





Fig 1-7. Exposed environments and impoverished soil conditions on restored landfill and quarry sites in Hong Kong have historically resulted in plantations of fast growing non-native tree species, with very few native species or signs natural succession.

Articles

Alternatives to non-native species in restoration planting

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ABSTRACT: Hong Kong has an abundance of native tree and shrub species that thrive in the prevailing climate and soil conditions of the Territory. Research studies have suggested that, without human intervention, low scrubland can regenerate on cleared land within 10 years and secondary woodland within 30-40 years. Following recognized ecological restoration practice, however, restoration planting of man-made landscapes in Hong Kong (landfills, quarries, borrow areas, man-made slopes, etc.) has commonly employed fast-growing non-native species within planting mixes to act as pioneers to support the establishment of native species. This article examines the reasons why non-native species almost always become dominant and the vegetation generated on these sites has limited floristic or faunal diversity. It also considers possible approaches that might now be adopted to re-nature these non-native plantations, and in turn how they might inform our urban planting practices.

Case studies of historic restoration planting projects

A team at HKU has been compiling landscape case studies of some thirty restoration planting projects (both terrestrial and wetland) undertaken in Hong Kong over the last 50 years. Prominent amongst these are a set of sites where the landscape had to be comprehensively re-constructed with the establishment of new soil layers and vegetation cover. Several of these remain largely intact[1] including restored quarries (Shek O, Lamma), and landfill sites (Gin Drinker's Bay, Siu Lang Shui, Shuen Wan, TKO Stages 1 and 2, SENT(early phases)). The sites are large (up to 100ha) and located at the urban periphery with links to both the natural landscape outside the city and man-made landscapes within.

Reviews of contract documents

and monitoring reports, and interviews with original project team members have helped to establish a history of each project, including the original site condition, the restoration intent, planting design and subsequent maintenance operations. Observations have been made of the current condition of the vegetation, soil, hydrological system, environment and ecology. Information has also been drawn from various research studies that have investigated the establishment of native plant species on these and similar degraded sites in Hong Kong.

The objectives of the planting for each of the eight restoration sites were stated as:

- control surface erosion by establishing a continuous vegetation cover;
- achieve a green appearance that visually blends into the adjacent landscape; and
- generate a native vegetation structure relevant to the ecology of adjacent natural landscapes.

The case study research found that in all cases the first two objectives were largely achieved, but the third was not. While the restoration planting of each has been viewed as being successful, i.e. they have a continuous green cover with substantial blocks of mature trees and from a distance appear naturalistic, the ecology of the non-native plantations is poor with limited floristic (mostly herb species) and faunal diversity (mostly insects).

The outcomes of these restoration planting projects are problematic - they are not natural as envisaged within current concepts of nature-based solutions and do not accord to internationally recognized principles of ecological restoration[2] i.e. they have not generated self-sustaining ecologies relevant to the context and supporting processes of natural succession. They represent something of a missed opportunity to enhance the biodiversity and ecology of the Territory and to maximize ecosystem service benefits (in particular carbon capture) that could be generated from self-sustaining native vegetation.

It has been commonly held in restoration planting that when the non-native species disappear (either removed or die out) native species will replace them. Ecological studies have found, however, that only a few native species survived and in very small numbers, and there was little indication of substantive colonization by self-seeded native species or long-term natural succession occurring[3]. In contrast, research studies on different aspects of hillslope reforestation have suggested that on Hong Kong hillsides, without any human intervention, self-sustaining native woodland communities will emerge within 40 years[4]. The aim of the case studies was to understand why non-native tree species become so dominant within the restored vegetation and how this relates to the specific conditions of the site and the planting approaches adopted.

While ongoing native tree planting studies and trials in Hong Kong[5] are helping to generate technical information, assessment of the results of these early restoration projects can help to identify principles and approaches that could inform future restoration planting practices, in particular efforts to re-nature plantation woodlands across the territory, as well as establishing and enhancing vegetation on man-made slopes, degraded sites, and even within our urban landscapes.

Observations from the restoration projects

The eight restoration sites all had very challenging environmental conditions. Their prominent locations and morphological characteristics left them exposed to sun and wind, and there was no initial cover or screening to protect newly planted trees and shrubs.

The topography of each of the sites combined areas of steep slope (up to 1 in 3) and areas that were either flat or very gently sloping. Soil layers of between 600 and 2000mm were initially formed over either rock or general fill material or over artificial liners (in later landfills). Soil layers were compacted to a high degree for geotechnical stability and grass hydroseeded for erosion control. Some projects (e.g. Shek O Quarry, SENT Landfill) also included biodegradable erosion control matting. Soil material used for planting was completely decomposed granite (CDG), although construction and demolition (C&D) fines or general fill material were sometimes used for subsoil layers.

Soils that can be observed on the sites now are all still highly compacted with low surface porosity and very low moisture content at depth. Water infiltration is inhibited by surface compaction exacerbated by the sloping topography, extensive surface water drainage systems, and high rates of surface evaporation where vegetation cover is incomplete. In addition, long-term irrigation systems were not installed to support the planting.

Soil conditioner (composted organic material) had been incorporated into the backfill to planting pits together with inorganic horticultural fertilizers[6]. The top 300mm of soil material on all sites now has very low nutrient content and almost no observable soil biology - microorganisms and soil fauna.

Most planting designs had aimed to restore the sites through establishing woodland habitats with areas of open grassland. Planting mixes had mostly comprised tree species (of varying mature sizes). None included species targeted specifically at developing low shrub or herb layers (other than standard grass hydroseeding).

In line with established practice, fast-growing non-native (exotic) tree species were included in all planting mixes as ‘pioneers’ to create environmental conditions (through soil amelioration and creating shade and shelter) more favorable for the establishment of native species and to encourage natural succession. The pioneer species were meant to have been ‘thinned out’ at a later date, possibly some 5 to 7 years after planting, but this operation was not undertaken on any of the sites. Native species were selected largely on the basis of tolerance of the conditions and commercial availability, rather than with a view to generating integrated long-term vegetation communities that could support local wildlife. Only in more recent projects (Shek O, SENT Landfill) was the selection of native species based on ecological surveys of adjacent natural landscapes, but these too were also affected by species availability.

In general, the non-native species thrived and became dominant. Current vegetation on each site consists principally of non-native tree species *Acacia spp., Casuarina spp., Eucalyptus spp.*, and *Lophostemon sp.* in both mixed and single species stands. The large majority of native trees and shrubs died out within two years of planting, i.e. did not survive long enough to benefit from any microclimatic adaptations from the pioneer species. Growth of those native species that survived has been slow[7] and they now comprise only small percentage of total tree populations. Self-seeded native tree or shrub specimens, mostly *Macaranga tanarius, Mallotus paniculatus, Ficus virens*, and *Lantana camara*, are present in small numbers in marginal areas, together with ornamental tree species that had been planted later along site boundaries. All sites have notable presence of the invasive weed species - *Leucaena leucocephala* and *Mikania micrantha*.

In the low light conditions beneath tree stands the ground surface is either bare or covered variously with grasses, ferns and *Alocasia macrorrhizos*. Within the open areas, the hydroseeded grass species are still present along with several self-seeded native herbs and shrub species, notably *Bidens pilosa*. Where grass areas are not cut regularly they often suffer infestation by *Leucaena leucacephala* (as at TKO1 and TKO2).

Seedlings had been planted in matrix grids, spaced at 1.0 to 1.5m centres, using small shallow pits (<200 dia.) formed through hydroseeded grass and erosion control matting where used. The steepness of the slopes and the durability of the matting had often made pit excavation and planting challenging, hence pit sizes were commonly smaller than intended.

Maintenance operations undertaken during establishment period (usually 1 year following planting) were not recorded at the older sites, but on more recent sites included occasional watering (via temporary irrigation systems), grass cutting and clearance of debris at the margins of planting blocks and alongside access tracks and drainage channels. Maintenance of vegetation was often omitted on steeper areas due to the difficulty of access. Beyond the establishment period, vegetation was usually considered self-sustaining and subsequent maintenance has been limited to peripheral grass cutting for operational needs. Except for the most recent projects there was no long-term monitoring of planting or actions to manage the vegetation for habitat development.

The failure of many native tree and shrubs species and the dominance of the aggressive non-natives, has inhibited the emergence of structured native vegetation communities. The ecological value of the restoration sites has been assessed as low. While vegetation and soils have been observed to develop over time[8] this has tended to be slow and of limited scope[9]. Faunal diversity within the plantation areas is notably low. Open grass areas have greater species diversity, notably insect species butterflies, dragonflies, beetles with some native avifaunal species and occasional sightings of frogs, skinks, snakes, or small mammals. Soil fauna is far more developed in grassland areas.

Reflection on the restored vegetation and possible alternative approaches

Planting strategies for each site looked to address issues of exposure and drought by including fast-growing non-native species (tolerant of the conditions) within planting mixes to create shelter for slower growing native species. Species selection within this approach prioritizes plant survival over development of structured vegetation communities or supporting natural ecological processes. Observing that native species establish naturally on hillsides across Hong Kong, the use of non-native species as pioneers in ecological restoration has been questioned[10].

The planting strategy of trying to establish woodland habitats within a set contractual timeframe and the resultant selection primarily of tree species has been problematic. Environmental conditions on these sites are similar to those of exposed hillslopes, suggesting that establishing low scrubland habitats might be an easier entry point into the natural vegetation development process[11]. Further, it would support the development of integrated vegetation communities, i.e. working from the ground upwards. Few scrubland species had been selected in restoration planting mixes, possibly through a lack of relevant plant information or poor availability of native seedlings, however current restoration planting exercises are increasingly prioritizing on the use of scrubland species.

Pioneer species (and invasive weed species) often make conditions more challenging for native species by taking up available rooting space, nutrient resources and water, and many are allelopathic. These need to be replaced, progressively[12]. However, non-native vegetation generated on these restoration sites primarily reflects issues with the man-made soil as a planting medium, as well as the planting methods used. Unless site conditions are changed even if the non-natives were completely removed it is likely that they would only be replaced by invasive weed species[13].

Planting designs need to give far greater emphasis to improving soil conditions, and in particular soil density (which has significant influence over soil hydrology, biology and nutrition) and biological activity to facilitate the use of native species.

High degrees of soil compaction inhibit rainwater infiltration into placed soil bodies[14]. While needed for geotechnical stability, heavy compaction results in highly desiccated planting media. The formation of planting soil over either rock fill or artificial liners also results in a physical separation from natural groundwater sources, the other means by which soil moisture might be replenished. Low levels of water infiltration (from either above or below) result in a soil environment that greatly favours fast-growing and aggressive surface rooting systems of genuses such as *Acacia, Eucalyptus* and *Leucaena* that are tolerant of drought. The small size planting pits used and the disparity between the planting medium within the pit and the surrounding compacted CDG restricted root development and thereby plant growth and stability.

Planting is often the final element within large works contracts and historically has often been undertaken outside the April-June hillside planting season to meet completion deadlines. This was usually on the promise of irrigation watering that was either limited in duration or not undertaken at all, resulting in high rates of plant failure. Both effective irrigation and planting within season should be considered non-negotiable requirements for hillside and restoration planting. Sectional completion of planting, or separate planting and irrigation contracts can help overcome this.

Ameliorating effects of soil conditioner and inorganic fertilizers on CDG, as a medium for plant growth, are often over-estimated and frequently short lived. Both can get washed away or leached out before they are taken up by plants. Self-sustaining vegetation requires active soil biology to convert organic material into soil nutrients available to plants (i.e. 'living' or 'bioactive' soil). The composted organic matter used as soil conditioner in Hong Kong does not include the native soil microorganisms or soil micro-fauna necessary for effective nutrient cycling or to stimulate plant growth. The planting medium on these restoration sites was effectively inert and limited plant growth, especially in the native seedlings. This was made more difficult by the physical isolation of the placed soil layers from surrounding natural soil bodies and their biological resources.

Planting design for restoration sites can develop functional soil by creating: (a) a more open soil structure with greater water holding capacity through the incorporation of organic materials such as wood materials (wood chip, bark, yard waste), coconut fibre and biochar; and (b) a positive nutrient cycle through the incorporation of native strains of soil microorganisms and soil fauna[15], and the addition of varieties of organic material that will support them. There is an urgent need for material specifications and commercial production processes to be developed for living bioactive soil material for use in all forms of landscape planting in Hong Kong[16]. Planting of species relevant to the local ecology and developing planting methods that allow leaf litter to be captured (e.g. with surface grading, retained deadwood or live fences) so it can be broken down and absorbed back into the soil, are also essential for early plant establishment.

At 1.0m centres, planting distance is too great for pioneer trees species to grow large enough to modify the microclimate conditions before the native species die of exposure. Pioneers need two or more years in normal conditions before they can offer shelter. On the exposed hillside this may take much longer. Recent phases of planting at SENT Landfill have had success in planting pioneer species some years in advance of native species.

Low-density pit planting across an entire area is a practice which derives from commercial forestry. It is notable that contemporary re-naturing initiatives such as Miyawaki / mini- forests recommend planting at much higher planting densities (3 or 4 plants per sq.m) to overcome challenging environments. Tactical planting to establish small islands of native species which support seed-dispersing wildlife has been shown to be successful in facilitating natural colonization. Dense planting may also help to address the challenges of root growth and soil development that are common in disconnected planting pits. Planting in trenches or furrows (as used in contour hedging[17]) allows larger volumes of planting soil to be established on slopes without compromising geotechnical stability, and for soil resources to be shared.

Restoration planting methods need to include measures to ensure both adequate infiltration of water into the soil and retention of moisture within the soil to support plants throughout the year. Localized shaping of soil surface topography at the planting site has been successfully used to capture surface water and promote infiltration in renaturing projects in arid regions around the world. Regular aeration (an essential but often overlooked maintenance operation) and the retention of leaf litter etc. at the surface can help prevent surface capping and overcome compaction. Fabric barriers to suppress weeds around planting sites can also help to retain soil moisture at the surface, and low-permeability liners to the base of pits or trenches may help retain moisture at depth. The inclusion of dead tree branches at depth can aid infiltration of water (as well as nutrients and oxygen), and the inclusion of coconut fibre and biochar within the soil mix can help to retain moisture. Organic fertilizer root dips and anti-desiccant sprays may also help initial establishment in low moisture soil environments.

Artificial growth tubes / tree shelters installed immediately around newly planted seedlings[18] are increasingly being used in hillside reforestation to improve survival rates in native species by moderating environmental conditions and deterring predation, although the beneficial effects of different shelter designs varies considerably. Retained deadwood and live fences can also be useful in moderating microclimatic conditions.

Finally, a recurrent reflection of practitioners involved in past restoration planting projects is that a new contractual framework is needed that facilitates long-term adaptive management based on regular ecological monitoring to guide the establishment and long-term health of planting on restoration sites, especially when the ecological aspects of the planting are formal commitments within environmental permits and planning permissions.

Lessons for future planting work

In many respects the environmental conditions for other types of landscape planting are similar, and there are two useful points we can take from the history of these restoration planting projects.

Planting on open hillsides, man-made slopes, and within the urban forest, commonly suffers from the exposed conditions, dense, dry, nutrient poor soils, with little or no active soil biology. Stressful planting environments favour fast growing, surface rooting species which in turn inhibit the development of self-sustaining vegetation communities. The design of all types of landscape planting needs to focus primarily more on the generation of functional soil as a means of countering the challenging conditions and facilitating plant growth, and as a way to expand the range of species that can be selected.

We need to create effective soil hydrology by promoting infiltration of rain water and retention of water within the soil, and bioactive soil material[19] through the addition of native strains of microorganisms and soil fauna and varieties of local organic material[20] as sources of nutrients for plants and soil fauna.

Nature-based solutions suggest that landscapes need to be more than just green, and that we should aim to create vegetation communities that are ecologically relevant and self-sustaining. The inclusion of non-native species in restoration planting mixes has not had the intended effect of fostering the development of native vegetation communities, quite the opposite. Alternative planting methods that create environments suitable for native trees offer an alternative approach to the use of non-native species in restoration planting.

Many planting practices in Hong Kong derive from historic forestry and horticultural nursery practices developed elsewhere in the world. There is a need to re-think our approach to planting design to ensure that sites are adequately prepared and can support the amazing diversity of native plant species that are available to use. Specifically, for future landscape planting in Hong Kong we need to: focus our native species selection guidelines around vegetation communities not individual species, develop soil and plant material specifications and planting methods (based on local practice-research) that they respond to the extreme planting environments; financially support the establishment of large-scale nursery operations for native species and bioactive soil production; develop maintenance approaches based on long-term adaptive management, informed by regular monitoring of planting performance, that emphasizes the health and continuity of vegetation communities rather than the individual plant.

Endnotes

1 Many other sites have subsequently been partially redeveloped.

2 Gann, G. D., McDonald, et al. (2019). International principles and standards for the practice of ecological restoration. *Restoration ecology*, 27(S1), S1-S46.

3 For example, Pang, C. C., Lo, W. F., Yan, R. W. M., & Hau, B. C. H. (2020). Plant community composition on landfill sites after multiple years of ecological restoration. *Landscape Research*, 45(4), 458-469 and Wong, J. T. F., Chen, X. W., Mo, W. Y., Man, Y. B., Ng, C. W. W., & Wong, M. H. (2016). Restoration of plant and animal communities in a sanitary landfill: A 10-year case study in Hong Kong. *Land Degradation & Development*, 27(3), 490-499.

4 Zhuang, X. Y., & Gorlett, R. T. (1997). Forest and forest succession in Hong Kong, China. *Journal of Tropical Ecology*, 13(6), 857-866.

5 Trials of tree seedling planting on hillsides using different soil additives (e.g. biochar, mycelium fungi, etc.) and planting methods.

6 Mixing soil conditioner material into the CDG (before or after placement) was generally considered to be impractical and likely to affect soil compaction

7 Chun-wing, C. H. O. N. G. (2003). *Tree Planting on Recently-restored Landfills: A Study of Native Species* (Doctoral dissertation, The Chinese University of Hong Kong).

8 Zhang, H., & Chu, L. M. (2011). Plant community structure, soil properties and microbial characteristics in revegetated quarries. *Ecological Engineering*, 37(8), 1104-1111.

9 As found by Wong, M. H., Cheung, K. C., & Lan, C. Y. (1992). Factors related to the diversity and distribution of soil fauna on Gin Drinkers' Bay landfill, Hong Kong. *Waste management & research*, 10(5), 423-434.

10 Civic Exchange (2005) P*reserving Hong Kong's Biodiversity the need for an ecological restoration Policy.*

11 Hau, B.C.H. and Corlett, R.T. 2002. A survey of trees and shrubs on degraded hillsides in Hong Kong. *Memoirs of the Hong Kong Natural History Society* 25:83-94.

12 The invasion of non-native Leucaena leucocephala and Mikania micrantha within landscape planting areas across the entire Territory is now at crisis level and urgently needs comprehensive action.

13 As evident at TKO1, where the clearance of non-natives on some slopes has allowed invasive species to come in.

14 Surface compaction also limits the infiltration of oxygen and nutrient materials into the soil, and natural succession

15 Locally sourced bacteria, mycorrhizal fungi, protozoa, nematodes, rotifers, springtails, mites, earthworms, ants, termites, beetles, centipedes, etc.

16 Trails of native species planting for landscape restoration work in Hong Kong using soils enhanced with native microorganisms and soil fauna are due to start in 2025.

17 Bioengineering technique for erosion control.

18 Growth tubes / tree shelters have to be removed after 1-2 years

19 Kong, H.H. (2024) *Generating Bioactive Soil: Rethinking Hong Kong Urban Planting Soil as Living System*. MLA Thesis. HKU

20 e.g. wood chip, bark, green manure, composted organic matter, peat, organic fertilizers, lime, etc., as per GLTMS Guidelines on soil improvement (2022), Development Bureau HKSAR.