FEATURE

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Potential value of weedy regrowth for rainforest restoration

By John Kanowski, Carla P. Catterall and Wendy Neilan

Weeds are (usually justifiably) considered 'bad'! But what about when weedy regrowth supports native species and facilitates the conversion of retired pasture back to functioning rainforest?

Figure 1. The Topknot Pigeon (*Lopholaimus antarcticus*), a rainforest pigeon which feeds on the fruit of Camphor Laurel (*Cinnamomum camphora*) in north-east New South Wales, Australia. The Topknot Pigeon forages in large flocks and can travel tens of kilometres daily. For these reasons, it is an important long-distance disperser of rainforest plants to stands of Camphor Laurel (as well as being a disperser of Camphor Laurel to other forest types). (Photo: Terry M. Reis.)

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Introduction

Australian rainforests have been the focus of much conservation and restoration effort in the past few decades. Governments, community groups and individuals have invested tens of millions of dollars to rehabilitate degraded remnants and replant rainforest trees in tropical and subtropical Australia (Catterall *et al*. 2004).

What has been the return on this investment? At a site scale, the outcomes of restoration for biodiversity have often been quite high. For example, in subtropical Australia, most (over 40) remnants of the former Big Scrub rainforest have been subject to rehabilitation (primarily weed control), with evident improvements in condition (Bower & Parkes 2002). In both tropical and subtropical Australia, many small restoration plantings have been established, mostly utilizing a diverse range of locally occurring species, planted at high densities (Kooyman 1996; Freebody 2007). Research has shown that these restoration plantings can develop a rainforest-like structure and support a moderate diversity of rainforest fauna (Fig. 1) within a decade of establishment (Kanowski *et al*. 2003, 2006; Catterall *et al*. 2004, 2008; Grimbacher *et al*. 2007).

However, at the landscape scale, the return on investment has been limited. No more than 1000 ha of restoration plantings, and a few thousand hectares of mixed species cabinet timber plantations, have been established in former rainforest landscapes in Australia: that is, less than 1% of the area of cleared land

Box 1. What is Camphor Laurel?

Camphor Laurel is a fast-growing, relatively shade-intolerant evergreen tree from subtropical Asia. Mature trees bear an abundant crop of small (*c*. 10 mm) fruits over winter (Fig. 2), a period when relatively few native rainforest trees are fruiting (Date *et al*. 1991; Scanlon *et al*. 2000). Dispersed seeds tend to remain dormant until the following wet season (Stewart 2000). Unlike many native rainforest trees, Camphor Laurel readily recruits into pasture (Fig. 3), is relatively drought and frost tolerant, and not heavily browsed by cattle or wallabies. The shade cast by dense Camphor Laurel stands suppress pasture grasses, creating conditions suitable for the recruitment of rainforest trees (McDonald 1996).

Figure 2. Camphor Laurel fruit and foliage. (Photo: Wendy Neilan.)

Figure 3. Stand of Camphor Laurel developing on retired agricultural land. (Photo: Wendy Neilan.)

in these regions (Catterall & Harrison 2006). This is partly because restoration plantings are expensive: at current prices, at least $30 000 per hectare.

Ironically, despite the best of human intentions, forest cover has greatly increased in some former rainforest landscapes over the last few decades. In the former 'Big Scrub' region, for example, from which more than 99% of rainforest was cleared, woody vegetation cover is now approaching 40% (Neilan *et al*. 2006). Only a small proportion of this is replanted rainforest; most is either *Macadamia* plantations and other tree crops, or regrowth forest dominated by the exotic tree Camphor Laurel (*Cinnamomum camphora*) on retired agricultural land (Box 1).

Regrowth forests dominated by exotic species are rapidly increasing in extent worldwide, and their management is often problematical (Box 2). There is a widespread tendency to disregard the potential ecological value of these forests, simply because they are dominated by exotics (Ewel & Putz 2004). Reading the popular and management literature on Camphor Laurel, for example, it is hard not to be struck by the repetition of poorly supported assertions concerning the negative impacts of this species on biodiversity, water quality and human health. In several shires in north-east New South Wales, landowners are legally obliged to fully or partially control Camphor Laurel, an obligation justified partly on environmental grounds (Scanlon & the Camphor Laurel Taskforce 2000).

As ecologists with research interests in rainforest restoration, we became interested in the potential value of regrowth forests for supporting rainforest biota and restoring forest cover to former rainforest land. Regrowth wasn't originally part of our research agenda, but we felt we couldn't completely ignore the vast stands of regrowth that we were driving past to get to our small restoration plantings! This was particularly the case for Camphor Laurel, which had already been recognized as providing a valuable resource for many rainforest birds

(Frith 1982; Date *et al.* 1991; Gilmore 1999; Stewart 2000). It was also known that rainforest plants often recruited under Camphor Laurel trees (Firth 1979; McDonald 1996), and restoration practitioners had begun to trial methods to accelerate rainforest regeneration in Camphor Laurel stands (Woodford 2000; Lymburner *et al.* 2006).

In this article, we summarize the research we have conducted on the potential values of Camphor Laurel regrowth for rainforest biota and the outcomes of restoration treatments aimed at improving those values.

Biodiversity values of weedy regrowth

Our initial research set out to examine the biodiversity value of various types of reforestation. We surveyed monoculture timber plantations, mixed species cabinet timber plantations, diverse ecological restoration plantings and regrowth forests, as well as reference sites in pasture and rainforest. In the subtropics, the regrowth forests we studied were dominated by Camphor Laurel and other exotics, especially Privets (*Ligustrum lucidum* and *Ligustrum sinense*). As far as possible, sites were matched for key environmental

Box 2. Emerging ecosystems, land use change and conservation management

Much of contemporary conservation biology is based in a binary view of terrestrial life, which considers landscapes as patches of native vegetation surrounded by a sea of uninhabitable human-modified land. This view has become widely entrenched in real-world decision-making about conservation issues. For example, in a number of jurisdictions, maps of 'remnant vegetation' provide the template for conservation planning, with the surrounding 'non-remnant' land considered to have negligible conservation value. In this view, species of conservation significance are those that depend on the habitats provided by remnant vegetation. The species found elsewhere are assumed to be of little interest unless they happen to be dispersers from the remnant forest or potential invaders of the remnants.

This view meshes well with another commonly used surrogate of conservation value: the distinction between native species (valued positively, often in proportion to rarity or threat) and exotic species (negatively valued). Although these world views remain useful in many situations, they are becoming increasingly challenged by current trends in the nature and extent of vegetation cover in real landscapes.

First, although deforestation continues to destroy large tracts of native vegetation globally, there is also a growing trend for the abandonment of agricultural activities over other large areas of land. Second, such abandoned land is frequently colonized by novel combinations of native and exotic plant species (Hobbs *et al*. 2006). Exotic plants are often the earliest colonizers of disturbed areas, and they arguably perform useful ecological roles (D'Antonio & Meyerson 2002; Ewel & Putz 2004; Lugo & Helmer 2004; Neilan *et al*. 2006). These include various 'ecosystem services', such as land stabilization, catchment protection and carbon sequestration, as well as 'conservation services' including the provision of food and habitat for conservation-dependent fauna, and the creation of environmental conditions that favour the recruitment of native plant species. Third, the goal of restoring preclearing ecosystems to disturbed areas is becoming increasingly unattainable. Change in key environmental drivers, such as climate, hydrology and soils, the extinction of keystone fauna, and alterations to disturbance regimes (such as the cessation of indigenous burning practices) will mean that the reference ecosystems of the future are likely to differ from those of the past.

Regrowth forests comprised of native and exotic species have been termed 'new forests' (Lugo & Helmer 2004) or, more broadly, 'emerging ecosystems' (Hobbs *et al*. 2006). Because of their unprecedented nature, many of their ecological properties are unknown. They pose a dilemma for ecologists and land managers who may wish, on one hand, to contain the spread of introduced plants, particularly species with the potential to invade native vegetation, but on the other hand to encourage the development of new forests as a restoration and conservation tool. Although such decisions will need to be made on a case-by-case basis, it is likely that retention and management of new forests is in many cases likely to be a cost-effective strategy for re-establishing a range of ecological functions, similar to those provided by native forests, over large areas of land (Lugo & Helmer 2004; Erskine *et al*. 2007; Zimmerman *et al*. 2007). This may be most successful when accompanied by management actions aimed at accelerating the development of the desired characteristics of mature native forest, such as species and functional diversity.

features of soil type, rainfall and elevation. We located 5–10 replicates in each site type, in both the tropics and subtropics, and surveyed sites for birds, reptiles, leaf-litter invertebrates, plant species composition and vegetation structure. Further details of the study design are provided in Kanowski *et al*. (2003) and Catterall *et al*. (2004).

The results of these surveys showed that regrowth forests in the subtropics had a surprisingly high biodiversity value, despite being dominated by exotic tree species. They often supported a similar number of rainforest animals as restoration plantings, and usually more than timber plantations (Fig. 4). We attributed these results partly to the structural complexity of these regrowth forests, which were 20–40 years old at the time of survey and had in most cases developed a closed canopy, a high density of woody stems, a shrubby understorey and a ground cover of tree seedlings, leaf litter and woody debris (Kanowski *et al*. 2003). The composition of the regrowth, particularly its dominance by tree species that bore abundant crops of fleshy fruit, was also likely to be important for rainforest birds.

In terms of rainforest restoration, this was exciting information, because the regrowth forests we studied covered large areas of land and had cost nothing to establish. However, our results came from only a few sites and could not answer some important questions. In particular, we wanted to gain a better understanding of the interactions between fleshy-fruited plants, fruit-eating birds and the plants they disperse in regrowth stands (Box 3). We also wanted to know whether these interactions were influenced by the proximity of regrowth stands to presumed source populations of birds and plants in remnant forests.

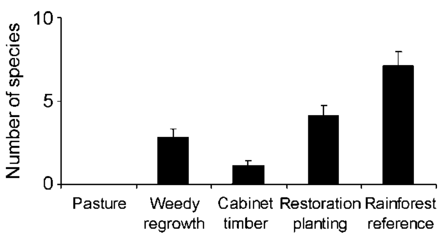

Figure 4. Number of species of rainforest birds (mean, SE) recorded in pasture, stands of weedy regrowth dominated by Camphor Laurel and/or Privet, mixed species cabinet timber plantations, restoration plantings and rainforest reference sites in subtropical Australia. Data from six 30 minute surveys of 0.3 ha per site (Catterall *et al*. 2004).

The use of Camphor Laurel stands by fruit-eating birds

To address these questions, we conducted surveys of fruit-eating birds and rainforest plants in 24 patches of well-developed Camphor Laurel regrowth spread across the Big Scrub region in north-east New South Wales (Neilan *et al*. 2006). To investigate the effect of landscape context on the results, some sites were selected to be 'close' (within 1 km) and others more distant (3–30 km) from the major remnant rainforests in the region (the Nightcap Range). Within each patch, we located a 0.6-ha site for detailed study.

Birds were surveyed seven times on each site, four times in summer and three in winter. We expected seasonal variation in bird assemblages, due to the winter fruiting of Camphor Laurel and the migratory movements of some bird species. We classified birds by their functional role in seed dispersal (Moran *et al*. 2004b), based on their gape size, how much fruit they eat and how they process seeds.

A total of 34 species of fruit-eating birds were recorded in Camphor Laurel stands during the study, including many species associated with subtropical rainforest (Moran *et al*. 2004b). Of these, 16 species were considered to have a moderate to high potential to disperse rainforest plants (Table 1) because they eat fruit regularly and disperse viable seeds. Species such as the Topknot Pigeon (*Lopholaimus antarcticus*) (Fig. 1) are capable of dispersing relatively large seeds over long distances, due to their wide-ranging movement patterns.

Frugivorous birds with moderate to high potential to disperse the seeds of rainforest plants were more abundant and represented by more species in stands of Camphor Laurel in winter, during its fruiting season, than in summer (Fig. 5). Close proximity to The Nightcap Range had little effect on the overall species richness of frugivorous

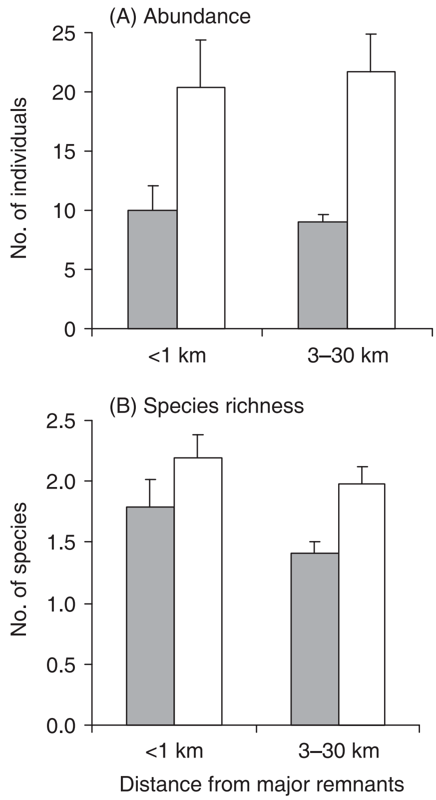

Figure 5. Abundance and species richness (mean, SE) of fruit-eating birds with moderate to high potential to disperse the seeds of rainforest plants recorded in stands of Camphor Laurel in north-east New South Wales. (Bird surveys are categorized by season: shaded bars, summer; open bars, winter. Sites are categorized by distance from major rainforest remnants (<1 km, $n = 7$; 3–30 km, $n = 17$). Survey area = 0.6 ha per site. Data from Neilan *et al*. (2006). There were more individuals and species of birds in Camphor Laurel stands in winter than in summer (paired *t*-test, $P < 0.001$ for both analyses), but abundance or richness did not vary significantly with proximity to remnants (repeated measures ANOVA, $P = 0.96$ and 0.11, respectively).)

Box 3. Frugivore – plant interactions and the future of human-dominated ecosystems

When forests are converted to farmland, soil seed banks are eventually lost. Consequently, seed-dispersal processes become a critical determinant of the type and diversity of vegetation which develops following the abandonment of agricultural activities. Endozoochory (the internal transport of seeds within the digestive system of a fruit-eating animal) is the dominant dispersal mode in rainforest ecosystems worldwide. For example, in the Australian Wet Tropics uplands, some 83% of 243 tree, shrub and vine species recorded in a total of 0.4 ha of rainforest bear fleshy fruits adapted for dispersal by vertebrate animals, of which regular seed-dispersers in the region include at least 20 genera of birds and two genera of bats (Catterall *et al*. 2008).

Within any region, each fleshy-fruited plant species is typically consumed by a number of birds, and each bird consumes a range of plants. Although many of the details of these relationships are still poorly understood, size clearly matters. For example, birds with small gapes (the opening size of the beak) will not be able to consume large seeds. Many mature-phase rainforest trees produce large seeds, and their ability to colonize new sites will depend on the dispersal services provided by large-gaped frugivores. In many landscapes, large-gaped frugivores are scarce or absent outside of extensive areas of intact forest (Corlett 2002).

Human-dominated landscapes typically support both native and exotic birds and plants, linked in complex webs of relationship (Buckley *et al*. 2006). Native frugivores often assist the spread of exotic plants, while the fruits of exotic plants can help sustain native frugivore populations, including threatened species. These interactions may lead to 'rescue and recovery' scenarios within extensively cleared rainforest landscapes, in which the fruits of exotic plants support native frugivores, which in turn spread the seeds of native plants into regenerating areas (Neilan *et al*. 2006). However, if the native vegetation is predominantly dry-fruited (e.g. Australian sclerophyll forests) and exotic plants are eaten by native frugivores, invasion by one fleshy-fruited exotic plant may promote the invasion of others (Lake & Leishman 2004). In the worst scenarios of 'degradation and meltdown', exotic plants support exotic frugivores, which in turn spread more exotic plants (Bourgeois *et al*. 2005). Which of these processes and outcomes takes place will depend on the particular ecological characteristics of a given landscape and the species in it.

Conservation conflicts are likely to arise when both positive and negative scenarios are possible (D'Antonio & Meyerson 2002). Some of the most invasive plants are dispersed by frugivores. However, where an invasive plant comprises part of the diet of native frugivores, and habitat destruction has reduced populations of native fruiting plants, it may be hard to decide whether to eliminate the invader, with the result that native biota may decline (or fail to recover), or whether to tolerate or actively manage it. Management and restoration need to be sensitive to the multiple ecological roles that frugivore-dispersed exotics play in human-dominated landscapes. These are new opportunities and challenges for both ecological restoration and weed management across the world's increasingly large area of retired agricultural land.

birds in Camphor Laurel stands (a tendency towards slightly more species, on average, in close sites), and no effect on overall abundance. However, some species, such as the Topknot Pigeon and Rose-crowned Fruit-dove (*Ptilinopus regina*), changed their patterns of distribution in Camphor Laurel coincident with its fruiting. In summer, these species were mostly recorded in sites close to major rainforest remnants, but in winter they were found across the landscape, foraging on Camphor Laurel. The Silvereye (*Zosterops lateralis*), a habitat generalist and disperser of small seeds, was more abundant in distant than close sites.

These results support the conclusions of other researchers (e.g. Frith 1982; Date *et al*. 1991) that Camphor Laurel provides an important resource for a number of rainforest birds in the Big Scrub region. Some of these species, such as the Rose-crowned Fruit-dove, were thought to be in serious decline in the mid-20th century, before Camphor Laurel became widespread (Frith 1982).

The recruitment of rainforest plants to Camphor Laurel stands

To find out whether frugivore activity was associated with the recruitment of rainforest plants to Camphor Laurel stands, we conducted botanical surveys of the same stands where birds had been assessed (Neilan *et al*. 2006). As part of this survey, we counted trees and shrubs >0.5 m high in five 50-m transects per site, the width of each transect ranging from 2 to 10 m depending on the size

Table 1. The birds that eat fruit regularly and disperse viable seeds in stands of Camphor Laurel in north-east New South Wales, recorded by Neilan *et al*. (2006)

Species	Potential size of seeds dispersed†	No. of sites recorded‡
Topknot Pigeon (*Lopholaimus antarcticus*)	Large	Many
Rose-crowned Fruit-dove (*Ptilinopus regina*)§¶	Medium	Most
Wompoo Fruit-dove (*Ptilinopus magnificus*)§¶	Large	Few
Channel-billed Cuckoo (*Scythrops novaehollandiae*)	Large	Few
Lewin's Honeyeater (*Meliphaga lewinii*)	Medium	Most
Varied Triller (*Lalage leucomela*)	Small	Many
Barred Cuckoo-shrike (*Coracina lineata*)¶	Medium	Few
Olive-backed Oriole (*Oriolus sagittatus*)	Large	Few
Figbird (*Sphecotheres viridis*)	Large	Most
Pied Currawong (*Strepera graculina*)	Large	Most
Paradise Riflebird (*Ptiloris paradiseus*)	Large	Few
Green Catbird (*Ailuroedus crassirostris*)§	Large	Many
Regent Bowerbird (*Sericulus chrysocephalus*)	Medium	Few
Satin Bowerbird (*Ptilonorhynchus violaceus*)	Large	Few
Mistletoebird (*Dicaeum hirundinaceum*)	Small	Many
Silvereye (*Zosterops lateralis*)	Small	Most

†Based on gape size (Moran *et al*. 2004b): small <10 mm; medium 10–15 mm; large >15 mm;
‡few = 1–5; many = 6–20; most >20 (of 24 sites)
§species which have declined in fragmented rainforest in south-east Queensland, a region without extensive stands of Camphor Laurel (Moran *et al*. 2004a)
¶threatened species under the New South Wales Threatened Species Conservation Act, 1995.

class of stems. We considered trees and shrubs <2.5 cm d.b.h. to be 'recruits' (surveyed on 0.05 ha per site), while trees >10 or 20 cm d.b.h. (surveyed on 0.25 ha per site) were classified as 'adults', depending on their size at maturity.

We recorded a total of 181 species of rainforest trees, shrubs, vines and other vascular plants in the 24 sites, as well as four other native plant species and 23 exotic species. Exotic recruits were more abundant than rainforest tree and shrub recruits, with Privets being especially common. However, among recruits, there were far more different species of rainforest trees and shrubs than exotics (99 *versus* 11 species, respectively). The great majority of recruits were dispersed by birds: 90% and 91% of individuals, and 77% and 65% of species, of native and exotics, respectively. Most had small (<10 mm) diaspores (the dispersible unit of the plant, usually the seed(s) and surrounding fruit pulp), hence could potentially have been dispersed by any of the frugivores recorded in Camphor Laurel stands. Both early and later successional tree species were present as recruits in Camphor Laurel stands, with later successional species relatively more abundant among recruits than as mature trees in these stands (Box 4; Figs 6 and 7).

Close proximity to The Nightcap Range had a noticeable effect on plant recruitment in Camphor Laurel stands (Fig. 8). On average, bird-dispersed rainforest trees with medium to large diaspores (>10 mm wide) were twice as abundant as recruits, and represented by twice the number of species, in Camphor Laurel stands within 1 km of The Nightcap Range than in more distant sites. Bird-dispersed trees with small diaspores also tended to be represented by more species in Camphor Laurel stands close to remnants, but the abundance of these species did not differ significantly with landscape context.

Management of Camphor Laurel stands for rainforest restoration

Because a diverse range of rainforest trees stands can recruit into stands of Camphor Laurel, a possible strategy for broadscale rainforest restoration in the Big Scrub region might simply be to wait for rainforest trees to replace the mature Camphor Laurels when they senesce. However, given the longevity of Camphor Laurel trees, this strategy is likely to require considerable patience: perhaps hundreds of years. At present, we do not know whether Camphor Laurel stands will make a transition to rainforest under natural processes, or what the composition of the resultant 'new forests' might be. Based on the relative abundance of recruits, shade-tolerant exotic species such as Privets might be expected to dominate many sites.

To accelerate the transition of Camphor Laurel stands to rainforest, a number of restoration practitioners in the Big Scrub region have been treating stands of Camphor Laurel with herbicide. Two main methods of 'camphor conversion' have been practised: staged and patch removal (Woodford 2000; Lymburner *et al*. 2006). In staged removal, a proportion of mature Camphor Laurels (e.g. one in three) are killed at a site, with months to years between stages. Trees beneath which there is good regeneration of rainforest plants are usually targetted first for control. In patch removal, all mature Camphor Laurel trees are killed at once, in 0.5–1-ha patches. The extensive canopy disturbance associated with patch treatment stimulates the mass recruitment of pioneers from the seed bank (Figs 9 and 10). Note that, while the dichotomy between staged and patch treatment describes two of the main approaches to camphor conversion, some practitioners vary the scale of treatment according to the amount of regeneration at a site (T. Roberts, pers. comm., 2008).

All 'camphor conversion' techniques also require the intensive control of immature Camphor Laurels and other exotic species on treated sites and subsequent maintenance weed control. Conversion methods typically retain the dead Camphor Laurel stems, which may persist for a decade or more on treated sites, providing perches for frugivores which disperse the seeds of rainforest plants and some shade for

Box 4. What types of rainforest plants recruit to Camphor Laurel?

To gain some insight into whether Camphor Laurel was facilitating or suppressing the recruitment of rainforest plants, we surveyed the relative abundance of rainforest tree species present as recruits and as mature individuals in stands of Camphor Laurel. Statistical analysis showed that later successional tree species tended to be relatively more abundant among recruits than among the cohort of adult trees in these stands, implying the stands of Camphor Laurel provide conditions which favour the establishment of later successional rainforest trees (Figs 6 and 7).

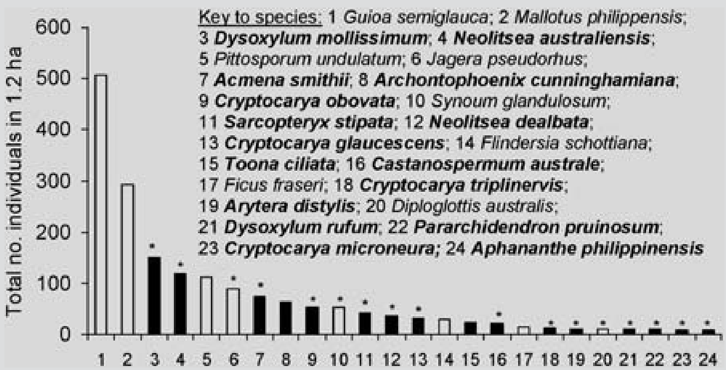

Figure 6. The relative abundance of rainforest tree species most commonly recorded as recruits in stands of Camphor Laurel in north-east New South Wales. (Recruits were defined as stems >0.5 m high but <2.5 cm d.b.h., categorized as early successional (open bars) or later successional (closed bars, bold font in key). Data pooled across 24 sites, from surveys of 0.05 ha per site. Data from Neilan *et al*. (2006). *species relatively more abundant among recruits than mature trees.)

Figure 7. Rainforest plants recruiting under untreated, mature Camphor Laurel. (Photo Wendy Neilan.)

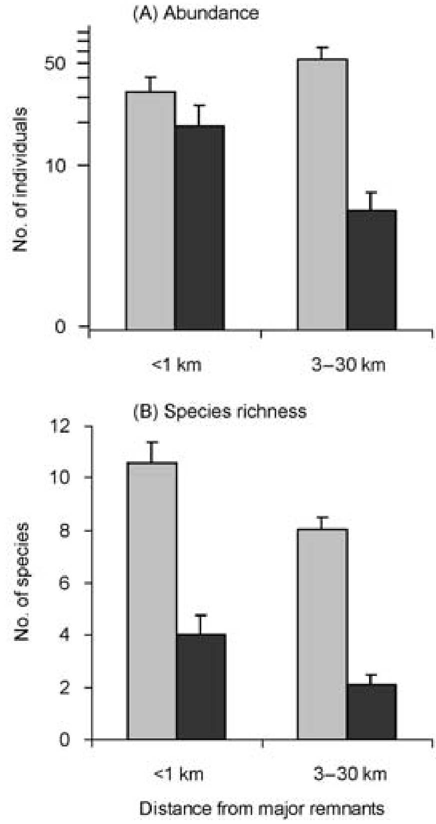

Figure 8. Abundance and species richness (mean, SE) of bird-dispersed native rainforest trees present as recruits in stands of Camphor Laurel in north-east New South Wales. (Trees are categorized by diaspore (~ seed) size: light shaded bars <10 mm; dark bars >10 mm. Sites are categorized by distance from major rainforest remnants (<1 km, $n = 7$; 3–30 km, $n = 17$). Survey area = 0.05 ha per site. Data from Neilan *et al*. (2006). There were more individuals and species of trees with diaspores >10 mm in Camphor Laurel stands close to major remnants than in more distant sites (ANOVA, abundance data log transformed, *P*-values determined by randomization: $P = 0.018$ and 0.015, respectively); the abundance and richness of trees with diaspores <10 mm did not differ significantly with landscape context ($P = 0.15$ and 0.068, respectively).)

seedlings (McDonald 1996; Woodford 2000). The dead stems and woody debris are also expected to provide resources for vertebrates, invertebrates and fungi; contribute to rebuilding soil carbon; and help retain water on treated sites (R. Woodford, pers. comm., 2008).

Figure 9. Treated stand of Camphor Laurel, 3 years after treatment. (Photo J. Kanowski)

Figure 10. Treated stand of Camphor Laurel, 8 years after treatment. (Photo J. Kanowski)

Among practitioners, there has been some debate as to the most effective 'camphor conversion' method. Proponents of staged removal argue that it maintains a structurally complex and shaded habitat during treatment, requires less intensive follow-up weed control, is unlikely to revert completely to weeds if treatment is interrupted, and will better maintain soil stability on steep and riparian sites. On the other hand, practitioners using patch removal argue that it promotes a more vigorous recruitment of pioneer species from the seed bank, greatly reduces competition for existing recruits, and has some logistical advantages when applied to broadscale restoration projects. Many of these claims, on both sides of the debate, are contested.

In collaboration with restoration practitioners (see Acknowledgements), we conducted a study of the costs and outcomes of existing 'camphor conversion' projects (Kanowski & Catterall 2007a). We studied 19 treated Camphor Laurel stands, eight treated by staged removal and 11 by patch removal, aged 1–12 years since treatment commenced. We also included six untreated Camphor Laurel stands and six sites in remnant rainforest in the study, to evaluate outcomes on the treated sites. Forest structural attributes, such as canopy cover and the density of woody stems, were surveyed on one or two 50-m transects per site (Kanowski & Catterall 2007b). We surveyed tree species composition on a single 50-m transect per site, the width varying with the size class of stems. Indicative costs of treatment were obtained from interviews with practitioners and landholders.

We found that both staged and patch removal methods could successfully convert stands of Camphor Laurel to regenerating rainforest (Fig. 11). Both treatment methods, particularly patch removal, initially simplified the structure of camphor stands. However, treatment stimulated the regeneration of early successional rainforest plants, which formed a closed canopy on most sites after 4–6 years. Older stands were still dominated numerically by early successional species, but had recruited increasing numbers of later successional tree species. By 6–12 years after treatment, treated sites supported about twice the number of later successional tree species as untreated Camphor Laurel stands, although still many fewer than rainforest sites.

Based on reported effort, both conversion methods cost around $10 000 per hectare (more on very weedy sites), or about one-third the cost of establishing a diverse restoration planting (Table 2). Most costs were incurred during primary treatment: that is, in the initial poisoning of mature Camphor

Table 2. Options for managing Camphor Laurel stands to promote rainforest restoration

Option	Costs	Advantages	Disadvantages
1. Leave alone and wait for rainforest trees to replace mature camphors.	Nothing.	Cheap. A diverse range of bird-dispersed rainforest plants recruit to Camphor Laurel stands, and the representation of mature phase rainforest plants in the stands is likely to increase over time.	It may take hundreds of years for rainforest trees to replace Camphor Laurel, and the resultant forests are likely to include many exotic species. The control of Camphor Laurel is presently a legal requirement in some shires.
2. Clear and replant with rainforest trees.	Clearing costs plus at least $30 000 per hectare for site preparation, planting and intensive weed control for 3 years, plus maintenance weed control.	A proven method that can rapidly (3–5 years) establish regenerating rainforest given appropriate species selection, site preparation and long-term maintenance.	Expensive, and does not utilize existing regeneration under Camphor Laurel stands. Clearing may be inappropriate on steep slopes, on streambanks or if regeneration includes threatened plants.
3. 'Camphor conversion': kill mature Camphor Laurel trees to promote the regeneration and growth of rainforest plants.	Around $10 000 per hectare (more on very weedy sites). Involves primary treatment (killing Camphor Laurels and other weeds), intensive follow-up weed control for 1–5 years and maintenance weed control.	Cheaper than planting in many sites, provided there is sufficient regeneration following treatment and sufficient long-term weed control. Takes advantage of existing regeneration, which may include threatened plants, and can be used on steep or riparian sites where clearing is undesirable.	To date, this approach has been trialled on a limited number of sites. May not be suited to young Camphor Laurel stands, or to sites distant from remnant forest, without supplementary planting.

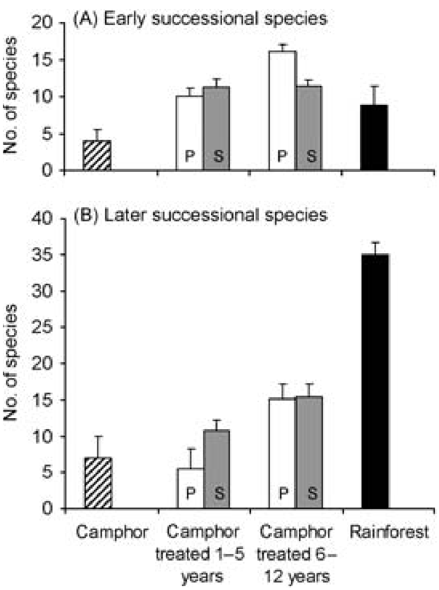

Figure 11. Comparison of the number of tree and shrub species (mean, SE) in stands of Camphor Laurel regrowth, treated stands of Camphor Laurel and rainforest in north-east New South Wales. (Plants classified as (A) early or (B) late successional species as per Kooyman (1996). Camphor treatment consisted of patch removal (P, open bars) or staged removal (S, shaded bars). Survey area per site varied by size class: 0.02 ha for stems >0.5 m high and <10 cm d.b.h.; 0.05 ha for stems >10 cm d.b.h. Data from Kanowski & Catterall (2007a).)

Laurels and understorey weeds. These costs were spread over several years in staged removal. Follow-up weed control comprised 20–40% of total costs, depending on the amount of rainforest regeneration on treated sites. According to practitioners, regeneration is favoured by proximity to remnant rainforest, but adversely affected by hot, dry weather following treatment and intensive wallaby browsing.

A definitive understanding of the relative merits of Camphor Laurel conversion methods will require an experimental approach, with a more rigorous documentation of effort and monitoring of outcomes over time. However, at first pass, the costs and outcomes of selective and patch removal methods appear to be similar. On this basis, the choice of method for a particular project may depend on logistical factors such as the availability and reliability of resources for follow-up weed control. For example, patch removal may be appropriate for restoration projects with guaranteed resources for follow-up weed control, whereas staged removal may suit projects with limited or irregular labour supply.

The future of Camphor Laurel stands

It is one of the ironies of restoration that practitioners must labour so hard to undo the equally diligent work of previous generations. The transformation of the former Big Scrub rainforest to an agricultural landscape was so comprehensive that it has taken many person-years of effort and large sums of money to restore rainforest to a small proportion of the region. The expense has not been wasted: it is wonderful to behold remnants largely freed of weeds, patches of planted rainforest on land that just a few years earlier was pasture or weeds, and the return of rainforest wildlife to some of these patches. However, we must not pretend that our efforts have addressed the scale of the degradation – or that they are even capable of addressing it, unless the quantum of resources available for restoration increases by several orders of magnitude.

In this context, there is increasing recognition among ecologists, restoration practitioners and conservation organizations of the potential value of weedy regrowth for rainforest biota,

Box 5. A burning issue

Widespread community concern over climate change caused by the burning of fossil fuels has led to great interest in the development of alternative energy sources. One of the more contentious proposals concerns the burning of plant materials to generate energy. Proponents of such 'biofuel' projects argue that they release less carbon than fossil fuel, when considered over the project cycle (the carbon dioxide released by burning biofuels may be partly taken up by regrowth vegetation, or plantations, developed through the project). Skeptics point to the net release of carbon dioxide, the direct effects of plantation establishment and harvest on biodiversity, and perverse impacts relating to the increased allocation of land to biofuels rather than crops.

At present, proposals are underway to use Camphor Laurel as a feedstock in electricity cogeneration plants attached to sugar mills in north-east New South Wales. If enacted, these proposals will result in extensive clearing of Camphor Laurel to produce up to 50 000 tonnes of woodchips per year, and the possible replacement of Camphor Laurel stands with fast growing eucalypt plantations to provide future feedstock (Scanlon *et al*. 2000). At present, the restoration of rainforest to cleared Camphor Laurel stands does not appear to be part of the project plan, although conservationists are lobbying the proponents and regulatory agencies to better consider the potential environmental impacts and opportunity costs for restoration associated with broad-scale clearing of Camphor Laurel.

and the additional potential for managing the regrowth to promote rainforest regeneration (Gilmore 1999; Big Scrub Rainforest Landcare Group 2005). This more sophisticated view of weedy regrowth has been adopted by some land managers in the region. For example, the Byron Biodiversity Conservation Strategy (Byron Shire Council 2004) considers forests dominated by Camphor Laurel to have relatively high ecological value in some cases, such as when they are located within identified 'wildlife corridors', or when they support threatened species. Removal of stands of Camphor Laurel in the Shire may require prior approval of a development application under the Byron Shire Council Tree Preservation Order, given the likelihood of protected native species occurring within these stands.

However, it will be a significant challenge to maintain the extensive cover of regrowth forest in the Big Scrub region in the face of high rates of urban growth, further cycles of agricultural development and industrial proposals such as the clearing of Camphor Laurel to fuel electricity generation (Box 5). There is a real risk that if Camphor Laurel regrowth is perceived as having negative values for biodiversity, it could be rapidly cleared and replaced over extensive areas by other land uses. However, some potential alternative land uses, such as pasture and short-rotation timber or 'biofuel' plantations, are likely to be much less valuable for rainforest biota than Camphor Laurel stands (Catterall *et al.* 2004, 2008).

If the role of Camphor Laurel regrowth in supporting rainforest biota and facilitating rainforest restoration were more widely recognized by landholders and governments, then it might be possible to devise forms of land use that enhance, or at least do not destroy, these values. For example, Lymburner *et al*. (2006) report an example of 'camphor conversion' being funded by a proportion of the profits of an agricultural enterprise, supported by government incentives. Another idea that may be worth testing is whether current proposals for the removal of Camphor Laurel for use as a biofuel (Box 5) might feasibly be part of a strategy for promoting the regeneration of rainforest trees on harvested sites. The ecological success of such a strategy would presumably depend on appropriate harvest regimes (e.g. limiting the size of coupes cleared, retaining some perch trees) and allocation of sufficient resources for follow-up weed control and monitoring. Feasibility trials (conducted over a range of sites, for example with different proportions of camphor and native recruits) would be required to determine whether sufficient natives could exist, survive or regenerate on such sites without planting, and what amount of weed control would be required following large-scale harvest.

The desire to eradicate weeds has informed rainforest restoration in subtropical Australia for many decades. This desire is clearly appropriate in remnants, but may be misplaced when applied indiscriminately to the rest of the landscape, which after all has been drastically altered by human action and seems unlikely to return to pre-European conditions over large areas. Although the considered removal of exotic plants from regrowth forests is an integral part of their restoration, the wholesale eradication of weedy regrowth forests may have negative consequences for native biota and the potential for reinstating functioning rainforest at a landscape scale.

In summary, the dilemma associated with the management of weedy regrowth forces us to think critically about our 'big picture' goals for restoration. What is the better outcome for extensively modified landscapes such as the Big Scrub region: a 'clean' landscape with small, isolated patches of rainforest, or a (temporarily?) weed-dominated landscape which supports a diverse rainforest biota? The former option commits practitioners to endless maintenance of small rainforest patches of questionable long-term viability; the latter at least allows the possibility of transition to a future landscape where native rainforest species can again play a major ecological role.

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Summary In subtropical Australia, regrowth forests in former rainforest landscapes are often dominated by the exotic tree, Camphor Laurel (*Cinnamomum camphora*). In this paper, we report on research into the value of these regrowth stands for rainforest biota. Our initial surveys indicated that Camphor Laurel stands supported a similar number of rainforest animals as restoration plantings, and usually more than timber plantations. Subsequent surveys found that stands of Camphor Laurel supported a high diversity of fruit-eating birds and had recruited a diverse suite of rainforest plants. More recently, we surveyed stands of Camphor Laurel treated by restoration practitioners using 'patch' or 'selective' removal of exotic plants. We found that both treatment methods accelerated the recruitment of rainforest plants to Camphor Laurel stands, and that treatment was usually much cheaper than the cost of establishing restoration plantings. Recognition of the value of weedy regrowth for native plants and animals, and the potential utility of manipulating weedy regrowth to achieve cost-effective restoration, could increase the likelihood of achieving the large-scale increases in forest cover that will be needed to restore biodiversity and ecosystem services to extensively cleared regions.

Key words: *abandoned agricultural land, frugivores, new forests, old fields, secondary forests, succession.*