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Natural regeneration in exotic tree plantations in Hong Kong, China

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Abstract

Tree plantations consisting mostly of a single exotic species have been established in Hong Kong, South China, for reforesting degraded lands since the 1950s. In this study, natural woody plant regeneration success under different types of closed-canopy plantations (*Acacia confusa*, *Lophostemon confertus*, *Melaleuca quinquenervia* and mixed-plantings) and natural secondary forests in the central New Territories were assessed. A total of 79 tree species, 64 shrubs and 23 woody climbers were recorded in 16 20 m $\times$ 20 m plantation plots. Stem density of woody plant regeneration was similar among all sites, ranging from 9031 to 10,950 stems $>$ 0.5 m in height per hectare. Multivariate analysis of understorey species composition showed that there were consistent differences between plantation types. *Lophostemon* plantations generally had poor native plant colonization in comparison with natural secondary forests and other types of plantations. These differences between forest types can be at least partly attributed to pre-existing site conditions, since the tree species planted were matched to the site. Native woody plant colonization was poor on sites isolated from natural seed sources. Plantation understories were generally dominated by a few species of bird-dispersed shrubs, suggesting that enrichment planting with poorly dispersed shade-tolerant native tree species will be needed to facilitate regeneration in those plantations where natural regeneration is inadequate.

Keywords: Plantations; Natural regeneration; Hong Kong; China; Succession

1. Introduction

Tree plantations are increasing throughout the world due to the demand for industrial timber and pulp. In Southeast Asia, plantations are established more for non-timber crops than timber, particularly coconuts, rubber, and oil palm (Corlett, 2005). There were an estimated 187 million ha of forest plantation worldwide in 2001 and Asia had 62% of the world's total plantation area (FAO, 2001). Although around 50% of the plantations are established for timber, the many uses of plantations are being recognized, especially in the past 15 years, and more areas are planted with trees for environmental reasons.

Plantations have been suggested to promote woody understorey regeneration, and hence increase biodiversity (Haggar et al., 1997; Lamb, 1998; Lugo, 1997; Powers et al., 1997; Otsamo, 2000; Cusack and

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Montagnini, 2004). Plantations may promote regeneration in the understorey by shading out grasses, increasing soil nutrients (through uptake by deep roots and litter fall), improving micro-climate, and generally increasing the chance for seed germination and establishment, which is difficult in highly degraded sites (Parrotta, 1992; Kuusipalo et al., 1995; Parrotta et al., 1997). In addition, plantations can also protect sites from further degradation by preventing soil erosion and reducing fire hazard. For these reasons, trees of exotic or native origin are planted on degraded lands or pastures for rehabilitation, in the hope of preventing further site degradation and catalysing native plant colonization.

Plantations in the tropics can indeed promote understorey native plant regeneration in comparison with unproductive degraded lands or weed-dominated pastures where natural succession has been arrested (Parrotta and Knowles, 1999; Carnevale and Montagnini, 2002; Senbeta et al., 2002; Yirdaw and Luukkanen, 2003; Cusack and Montagnini, 2004). However, few studies have compared plantations with naturally regenerated forest of similar age. Natural succession with little or no intervention might have been a more effective rehabilitation method, as suggested by Fimbel and Fimbel (1996), Duncan and Chapman (2003) and Healey and Robert (2003). With plenty of 30–50-year closed-canopy plantations in Hong Kong, this study assessed native woody succession in exotic plantations. The understorey plant communities of natural secondary forests of similar ages were also studied for comparison. Hong Kong was probably the first area in the tropics where trees were planted purely for environmental reasons (Corlett, 1999), and the absence of logging pressure creates an unusual opportunity to study natural succession in mature plantations.

2. Methods

2.1. Study area

Hong Kong (22°08′–22°35′N; 113°49′–114°31′E) is situated to the east of the Pearl River (Zhujiang) Estuary on the South China Coast, and includes part of the Chinese mainland (Kowloon and the New Territories), and 235 outlying islands. Hong Kong has a total land area of around 1102 km^2, including approximately 66.4 km^2 of land reclaimed from the sea and all the offshore islands (HK Lands Department, 2004). Much of the territory has rugged topography. Most of the 6.8 million people reside in the lowland 20% of the total land area, and the remaining 80% of the land area is relatively undeveloped, and is mostly steep hillsides covered in secondary grasslands and shrublands. Hong Kong has a subtropical climate with a hot wet summer and cool dry winter (Dudgeon and Corlett, 2004). Mean annual rainfall in urban Kowloon is 2616 mm (1997–2003), the mean temperature of the coldest month is 16.9 °C, and the mean temperature of the warmest month is 28.8 °C. The original broad-leaved rainforest was cleared centuries ago, and most of the natural secondary forests have developed since 1945 (Dudgeon and Corlett, 2004). The canopy of these secondary forests, which cover around 16.3% of the total land area, is dominated by light-demanding *Machilus* spp. (Lauraceae), suggesting these forests are still in an early successional state (Zhuang and Corlett, 1997). About 23% of the territory is covered with grasslands maintained by frequent anthropogenic hill fires, which remain the main barrier to forest succession (Dudgeon and Corlett, 2004).

The principle aims of afforestation since the 1960s have been to: control soil erosion, protect water catchment areas, and conserve natural vegetation and wildlife (Corlett, 1999). A wide range of native and exotic tree species have been planted on sites with different levels of degradation; however, the foresters in Hong Kong depend mostly on a few easily propagated exotic tree species for afforestation, and the plantation area now covers around 5% of the territory (Ashworth et al., 1993). *Lophostemon confertus*, *Acacia confusa* and *Pinus elliottii* were the most common exotics planted, mostly on badly degraded sites. More recently, mixed plantings and native trees, including *Castanopsis fissa*, *Liquidambar formosana* and *Schima superba*, have been used to reforest areas with better soil conditions (Corlett, 1999).

2.2. Data collection and analysis

This study included natural regeneration surveys of plantations in the central New Territories, around the highest hill Tai Mo Shan, at altitudes below 500 m. Woody regeneration under four exotic plantation sites of each of the four types (monocultures of *A. confusa*, *L. confertus*, *Melaleuca quinquenervia*, and mixed-species plantations), as well as four natural secondary forests of similar age, were studied. To reduce the risk of spatial autocorrelation the sites of each type were interdispersed in the study area. At each site, the abundance and species of understorey woody plants were recorded in a 20 m × 20 m plot which was haphazardly located at least 10 m from the plantation edge. All woody species were counted and divided into five height classes: <0.5, 0.5–1, 1–1.5, 1.5–2 and >2 m. Nomenclature follows Corlett et al. (2000). Diameter at breast height (dbh) of each planted exotic tree within the plot was measured. Photosynthetically active radiation (PAR) in the plantation understorey was measured at breast height (ca. 1.3 m) by a Skye PAR special sensor (SKP 210), and expressed as a percentage of readings taken within the same hour in an open area nearby. Canopy closure was measured in four corners of the plot with a spherical crown densiometer (Forestry Suppliers Ltd.) at breast height. Stand characteristics, including canopy height, aspect, slope and altitude, were also noted. If there was no nearby seed source (secondary forest) within 500 m of the plantation, the site was marked as isolated. Plantation ages were determined by finding the earliest aerial photographs in which the regular planting pattern was visible. For natural secondary forests, the ages were found by searching for the year that showed the first signs of colonization by trees. Stand characteristics of the 20 survey sites are summarized in Table 1. The ages of the natural secondary forests and plantations range from 25 to 50 and 15 to 50 years, respectively.

Species richness (number of woody species), Simpson's evenness and regeneration stem density

Table 1
Characteristics of the sites sampled for the vegetation survey

Vegetation type	Site no.	Aspect	Slope (°)	Altitude (m)	Basal area (m^2/ha)	Tree density (stem/ha)	PAR (%)[a]	Canopy closure (%)[a]	Canopy height (m)	Age
A. confusa	AC1	S	30	330	12.0	350	9.3 (8.7)	99.2 (0.4)	12	35
	AC2	SW	30	240	31.4	1400	4.8 (2.2)	97.1 (1.3)	15	15
	AC3	NE	15	140	18.3	500	4.7 (3.4)	98.0 (0.8)	20	35
	AC4	SW	15	190	11.5	375	7.6 (3.5)	97.6 (0.8)	20	15
L. confertus	LC1	NW	10	310	21.4	800	12.9 (1.3)	94.7 (1.3)	17	35
	LC2	SE	30	320	18.9	3075	16.0 (11.5)	91.4 (5.4)	10	25
	LC3	SW	10	240	28.9	1025	8.2 (3.5)	90.4 (5.0)	13	30
	LC4	NW	10	160	30.3	1275	5.9 (2.5)	94.8 (1.8)	20	35
A. auriculiformis, *A. confusa*, *A. mangium*, *L. confertus*, *Eucalyptus citriodora*, *Cunninghamia lanceolata*	M1	SE	20	200	28.7	2700	17.8 (1.5)	92.0 (0.4)	15	25
A. confusa, *L. confertus*, *P. elliottii*	M2	SW	30	100	21.6	1325	37.0 (6.1)	85.3 (4.0)	15	20
A. confusa, *L. confertus*, *C. fissa*	M3	SW	30	271	31.3	1425	5.7 (1.9)	97.5 (0.7)	20	15
A. confusa, *L. confertus*	M4	S	10	400	25.7	850	4.9 (3.9)	94.0 (2.5)	20	35
M. quinquenervia	MQ1	S	10	210	41.8	465	5.3 (0.2)	92.8 (1.8)	23	45
	MQ2	NW	10	120	31.5	650	2.9 (1.5)	96.8 (0.5)	30	35
	MQ3	E	10	220	69.4	525	4.3 (2.0)	97.3 (0.8)	30	45
	MQ4	W	20	200	102.1	625	4.0 (1.4)	97.4 (0.6)	30	50
Natural secondary forests	N1	SW	15	290	–	–	–	96.5 (0.9)	15	50
	N2	N	15	170	–	–	–	99.3 (0.2)	20	50
	N3	N	15	290	–	–	–	98.1 (1.0)	10	30
	N4	NE	20	410	–	–	–	96.8 (1.4)	15	25

[a] Means with standard deviations in parentheses.

Table 2
Species occurring in over half of the plantation sites

Species	Frequency in plantations	Mean density (stems/ha)[a]	Growth abit[b]	Dispersal agent[c]
Annonaceae				
Desmos chinensis Lour.	13	1356 (1472)	C	Bird and bat
Aquifoliaceae				
I. asprella Champ.	14	373 (353)	S	Bird
Araliaceae				
S. heptaphylla (L.) D.G. Frodin	15	895 (1036)	T	Bird
Asclepiadaceae				
Gymnema sylvestre (Retz.) Schult.	8	–	W	Bird
Caprifoliaceae				
Viburnum odoratissimum Ker-Gawl.	8	88 (104)	T	Bird
Chloranthaceae				
Sarcandra glabra (Thunb.) Nakai	12	3073 (3761)	S	Bird
Daphniphyllaceae				
Daphniphyllum calycinum Benth.	10	645 (896)	S/T	Bird and civet
Euphorbiaceae				
M. paniculatus (Lam.) Muell. Arg.	8	122 (179)	T	Bird
Guttiferae				
Cratoxylum cochinchinense (Lour.) Blume	8	94 (97)	T	Wind
Lauraceae				
L. rotundifolia var. *oblongifolia* (Nees) Allen	15	3037 (4665)	S	Bird
M. pauhoi Kanehira	11	661 (611)	T	Bird
Mimosaceae				
A. lucidum (Benth.) Nielsen	8	2063 (1941)	T	?
Moraceae				
Ficus hirta Vahl.	12	133 (145)	S	Bird
Myrsinaceae				
A. crenata Sims	11	377 (711)	S	Bird
Embelia ribes Burm. f.	9	–	W	Bird
Myrtaceae				
S. jambos (L.) Alston*	10	240 (307)	T	Bat
Phyllanthaceae				
A. dioica (Roxb.) Muell. Arg.	16	2295 (4380)	T	Bird
Breynia fruticosa (L.) Hook. f.	14	100 (69)	S	Bird
B. tomentosa Blume	8	269 (346)	S	Bird
Glochidion eriocarpum Champ. ex. Benth.	12	248 (267)	S	Bird
Rosaceae				
R. indica (L.) Lindl.	12	1429 (2061)	S	Bird
Rubus reflexus Ker	9	617 (1321)	C	Bird
Rubiaceae				
Mussaenda pubescens Ait f.	10	78 (53)	C	Bird
P. asiatica L.	16	9550 (9731)	S	Bird
Rutaceae				
M. pteleifolia (Champ. ex Benth.) T. Hartley	14	364 (438)	S/T	Bird
Zanthoxylum avicennae (Lam.) DC	12	117 (109)	T	Bird

Table 2 (*Continued*)

Species	Frequency in plantations	Mean density (stems/ha)[a]	Growth abit[b]	Dispersal agent[c]
Zanthoxylum nitidium (Roxb.) DC	11	–	W	Bird
Smilacaceae				
Smilax china (L.)	8	138 (166)	C	Bird

[a] Frequency of plants is out of 16 plantation vegetation survey sites. Standard deviation of density is in parentheses.
[b] Growth habit: C, climbing shrub; S, shrub; T, tree; and W, woody climber. (*) exotic or naturalised plant.
[c] Dispersal agent: source from Corlett (1996).

were found for all sites. Stems shorter than 0.5 m were not included in the regenerated stem density calculation since they often have high mortality (Otsamo, 2000). Simpson's evenness ($E_{1/D}$) was calculated as:

$$\frac{1/\sum p_i^2}{S}$$

where p_i is the proportion of individuals in the ith species, and S is the number of species (Magurran, 2004).

The abundance data was log transformed and a species composition matrix for the sites was calculated by Bray–Curtis similarity (Clarke and Warwick, 2001). The log transform down-weights the importance of the highly abundant species so that less common species are also reflected in the Bray–Curtis similarity. The non-metric multidimensional scaling (MDS) ordination was used to create a graphical representation of similarities between sites. This is an iterative procedure whereby the MDS plot is constructed by successively refining the positions of the points until they satisfy as closely as possible the dissimilarity (or similarity) relations between samples. Analysis of similarity (ANOSIM) was used to check for differences in species composition between vegetation types. A separate matrix was created using stand characteristics (which were square-root transformed to reduce right-skewness and stabilize the variance of the data), including the variables: age, %PAR, canopy closure, tree density, planted basal area, altitude, canopy height, and isolation. For plantation sites only, the BIO-ENV procedure was used to link these abiotic site variables to the species composition using Spearman's rank correlation coefficient (ρ_s). This exploratory procedure can determine the suite of environmental variables that is most likely to have shaped the MDS ordination of the understorey community. Thus, it enables further studies to be planned on how this suite of variables shapes the community. All of the multivariate tests above were conducted using PRIMER v5 (Primer-E Ltd., 6 Hedingham Gardens, Roborough, Plumouth PL6 7DX, UK, http://www.primer-e.com). Finally, we plotted the *k*-dominance curves for abundance of all four types of plantations and natural secondary forests in order to compare species dominance in the understorey communities of these sites.

3. Results

3.1. Stand characteristics and species richness

A total of 165 native or naturalised woody species, including 79 trees, 45 shrubs, 23 woody climbers, and

Table 3
Mean values of woody species richness, tree species richness, Simpson's evenness, and regeneration stem density of woody species regeneration under four types of plantation and spontaneous secondary forests

Plantation species	No. of all woody plant species	No. of tree species	Simpson's evenness ($E_{1/D}$)	Regeneration stem density (stems/ha)
A. confusa ($n = 4$)	38 (2.8)	15.3 (3.6)	0.114 (0.036)	9031 (3503)
Losphostemon confertus ($n = 4$)	35 (7.0)	10.8 (4.6)	0.153 (0.117)	9094 (6375)
Mixed-plantation ($n = 4$)	41 (5.4)	15.5 (2.1)	0.131 (0.048)	10000 (4967)
M. quinquenervia ($n = 4$)	50 (6.9)	25.3 (8.7)	0.120 (0.042)	10950 (4934)
Natural secondary forest ($n = 4$)	62 (16.8)	28.3 (7.8)	0.191 (0.050)	15531 (4808)

Standard deviations are in parentheses.

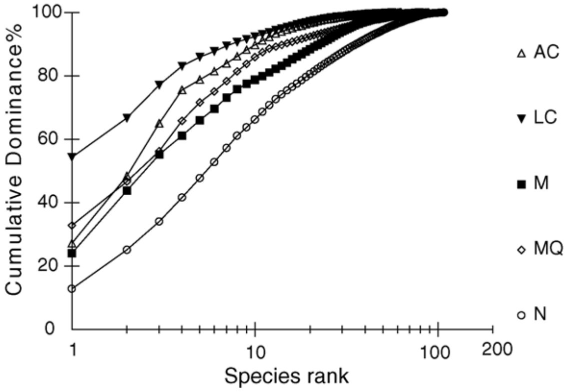

Fig. 1. *k*-Dominance plot of woody plants regeneration under plantations and natural secondary forests (AC: *A. confusa*; LC: *L. confertus*; M: mixed-planting; MQ: *M. quinquenervia*; N: natural secondary forest).

19 climbing shrubs, from 59 families were recorded in plantations. Phyllanthaceae, Lauraceae and Rubiaceae were the most common families of plants found under the plantations. Table 2 lists the 28 species occurring in over half of the sites surveyed. *Aporosa dioica* and *Psychotria asiatica* were found in all plantation and secondary forest sites. *Litsea rotundifolia*, *Schefflera heptaphylla*, *Ilex asprella* and *Melicope pteleifolia* were also very common. The mean values of woody species richness, number of tree species, Simpson's evenness and regeneration stem density are shown in Table 3. Fig. 1 shows the *k*-dominance plot of four types of plantations and natural secondary forests. *Lophostemon* plantations clearly show high dominance by a single species in their understorey (*P. asiatica*), while mixed-plantings have a species accumulation pattern closer to natural regeneration.

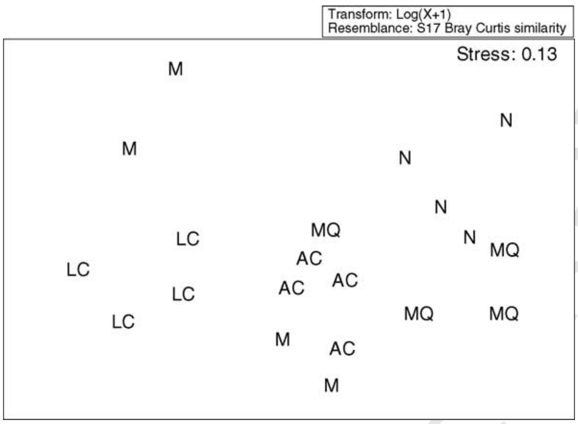

Fig. 2. Multidimensional scaling (MDS) ordinations of species composition of woody regeneration (AC: *A. confusa*; LC: *L. confertus*; M: mixed-planting; MQ: *M. quinquenervia*; N: natural secondary forests).

Table 4
Analysis of similarity between the species composition of different types of plantations and natural secondary forests

Types	*R* statistic	*p*
AC, LC	0.74	0.029**
AC, M	0.115	0.286
AC, MQ	0.26	0.114
AC, N	0.771	0.029**
LC, M	0.323	0.057
LC, MQ	0.917	0.029**
LC, N	1	0.029**
M, MQ	0.469	0.029**
M, N	0.656	0.029**
MQ, N	0.26	0.086

** $p < 0.05$.

3.2. Species composition

The MDS ordination (Fig. 2) shows the relative similarity between sites. The low stress level (0.13) shows that this is a relatively good two-dimensional representation with no real prospect of a misleading interpretation (Clarke and Warwick, 2001). *L. confertus* (LC) plantation sites form a group away from other types of plantation, and are the furthest away from natural secondary forests (N). *A. confusa* (AC) plantation sites form a closer group and are rather dissimilar to LC and N, while mixed-plantings (M) and *M. quinquenervia* (MQ) sites show a wide variation. The results of the one-way ANOSIM agree well with the pattern on the MDS (Table 4). BIO-ENV identified %PAR, canopy closure, tree density, planted basal area, and isolation as the most important variables controlling understorey species composition in plantations.

4. Discussion and conclusions

Many woody species occur in both plantations and natural secondary forests, but are often more abundant and older in the latter. Among the species shown in

Table 2, trees like *A. dioica*, *S. heptaphylla*, *M. pteleifolia* and *Machilus pauhoi* are present in both plantations and secondary forests of similar age, but are often much larger in secondary forests. Better regeneration in natural secondary forests is very probably a reflection of better site conditions for plant growth, as most of the sites selected for afforestation with exotic tree species were severely degraded (with serious surface soil erosion after prolonged disturbance by cutting and then fire), while natural forest succession is concentrated on the least degraded sites (Corlett, 1999). Three species were found only in the plantation sites: *Ardisia crenata*, *Bridelia tomentosa* and *Mallotus paniculatus*. These are light-demanding early succession species that are common in shrublands (Hau and Corlett, 2002), and their presence presumably reflects the generally lower degree of canopy closure in plantations. On the other hand, some very common secondary forest species, including *Garcinia oblongifolia*, *Syzygium hancei*, *Wikstroemia nutans* and *Ardisia quinquegona*, were rare in plantations, being confined to sites with good soil conditions and near to natural seed sources. Finally, *Syzygium jambos*, a bat-dispersed exotic tree which has established self-sustaining wild populations in Hong Kong (Corlett, 1999), was only found in plantations. Although none of the exotic tree species used in Hong Kong's plantation is locally invasive, some signs of natural regeneration of *M. quinquenervia* in Hong Kong have been detected in recent years (Hau, 2001). *M. quinquenervia* is a well-known invasive tree in Florida (Turner et al., 1998) and elsewhere, and both *L. confertus* and *A. confusa* are locally naturalised in Hawaii (Wagner et al., 1990), so exotic plantations should be monitored to prevent them from becoming invasion foci for exotic trees in Hong Kong.

Other studies on natural regeneration under plantations have shown that the canopy characteristic of the planted species is a possible influence on the understorey communities (e.g. Lugo, 1992; Parrotta, 1995). However, species effect cannot be recognized in this study because comparisons between the different forest types are confounded by pre-existing site differences as the species planted were matched to the site conditions. *M. quinquenervia* was mostly planted on abandoned paddy fields and other areas subject to flooding (Corlett, 1999), *L. confertus* was largely planted on sites with poor soil, as it is believed to be tolerant of drought, while natural secondary forests always occupy the best sites. A controlled experiment in which plantation species are randomly assigned to sites is theoretically possible, but is unlikely to be carried out in practice. Cautious interpretation of observational studies, such as this one, is therefore the only practical approach. Both the MDS and ANOSIM show that the species composition in natural secondary forests is significantly different from the plantations, with the exception of the *M. quinquenervia* sites. *Lophostemon* plantation sites differ significantly from other types of plantation. The fact that only four species, *P. asiatica*, *Archidendron lucidum*, *L. rotundifolia* and *Rhaphiolepis indica*, accounted for 83% of the total woody stems found in the *Lophostemon* plantations understorey (Fig. 1), and the low number of woody species found, shows that the woody plant invasion is poor under *Lophostemon* plantations. All *A. confusa* plantation sites show similar species composition, as seen in the MDS ordination and a lower dispersion of species richness, Simpson's evenness value and regeneration stem density (Table 3). Mixed-plantings and *M. quinquenervia* plantation sites, however, show a wider range of variation. The understorey of *Melaleuca* plantations had more abundant natural regeneration, similar to that of natural secondary forests, as shown by the closer distances in the MDS ordination and the ANOSIM results. Moreover, *M. quinquenervia* grows very well at the studied sites, reaching a canopy height of around 30 m, and basal area up to 100 m^2/ha. The good performance of both the planted trees and the subsequent native plant regeneration probably reflect the deeper, moister soils of these sites. The BIO-ENV results show that understorey light availability, tree density, planted basal area, and isolation are good predictors of the species composition in the understorey. Again, this result is at least partly confounded by pre-existing site conditions, since these factors will be influenced by site quality and location.

A previous study by Zhuang (1997) also showed that the understorey in eight plantation sites had lower species diversity than secondary forests. This suggests that simply reforesting hillsides with trees – at least with the exotic monocultures studied here – is not sufficient to restore natural forest diversity in Hong Kong. Other factors, for example the seed dispersal ability of colonizing plants, should be considered in the planning stage of plantation establishment. Seed dispersal into plantations seems to be a limiting factor for forest succession in the understorey, as in degraded grassland in Hong Kong (Hau, 2000) and elsewhere in the tropics (Parrotta et al., 1997; Holl, 1999; Holl et al., 2000). In areas that are far away from seed sources and have poor soil conditions, the plantation understorey is dominated by a few early successional shrub species even 40 years after plantation establishment. Martínez-Garza and Howe (2003) point out that this ‘pioneer desert’ could retard the influx of deep-forest trees and slow down the natural succession process. Plantations may be needed to control soil erosion on severely degraded sites, but encouraging natural succession is preferable where the principal aim of reforestation is the restoration of natural habitats. In Hong Kong, the control of anthropogenic fires is the main step needed to promote forest succession. In view of the large areas of already established exotic plantations in Hong Kong, management measures such as thinning of the exotic trees, planting shade-tolerant native tree species (such as many of the Fagaceae) and planting native tree species with fleshy fruits for attracting seed dispersers, are needed to rehabilitate the understorey community and speed up natural succession.

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