**Restoration of forest structure in managed regrowth at Rocky Creek Dam,
Australia.**

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Introduction

Secondary forests cover extensive areas of tropical and subtropical landscapes, and play an increasingly important role in the conservation of biodiversity and the provision of ecosystem services (Lugo & Helmer 2004). Under optimal conditions, secondary forests can develop structural characteristics which resemble remnant forests within several decades (Guariguata & Ostertag 2001; Holl 2007). However, the composition of secondary forests may vary considerably from remnant forests, particularly in extensively cleared areas where regrowth is often dominated by exotic plant species.

Exotic plants can play complex roles in rainforest regeneration. On the one hand, they can facilitate the recruitment of rainforest plants to cleared land, first by attracting frugivorous birds which disperse the seeds of fleshy-fruited plants (Neilan *et al.* 2006) and second by creating a closed canopy which suppresses grasses and enhances the recruitment and survival of rainforest plants (Catterall *et al.* 2008). On the other hand, exotic plants may subsequently inhibit the growth of recruited native plants and slow down succession towards a rainforest-dominated assemblage (Erskine *et al.* 2007). Consequently, restoration practitioners wishing to accelerate the regeneration of native species to regrowth may seek to control exotic plants (Lymburner *et al.* 2006). The treatment of weedy regrowth to promote the growth of rainforest plants is potentially a cost-effective form of restoration, when compared with replanting (Kanowski & Catterall 2007a). Unfortunately, the ecological outcomes of such treatment have rarely been quantified.

In this note, we assess the restoration of forest structure to treated regrowth at Rocky Creek Dam, northern New South Wales, Australia. The history of restoration at this property was described by Woodford (2000). Briefly, after acquisition for the construction of a dam in the 1950's, the former dairy farm reverted to weedy regrowth dominated by Lantana (*Lantana camara* L.) and Camphor Laurel (*Cinnamomum camphora* (L.) T. Nees & C. H. Eberm), with scattered rainforest trees. A 25 ha patch of weedy regrowth was progressively treated in 1-2 ha blocks between 1991 and 2000, by

poisoning and slashing weeds to facilitate the growth of suppressed rainforest plants and to promote recruitment from the soil seed bank. There property also contains untreated patches of regrowth, dominated by rainforest trees or exotics. The property abuts the former Big Scrub Flora Reserve, the largest patch of remnant subtropical rainforest in the region, and the extensive forests of the Nightcap Range.

Methods

This study surveyed a chronosequence of 10 regrowth sites aged 7 – 16 years since treatment, as well as four reference sites adjacent to Rocky Creek Dam: one in untreated 60 year old regrowth dominated by rainforest trees, and three sites in intact rainforest. Structural data were collected from two 50 x 10 m plots at each site. Attributes assessed included percentage ground cover (various categories, including leaf litter, grasses, herbs, ferns, tree seedlings), percentage canopy cover (determined from wide-angle photographs of the canopy vegetation), canopy height, counts of trees by diameter class, estimates of woody debris volume using a line intercept method, and tallies of the frequency of special life forms characteristic of rainforest. For a complete list of attributes and description of survey protocols, see Kanowski and Catterall (2007b).

We examined the correlation of selected structural attributes with age of the treated regrowth sites. A multivariate distance index was constructed to examine the overall structural relationship between sites, based on the mean Euclidian distance between each site and the intact rainforest reference sites, using all measured structural attributes which were range-standardised prior to analysis. A multi-dimensional scaling (MDS) plot was used to show patterns of resemblance between the treated regrowth sites and reference sites, based on this index, using PRIMER (Clarke & Warwick 2001).

Results

Overall, the structure of the treated regrowth sites became increasingly similar to reference rainforest sites with age since treatment (Fig. 1). Some attributes, such as

canopy cover and leaf litter cover, rapidly attained values similar to reference sites (within 10 years of treatment), while basal area had attained values of two of the three rainforest reference sites by 16 years. The density of stems across a range of size classes also converged rapidly on rainforest sites. The very high density of smaller stems (<10 cm dbh) present in the younger treated sites decreased exponentially with age and was only slightly higher than rainforest reference sites by 16 years after treatment. Densities of larger size classes showed a corresponding increase with age of regrowth, although the rainforest reference sites had a higher representation of stems in the largest size class (>50 cm dbh) than the oldest treated sites.

Not all structural attributes of treated sites converged on rainforest conditions. An index of the overall frequency of special life forms showed no correlation with age since treatment (Fig. 1). However, certain life forms such as thorny scramblers were more abundant in the younger sites, while others such as palms and epiphytic ferns were more common on the older sites. Even the oldest treated sites lacked some life forms characteristic of reference sites, such as robust vines, hemi-epiphytes and strangler figs. Some of these were present in the 60 year untreated regrowth site.

Both the multivariate distance measure and an ordination of sites, based on all measured structural attributes, show a steady progression from the younger treated regrowth sites through the 60 year old untreated regrowth to the rainforest reference sites (Figs. 1, 2). The development of structure over time is also evident in photos of treated sites (Fig. 3).

Discussion

The results of this study show that treatment of weedy regrowth at Rocky Creek Dam has led to the rapid recovery of structural attributes at treated sites, with many attributes converging on rainforest reference sites within 16 years of treatment. Similar trends have been reported for secondary regrowth from other rainforest landscapes, with some attributes such as biomass requiring only 20 – 40 years to resemble remnant forests (Guariguata & Ostertag 2001; Holl 2007).

The relatively rapid development of forest structure at the Rocky Creek Dam site may be attributed to several factors. First, while the sites had been treated within the last 16 years, regrowth on the site had proceeded for nearly 50 years, and treated sites may have contained some elements of advanced regrowth. Second, treated sites were in close proximity (10 – 500 m) to remnant rainforest, strongly favouring the dispersal of rainforest plants to treated sites (White *et al.* 2004; Holl 2007). Third, the fleshy-fruited exotic plants that dominated the site prior to treatment are known to attract frugivorous birds and bats which disperse the seeds of a high proportion of rainforest plants (Neilan *et al.* 2006). Fourth, the site has favourable environmental conditions for plant growth (high rainfall and fertile soils). Finally, treated sites were subject to regular weed control after initial treatment (Woodford 2000).

Interestingly, Woodford (2000) reported a dramatic increase in the abundance of herbivorous marsupials (pademelons: *Thylogale spp.*) in treated sites after 1996-97, which he suggested caused a reduction in the abundance of pioneer species establishing on treated sites. From the structural data presented here, there is no evidence that the development of structure on younger treated sites has been significantly delayed by herbivory, compared with trends evident in older treated sites. However, the floristic composition of young sites may have been altered by herbivory, which favours the dominance of unpalatable species (Woodford 2000).

Although the structure of the older treated regrowth sites appear to be converging on rainforest conditions, their floristic composition is obviously distinct, as treated sites are dominated by early successional species (Kanowski & Catterall 2007a). Studies elsewhere report that the composition of secondary forests may take much longer than structure to resemble remnant forests (Guariguata & Ostertag 2001; Holl 2007). Therefore, while an assessment of forest structure can provide useful information on the progress of restored sites towards reference conditions, and can be conducted rapidly by non-specialists (Kanowski & Catterall 2007b), a comprehensive assessment of

restoration success will also require more specialised survey of floristic and perhaps faunal composition (Catterall *et al.* 2008).

The manipulation of weedy regrowth at Rocky Creek Dam has caused treated sites to develop rapidly on reference conditions. Considering the lower cost of treating weedy regrowth compared with reforestation (Kanowski & Catterall 2007a), together with the extensive areas of regrowth in former rainforest landscapes (Erskine *et al.* 2007), this approach may be useful for large scale restoration projects. However, Rocky Creek dam – being located next to remnant forest, on fertile soils, and with high rainfall - probably represents an optimum situation for application of this approach, at least in the subtropics. Success may be slower (or more difficult to achieve) in other contexts. Conversely, rainforest regeneration after the treatment of weedy regrowth could be even more rapid in moist tropical sites, where conditions favour year-round growth.

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Figure 1. Changes in structural attributes with age of treated regrowth at Rocky Creek Dam, compared with values for a 60 year old natural regrowth site (60) and three rainforest reference sites (RF). Correlations are between structural attributes and age of treated regrowth sites. The multivariate distance index is a measure of the difference between each site and rainforest reference sites over all measured structural attributes.

Figure 2. Multi-dimensional scaling plot showing patterns of resemblance between the treated regrowth sites (plotted as age of regrowth; 7-16), 60 year old natural regrowth site (60) and the three rainforest reference sites (RF), based on all measured structural attributes. Stress = 0.05.

Figure 3. Eight year old (A) and 12 year old (B) treated regrowth sites at Rocky Creek Dam.