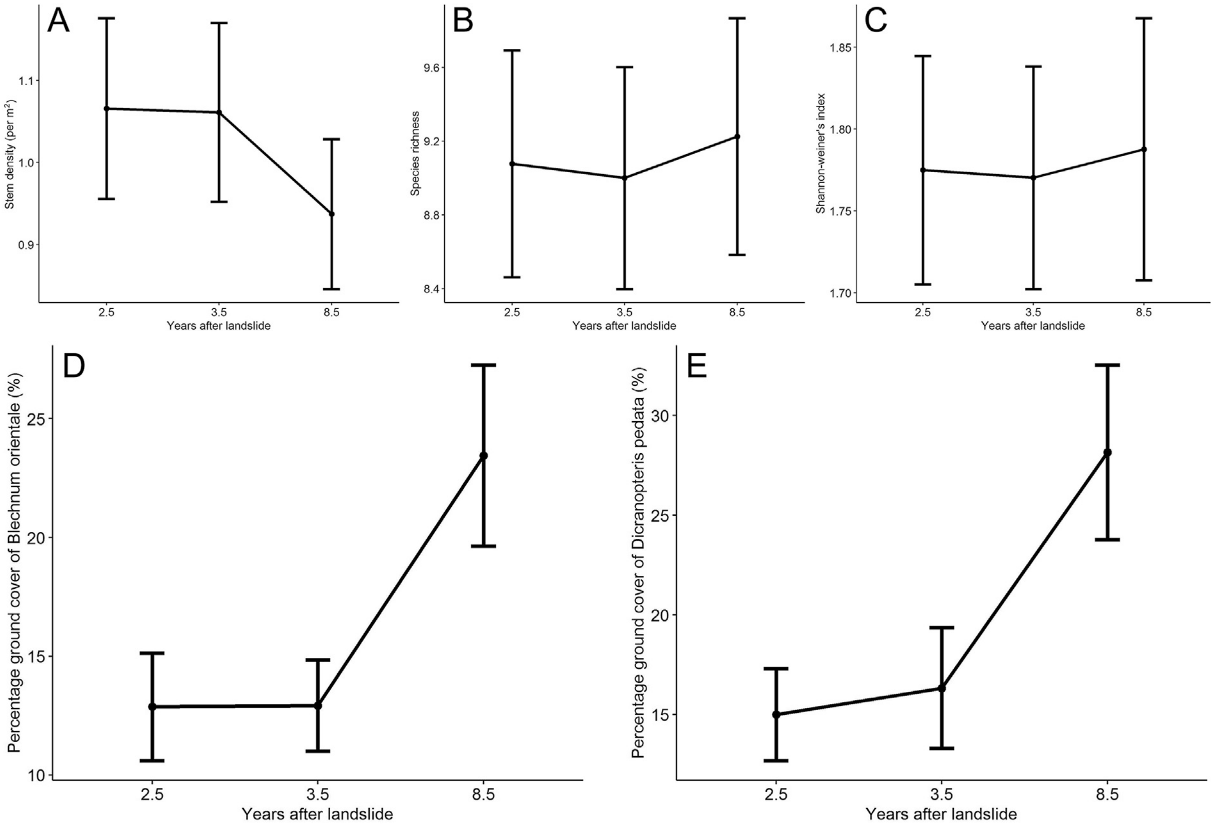

Fig. 2. Natural regeneration of woody individuals and dominating fern species on landslides over 8.5 years of succession. (A) Stem density (individual m^{-2}); (B) Species richness per 25 m^2 sampling plots; (C) Shannon-Weiner's index per sampling plots; and percentage ground cover of (D) *Blechnum orientale* and (E) *Dicranopteris pedata.*

However, density of seedlings declined, suggesting that the recruitment was less successful along the successional continuum, compared to other studies (Norden et al., 2011, 2012; van Breugel et al., 2007). The reduced density of seedlings is probably attributed to the increased vegetation cover on the landslide trails, i.e. less space was allowed for the establishment of seedlings over time. Furthermore, most pioneer species are light demanding which germinate poorly if seeds are shaded. The decline in seedling density was also supported by the absence of seedlings of late-successional species although their colonization rate is not necessarily comparable to those of pioneer species.

Species richness established on the landslides sharply increased soon after disturbance but remained stable afterwards. Our NMDS analysis further suggests that there was a subtle species turnover in the study period. Such asymptotic phenomena were reported for degraded areas in tropical Andes (Sarmiento et al., 2003), Switzerland (Stampfli and Zeiter, 2004) and Argentina (Tognetti et al., 2010). However, even though the species number remained stable over time, species turnover varied between studies. In some studies, the relative abundance of shade-tolerant species increased which replaced the

Table 2
The ten species with highest mean Importance Value Index (IVI) on the landslides.

Scientific name	Mean relative frequency	Mean relative abundance	Mean relative density	Importance Value Index			
				Census 1	Census 2	Census 3	Mean ± S.E.
Melastoma sanguineum	8.77	4.41	20.11	32.36	32.19	35.31	33.29 ± 1.01
Mallotus paniculatus	6.37	2.20	7.21	16.12	15.78	15.45	15.78 ± 0.19
Sapium discolor	5.92	1.68	5.15	14.38	15.22	8.66	12.75 ± 2.06
Cratoxylum cochinchinense	3.42	3.28	5.75	15.15	15.08	7.11	12.45 ± 2.67
Melastoma candidum	4.42	1.90	4.65	8.96	8.68	15.29	10.97 ± 2.16
Itea chinensis	3.61	2.22	4.12	10.28	10.13	9.43	9.95 ± 0.26
Sterculia lanceolata	2.41	3.38	4.03	9.69	9.56	10.19	9.81 ± 0.19
Phyllanthus cochinchinensis	2.22	3.32	3.64	11.53	11.38	4.60	9.17 ± 2.28
Adina pilulifera	1.75	3.65	3.21	9.44	9.33	7.07	8.61 ± 0.77
Rhodomyrtus tomentosa	4.15	1.34	3.07	7.19	7.08	11.41	8.56 ± 1.42

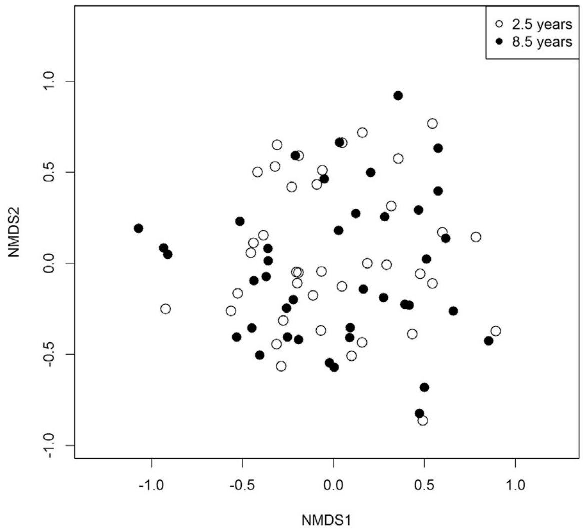

Fig. 3. Non-metric multidimensional scaling (NMDS) plots of the woody composition on the landslides. The community data was square-root transformed and then submitted to Wisconsin double standardization. The plot has a stress of 0.21. Compositional difference was not significant among censuses using ANOSIM (analysis of similarity). The second census (i.e. 3.5 years after the disturbance) was excluded in the analysis.

pioneer species, resulting in null net change of species number (e.g. Collins et al., 1995; van Breugel et al., 2007). Conversely, a study in paramo regeneration demonstrated a successional dynamics known as auto-succession where the plant community changes in abundance more than species replacement (Sarmiento et al., 2003). In most cases, late-successional species established in early stages and increased in abundant over time. In contrary, our study demonstrated a different path of succession: landslides were colonised by pioneer species which persisted over time but without significant increase in abundance. On the other hand, the pioneer species were not replaced by mid- and/or late-successional species in almost a decade. We believe that there are multiple reasons explaining such a pattern. Perhaps the most influential factor is that most natural terrain in Hong Kong had been degraded before, either by human-induced hill fire or non-selective logging in the past (Dudgeon and Corlett, 2004). Many late-successional species, typically slow-growing and/or poorly-dispersed trees, were restricted to isolated patches or lost since the pre-colonial period of Hong Kong (Dudgeon and Corlett, 2004; Pang et al., 2018). There was simply no seed dispersal of the late successional species to the landslides.

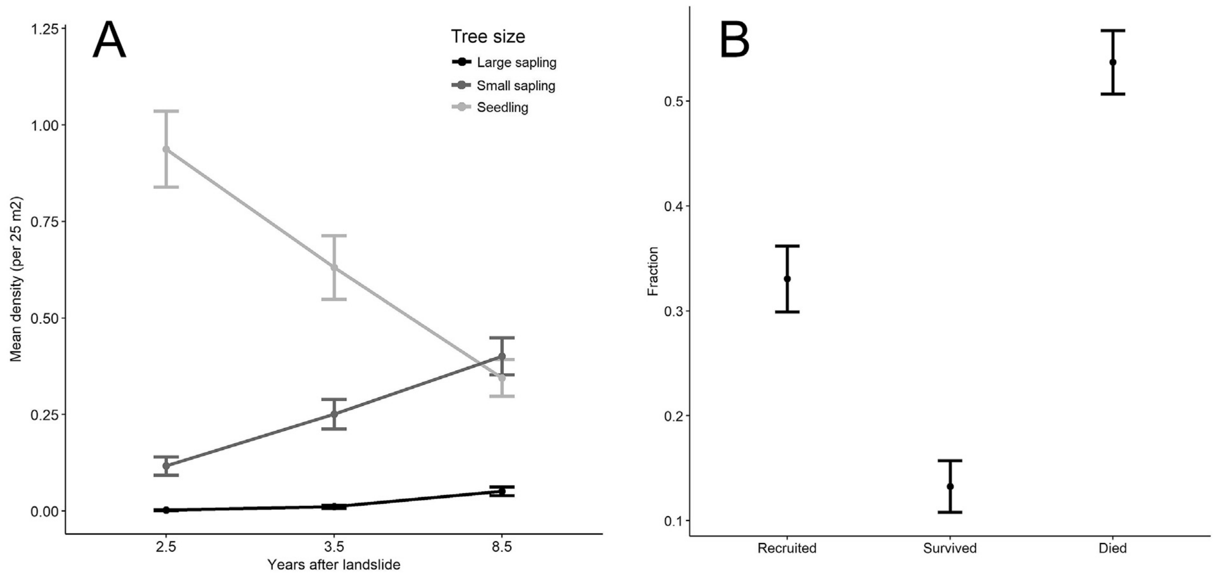

Fig. 4. Establishment and survival of woody individuals on the landslides. (A) Mean stem density of trees in different sizes across the three censuses; and (B) dynamics of the fraction of the woody individuals in the successional communities. “Recruited” is defined as the fraction of individuals recorded only in census 3; “Survived” are those survived since census 1 and 2; and “Died” are those that died or disappeared.

Table 3
Statistical summary of the One-way Repeated Measures ANOVA for the effect of census year on the mean stem density of seedlings, small saplings and large saplings.

Source of variations	d.f.	SS	MS	*F*-ratio	*p*
Seedlings	2	6.93	3.47	14.1	<0.001
Small saplings	2	1.60	0.80	13.8	<0.001
Large saplings	2	0.05	0.03	14.0	<0.001

On the other hand, our dataset also suggested that the growing coverage of the dominating fern species on the disturbed landscape probably deter the regeneration of woody species. The coverage of *Dicranopteris pedata* and *Blechnum orientale* steadily increased in the 8.5-years of succession. Such result contradicted our hypothesis where herbaceous community would be replaced by woody component over time on disturbed area. Fern thickets had repeatedly been shown to have negative effect on vegetation succession due to their persistent networks of roots, rhizomes and dense fronds despite their ability in improving soil fertility, increasing soil moisture, nitrogen levels and organic litter thickness (Blackham et al., 2014; Cleary and Priadjati, 2005; Shono et al., 2006; Velázquez and Gómez-Sal, 2009; Walker et al., 2010). Although empirical study is lacking, the absence of late-successional species on landslides could also be attributed to the poor fungal community in the soil as their establishment is highly responsive to mycorrhizal inoculum (Koziol and Bever, 2015).

4.2. Plant growth and survival on landslides

Although the landslides were mostly colonized by pioneer species (Pang et al., 2018), survivorship and growth rate differed between species. In general, high mortality rate of seedlings was observed for those established since the first census. Although most pioneer species was demonstrated to have high survival rate when planted in degraded shrubland (Hau and So, 2002), our findings suggested that plant survival was lower on landslides probably because of the loss of top soil with poor fertility. In addition, the seedlings on landslide trails were more susceptible to seasonal spates during heavy rainstorms. Also, the low survival was again likely associated with the development of the *Dicranopteris-Blechnum* fern thickets which shaded out the small seedlings that managed to germinate. In fact, the height increment of the thicket outcompeted that of most seedlings (Blackham et al., 2014; Shono et al., 2007; Walker et al., 2010). Fast-growing species therefore had higher survival before the thicket is established. Their survival further offers a positive effect on succession as large saplings and trees on landslides may shade out the fern thicket and facilitate the growth of other woody species (Pang et al., 2018).

Pinus massoniana was the most fast-growing species in the plant community. It was repeatedly shown to function as a light-demanding tree in disturbed habitats (Cheng et al., 2011; Xing et al., 2012; Xue and Hagihara, 2001). Its fast growing yet high mortality is a typical R-selection type trait associated with small seeds and low tolerance of competition (Strauss and Ledig, 1985). It is difficult to explain the high survival rate of *Gardenia jasminoides* which does not show strong K-selection traits (e.g. moderate seed mass and fruit production: Corlett, 1996). However, its bird-dispersed and its seeds may have been deposited under perches which provided adequate shadiness without strong competition with fern thickets, resulting in lower mortality. Although it is not the only bird-dispersed species, more exploration is required to study the plant-bird interaction in such sites. The assessment of survival and growth rate of the established pioneer species provides baseline information to identify potential species to restore the vegetation of landslides (Doust et al., 2008). However, species with high survival rate or height increment do not necessarily dominate on the landslides, suggesting that further research is needed to explain the dominance of a species, including the effects of morphological traits, demographical factors and regeneration niche (Blundo et al., 2015).

4.3. Constraints and recommendations of ecological restoration

Previous studies in Hong Kong had suggested that degraded land with nearby seed sources would develop from grassland to shrubland in 5–10 years, followed by secondary forest in another 20 to 30 years (Hau and So, 2002; Zhuang and Corlett, 1997). This is generally true but our findings suggest that landslides may require a longer time to transform into shrubland. Since landslides occurred almost exclusively in gullies, their delayed succession may contribute to further erosion during rainstorms and may develop into debris flows. The formation of *Dicranopteris-Blechnum* fern thickets was identified as a major obstacle to woody regeneration on landslides, which showed continual expansion in the 8.5 years' period. Despite of its ability to protect top soil from erosion and facilitate soil-building process, the fern thicket was associated with low recruitment of woody individuals and species turnover, and high mortality of seedlings. Meanwhile, the fern-dominating community is prone to human-induced fire (Lai and Wong, 2005; Thrower, 1975). Repeated exposures to hill fire may further delay the succession in this habitat unless tree cover is formed. Although many studies recommended actively removing fern thickets to speed up succession (Cohen et al., 1995; Shono et al., 2007; Walker, 1994), landslides are often difficult to access, making it impractical to eliminate them efficiently. Given that fast-growing pioneer trees were credited for high competitiveness with dominant herbaceous components (Douterlungne et al., 2013), early sowing of them onto the landslides may counter the negative effect of fern thickets, or slow down their establishment. We identified several native fast-growing species on the landslides, such as *Pinus massoniana*, *Litsea cubeba* and *Sapium discolor*; and species with higher

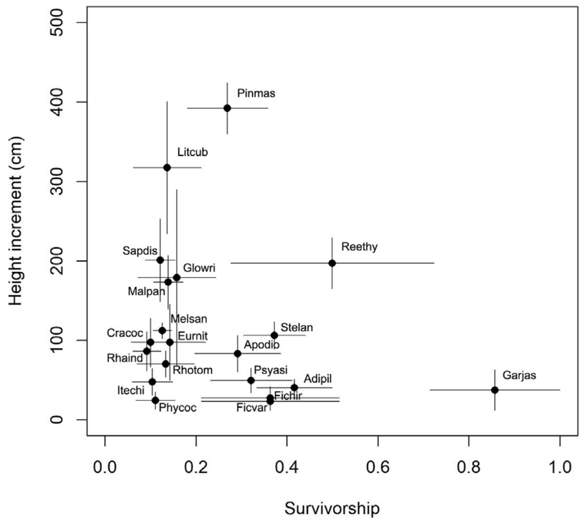

Fig. 5. Species success on the landslides between census 1 (2.5 years after disturbance) and census 3 (8.5 years after disturbance). *Adina pilulifera* (Adipil), *Aporusa dioica* (Apodio), *Cratoxylum cochinchinense* (Cracoc), *Eurya nitida* (Eurnit), *Ficus hirta* (Fichir), *Ficus variolosa* (Ficvar), *Gardenia jasminoides* (Garjas), *Glochidion wrightii* (Glowri), *Itea chinensis* (Itechi), *Litsea cubeba* (Litcub), *Mallotus paniculatus* (Malpan), *Melastoma sanguineum* (Melsan), *Phyllanthus cochinchinensis* (Phycoc), *Pinus massoniana* (Pinmas), *Psychotria asiatica* (Psyasi), *Reevesia thyrsoidea* (Reethy), *Rhaphiolepis indica* (Rhaind), *Rhodomyrtus tomentosa* (Rhotom), *Sapium discolor* (Sapdis) and *Sterculia lanceolata* (Stelan). Pinmas and Litcub show good height increment and Garjas shows good survival. Reethy shows good survival and height increment.

survival rate, for example, *Gardenia jasminoides*. We encourage further research to test the potential of landslide restoration using these species. Field planting experiments during the early stage of succession and sowing of seeds of pioneer as well as late successional species using unmanned aerial vehicles (UAV) should be tested for improving plant regeneration in remote locations that are difficult to access. Finally, studies on the change in soil structure and properties of landslides over time would also provide useful information in restoration.

5. Conclusion

This study documented the change of vegetation composition over 8.5 years on eight landslides in Hong Kong. We observed an atypical successional path on the landslides which were quickly occupied by pioneer species but not subsequently replaced by later-successional species. Such phenomenon was probably associated with the lack of late-successional species in the surrounding vegetation, domination of *Dicranopteris-Blechnum* fern thickets and poor soil fertility and mycorrhizal community. Although fern removal was credited repeatedly in other regions for speeding up succession, it would only be restricted to easily accessible sites. We have identified fast-growing trees and species with high survival rates which naturally regenerate on the landslides. To speed up succession and prevent further erosion, we recommend field experiments to test the effectiveness for ecological restoration using these species. We also stress the importance of early sowing of seeds of both pioneer and late successional species on landslides, probably by UAV, before the establishment of fern thickets. Early provision of greater shadiness and bird perches by fast-growing trees could potentially improve the seed rain and suppress the fern growth on the landslides, therefore speeding up natural succession.

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