THE FRAMEWORK SPECIES METHOD: RESTORING TROPICAL FOREST BIODIVERSITY IN A CHANGING CLIMATE

Elliott[1], S.[*], D. Blakesley[2], K. Hardwick[3], K. Sinhaseni[1], G. Pakkad[1] and S. Chairuangsri[1]

[1*]Forest Restoration Research Unit, Science Faculty, Chiang Mai University,
Chiang Mai, Thailand, 50200. Email: stephen_elliott1@yahoo.com
[2]Wildlife Landscapes, UK
[3] Millennium Seed Bank Partnership, Royal Botanic Gardens, Kew, UK

Summary: The ultimate goal of forest restoration is to re-establish climax forest, with maximum biomass, structural complexity and species diversity that can be supported by the soil conditions and climate of the restoration site. Since the climax forest type depends on the climate, and the climate is changing in uncertain ways, it becomes impossible to know which climax forest type to aim for, when carrying out restoration on any particular site. So restoration should seek to maximize the capability of forest ecosystems to adapt to future climate change, by i) maximizing both species diversity and genetic diversity and ii) facilitating mobility of genes across landscapes. These two processes are central to the framework species method of forest restoration, making it an ideal approach for restoring tropical forest ecosystems in a changeable climate. The method relies on enhancing natural seed dispersal mechanisms to achieve rapid biodiversity recovery, by planting mixtures of 20-30 indigenous forest tree species, which i) survive well and grow rapidly when planted in deforested sites, ii) have dense crowns to shade out weeds and iii) provide resources (food, nesting sites and so on) at a young age, which attract seed-dispersing wildlife. Conserving genetic diversity during seed collection, planting up to 30 tree species, and preserving existing natural regeneration, all increase the chances that some species/genotypes will thrive in a future climate, whatever the climatic conditions might be. Furthermore, the method's capability to attract seed-dispersers, over distances of up to 10 km, facilitates gene migration. Some results of trials of the framework species method in northern Thailand are summarized.

Keywords: forest restoration, framework species, global climate change

INTRODUCTION

Climate change is one of the greatest threats to tropical biodiversity. With international talks, to shift the global economy from carbon-dependence to carbon-neutrality, stalled, increasing emissions of greenhouse gases continue to warm the planet. Computer models predict that, with moderate economic growth and rapid adoption of green technologies, surface air will warm by an average of 1.8°C (range 1.1 - 2.9°C), by the end of this century. Rainfall patterns will also change. Latest predictions suggest that precipitation will increase over tropical Africa and Asia, but decrease over tropical South America (+42, + 73 and -4 mm y^{-1}, respectively with 2°C warming; double these values with 4°C warming (Zelazowski et al., 2011)).

Forest restoration is defined as "actions to re-instate ecological processes, which accelerate recovery of forest structure, ecological functioning and biodiversity levels towards those typical of climax forest" i.e. the end-stage of natural forest succession – relatively stable ecosystems that have developed the maximum biomass, structural complexity and species diversity possible within the limits imposed by climate and soil and without continued disturbance from humans. Since the climax forest type depends on the climate, climate change alters the climax forest type, suited to any particular site and consequently the aim of restoration. In South America, areas currently capable of supporting wet tropical forests will probably contract, whereas in Africa and Southeast Asia they will expand (Zelazowski et al., 2011). In South

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[*] Corresponding author

America, former ever-wet rain forests may become seasonally-dry forests. Climate change will also affect the distribution of forest types on mountains. In drier areas, higher temperatures might allow dry forest types to spread higher up mountains†, displacing evergreen forests, but where rainfall increases, montane evergreen forest could spread to lower elevations. Climate changes will also affect the flowering and fruiting times of plants, which could result in a "de-coupling" of reproductive mechanisms e.g. flowers opening when their insect pollinators are not flying.

The problem is that we do not know how far global climate change may proceed, before measures to reverse it become effective. With such uncertainty, it becomes impossible to know which climax forest type to aim for at any particular site. Some tree species, selected for forest restoration projects, from today's remnants of climax forest might be tolerant of climate change, but some might not be. So, forest restoration projects should aim at establishing forest ecosystems that are capable of adapting to future climate changes. The keys to securing the adaptability of tropical forest ecosystems to climate change are: i) maximizing diversity (both species and genetic diversity) and ii) facilitating mobility of genes across landscapes.

The more tree species present, at the start of restoration, the more likely it is that at least some of them will tolerate future changes in the climate. Within species, responses among genotypes to climate change also vary. So maintaining high genetic diversity within species increases the probability that at least some genotypes will survive to perpetuate the species in the future climate. It is a genetic lottery; the more tickets you have, the greater is the chance that a winning ticket is among them. Trees cannot run away from climate change, but their seeds can. So, any actions that facilitate seed dispersal across landscapes increase survival chances for more tree species. Mobility of seeds across landscapes can be maximized by planting tree species that are selected for their attractiveness to seed-dispersing wildlife.

Although not originally designed as a climate change mitigation technique, the framework species method of forest restoration has great potential to adapt forest ecosystems to future uncertain climates, by maximizing biodiversity and gene mobility. First developed in Queensland, Australia (Lamb, 2011), the method involves planting mixtures of 20-30 indigenous forest tree species that rapidly re-establish forest structure and ecosystem functioning. Tree species are specifically selected for their capability to attract seed-dispersing animals, which increase the density and species diversity of the seed rain in restoration sites, whilst the cooler, more humid and weed-free conditions, created by the planted trees, favour seed germination and seedling establishment. The result is rapid recruitment of additional (i.e. non-planted) tree species and a highly diverse understorey.

MATERIALS AND METHODS

Extensive research was carried out on the tree species of tropical evergreen forest in Doi Suthep-Pui National Park, N. Thailand (including flowering, fruiting phenology, seed germination and seedling growth in an experimental tree nursery) to identify candidate "framework tree species" i.e. indigenous forest tree species likely to: i) survive and grow well in deforested sites, ii) shade out competing weeds and iii) attract seed-dispersing wildlife. In a research nursery, saplings of candidate species were grown from seeds, collected locally from many different parent trees to maximize genetic diversity. Research on seed germination and seedling growth was carried out in the nursery to develop production schedules for the most promising species.

Every rainy season since 1997, trial plots, ranging in size from 1.4 to 3.2 ha/y, have been planted with 20-30 candidate framework tree species in the Upper Mae Sa Valley (1,300 m elevation) of the park. The objectives of these plots were to: i) assess the potential of the

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[†] The upper limit of their preferred temperature will ascend, on average, about 100 m elevation for every 0.6 °C increase in temperature.

planted tree species to perform as framework species, ii) test the responses of the trees to various silvicultural treatments applied to maximize field performance and iii) assess biodiversity recovery. Before planting, naturally established tree seedlings/saplings were marked for protection. The plots were then cleared of herbaceous weeds by slashing and spraying with glyphosate, taking care not to damage any existing tree seedlings/saplings. Trees were planted randomly across the plots, averaging 1.8 m apart (or same distance from existing trees). Various fertilizer, mulching and weeding regimes were tested during the first two rainy seasons after planting. Fire breaks were cut every January and fire prevention patrols worked throughout the dry season. Samples of planted trees were labelled and monitored 2 weeks after planting and at the end of each subsequent rainy season. Surveys of naturally established trees and birds were carried out before planting and at various intervals thereafter, both in planted plots and in non-planted control plots. Camera trapping was used to determine if the plots attracted seed-dispersing mammals.

RESULTS AND DISCUSSION

Monitoring of planted trees enabled determination of the best-performing framework tree species (Elliott et al., 2003) and optimal silvicultural treatments (FORRU, 2006). Canopy closure was achieved in most plots within 3 years after planting.

Camera trapping confirmed the return of seed-dispersing mammals such as hog badger, large Indian civet, palm civet and barking deer. They deposited seeds of some tree species that did not occur within several kilometres of the study plots (e.g. lychee (nearest source, 3 km), coffee (5 km) and *Aquilaria crassna* (8 km)). Bird species richness increased markedly from about 30 species before planting to 88 after 6 years, representing about 54% of birds recorded in the nearest remaining patch of climax forest (Toktang, 2005). Seeds, mostly brought into the plots by birds and mammals, resulted in rapid increase in tree species richness. Planting up to 30 framework tree species fostered the recruitment of an additional 73 (non-planted) tree species within 8-9 years, resulting in an overall total of more than 100 tree species (Sinhaseni, 2008)), i.e. 47% of all tree species recorded in climax evergreen forest at the same elevation (compared with only 42 species in non-planted control plots). The recruit tree species in planted plots included some that are characteristic of lowland deciduous forest types, previously rarely found above 1,000 m elevation (e.g. *Dipterocarpus costatus*, wind dispersed, nearest known seed source about 8 km away, 900 m elevation), suggesting that the framework species plots may already have begun to foster establishment of tree species more suited to drier, warmer climatic conditions.

Results showed that the framework species method has great potential for maximizing the adaptability of forest ecosystems to future climate change by: i) rapidly increasing biodiversity in restored forest plots within the first few years after restoration work commences and ii) attracting wildlife, capable of moving seeds over several kilometres from surviving forest remnants to restoration sites. Initial studies also confirm that the method retains high genetic diversity within tree species, but so far studies have been restricted to very few framework tree species (Pakkad et al., 2004).

CONCLUSIONS

The framework species method is not a universal solution to adapting forest restoration projects to uncertain future climates. It only works well where remnants of the target climax forest type survive within a few kilometres of restoration sites (as seed sources) and where animals (mostly birds, bats and medium sized mammals), capable of dispersing seeds from those forest remnants to restoration sites, remain fairly common. Preventing the hunting of seed-dispersing animals is obviously also essential for the success of the framework species method.

Adaptability to climate change could be further increased by supplementing locally collected seeds with seeds from the warmer limits of a species' distribution‡, to broaden the genetic base of planted trees. It is more likely that genetic variants, suited to a future unknown climate, may emerge from this more diverse gene pool, through natural selection (i.e. "composite provenancing" of Broadhurst et al., 2008). Tree species with large seeds, particularly those that would have depended on extirpated large animals (e.g. elephants, rhinos, and so on) for dispersal, should also be targeted for planting. Without their seed dispersers, human intervention may be their only remaining chance of dispersal. Increasing forest connectivity at the landscape level also facilitates seed dispersal, since many seed-dispersing animal species are reluctant to cross over large open areas. This can be achieved by using the framework species method to create "corridors" or "stepping stones" to re-connect isolated forest patches. Whilst it is fanciful to suppose that something as dynamic and variable as tropical forest can be "climate proofed", some of the measures suggested above may at least help to secure the long-term future of some form of tropical forest ecosystem at today's restoration sites.

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[‡] Southern populations in the northern hemisphere, northern populations in the southern hemisphere and, for montane species, trees growing near the lower elevation limit.