Consequences of broadscale timber plantations for biodiversity in cleared rainforest landscapes of eastern Australia

Kanowski [a], J., Catterall [a], C.P. and Wardell-Johnson [b], G.W.

Rainforest Cooperative Research Centre, and

[a] Environmental Sciences, Griffith University, Nathan 4111, Australia.

[b] Natural and Rural Systems Management, University of Queensland, Gatton 4343, Australia.

Corresponding author:

John Kanowski, ph 61 7 3875 3823, fax 61 7 3875 7459, email: J.Kanowski@griffith.edu.au

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Abstract

In Australia, as in many countries, there has been a shift in timber production from native forests to plantations. While plantations are primarily considered an efficient means of producing timber, there is increasing interest in their potential contribution to biodiversity conservation, particularly when used for the reforestation of cleared land. Plantations may have both positive and negative consequences for biodiversity, at a range of scales. We compiled a list of these consequences from the literature, and used them as criteria to assess plantation scenarios proposed for cleared rainforest landscapes in eastern Australia. The scenarios were monocultures of hoop pine, monocultures of eucalypts, mixed species cabinet timber plantations, a mosaic of monoculture plantations of different species, and a mosaic of plantations and restoration plantings. Of these scenarios, eucalypt plantations have the least positive consequences for biodiversity: they have little intrinsic value, provide poor quality habitat for rainforest biota, and are characterised by an open canopy which in cleared landscapes favours the recruitment of grasses and weeds at the expense of rainforest plants. The three scenarios based on plantations of rainforest trees have similar, moderately positive consequences for all criteria, while a mosaic of plantations and restoration plantings has the most positive consequences for biodiversity in cleared rainforest landscapes. All scenarios may have negative impacts on biodiversity conservation if plantations replace remnant forest, provide habitat for weeds, or the trees used in plantations or their genes escape into native forests. In practice, the relative importance of positive and negative impacts, and hence the ranking of plantation scenarios, may vary with landscape forest cover. In well-forested landscapes, it may be more important to minimise the negative impacts of plantation development on native forests than to maximise the positive contributions that plantations can make for biodiversity. Consequently, any plantation of rainforest trees may have acceptable consequences for biodiversity in well-forested landscapes, provided trees are not invasive or from exotic genotypes, and plantations are managed to control weeds and feral animals. In contrast, a mosaic of plantations and restoration plantings would be strongly favoured for the reforestation of heavily cleared landscapes. At present, our capacity to design and manage rainforest plantations to produce both timber and biodiversity benefits is limited by a lack of information on trade-offs or synergies between these objectives. Obtaining this information will require the integration of large-scale, long-term biodiversity research projects in broadscale plantation projects.

Keywords: monoculture, mixed species plantation, restoration, landscape, biodiversity value, economic value

1. Introduction

For the two centuries after European colonisation of Australia, the continent's tropical and subtropical rainforests provided a rich harvest of cabinet timbers. High value species such as red cedar (*Toona ciliata*) and the austral conifers hoop pine (*Araucaria cunninghamii*), bunya pine (*A. bidwillii*) and kauri pine (*Agathis robusta*) were extracted from these forests ahead of, or as part of, the frontier of settlement which converted large areas of rainforest to pasture (Webb, 1966; Dargavel, 1995). As the resource began to dwindle in the early part of the 20th century, foresters began establishing plantations of rainforest trees to meet the projected future demand. Due to conflict between foresters and agriculturalists over utilisation of the remaining rainforest tracts, these plantations were mainly established by conversion of native forest. By the 1980's, about 50,000 ha of rainforest timber plantations had been established in eastern Australia, primarily hoop pine, with smaller areas of bunya pine, kauri pine, red cedar, Qeensland maple *Flindersia brayleyana* and other cabinet timbers (Keenan et al., 1997).

In recent decades, in response to increasing community awareness of the outstanding natural values of Australian rainforests, rainforest timber plantations have generally been established on cleared land that has proved marginal for agriculture (Lamb et al., 2001). These include monoculture plantations of hoop pine and eucalypts, and mixed species plantations of rainforest cabinet timbers, established by joint ventures between state forest agencies and private landholders. In north Queensland, for example, about 2,000 ha of mixed species plantations were established on cleared, privately-owned land by the Community Rainforest Reforestation Program, a government funded scheme set up in the 1990's following the cessation of logging in state-owned rainforests (Lamb et al., 1997). At present, the size of the plantation estate on cleared rainforest land in tropical and subtropical Australia is relatively small, but there are proposals to greatly expand the size of the resource in both regions due to the collapse of traditional agricultural industries (Spencer et al., 1999; CRA/RFA Steering Committee, 2000; Annandale et al., 2003).

While the relative merits of plantation scenarios are routinely assessed against economic criteria, we argue that the potential consequences of plantations for biodiversity also deserve serious consideration from industry proponents. It is reasonable to assume that impacts on biodiversity will have a major bearing on public acceptance of development proposals, with negative impacts being unpopular, contested or circumscribed by law (Wet Tropics Management Authority, 2003). Impacts on biodiversity are likely to affect the willingness of landholders to participate in plantation schemes, and the likelihood that such schemes will be supported by governments or large corporations (Emtage et al., 2001). Impacts on biodiversity may also determine whether projects can attract environmentally-linked funds (e.g., ethical investments, various forms of environmental credits) or sell products at a premium through environmental certification schemes (Chomitz et al., 1999; Binning et al., 2002; Salt et al., 2004).

At the same time, the potential for plantations to have positive consequences for biodiversity also deserve consideration by government agencies, organisations and individuals interested in conservation. In Australia, for example, tens of millions of dollars have been spent restoring rainforest patches and corridors to cleared land over the past decade (Erskine, 2002; Catterall et al., 2004b). However, only relatively small areas have been reforested using this approach, as the restoration plantings are expensive. Without a large increase in government funding or a substantial reduction in the cost of establishment, the extent of restoration plantings is likely to remain small. In contrast, timber plantations have the potential to reforest large areas of land for a financial gain. If plantations can be designed and managed to provide benefits to native biota, they may be a cost-effective means of restoring biodiversity to cleared rainforest landscapes (Lugo, 1997; Lamb, 1998).

In this paper, we consider the consequences for biodiversity of a range of broadscale plantation scenarios in cleared rainforest landscapes in tropical and subtropical Australia, including: (i) hoop pine plantations, (ii) eucalypt plantations, (iii) mixed species cabinet timber plantations, (iv) a mosaic of monoculture plantations of different species, and (v) a mosaic of plantations and restoration plantings. These scenarios are either likely to eventuate (e.g., they are expansions of existing schemes) or have been promoted as having benefits for production and biodiversity (e.g., Tracey, 1986; Shea, 1992; Lamb et al., 1997; Lamb and Keenan, 2001; Catterall et al., 2004a). Because attempts at broadscale reforestation in these landscapes are comparatively recent and relatively small scale, and some of the proposed plantation scenarios are novel, we are forced to rely on extrapolation from other studies and reasoned speculation to assess some scenarios. Despite these limitations, we believe such an assessment is opportune, given the proposed expansion of broadscale plantations in these regions in the near future.

2. Consequences of plantation development for biodiversity

Plantations may have a range of positive or negative consequences for biodiversity, at a range of scales (Table 1). For example, plantations may provide habitat for native plants and animals and, at a broader scale, facilitate the dispersal of wildlife across cleared landscapes (Lamb, 1998; Lindenmayer, 2002). Conversely, plantations may harbour and promote the spread of weeds, or the trees used in plantations may themselves become weeds (Richardson, 1998). The consequences of plantations for biodiversity will vary with aspects of design (e.g., the species planted, planting density, the size and configuration of coupes, the retention or restoration of native forest), management (e.g., chemical application, thinning, pruning and harvest regimes), and other factors such as landscape context. These issues have been reviewed by a number of authors (e.g., Parrotta et al., 1997 and references therein; Lamb, 1998; Norton, 1998; Richardson, 1998; Ashton et al., 2001; Hartley, 2002; Lindenmayer, 2002; Lindenmayer and Franklin, 2002; Salt et al., 2004; and specifically for rainforest landscapes of Australia by Catterall 2000; Catterall et al. 2004a, b; Kanowski et al. 2003a, 2004a.).

[Author’s note: Table 1 approximately here]

We used the consequences listed in Table 1 to assess the impacts of plantation scenarios proposed for cleared rainforest landscapes in eastern Australia. We were concerned mostly with the consequences of plantation development for rainforest-dependent biota, which are the primary focus of conservation and restoration efforts in these landscapes (see also Catterall et al., 2004b; Kanowski et al., 2004a). Primary data sources were surveys of rainforest timber plantations and other types of reforestation in tropical and subtropical Australia (Catterall, 2000; Kanowski et al., 2003a; Catterall et al., 2004a, 2004b; Kanowski et al., 2004a; Wardell-Johnson et al., 2004), and surveys of eucalypt plantations in subtropical Queensland (Boorsboom et al. 2002). We interpreted the results of these studies cautiously in relation to broadscale plantation scenarios, due to the relatively young age of most types of reforestation, the relatively small scale at which reforestation has been attempted to date, and aspects of the location, design and management of existing plantations which may not pertain to broadscale plantation scenarios.

3. Consequences for biodiversity of plantation scenarios in cleared rainforest landscapes in eastern Australia

3.1 Hoop pine plantations

Expansion of the hoop pine plantation estate is one of the more likely scenarios for plantation development in former rainforest landscapes in eastern Australia, as there is an established resource, an industry geared to processing the logs and a ready market for the timber. Hoop pine is also one of the few Australian rainforest timber trees which has been the subject of an improvement program and whose silviculture is well known (Lamb and Keenan, 2001). Some hoop pine plantations have already been established on cleared land in tropical and subtropical Queensland under joint venture schemes.

Hoop pine plantations are either known to have, or are likely to have, a range of positive consequences for biodiversity in cleared rainforest landscapes. While the intrinsic biodiversity value of a hoop pine monoculture is low relative to native rainforest, many existing hoop pine plantations have recruited an understorey of rainforest plants and support a relatively high diversity of rainforest-dependant biota (Fisher, 1980; Keenan et al., 1997; Bentley et al., 2000; Catterall et al., 2004b; Kanowski et al., 2003a, 2004a; Wardell-Johnson et al., 2004). Important caveats to these findings are that most hoop pine plantations have been established by conversion of native forest and are located adjacent to remnant rainforest, factors which are likely to increase their value for rainforest biota relative to broadscale timber plantations used to reforest cleared land (Kanowski et al., 2003a, 2004a). Some of the positive impacts of hoop pine plantations on biodiversity are generic to plantation development. These include reduced pressure to harvest rainforests elsewhere, the buffering of adjacent rainforest remnants from climatic extremes, carbon sequestration (with consequences to biodiversity at a global scale, although the contribution of any single plantation would be small), and possibly improvements in water quality, depending on management.

Hoop pine plantations appear to have few negative impacts on rainforest biodiversity, other than those common to plantation development (e.g., remnant forest patches may be cleared to establish plantations). At present, mature hoop pine plantations generally support few weeds (Fisher, 1980; Keenan et al., 1997; Wardell-Johnson et al., 2004), although this may not be the case for plantations established on cleared land, away from remnants, or in future rotations. Hoop pine itself is not a potential weed, but there is a risk of genetic introgression from plantations of hoop pine into local populations as a result of breeding programs which have used non-local genetic material (including New Guinean provenances) to increase timber production.

3.2 Eucalypt plantations

Broadscale eucalypt plantations have been established in many parts of Australia, including the cleared rainforest landscapes of northern New South Wales and south-east Queensland (Wood et al., 2001). There are active programs to expand the area of eucalypt plantations in cleared rainforest landscapes because of the high productivity than can be achieved on moist, fertile sites (Spencer et al., 1999; CRA/RFA Steering Committee, 2000; Lamb and Keenan, 2001).

Although relevant data are limited, eucalypt plantations are likely to have few positive impacts on rainforest biodiversity other than those generic to plantation development. Even those benefits are modest. For example, eucalypt plantations may not greatly reduce the pressure to harvest native rainforests, because their products (primarily pulp, poles and sawlogs) will not readily substitute for some of the products of rainforest species (especially cabinet timbers). Eucalypt plantations tend to have a relatively open canopy compared with plantations of rainforest species, and hence are likely to be only moderately effective as buffers of rainforest remnants. Eucalypts may be more effective carbon sinks than slower-growing rainforest trees, but this particular benefit to biodiversity is negligible at a site or landscape scale.

Eucalypt plantations have little intrinsic biodiversity value in rainforest landscapes, unless they are used to reforest those parts of the landscape which once supported eucalypt forests (generally, the drier margins of rainforest landscapes, pockets of infertile soil or other fire-prone locations: Bowman, 2000). Because of their open canopy, the understorey of eucalypt plantations tends to be dominated by light-demanding grasses and weeds in cleared or disturbed rainforest landscapes, which suppress the recruitment of rainforest plants (Harrington and Ewel, 1997; Kanowski et al., 2003a; Wardell-Johnson et al., 2004). Further, the type of habitat provided by eucalypt plantations does not favour specialist rainforest biota (Boorsboom et al., 2002). For example, plantations of Gympie messmate *Eucalyptus cloeziana* support many fewer rainforest birds (as a proportion of the avifauna) than hoop pine plantations in south-east Queensland (Fig. 1). The value of eucalypt plantations to rainforest birds in eastern Australia may also be reduced by the colonisation of plantations by an aggressive colonial bird species, the noisy miner *Manorina melanocephala*. The noisy miner is capable of excluding many smaller forest-dependent bird species from local areas (Catterall, 2004).

[Author’s note: Fig. 1 approximately here]

Eucalypt plantations may have a number of negative consequences for biodiversity in rainforest landscapes. For example, eucalypt plantations appear to be particularly susceptible to weed invasion in cleared rainforest landscapes (Wardell-Johnson et al., 2004). While eucalypts will not invade rainforests, there is potential for genetic introgression from plantations into naturally occurring eucalypt populations, due to the widespread use of hybrids and non-local provenances in eucalypt plantations (Potts et al., 2001). Eucalypt plantations are also likely to be much more likely to carry a fire than plantations of rainforest species.

3.3 Mixed species plantations

Several thousand ha of mixed species plantations have been established on cleared rainforest land in eastern Australia over the past two decades, mostly as small farm forestry plots (Vize and Creighton, 2001; Catterall et al., 2004b). There is continued interest in mixed species plantings amongst landholders and researchers in tropical and subtropical Australia, and it is possible that mixed species plantations could be established on a broader scale in both regions (Lamb and Keenan, 2001).

Mixed species plantations have been proposed as a 'win-win' situation for timber production and biodiversity (e.g., Lamb, 1998; Herbohn et al., 2000; Hartley, 2002). However, this claim appears to be overstated, at least for biodiversity conservation in rainforest plantations. If native trees are used, mixed species plantations (which in eastern Australia typically comprise 6 – 20 tree species) will have more intrinsic biodiversity value than monocultures. However, mixed species plantations are much less diverse than native rainforests, which are comprised of hundreds of tree species (Lamb et al., 1997; Tucker et al., 2004). Mixed species timber plantations also tend to support few rainforest specialists, at least in the decade following establishment (Catterall et al., 2004b; Kanowski et al., 2004a; Wardell-Johnson et al., 2004). For example, in tropical Queensland, young mixed species plantations do not appear to support any more rainforest bird species than monocultures of hoop pine (Fig. 2). The relatively low value of mixed species plantations for rainforest biota is presumably a consequence of their simple structure and floristic composition, their use of few fleshyfruited tree species, and the high proportion of eucalypts used in many plots. Hence, even when these plantations mature, their value for rainforest biota is likely to remain low (Catterall, 2000; Kanowski et al., 2003a, 2004a; Tucker et al., 2004).

[Author's note: Fig. 2 approximately here]

Mixed species plantations may have a number of negative consequences for biodiversity. In particular, the rainforest species used in plantations may invade remnant forests when planted outside their natural range. For example, Queensland maple (endemic to north Queensland), a widely planted cabinet timber species, is considered a potential weed in subtropical Australia (Big Scrub Rainforest Landcare Group, 2000). There is also a potential for genetic introgression into local populations if non-local provenances are used in plantations, as is often the case. When established at a relatively low density and especially with a high proportion of eucalypts, mixed species plantations tend to have a relatively open canopy and are susceptible to weed invasion (Wardell-Johnson et al., 2004).

3.4 Mosaic of monocultures

Broadscale mixed species plantations of rainforest trees are uncommon, largely because they are considered difficult to manage and harvest. Lamb (1998) suggested that a mosaic of monoculture plantations would provide the same level of biodiversity as mixed species plantings at the landscape scale, while retaining the production benefits of monocultures. While this approach has not been used for broadscale reforestation in Australia, mosaics of monoculture plantations occur in a number of state forests in tropical and subtropical Queensland (Keenan et al., 1997).

According to Herbohn et al. (2000, p.19), a mosaic of monocultures could "confer a high degree of heterogeneity and biodiversity to the landscape" and result in "a diversity of potential wildlife habitats." However, we suggest that the value of a mosaic of monocultures for rainforest biodiversity is likely to be intermediate between monocultures and mixed species plantings: i.e., not particularly high. Certainly, a mosaic of monocultures would have more intrinsic value than extensive monocultures, but the number of species planted would still be a fraction of native forest. A mosaic of monocultures would also be expected to recruit a greater diversity of plant species than extensive monocultures (Keenan et al., 1997; Lamb et al., 1997). However, the effect of different plantation species on regeneration may be limited, unless the trees used in plantations differ markedly in attributes which influence regeneration, such as canopy cover or litter depth (Harrington and Ewel, 1997; Jones et al., 2004; Lemenih et al., 2004). For example, plantations of hoop pine, kauri pine and Queensland maple at Gadgarra State Forest, north Queensland, have recruited relatively similar assemblages of rainforest plants (Table 2), despite some differences in vegetation structure between these plantations (Kanowski et al., 2003a). In contrast, Keenan et al. (1997) reported that plantations of hoop pine, Queensland maple and red cedar at Gadgarra State Forest and elsewhere in north Queensland had recruited relatively different assemblages of plants. However, the methodology used by Keenan et al. (1997) is biased towards finding differences between assemblages, as they surveyed small plots (typically, 0.0024 - 0.06 ha per plantation, for seedlings and trees, respectively), relative to the size of plantations (2 – 40 ha), and used a measure of similarity (Sorenson's index) which is sensitive to small sample size (Plotkin and Muller-Landau, 2002).

[Author's note: Table 2 approximately here]

Further, a mosaic of monoculture plantations is likely to have fewer benefits for fauna, particularly vertebrates, than for plants. Most rainforest vertebrates require a diverse suite of floristic and structural resources at the scale of an individual's home range (Winter et al., 1988; Kikkawa, 1990; Jones and Crome, 1990; Kanowski et al., 2003b). Hence, while plantation mosaics may provide a greater diversity of floristic resources than monocultures at the landscape scale, only wide-ranging vertebrates would be able to harvest or use those resources, assuming plantations were in the order of 10 – 50 ha as is generally the case in eastern Australia. In comparison, most arboreal marsupials in Australian rainforests, for example, utilise a home range only a few ha in size (Newell, 1999; Wilson, 2000). Nor would a mosaic of monocultures provide any more of the structural resources required by many vertebrates (e.g., woody debris, hollows) than an extensive monoculture. For these reasons, a mosaic of monocultures is unlikely to support a much more diverse fauna than an extensive monoculture. These arguments are supported by surveys of birds in plantations of Queensland maple, kauri pine and hoop pine in Gadgarra State Forest (the same plantations surveyed for plants, above). In these surveys, most bird species recorded in one plantation species were also recorded in another (Table 2), suggesting that the mosaic of plantations was not providing much greater habitat value for birds than each monoculture plantation on its own.

An important caveat on extrapolating these results to a scenario of broadscale reforestation is that many of the old rainforest timber plantations established in north Queensland represent a highly favourable situation for the recruitment of rainforest biota. The plantations were established by conversion of rainforest, located adjacent to extensive forest and subject to minimal management for timber production. The Gadgarra plantations surveyed above, for example, have recruited about 50% of the plants and are used by 70 – 80% of the birds recorded in adjacent rainforest plots (Table 3). However, if plantations were used for the broadscale reforestation of cleared land, it is likely that many fewer species would be able to disperse to plantations (Bell, 1979; Catterall et al., 2004b; Kanowski et al., 2003a, 2004a). In that case, biota using plantations are more likely to come from a small pool of pioneer or generalist species (Haggar et al., 1997), and the biodiversity value of a mosaic of monocultures relative to an extensive monoculture would be even less pronounced.

3.5 Mosaic of plantations and restoration plantings

Instead of attempting to meet both production and biodiversity objectives from the one stand of trees in timber plantations, it may be preferable to meet these objectives from different parts of the plantation estate: e.g., from a mosaic of plantations and restoration plantings (Lamb, 1998; Lindenmayer and Franklin, 2002; Catterall et al., 2004a). While this approach has not been used for broadscale reforestation in eastern Australia, an analogous approach has long been practised in state forests, where plantations of hoop pine and other rainforest species have been established amongst a network of retained rainforest, primarily in an attempt to control the spread of fire.

This scenario is likely to have positive impacts on biodiversity for all criteria presented in Table 1. The plantations themselves may have some positive impacts on biodiversity, depending on the species used and other aspects of design and management, as discussed above. However, most of the positive impacts of this scenario are due to the inclusion of restoration plantings in the plantation estate. Restoration plantings typically have a high intrinsic value (e.g., up to 100 locally occurring species of rainforest plants are used in restoration plantings in eastern Australia: Goosem and Tucker, 1995; Kooyman, 1996). Furthermore, restoration plantings have the potential to support many species of rainforest plants, birds and invertebrates within a few decades of establishment (Catterall et al., 2004b; Kanowski et al., 2004a) (Fig. 2). If riparian areas in plantations were targetted for restoration plantings (as suggested by many authors, e.g., Lamb et al., 1997; Lindenmayer, 2002; Salt et al., 2004; Tucker et al., 2004), then these plantings may form a network of high quality habitat which would potentially increase the dispersal of rainforest biota across the landscape, especially if plantings were contiguous with remant rainforest (Tucker, 2000; Kanowski et al., 2003c). Biota using or dispersing from these plantings would also provide a source of colonists to plantations over the harvest cycle. Riparian plantings would also help minimise the potential negative impacts of plantation management on water quality and aquatic biota (Bunn et al., 1999).

The potential negative impacts of a mosaic of plantations and restoration plantings on biodiversity are similar to those discussed for other plantation scenarios. Depending on the species and provenances planted, there may be a risk of species invading native forests or genetic introgression into local populations of trees, and the plantations may harbour weeds and feral animals.

4. Discussion

4.1 The value of plantation scenarios for biodiversity

A simple tally of positive and negative consequences suggests there are three distinct outcomes for biodiversity in cleared rainforest landscapes from the scenarios considered in this paper (Table 3). Eucalypt plantations are likely to provide few positive benefits and a number of negative impacts on biodiversity in cleared rainforest landscapes. Three scenarios - hoop pine plantations, mixed species plantations and a mosaic of monocultures – are likely to have similar, moderately positive impacts on biodiversity, while a mosaic of plantations and restoration plantings is likely to have a strongly positive impact on biodiversity in cleared rainforest landscapes.

[Author’s note: Table 3 approximately here]

In cleared rainforest landscapes of eastern Australia, there has been a long-standing interest in the potential for mixed species plantations to provide both production and biodiversity benefits (Lamb et al., 1997; Lamb, 1998; Herbohn et al., 2000; Lamb and Keenan, 2001; Tucker et al., 2004). However, we suggest that the opportunities for combining production and biodiversity in plantations are probably more limited in rainforest landscapes than they are in other, less diverse, ecosystems. This is because timber plantations (even mixed species plantations) tend to be very much simpler, both floristically and structurally, than intact rainforest (Kanowski et al., 2003a; Catterall et al. 2004 a, 2004b). Furthermore, routine management for timber production is likely to further compromise the structural complexity, floristic diversity and hence habitat value of plantations (Kanowski et al. 2004a). Instead, production and biodiversity objectives may best be met from different parts of the plantation estate (i.e., a mosaic of plantations and restoration plantings) in rainforest landscapes.

In practice, the relative importance of positive and negative consequences, and hence the ranking of plantation scenarios, may vary with landscape forest cover. For example, the positive contributions that plantations could make to biodiversity (e.g., habitat, dispersal corridors) may be the primary consideration in poorly forested landscapes. In contrast, in well-forested landscapes, biodiversity objectives may best be served by minimising the potential negative impacts of plantations (e.g., weeds, genetic introgression) on native forests, rather than by maximising positive impacts. This assymetry of impacts has implications for the planning of reforestation projects at a regional scale. On the analysis presented here, a mosaic of plantations and restoration plantings (the scenario with the most positive consequences for biodiversity) would be strongly favoured for the reforestation of heavily cleared landscapes. In contrast, on the margins of extensive rainforest or other well-forested parts of the landscape, any plantation of rainforest trees may be acceptable, provided those trees are not potentially invasive or from non-local genotypes, and are managed to minimise their habitat value for weeds and feral animals.

4.2 Integrating biodiversity and production objectives in broadscale plantations in cleared rainforest landscapes

While plantations have traditionally been viewed as an efficient means of producing timber, there is increasing interest in the role that plantations might play in the conservation of biodiversity while still meeting production objectives (e.g., Parrotta et al., 1997; Lamb, 1998; Hartley, 2002; Lindenmayer, 2002; Salt et al., 2004). Suggestions include using locally-occurring trees rather than exotics; establishing mixed species plantations rather than monocultures; staggering the harvest of coupes; retaining or restoring native forest; and so on. However, our capacity to design and manage rainforest plantations to produce both timber and biodiversity benefits is limited by a lack of information on trade-offs or synergies between these objectives, particularly at the landscape scale. For example, in a mosaic of plantations and restoration plantings, we do not know what proportion of a plantation estate would need to be allocated to restoration plantings to achieve particular conservation goals. This question is fundamental to achieving outcomes for production and biodiversity, yet an optimal answer is likely to vary with the amount and spatial configuration of remnant forest, the habitat suitability of the plantations, and the habitat requirements of particular taxa (e.g., Lindenmayer and Franklin, 2002; Catterall et al., 2004a). Answers to these types of questions will require the integration of large-scale, long-term biodiversity research projects in broadscale plantation projects (Lindenmayer, 2002). There is also a need for better information on the economic value of different plantation scenarios, particularly in cases where the consequences of plantations for biodiversity are explicitly valued, e.g., where payments are made for environmental services (Binning et al., 2002). Joint consideration of both objectives may have some surprising results: for example, a mosaic of plantations and restoration plantings would not only have more biodiversity value than mixed species plantings, but would be cheaper to establish. At current prices (e.g., Erskine, 2002), up to

25% of a plantation estate could be devoted to restoration plantings before the cost of establishment exceeded that of mixed species plantings.

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Table 1. Potential consequences of plantation development for biodiversity in cleared rainforest landscapes.

Scale of impact	Positive consequences	Negative consequences
On-site	1. Trees used in plantations may have more conservation value than existing vegetation such as pasture 2. May provide habitat for rainforest specialist biota 3. May facilitate the regeneration of rainforest plants (e.g., by shading out grasses, creating a favourable microclimate, fire suppression)	1. Plantations may replace existing rainforest habitat (e.g., remnant forest patches and regrowth) 2. May provide habitat for weeds and feral animals
Off-site (landscape to global)	1. May buffer remnant forests from adverse environmental conditions 2. May facilitate the dispersal of rainforest species between remnant forest patches 3. May increase population sizes of rainforest species as a result of additional habitat or resources 4. May improve downstream water quality and provide habitat for aquatic biota 5. May lead to reduced pressure on the harvest of rainforests elsewhere 6. Will sequester carbon and hence contribute to mitigating or reducing climate change	1. Exotic tree species used in plantations may invade native forests 2. Exotic genotypes of native trees used in plantations may invade local gene pools 3. Weeds and feral animals harboured by plantations may invade remnant forests

Table 2. Assemblage similarity of biota recorded in old plantations of hoop pine, kauri pine and Queensland maple, and intact rainforest, Gadgarra State Forest, north Queensland.

(i) plant species

Forest type	Plantation: hoop pine	Plantation: kauri pine	Plantation: Qld maple
Plantation: kauri pine	0.62		
Plantation: Qld maple	0.61	0.63	
Rainforest	0.52	0.53	0.49

(ii) bird species

Forest type	Plantation: hoop pine	Plantation: kauri pine	Plantation: Qld maple
Plantation: kauri pine	0.71		
Plantation: Qld maple	0.78	0.72	
Rainforest	0.69	0.79	0.77

Note: Plants were surveyed on five 78.5 m^2 quadrats per site (Wardell-Johnson et al., 2004); birds were recorded from eight 30 minute surveys of a 0.30 ha transect per site (Catterall et al., 2004b). Data were pooled from surveys of two replicate sites of each forest type, giving total survey area per plantation of 0.08 ha for plants, 0.60 ha for birds. Assemblage similarity based on Sorenson's index (the proportion of species shared between sites), as per Keenan et al. (1997).

Table 3. Potential consequences of plantation scenarios for biodiversity in cleared rainforest landscapes of eastern Australia.

Scenario	Positive consequences									Negative consequences				
	On-site			Off-site						On-site		Off-site		
	1	2	3	1	2	3	4	5	6	1	2	1	2	3
Eucalypt monoculture plantations			+	+	+		?	+	++	?	--		--	--
Hoop pine monoculture plantations	+	+	++	++	++	+	?	++	+	?	-		--	-
Mixed species cabinet timber plantations	++	+	++	++	++	+	?	++	+	?	-	-	-	-
Mosaic of monoculture plantations	++	+	++	++	++	+	?	++	+	?	-	-	-	-
Mosaic of plantations and restoration	+++	+++	+++	++	+++	+++	+	++	+	?	-	-	-	-

Note: + positive consequence; -, negative consequence; ?, consequences vary primarily with design and/ or management. For each criterion, the relative impacts of scenarios are ranked from low (one symbol) to high (three symbols). For list of consequences, see Table 1.

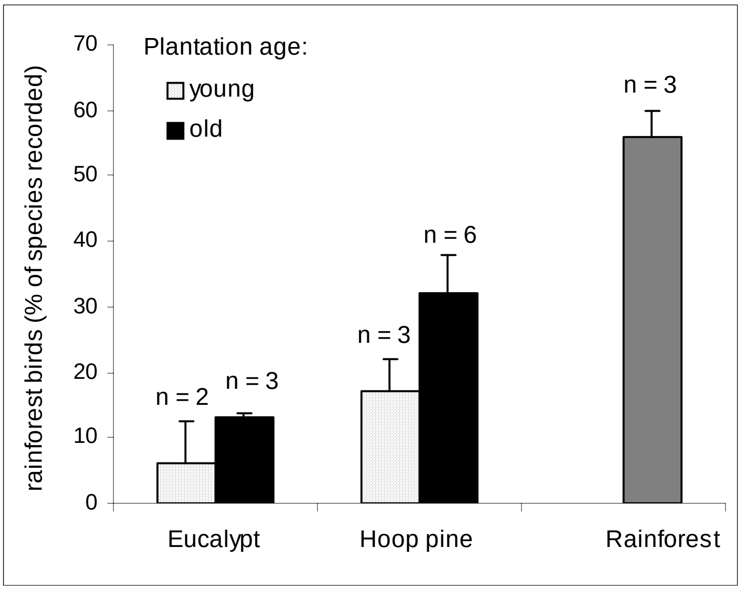
List of figures.

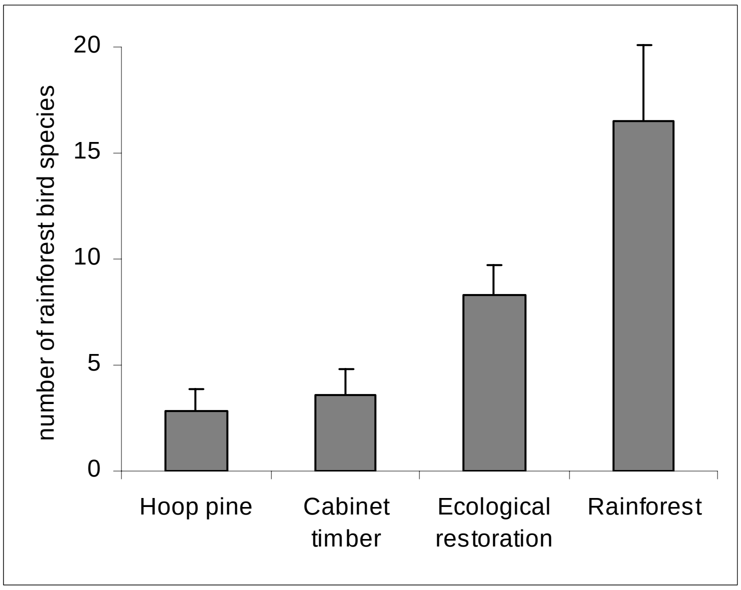
Fig. 1. The proportion of 'rainforest' bird species (mean, S.E.) recorded in surveys of eucalypt plantations, hoop pine plantations and intact rainforest, subtropical Queensland.

Note: 'Rainforest' birds are species apparently dependent on or associated with rainforest in south-east Queensland and north-east New South Wales (based on a variety of sources, principally Kikkawa, 1968, 1991; see list in Kanowski et al., 2004a). Data for eucalypt plantations are from Boorsboom et al. (2002); for details of surveys in hoop pine plantations and rainforest, see Catterall et al. (2004b). In eucalypt (*E. cloeziana*) plantations, 'young' = 16 years, 'old' = 40 years; in hoop pine plantations, 'young' = 9 – 15 years, 'old' = 45 - 70 years. The number of sites in each category is shown on the graph.

Fig. 2. Richness of 'rainforest' bird species (mean, S.E.) recorded in young hoop pine plantations, mixed species cabinet timber plantations, ecological restoration plantings and intact rainforest, tropical Queensland.

Note: 'Rainforest' birds are species apparently dependent on or associated with rainforest (based on a variety of sources, principally Kikkawa, 1968, 1991; Crome et al., 1994; see list in Kanowski et al., 2004a). Data from eight 30 minute surveys of a 0.3 ha plot per site. See details in Catterall et al. (2004b). Age and number of sites as follows: hoop pine (age 6 – 11 years, n = 5), cabinet timber (age 7 – 9 years, n = 5); ecological restoration (age 6 – 16 years, n = 10); rainforest (n = 10).


Plantation age:
young
old
rainforest birds (% of species recorded)
70
60
50
40
30
20
10
0
n = 2
n = 3
n = 3
n = 6
n = 3
Eucalypt
Hoop pine
Rainforest


20
15
10
5
0
number of rainforest bird species
Hoop pine
Cabinet timber
Ecological restoration
Rainforest