Vegetation regeneration on natural terrain landslides in Hong Kong: direct seeding of native species as a restoration tool

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Abstract

Landslides are common in tropical and subtropical regions with hilly terrains and heavy rainstorms, which cause significant economic, ecological, and social impacts. Natural forest succession is usually slow on landslide scars due to poor soil structure and the lack of seeds of woody plant seeds, and often comes with a higher risk of repeated landslide. Ecological forest restoration has recently been suggested as an effective alternative to restore the exposed landslide scars, however, a comprehensive study to identify effective landslide restoration strategies remains lacking, particularly associated with seed treatment methods and species selection. Here we evaluated the effectiveness of different seed coating treatments of both pioneer and later successional tree species of different seed sizes on seed germination in a one-year study on three landslides in Hong Kong. Our results show that bare seeds had germination rates of 17 to 67% across all selected species (n=7). Biochar-dominant seed coating formulation boosted an additional 9.33 (SE= 0.04) in seed germination rate, while the clay-dominant seed coating formulation did not show significant effect on germination. Our results also show that medium and large-seeded non-pioneer species have significantly higher germination rates than pioneer species. These results collectively suggest that direct seeding using a biochar seed coat is a manageable and useful method to enhance tree seed germination—an essential first step to restore the forests after landslide disturbances in Hong Kong, with potential to be extended to other humid tropical and subtropical forests.

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Abstract

Landslides are common in tropical and subtropical regions with hilly terrains and heavy rainstorms, which cause significant economic, ecological, and social impacts. Natural forest succession is usually slow on landslide scars due to poor soil structure and the lack of seeds of woody plant seeds, and often comes with a higher risk of repeated landslide. Ecological forest restoration has recently been suggested as an effective alternative to restore the exposed landslide scars, however, a comprehensive study to identify effective landslide restoration strategies remains lacking, particularly associated with seed treatment methods and species selection. Here we evaluated the effectiveness of different seed coating treatments of both pioneer and later successional tree species of different seed sizes on seed germination in a one-year study on three landslides in Hong Kong. Our results show that bare seeds had germination rates of 17 to 67% across all selected species (n =7). Biochar-dominant seed coating formulation boosted an additional 9.33 (SE= 0.04) in seed germination rate, while the clay-dominant seed coating formulation did not show significant effect on germination. Our results also show that medium and large-seeded non-pioneer species have significantly higher germination rates than pioneer species. These results collectively suggest that direct seeding using a biochar seed coat is a manageable and useful method to enhance tree seed germination—an essential first step to restore the forests after landslide disturbances in Hong Kong, with potential to be extended to other humid tropical and subtropical forests.

Keywords: forest restoration, direct seeding, seed coating, biochar, landslide

Introduction

Landslides are ubiquitous in any hilly terrestrial environment, especially in high rainfall tropical and subtropical regions (Kirschbaum, Stanley, & Zhou, 2015). Over the past three decades, many global studies have documented a nearly 40% increase in fatal landslides in terms of both frequency and intensity due to the combined effects of extreme rainfall events and human activities (Froude & Petley, 2018; Haque et al., 2019; Lin & Wang, 2018; Petley et al., 2007). Not only do these landslide events have large socio-economic impacts (Petley, Dunning, & Rosser, 2005; Sultana, 2020; F. Zhang & Huang, 2018), they also have significant ecological consequences. Landslides can change the morphology of the affected earth's surface, removing vegetation and habitats, directly affecting wildlife populations (Schuster & Highland, 2001). Landslides remove topsoil and seed banks, hindering vegetation regeneration (Walker & Wardle, 2014), with some affected areas maintaining low species richness and diversity decades after the landslide (Pang, Ma, Hung, & Hau, 2018; Ren, 2007). Moreover, these slopes are particularly vulnerable to repeated disturbances before regeneration and during the pioneer community stage due to low soil stability, especially in comparison with forests in later successional stage with high biomass and species richness (Kobayashi & Mori, 2017; Osman & Barakbah, 2011).

The extreme conditions of landslide scars, such as high soil surface temperature, low water availability, and soil infertility, limit seed establishment and survival (Aide & Cavelier, 1994), hindering natural regeneration (Pickett, 1987). As such, the ability for seeds to germinate and establish seedlings successfully under these harsh environmental conditions is an essential first step of forest restoration after landslides. Apart from seed germination and seedling establishment, successful restoration should also lead to forests with high species diversity and complex vegetation structure (Ruiz-Jaen & Mitchell Aide, 2005; Wortley, Hero, & Howes, 2013). Plant species diversity can benefit soil hydrology (Gould, Quinton, Weigelt, De Deyn, & Bardgett, 2016), soil aggregate stability (Pérès et al., 2013; Pohl, Alig, Körner, & Rixen, 2009), and enhance the rate of belowground ecosystem recovery (Klopf, Baer, Bach, & Six, 2017). However, naturally, low seed dispersal rate and long distance from neighbouring seed source means less late successional species that can reach the landslide sites. Meanwhile, some pioneer species like ferns which first colonize the bare grounds are highly competitive to woody plant species by releasing allelopathic chemicals (Walker, 1994; Walker, Landau, Velazquez, Shiels, & Sparrow, 2010), preventing the establishment of a diverse and complex forest. An active and human mediated restoration programme has thus been increasingly advocated to help boosting forest recovery on such disturbed sites.

Among human mediated restoration strategies, direct seeding or planting young seedlings has been most commonly implemented (Dimson & Gillespie, 2020). Although germination rates when employing direct seeding are often lower in degraded sites than under ideal nursery conditions, direct seeding is still more cost-effective than seedling plantation (Pérez, González, Ceballos, Oneto, & Aronson, 2019; Palma, 2015). It is also a useful method for large scale restoration in disturbed areas due to massive deforestation and climate change (Grossnickle & Ivetić, 2017). Moreover, direct seeding is effective in promoting a more complex-layered forest, which is more similar to resilient natural regeneration sites than homogeneous seedling plantation sites (Freitas et al., 2019). Additionally, direct seeding has been proved to be successful in restoring forests across different habitats such as abandoned pasture, agricultural fields, Brazilian savanna, gullies, and young forests all over the tropics (Cole, Holl, Keene, & Zahawi, 2011; Doust, 2006; Pellizzaro, 2017; Rodrigues et al., 2019). However, the effectiveness of direct seeding on landslides remains unclear.

When employing direct seeding, the plants' early establishment has been shown to depend on both seed coating and species selection. Seed coating is the process of applying additional materials to the surface of a seed coat and is widely used in the agricultural sector to improve seed handling, modification of seed shape and size, and germination improvement (Kaufman, 1991; Pedrini, Merritt, Stevens, & Dixon, 2017). During the past two decades, seed coating has gained increasing popularity in natural habitat restorations to enhance seed germination ((Lee & Park, 2006; Madsen, Kostka, Inouye, & Zvirzdin, 2012), seedling growth, and to reduce predation risk (D. E. Pearson et al., 2019; Taylor et al., 2020). Various materials could be used for seed coating depending on the objective. Fertilizer and clay are commonly used while insect and rodent repellent or even fungicide and herbicide could also be added into the formulation to control pathogen infection (Gornish, Arnold, & Fehmi, 2019). Coated seeds have higher germination rates than bare seeds in the greenhouse environment (Brown et al., 2018; Richardson et al., 2019), benefited by a nutritive, water holding medium for root development. The coatings enhance plant metabolism and reduce nutrient loss during germination to help the seeds to withstand drought stress and salinity stress (Afzal, Javed, Amirkhani, & Taylor, 2020; Overdyck, Clarkson, Laughlin, & Gemmill, 2013).

From the ecological perspective, choosing suitable species for restoration is equally important. Plants of different successional groups and/or seed sizes could contribute to different seed germination success, which could also help to form a diverse forest community and increase the post-disturbance forest restoration success. Previous research demonstrated that large or intermediated size seed species often lead to a higher survival rate (St-Denis, Messier, & Kneeshaw, 2013; Tunjai & Elliott, 2012) while non-pioneer species were also observed to have higher rate of establishment in the habitats of tropical forests (D. C. de Souza & Engel, 2018; Martínez-Garza, Pena, Ricker, Campos, & Howe, 2005).

To investigate the effectiveness of direct seeding on the seed germination success in the landslide trails, here we used Hong Kong as our study area, where rain-triggered landslides are very common and frequent phenomena, making it a good representative for this investigation. There are on average 320 landslides per year on natural terrains in Hong Kong since 1945 (CEDD, 2019). Despite the lack of seismic activity, Hong Kong experiences frequent landslides due to high precipitation, steep slope, and vulnerable geology. Located in the sub-tropical monsoon climate with a mean annual temperature of 23.5 °C (Hong Kong Observatory, 2021), precipitation, at a mean annual rate of 2431 mm, is the main driver of landslide in Hong Kong (Gao, Zhang, & Cheung, 2017). Occasional intense rainstorms and typhoons further making slopes unstable and susceptible to failure (Ngecu & Ichang'i, 1999). Additionally, Hong Kong has a hilly terrain where over 60% of the land areas are on slopes with gradients greater than 20° (Au, 1998; Lan, Zhou, Lee, Wang, & Wu, 2003; Yao, Tham, & Dai, 2008). Lastly, 66% of Hong Kong's landslides occurred in soil originated from decomposed volcanic rocks. With this geology under hot and wet climate, Hong Kong's hillside is vulnerable to weathering (Chau et al. (2004). For these reasons, Hong Kong is a good trial site to investigate a suitable strategy on post-landslide forest restoration.

In this study, we investigated the effectiveness of different types of seed coats and species in promoting germination rate of directly seeded plants on landslide scars in tropical Hong Kong. With the data collected from this experiment, we address the following two questions: 1) Does seed coating affect the germination rate of sowed seeds? 2) Do seeds of different sizes and functional groups have different germination success? We hope to offer important insights and recommendations for the effective human mediated strategies to facilitate post-landslide forest restoration in Hong Kong and other tropical hilly regions.

2. Material and Methods

We conducted two experiments in Hong Kong over 2020 to 2021, each subjected to different treatment methods (seed coating and surface soil). The procedure is described in detail in the sections below, where we define the study site in Section 2.1, identify the species collection method in Section 2.2, describe the experimental designs of seed coating treatment and surface soil treatment, respectively in Section 2.3, and describe the data analysis methods to evaluate the effectiveness of treatment measures and species characteristics on seed germination success in Section 2.4.

2.1 Study site

The experiment was conducted on three recent natural terrain landslides (approximate 200m altitude) in the New Territories of Hong Kong, China (Figure. 1; 22° 27' 35" N, 114° 06' 13" E). The three selected landslide sites were formed in late August 2018 under a rainfall exceeding 200 mm within a day in the New Territories (Hong Kong Observatory, 2021). Prior to the landslides, grassland and shrubland were the most abundant vegetation types in these sites due to repeated human-induced hill fires in the surrounding areas. After the disturbances, the landslide scars remained barren for two years, and were not even occupied by pioneer grasses or ferns. Soil in these three sites was composed of highly decomposed crystal tuff with decomposition grade VI to VII (Geotechnical Engineering Office, 1988). The soil was shallow, with good drainage and aeration, but low in fertility. The terrain is unstable and easy to collapse.

2.2 Species collection and storage

We focused on 10 native species spanning different successional stages (pioneer and late successional) and a large variety of seed size with a diameter ranging from 3 to 13 mm (Table 1). These species were selected based on the fruiting cycles of local trees and the availability of sufficient quantities of seeds at the time of the study. The major fruiting season of Hong Kong's vegetation is in the winter dry season (September to March), during which we collected seeds of each species from at least three mother trees. The collected seeds were cleaned and capsule separated within a week after collection. The successional characteristics of these species were assigned according to information in the literature (Zhuang & Corlett, 1997, Kammesheidt, 2000; Han, 2001).

To minimize the negative effect of long storage time, a suitable storage method is needed to keep the seeds viable. We stored the recalcitrant seed species such as *Machilus breviflora, Sterculia lanceolata*and Fagaceae family in wet sand beds in refrigerators kept at 5 to 10 °C, following the storage suggestion from the Chinese Forestry Ministry (2001). Orthodox seeds were stored in unzipped plastic bags at room temperature. Summer fruiting species storage did not exceed three weeks to ensure their quality. The seeds were not subjected to treatments to break dormancy. To ensure seed viability and quality, we screened out any floating, unhealthy seeds prior to storage and planting. The planting experiment was conducted in spring when the climate was wet and warm. Additionally, we planted plain seeds in an outdoor nursery as controls of seed viability at the same time with the field experiment.

2.3 *Experimental design*

Seed coating experiment

To examine the effect of seed coats on native seed germination success, we used two formulations of seed coats and one control (i.e., raw seed without any treatment). The two formulations refer to seeds encrusted with mixtures of clay powder and biochar powder at ratios of 7:3 (clay-dominant) and 4:6 (biochar-dominant) in weight respectively. The biochar composed of mixed woods, mainly *Acacia confusa* ,*Dimocarpus longan* and *Bauhinia* spp. The wood debris is heated up to approximately 500 °C in a low oxygen environment for 30 minutes to create the biochar. Large seeds (over 10 mm in diameter) were treated using a sweet dumpling rotating machine (Model YX-65, China), while small and medium-sized seeds (3-5.9 mm; 6-9.9 mm in diameter) were treated using a DIY modified centrifuge (EBA 8, Hettich, Germany).

Seeds were planted on three landslide sites between April and June 2020 (Figure. 1a). Within each site, there were nine plots (each 1.6 m by 1.8 m), and the plots were at least 2 m from each other (Figure 1b). Within each plot, we further divided it into six equal grids as six species were tested (Table 1). We planted 24 seeds per grid for each species (Figure 2a). There were three replicate plots for each of the two treatments and the control, hence nine plots per site.

Surface soil treatment experiment

In order to test whether surface soil treatment could improve the germination rate of native seeds, a pair of biochar treatment and control plots (3.6 m x 1.8 m each) were set at each of the three landslide sites. Biochar powder ($0.62kg/m^2$) were mixed with surface soil (around 3 cm at the top) in each treatment plot. Each plot was sub-divided into four equal grids as four species were tested (Table 1). For each species, 60 plain seeds were planted in one grid of each plot (Figure 1 and 2b).

Monitoring

Biweekly field monitoring of seed germination was conducted over a year from April 2020 to May 2021. During each monitoring session, we recorded and labelled each seed germinated. Overall, over 90% of the geminated seeds were recorded within 1-3 months after seed sowing. Very few seed germination ($< 5\%$) was observed beyond 6 months after seed sowing.

2.4 *Statistical analysis*

We used generalized linear mixed models (GLMM) to analyse the results of the seed coating and surface soil treatment experiments. These were performed using R version 3.6.3 with the 'nlme' package (Pinheiro et al., 2021). We used germination rate as the response variable in both experiments, while the three seed coating treatments (clay-dominant, biochar-dominant and control) and two surface soil treatment (biochar and control) were considered as fixed covariates respectively. In order to incorporate the dependency among observations in the same site and nested structure of our experiment, we used site and species as random effects. We did not include any interaction term due to small sample size. Moreover, due to the poor seed viability, some of the species such as *Eurya nitida, Tetradium glabrifolium* and *Zanthoxylum avicennae* failed to germinate in both nursery and field trials and were excluded from further analyses.

We separated the analysis into two parts: 1) across all species and 2) each species independently. For all species, we ran four models by including different covariates and selected the model with the lowest Akaike information criterion (AIC) value (Table 2). For the species models, we modelled the relationship between germination rate and treatment with site as a random factor. Model assumptions of normality and homogeneity of variances were verified by plotting model residuals. Post hoc analyses for pair-wise comparisons of means were undertaken using least square means using the lsmeans package (Russell, 2016).

Additionally, to test the effect of seed size and successional stage on germination rate of native seeds on landslide scars, data from the controls of the two experiments were pooled and analysed. We used linear mixed models to compare seed germination rate of different successional groups and seed sizes. All analyses were conducted using R version 3.6.3 (R Core Team, 2020) for GLMM.

Results

Seed coating experiment

We observed an increase of 9.33% in seed germination rate when seeds were treated with the biochar-dominant seed coat in comparison with the control at all three sites (SE=0.04, $p < 0.05$; Figure. 3). The clay-dominant seed coat did not significantly improve germination rate ($p=0.38$; Figure 3), and there was no significant difference in seed germination rates between the seed coat treatments ($p=0.15$; Figure 3). Exploring the seed germination and seed treatment relationships further, we found that different species had different effect sizes for the different seed treatments. 14.35% of *Celtis sinensis* seeds (SE=0.07, $p < 0.05$) and 10.65% of *Sterculia lanceolata*seeds (SE= 0.05, $p < 0.05$) germinated more when treated with a biochar-dominant seed coat than the control seeds (Figure 4). However,*Reevesia thyrsoidea* and *Ormosia semicastrata* did not have significantly different germination rates between the three treatments. We noted that heavy rain washed away a substantial amount of seeds, leading to a small remaining sample size of these two species.

Surface soil treatment experiment

We found no significant germination rate difference in the surface soil treatment compared to the control including *Cyclobalanopsis myrsinifolia* , *Machilus breviflora,* and *Syzgium levinei*(Figure 5). The mean germination rate for all species across sites was 56.10% (SE = 0.14). The highest germination record was *Machilus breviflora* in site two (75%, SE= 0.14) whereas the lowest germination rate was also *Machilus breviflora* in site three (40%, SE=0.02). Germination rates of each independent species were also observed with no significant difference (Figure 6).

Influence of successional group and seed size on seedling establishment

Combining the control data from the two experiments together, we found that successional group and seed size greatly affected germination rates on landslide sites. Late successional group species had a 30% higher germination rate than pioneer species by direct seeding on landslide scars ($p<0.001$; Figure 7). Meanwhile, medium and large seeded species have 31.6% - 36.3% higher germination rates than small size species ($p<0.01$; Figure 8). There was no significant difference of seed germination percentage between medium and large size seeded species (Figure 8), which might largely be because only one large-size seeded species was explored here.

Discussion

Landslides are natural disturbances that affect forest ecosystems in high rainfall tropical and subtropical regions and can incur substantial socioeconomic loss and ecological damage. We investigated potential methods of enhancing forest regeneration after landslide events via human mediated restoration efforts, focusing on ways to increase native seed germination rate. Our results show that, first, seed coating technique improves seed germination rate of native tree species. Second, selecting suitable successional groups and seed size can lead to higher germination rates and restoration success.

We found that biochar dominant seed coats had a significantly positive effect on seed germination success across our study sites, and there is evidence that seed coating can further encourage growth for young seedlings (Jones, Schwinning, & Esque, 2014; Lee & Park, 2006; Scott, 1975). Biochar coating also had differential effectiveness in enhancing seed germination in landslide scars across the species we investigated, agreeing with results from other studies showing that seed coating improves seed emergence under different soil conditions (Liu, 2010; Madsen, Davies, Boyd, Kerby, & Svejcar, 2016). Landslide scars are characterised by soil compaction and lack of organic matter, reducing soil nutrients availability and limiting vegetation growth and restoration potential (Błońska, Lasota, Zwydak, Klamerus-Iwan, & Gołąb, 2016; Fetcher et al., 1996). Treating seeds with additional coating helps seeds to overcome this initial barrier to germination due to poor site properties by serving as a carrier of nutrients and a physical shield to avoid physical damage to the seeds. Moreover, the seed coat increases the likelihood of seeds reaching germination favoured microsites, reducing the chance of the seeds being blown or washed away and minimises seed loss from predation (Overdyck et al., 2013; Taylor et al., 2020; A. G. Taylor, Eckenrode, & Straub, 2001). Moreover, adding active ingredients in coating formulation boosts the seed germination rate. In modern seed coating technology, seed coats act as a carrier of different ingredients including nutrients, plant protectant or even plant beneficial microbes for several purposes (Afzal et al., 2020; Rocha, 2019). For instance, in our experiment, biochar dominant seed coating has a 30% higher than clay dominant seed coat and raw seeds which agree with previous findings that biochar coating serves as soil conditioner and enhances water holding ability of soil (Brown et al., 2018; Madsen, Davies, Mummey, & Svejcar, 2014).

In the soil surface treatment experiment, we found no evidence of sowing biochar powder on top of soil surface affecting native seed germination on the landslide scars. Previous research has found that biochar powder applied to topsoil can enhance tree and crop growth through an increase in soil pH, fertility, and water holding ability, resulting in plants with higher biomass (Mohamed, 2015; Thomas, 2015). It seems that biochar soil surface treatment is only able to enhance growth after seed germination but does not offer direct advantages in enhancing seed germination rate.

In our study, the overall germination rates of raw seeds were 17% - 67% (Table 3) while having biochar dominant seed coat gave an additional 9.33% improvement of germination rates. Our finding was much higher than a meta-analysis of direct seeding indicating that the seed germination rate was 23.9% on average (Ceccon, 2016). It is also much higher than many restoration programmes, in which seedling establishment rates are often observed at less than 10% (Merritt & Dixon, 2011). The observed much higher seed germination rate in our study can likely be because of the use of native species seed or the test-site in a favourable condition of humid tropical environment, and a more in-depth understanding of the underlying difference and mechanism remain needed in the future attempts.

Our results showed that species selection was an important factor affecting seed germination rates. First, different successional groups of plant species had different seed germination rates, as they require different environmental conditions from the colonizing pioneer species to establish on landslides (Walker, Velázquez, & Shiels, 2009). This also agreed with previous studies showing that species in late-successional group had an advantage in germination rates in other landscapes (D. C. de Souza & Engel, 2018; R. P. de Souza & Válio, 2001). Late successional species have a germination strategy that conserves nutrients, allowing them to be more shade tolerant when compared to pioneer species (Kleijn, 2003). This gives them higher competitive ability but low colonizing ability (Kleijn, 2003; H. Zhang, Qi, & Liu, 2018), which is a potential reason for our observed result. Moreover, pioneer species require special environmental conditions for dormancy break to germinate, so food reserves in seeds may be depleted before these conditions are created, resulting in lower overall germination rates (Baskin & Baskin, 1998). Our results showed that non-pioneer or late-successional species could successfully establish on degraded hillsides, and that late successional species establishment is limited by seed dispersal rather than tolerance to harsh site conditions. Thus, late successional species may be used in direct seeding restoration in landslide scars.

Second, we found a positive relationship between seed size and germination rate, implying that a larger seed size improves germination rate. This also agreed with previous studies that compared the sizes of different tree species (St-Denis et al., 2013; Tunjai & Elliott, 2012). In the natural environment, large and small seeded species have different establishment strategies. Large seeded species appears to be more tolerant to stresses such as drought and shade than small seeded species as they have a larger initial energy reserve (Leishman & Westoby, 1994). Their large cotyledons support embryo development when seedlings compete for limited resources, which may be an advantage in habitats where gaps in the canopy are regularly created. Moreover, large seeded species are able to germinate equally in light and darkness and is more resistant to temperature fluctuation (T. R. H. Pearson, Burslem, Mullins, & Dalling, 2002), while small seeded species produce seedlings that are more susceptible to extreme environmental conditions and do not resist long periods of unfavourable growing conditions (Camargo, 2002). Although small seeded species have an advantage in quantity during seed production (Moles & Westoby, 2004), in human mediate restoration efforts, large seeds mask the effect of production by having rich energy source in cotyledons to enhance the chances of restoration success.

In addition to seed coat treatment and species selection, there are other methods of enhancing restoration success which were not assessed in this study. Pre-sowing seed treatments and site treatments are most commonly used in practice. Pre-sowing seed treatments such as scarification (Kaye & Kuykendall, 2001) and sowing agglomerated seeds (Madsen, Davies, Williams, & Svejcar, 2012), were shown to give higher germination rates than sowing singular raw seeds. Field treatments, such as sowing seeds at different microhabitats and biotopes (Chantal, Kuuluvainen, Lindberg, & Vanha-Majamaa, 2005; Doust, 2006), and creating grass canopy on soil surface before direct seeding (Guarino & Scariot, 2014), were also shown to increase seed germination and establishment rates. In addition to seed and site treatments, the method of seed sowing can also affect seed germination rates. In this study, we focused on direct seeding with seed burial, as seed burial can minimise animal predation on the sowed seeds (Alem, 2020; Garcia-Orth & Martinez-Ramos, 2008). The difference between seed coating and bare seeds on germination rate is potentially greater when broadcasting seed than seed burial as the seed balls themselves can act as physical protection to the seeds (Leverkus, Rojo, & Castro, 2015). Broadcasting native seeds on landslide scars is still under investigation and a potential avenue for further research. Furthermore, in our current results, large seeded species only occurred in the late successional stage. It would be interesting to investigate how small seeded late successional species and large seeded species in other successional stages behave on landslide scars.

Landslides are natural disturbances that can cause enormous social-economic loss and severe ecological consequences. Forest restoration on landslide scars can contribute substantially to soil surface protection, reducing future disturbance risk and help to protect human lives and properties whilst restoring destroyed habitats. Effective regeneration of these degraded areas requires successful germination of seeds, which can often be a slow natural process. Human mediated restoration can help to speed up this process. We were able to show the effectiveness of biochar seed coating and planting non-pioneer species with medium to large seeds in improving seed germination rates on landslide scars. We used Hong Kong in this study, but the findings could be applied to post disturbance vegetative restoration and recovery on landslides of other hilly terrain in the seasonal tropics.

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