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A 70-year perspective on tropical forest regeneration

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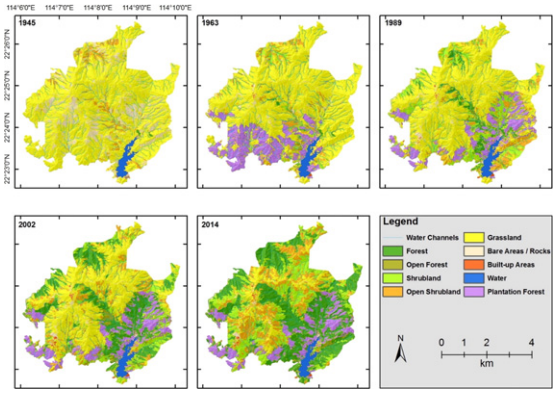
HIGHLIGHTS

- The practice of afforestation as a nursery stage for succession is not supported by the evidence
- Succession to forest proceeds much more rapidly than conversion of grassland to shrub.
- Establishment of linear-shaped riparian shrublands, helped faster colonization of forest.

GRAPHICAL ABSTRACT



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ABSTRACT

Forested areas of the world decreased by 129 million hectare during the past quarter-century, and only 35 % of remainder is primary forest. Secondary forests are therefore relatively more important for biodiversity conservation, catchment protection, climate control, and the ecological services they provide. Many governments expend large resources on afforestation projects, which may not be supported by objective data on rates and pathways of natural succession in secondary forest. This paper describes a 70-year succession of tropical forest in Hong Kong under different management regimes including afforestation programs, frequent fire, and fire protection. From complete destruction of its forest during the Second World War, forest has established rapidly in areas where a shrub cover was able to colonize. The practice of afforestation as a nursery stage on degraded hillsides, for establishment of forest seedlings by natural invasion is not supported by the evidence, as when the native *Pinus massoniana* plantations were eliminated by disease during the 1970s, no forest or woody species were seen in the areas affected. In fact there was a reversion to grassland, which persisted there for almost three decades, until recent shrub invasion. The fastest period of forest regeneration, at 10.9% annually between 1989 and 2001, occurred when shrubland edge was greatest and forest was able to colonize across interfluves between linear-shaped riparian shrublands in valley bottoms. After 2001, succession to forest was slower, at 7.8% annually, as forest patches consolidated and edge habitats reduced. Effective forest management policies could include seeding of native shrubs extending linearly from established forest, to maximize edge length between woody species and grasslands, and planting of late successional species in areas where forest pioneers are in decline.

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1. Introduction

Hong Kong's vegetation is extremely diverse, with more species of vascular plants in its 1100 km^2 of land area than the whole of Great Britain (Dudgeon and Corlett, 2011). However, Hong Kong is one of the earliest examples of tropical degradation, as it is estimated that complete clearance of the broad-leaved evergreen forest occurred around 400–600 years ago (Meachem, 1994). Although plantation forestry for environmental purposes commenced in mid-19th century (Evan, 1992), complete destruction of forest including plantations took place during the blockade years of World War II (WWII), accompanied by soil erosion on the steep slopes. Hong Kong's present day flora and fauna represent recovery since 1945 due to both natural regeneration from tiny remnants in inaccessible sites and possibly from post-war plantation of a limited range of native and exotic species. Post-war planting was aimed at controlling soil erosion in the degraded hills and water catchments, as well as for recreation and wildlife conservation (Corlett, 1999). Currently, secondary vegetation is succeeding in vertical structure as well as horizontal expansion (Wang et al., 2006), and observations suggest that forest may be regenerating naturally, and independently of assistance from afforestation programs.

As in many developed countries, Hong Kong's natural vegetation is confined to steeply sloping mountainous areas unsuitable for building, and 40% of Hong Kong's land area is reserved in Country Parks, where natural regeneration is evident. These changing patterns of landscape, with vegetation succession from open ground to forest, are indicative of changing ecological processes operating along the successional gradient, and can be informative for devising realistic conservation policies. For example, succession almost always proceeds with increasing structural complexity from grass through a shrubland stage to closed forest and at each structural stage, landscape parameters such as patch size, shape and distance vary, such that future change is a result of cumulative augmentation following the Compound Interest Law (Teferi et al., 2013). Thus once a late successional stage has been reached over a significant proportion of the landscape, subsequent change would be expected to occur more rapidly. Another effect is that increasing patch size brings patch edges closer together, enabling more effective seed dispersal in the intervening areas, thus again implying faster regeneration than at previous stages. It has been stated that it takes 10 years to convert from grassland to shrubland, and 30–40 years to transform shrubland into forest (Zhuang and Corlett, 1997), although no comprehensive spatial/temporal study has been undertaken to confirm this. Because differences in canopy structure and stand height produce distinctive tone and texture on aerial photographs and satellite images (Delang and Hang, 2009; Song and Woodcock, 2002; Teferi et al., 2013), the succession can be mapped using high resolution historic aerial photographs and recent satellite images (Lucas et al., 2002; Qi et al., 2013). The aim of this study is to use remotely sensed images to investigate processes of vegetation succession in Hong Kong's natural vegetation since the clearance of WWII, and their implications for regeneration of similar tropical forests elsewhere. The specific objectives of this paper are: 1) to map the changes in natural vegetation in Hong Kong over the last 70 years, 1945 to 2014, by analysis of sequential aerial photographs and recent high resolution satellite images; 2) to determine the influences of fire and forest plantation on the rate of natural vegetation succession in tropical secondary forest; 3) to examine patterns of forest succession related to topography.

1.1. Description of the study area

Hong Kong is situated on the northern margins of the Asian tropics (Fig. 1). The terrain is mountainous (Fig. 1) with a highest point of 957 m at Tai Mo Shan in the New Territories. Due to steep terrain, more than 75% of Hong Kong is undeveloped and 40% of the land area is protected in Country Parks and nature reserves (Corlett, 1999). Extremely high species diversity among flora and fauna is attributed to Hong Kong's climatic situation with features of both tropical and temperate regions (Dudgeon and Corlett, 2011), with a hot wet summer (May–September) and a cool dry winter (November–February). Mean annual rainfall is 2398 mm but 80% of this amount falls between May and September and mean annual temperature is 23.3 °C.

The study area comprises Tai Mo Shan and Shing Mun Country Parks in the New Territories of Hong Kong (Fig. 1), an area of ~2800 ha. Topography is rugged, with convex slopes rising to Hong Kong's tallest peak (957 m) Tai Mo Shan, and steep-sided slopes around Shing Mun reservoir. Due to frequent burning in the past, the upper valleys are covered with fire-maintained grasses, and lower elevations support patches of shrub, secondary forest and plantations. Temperatures above 400 m elevation fall below zero several times a decade, thus favoring tropical species (Dudgeon and Corlett, 2011; Weir and Corlett, 2006). The current study area covers ~3% of Hong Kong's land area and the other areas may have been managed differently in terms of fire protection strategies, and plantation activities.

1.2. Hong Kong's vegetation

Current forest cover in Hong Kong comprises Feng Shui Woods,[1] natural secondary forest, and plantations. Since 1841, 390 native tree species (Corlett, 1999), belonging to 61 families have been recorded in Hong Kong (Zhuang and Corlett, 1996). The majority of secondary forest has developed through structural succession on lands protected from fire since 1945.

Hong Kong's primeval vegetation was a diverse seasonal rain forest with at least 90–150 woody species per hectare as found in nearby protected areas in South China (Cao et al., 2013; Jingyun et al., 2004). Only tidal areas, swamps, river estuaries and areas with thin soil unsuitable for tree growth, would have naturally supported grasslands and shrubby vegetation (Dudgeon and Corlett, 2011). Due to human activities over hundred of years, most of the forests were either completely lost or strongly altered. On barren land, centuries of erosion removed more than 10 m of topsoil, and together with unsustainable agricultural practices, the weathered bedrock was exposed in many places making the establishment of native trees very difficult (Lam, 1977). Harsh environmental conditions such as torrential rains, strong sunshine, frequent hill fires, occasional droughts and irregular low winter temperatures often below 10 °C to the establishment of vast areas of grassland. Natural forest succession in these grasslands is very slow and dominated by hardy native pioneers and often invasive exotic species (Dudgeon and Corlett, 2011). These early successional forests are mosaics of shrubs and trees and normally not more than 30 tree species are found per hectare (Fischer pers. Observ). Preliminary data from a one ha plot in 17-year old secondary vegetation revealed 69 woody species of which only 31 were native, the rest being pioneer shrubs and invasive exotic trees (Fischer et al. unpubl. Data). Most of the climax trees are absent from the secondary forests and are mostly restricted to very small pockets of remnant forests along streams and better protected places near villages. Recent studies of forest plots in Hong Kong have shown that natural invasion of secondary forests and plantations by shade tolerant climax trees, if possible at all due to the very restricted distribution of remaining mother trees and the lack of important dispersal agents, is very slow. This may take centuries, leading to the current situation in which sun loving pioneer species replace themselves in tree fall gaps (Fischer et al. unpubl.). Such species-poor, often monotypic stands of a single species are very vulnerable to pests and diseases and one outbreak could potentially have devastating effects on populations as experienced before in Hong Kong when the native Pinus massoniana was almost completely wiped out by a nematode (Dudgeon and Corlett,

[1] Feng Shui Woods are those near to villages, and preserved over centuries by villagers, often having multi-layered canopy, large trees, and large woody lianes. They are considered the closest present-day representation of primary forest in Hong Kong (Zhuang and Corlett, 1997).