

**Consequences of broadscale timber plantations for biodiversity
in cleared rainforest landscapes of tropical and subtropical
Australia.**

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1 habitat for rainforest biota, and are characterised by an open canopy which in cleared
2 landscapes favours the recruitment of grasses and weeds at the expense of rainforest plants.
3 The three scenarios based on plantations of rainforest trees have similar, moderately positive
4 consequences for all criteria, while a mosaic of plantations and restoration plantings has the
5 most positive consequences for biodiversity in cleared rainforest landscapes. All scenarios
6 may have negative impacts on biodiversity conservation if plantations replace remnant forest,
7 provide habitat for weeds, or the trees used in plantations or their genes escape into native
8 forests. In practice, the relative importance of positive and negative impacts, and hence the
9 ranking of plantation scenarios, may vary with landscape forest cover. In well-forested
10 landscapes, it may be more important to minimise the negative impacts of plantation
11 development on native forests than to maximise the positive contributions that plantations can
12 make for biodiversity. Consequently, any plantation of rainforest trees may have acceptable
13 consequences for biodiversity in well-forested landscapes, provided trees are not invasive or
14 from exotic genotypes, and plantations are managed to control weeds and feral animals. In
15 contrast, a mosaic of plantations and restoration plantings would be strongly favoured for the
16 reforestation of heavily cleared landscapes. At present, our capacity to design and manage
17 rainforest plantations to produce both timber and biodiversity benefits is limited by a lack of
18 information on trade-offs or synergies between these objectives. Obtaining this information
19 will require the integration of large-scale, long-term biodiversity research projects in
20 broadscale plantation projects.

21

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

1 **1. Introduction**

2 For the two centuries after European colonisation of Australia, the continent's tropical and
3 subtropical rainforests provided a rich harvest of cabinet timbers. High value species such as
4 red cedar (*Toona ciliata*) and the austral conifers hoop pine (*Araucaria cunninghamii*), bunya
5 pine (*A. bidwillii*) and kauri pine (*Agathis robusta*) were extracted from these forests ahead
6 of, or as part of, the frontier of settlement which converted large areas of rainforest to pasture
7 (Webb, 1966; Dargavel, 1995). As the resource began to dwindle in the early part of the 20th
8 century, foresters began establishing plantations of rainforest trees to meet the projected
9 future demand. Due to conflict between foresters and agriculturalists over utilisation of the
10 remaining rainforest tracts, these plantations were mainly established by conversion of native
11 forest. By the 1980's, about 50,000 ha of rainforest timber plantations had been established in
12 eastern Australia, primarily hoop pine, with smaller areas of bunya pine, kauri pine, red
13 cedar, Queensland maple *Flindersia brayleyana* and other cabinet timbers (Keenan et al.,
14 1997).

15 In recent decades, in response to increasing community awareness of the outstanding natural
16 values of Australian rainforests, rainforest timber plantations have generally been established
17 on cleared land that has proved marginal for agriculture (Lamb et al., 2001). These include
18 monoculture plantations of hoop pine and eucalypts, and mixed species plantations of
19 rainforest cabinet timbers, established by joint ventures between state forest agencies and
20 private landholders. In north Queensland, for example, about 2,000 ha of mixed species
21 plantations were established on cleared, privately-owned land by the Community Rainforest
22 Reforestation Program, a government funded scheme set up in the 1990's following the
23 cessation of logging in state-owned rainforests (Lamb et al., 1997). At present, the size of the
24 plantation estate on cleared rainforest land in tropical and subtropical Australia is relatively

1 small, but there are proposals to greatly expand the size of the resource in both regions due to
2 the collapse of traditional agricultural industries (Spencer et al., 1999; CRA/RFA Steering
3 Committee, 2000; Annandale et al., 2003).

4 While the relative merits of plantation scenarios are routinely assessed against economic
5 criteria, we argue that the potential consequences of plantations for biodiversity also deserve
6 serious consideration from industry proponents. It is reasonable to assume that impacts on
7 biodiversity will have a major bearing on public acceptance of development proposals, with
8 negative impacts being unpopular, contested or circumscribed by law (Wet Tropics
9 Management Authority, 2003). Impacts on biodiversity are likely to affect the willingness of
10 landholders to participate in plantation schemes, and the likelihood that such schemes will be
11 supported by governments or large corporations (Emtage et al., 2001). Impacts on
12 biodiversity may also determine whether projects can attract environmentally-linked funds
13 (e.g., ethical investments, various forms of environmental credits) or sell products at a
14 premium through environmental certification schemes (Chomitz et al., 1999; Binning et al.,
15 2002; Salt et al., 2004).

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

1 provide benefits to native biota, they may be a cost-effective means of restoring biodiversity
2 to cleared rainforest landscapes (Lugo, 1997; Lamb, 1998).

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

16 **2. Consequences of plantation development for biodiversity**

17 Plantations may have a range of positive or negative consequences for biodiversity, at a range
18 of scales (Table 1). For example, plantations may provide habitat for native plants and
19 animals and, at a broader scale, facilitate the dispersal of wildlife across cleared landscapes
20 (Lamb, 1998; Lindenmayer, 2002). Conversely, plantations may harbour and promote the
21 spread of weeds, or the trees used in plantations may themselves become weeds (Richardson,
22 1998). The consequences of plantations for biodiversity will vary with aspects of design (e.g.,
23 the species planted, planting density, the size and configuration of coupes, the retention or
24 restoration of native forest), management (e.g., chemical application, thinning, pruning and

1 harvest regimes), and other factors such as landscape context. These issues have been
2 reviewed by a number of authors (e.g., Parrotta et al., 1997 and references therein; Lamb,
3 1998; Norton, 1998; Richardson, 1998; Ashton et al., 2001; Hartley, 2002; Lindenmayer,
4 2002; Lindenmayer and Franklin, 2002; Salt et al., 2004; and specifically for rainforest
5 landscapes of Australia by Catterall 2000; Catterall et al. 2004a, b; Kanowski et al. 2003a,
6 2004a.).

7 [Author's note: Table 1 approximately here]

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

1 **3. Consequences for biodiversity of plantation scenarios in cleared rainforest landscapes** 2 **in eastern Australia**

3 *3.1 Hoop pine plantations*

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

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

1 plantation would be small), and possibly improvements in water quality, depending on
2 management.

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

12 *3.2 Eucalypt plantations*

13 Broadscale eucalypt plantations have been established in many parts of Australia, including
14 the cleared rainforest landscapes of northern New South Wales and south-east Queensland
15 (Wood et al., 2001). There are active programs to expand the area of eucalypt plantations in
16 cleared rainforest landscapes because of the high productivity than can be achieved on moist,
17 fertile sites (Spencer et al., 1999; CRA/RFA Steering Committee, 2000; Lamb and Keenan,
18 2001).

19 Although relevant data are limited, eucalypt plantations are likely to have few positive
20 impacts on rainforest biodiversity other than those generic to plantation development. Even
21 those benefits are modest. For example, eucalypt plantations may not greatly reduce the
22 pressure to harvest native rainforests, because their products (primarily pulp, poles and
23 sawlogs) will not readily substitute for some of the products of rainforest species (especially
24 cabinet timbers). Eucalypt plantations tend to have a relatively open canopy compared with

1 plantations of rainforest species, and hence are likely to be only moderately effective as
2 buffers of rainforest remnants. Eucalypts may be more effective carbon sinks than slower-
3 growing rainforest trees, but this particular benefit to biodiversity is negligible at a site or
4 landscape scale.

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

20 [Author's note: Fig. 1 approximately here]

21 Eucalypt plantations may have a number of negative consequences for biodiversity in
22 rainforest landscapes. For example, eucalypt plantations appear to be particularly susceptible
23 to weed invasion in cleared rainforest landscapes (Wardell-Johnson et al., 2004). While
24 eucalypts will not invade rainforests, there is potential for genetic introgression from

1 plantations into naturally occurring eucalypt populations, due to the widespread use of
2 hybrids and non-local provenances in eucalypt plantations (Potts et al., 2001). Eucalypt
3 plantations are also likely to be much more likely to carry a fire than plantations of rainforest
4 species.

5 *3.3 Mixed species plantations*

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

12 Mixed species plantations have been proposed as a ‘win-win’ situation for timber production
13 and biodiversity (e.g., Lamb, 1998; Herbohn et al., 2000; Hartley, 2002). However, this claim
14 appears to be overstated, at least for biodiversity conservation in rainforest plantations. If
15 native trees are used, mixed species plantations (which in eastern Australia typically
16 comprise 6 – 20 tree species) will have more intrinsic biodiversity value than monocultures.
17 However, mixed species plantations are much less diverse than native rainforests, which are
18 comprised of hundreds of tree species (Lamb et al., 1997; Tucker et al., 2004). Mixed species
19 timber plantations also tend to support few rainforest specialists, at least in the decade
20 following establishment (Catterall et al., 2004b; Kanowski et al., 2004a; Wardell-Johnson et
21 al., 2004). For example, in tropical Queensland, young mixed species plantations do not
22 appear to support any more rainforest bird species than monocultures of hoop pine (Fig. 2).
23 The relatively low value of mixed species plantations for rainforest biota is presumably a
24 consequence of their simple structure and floristic composition, their use of few fleshy-

1 fruited tree species, and the high proportion of eucalypts used in many plots. Hence, even
2 when these plantations mature, their value for rainforest biota is likely to remain low
3 (Catterall, 2000; Kanowski et al., 2003a, 2004a; Tucker et al., 2004).

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

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

14 *3.4 Mosaic of monocultures*

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

22 According to Herbohn et al. (2000, p.19), a mosaic of monocultures could “confer a high
23 degree of heterogeneity and biodiversity to the landscape” and result in “a diversity of

1 potential wildlife habitats.” However, we suggest that the value of a mosaic of monocultures
2 for rainforest biodiversity is likely to be intermediate between monocultures and mixed
3 species plantings: i.e., not particularly high. Certainly, a mosaic of monocultures would have
4 more intrinsic value than extensive monocultures, but the number of species planted would
5 still be a fraction of native forest. A mosaic of monocultures would also be expected to
6 recruit a greater diversity of plant species than extensive monocultures (Keenan et al., 1997;
7 Lamb et al., 1997). However, the effect of different plantation species on regeneration may be
8 limited, unless the trees used in plantations differ markedly in attributes which influence
9 regeneration, such as canopy cover or litter depth (Harrington and Ewel, 1997; Jones et al.,
10 2004; Lemenih et al., 2004). For example, plantations of hoop pine, kauri pine and
11 Queensland maple at Gadgarra State Forest, north Queensland, have recruited relatively
12 similar assemblages of rainforest plants (Table 2), despite some differences in vegetation
13 structure between these plantations (Kanowski et al., 2003a). In contrast, Keenan et al. (1997)
14 reported that plantations of hoop pine, Queensland maple and red cedar at Gadgarra State
15 Forest and elsewhere in north Queensland had recruited relatively different assemblages of
16 plants. However, the methodology used by Keenan et al. (1997) is biased towards finding
17 differences between assemblages, as they surveyed small plots (typically, 0.0024 - 0.06 ha
18 per plantation, for seedlings and trees, respectively), relative to the size of plantations (2 – 40
19 ha), and used a measure of similarity (Sorenson’s index) which is sensitive to small sample
20 size (Plotkin and Muller-Landau, 2002).

21 [Author’s note: Table 2 approximately here]

22 Further, a mosaic of monoculture plantations is likely to have fewer benefits for fauna,
23 particularly vertebrates, than for plants. Most rainforest vertebrates require a diverse suite of
24 floristic and structural resources at the scale of an individual’s home range (Winter et al.,

1 1988; Kikkawa, 1990; Jones and Crome, 1990; Kanowski et al., 2003b). Hence, while
2 plantation mosaics may provide a greater diversity of floristic resources than monocultures at
3 the landscape scale, only wide-ranging vertebrates would be able to harvest or use those
4 resources, assuming plantations were in the order of 10 – 50 ha as is generally the case in
5 eastern Australia. In comparison, most arboreal marsupials in Australian rainforests, for
6 example, utilise a home range only a few ha in size (Newell, 1999; Wilson, 2000). Nor would
7 a mosaic of monocultures provide any more of the structural resources required by many
8 vertebrates (e.g., woody debris, hollows) than an extensive monoculture. For these reasons, a
9 mosaic of monocultures is unlikely to support a much more diverse fauna than an extensive
10 monoculture. These arguments are supported by surveys of birds in plantations of
11 Queensland maple, kauri pine and hoop pine in Gadgarra State Forest (the same plantations
12 surveyed for plants, above). In these surveys, most bird species recorded in one plantation
13 species were also recorded in another (Table 2), suggesting that the mosaic of plantations was
14 not providing much greater habitat value for birds than each monoculture plantation on its
15 own.

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

1 generalist species (Haggard et al., 1997), and the biodiversity value of a mosaic of
2 monocultures relative to an extensive monoculture would be even less pronounced.

3 *3.5 Mosaic of plantations and restoration plantings*

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

12 This scenario is likely to have positive impacts on biodiversity for all criteria presented in
13 Table 1. The plantations themselves may have some positive impacts on biodiversity,
14 depending on the species used and other aspects of design and management, as discussed
15 above. However, most of the positive impacts of this scenario are due to the inclusion of
16 restoration plantings in the plantation estate. Restoration plantings typically have a high
17 intrinsic value (e.g., up to 100 locally occurring species of rainforest plants are used in
18 restoration plantings in eastern Australia: Goosem and Tucker, 1995; Kooyman, 1996).
19 Furthermore, restoration plantings have the potential to support many species of rainforest
20 plants, birds and invertebrates within a few decades of establishment (Catterall et al., 2004b;
21 Kanowski et al., 2004a) (Fig. 2). If riparian areas in plantations were targetted for restoration
22 plantings (as suggested by many authors, e.g., Lamb et al., 1997; Lindenmayer, 2002; Salt et
23 al., 2004; Tucker et al., 2004), then these plantings may form a network of high quality
24 habitat which would potentially increase the dispersal of rainforest biota across the landscape,

1 especially if plantings were contiguous with remnant rainforest (Tucker, 2000; Kanowski et
2 al., 2003c). Biota using or dispersing from these plantings would also provide a source of
3 colonists to plantations over the harvest cycle. Riparian plantings would also help minimise
4 the potential negative impacts of plantation management on water quality and aquatic biota
5 (Bunn et al., 1999).

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

11 **4. Discussion**

12 *4.1 The value of plantation scenarios for biodiversity*

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

21 [Author's note: Table 3 approximately here]

22 In cleared rainforest landscapes of eastern Australia, there has been a long-standing interest in
23 the potential for mixed species plantations to provide both production and biodiversity

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

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

1 *4.2 Integrating biodiversity and production objectives in broadscale plantations in cleared*
2 *rainforest landscapes*

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

1 25% of a plantation estate could be devoted to restoration plantings before the cost of
2 establishment exceeded that of mixed species plantings.

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1 **Table 1. Potential consequences of plantation development for biodiversity in cleared**
 2 **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

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

4 **(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

5

6 **(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

7 Note: Plants were surveyed on five 78.5 m² quadrats per site (Wardell-Johnson et al., 2004);
 8 birds were recorded from eight 30 minute surveys of a 0.30 ha transect per site (Catterall et
 9 al., 2004b). Data were pooled from surveys of two replicate sites of each forest type, giving
 10 total survey area per plantation of 0.08 ha for plants, 0.60 ha for birds. Assemblage similarity
 11 based on Sorenson's index (the proportion of species shared between sites), as per Keenan et
 12 al. (1997).

1 **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	+++	+++	+++	++	+++	+++	+	++	+		?	-	-	-	-

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

1 **List of figures.**

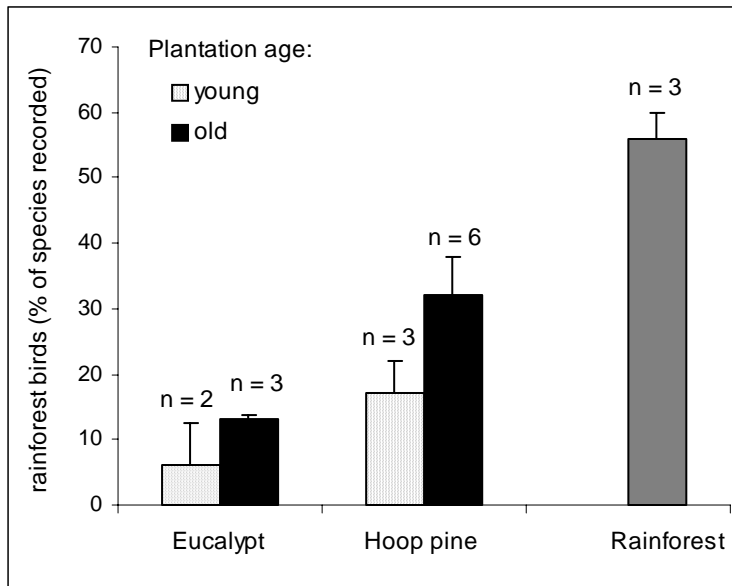
2 **Fig. 1. The proportion of ‘rainforest’ bird species (mean, S.E.) recorded in surveys of**
3 **eucalypt plantations, hoop pine plantations and intact rainforest, subtropical**
4 **Queensland.**

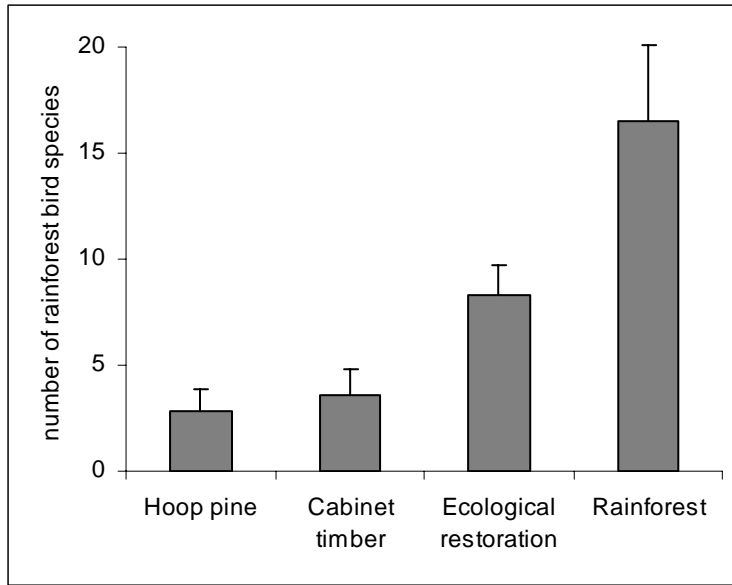
5 Note: ‘Rainforest’ birds are species apparently dependent on or associated with rainforest
6 in south-east Queensland and north-east New South Wales (based on a variety of sources,
7 principally Kikkawa, 1968, 1991; see list in Kanowski et al., 2004a). Data for eucalypt
8 plantations are from Boorsboom et al. (2002); for details of surveys in hoop pine
9 plantations and rainforest, see Catterall et al. (2004b). In eucalypt (*E. cloeziana*)
10 plantations, ‘young’ = 16 years, ‘old’ = 40 years; in hoop pine plantations, ‘young’ = 9 –
11 15 years, ‘old’ = 45 - 70 years. The number of sites in each category is shown on the graph.

12

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

16 Note: ‘Rainforest’ birds are species apparently dependent on or associated with rainforest
17 (based on a variety of sources, principally Kikkawa, 1968, 1991; Crome et al., 1994; see
18 list in Kanowski et al., 2004a). Data from eight 30 minute surveys of a 0.3 ha plot per site.
19 See details in Catterall et al. (2004b). Age and number of sites as follows: hoop pine (age 6
20 – 11 years, n = 5), cabinet timber (age 7 – 9 years, n = 5); ecological restoration (age 6 –
21 16 years, n = 10); rainforest (n = 10).





1