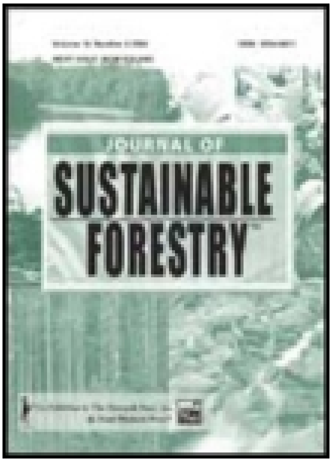

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Ecosystem Management in Tropical Timber Plantations

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Ecosystem Management in Tropical Timber Plantations: Satisfying Economic, Conservation, and Social Objectives

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SUMMARY. Management of tropical timber plantations is generally based on a single-product output, high-input model, often using an exotic species, that has been successfully used for plantation timber production in many temperate regions. This intensive model may be appropriate in areas designated solely for wood production but where the aim is to produce a wider range of conservation benefits and maintain more ecosystem functions, alternative plantation management ap-

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proaches will be required. In this paper we describe some alternative management options for tropical forest plantations, incorporating ecosystem management concepts, that can potentially result in a wider range ecosystem benefits from tropical landscapes. Some of these practices have been used by plantation management agencies for some time. Others have been applied on a small scale or are still to be tested operationally. Options include: (1) consideration of the forest landscape and management of the matrix in which the plantation is established, (2) the use of native rather than exotic species, (3) using mixed species plantations rather than monocultures, (4) using the plantation to facilitate natural understorey regeneration, and (5) incorporating more structural and compositional diversity in plantations for wildlife habitat.

KEYWORDS. Biodiversity, mixed species plantations, forest restoration, wildlife habitat

INTRODUCTION

Reducing the rate of decline in biological diversity while maintaining reasonable living standards for an expanding human population is a major conservation dilemma. Many industrialised countries have achieved their present levels of social and economic development through the capitalisation of natural resources and reducing their native forest estate, and this model has often been proposed to meet development needs of rapidly growing populations in the tropics (Kahn and McDonald 1997). However, development of tropical landscapes is problematic because of the comparatively greater loss of biological diversity likely to result from deforestation in the tropics compared with temperate regions and because many tropical landscapes have a high susceptibility to decline in productive capacity when developed for intensive agriculture (Kahn and McDonald 1997).

Timber plantations are seen as a major potential contributor to economic development in many parts of the tropics. In 1990 there was an estimated 15.6 million ha of industrial forest plantations in the tropics, and 28.2 million ha of non-industrial plantations, including fuelwood plantations. The rate of plantation establishment is increasing, largely for wood production purposes. Policies for the development of forest plantations in tropical developing countries usually target previously-cleared or degraded forest lands but there is also considerable conversion of natural forest to plantations.

Development and implementation of policies for the sustainable development of tropical landscapes will require a complex mix of economic, political and ecological solutions. For forested landscapes there are three broad land use options that can be applied in varying proportions to meet different policy objectives (Seymour and Hunter 1992): nature reserves, extensively-managed and intensively-managed forests. A viable and representative system of reserves is the core of any conservation strategy but there is increasing recognition that conservation objectives cannot be achieved through reserves alone. Management of vegetation outside reserves will be crucial to the survival of many forest dwelling species (Hale and Lamb 1997, Lindenmeyer and Recher 1998). Extensive management involves managing for a wider range of conservation and environmental benefits in addition to the production of timber or other resources and is generally adopted in natural forests. Intensive management usually involves plantations managed to maximise the production of timber, but plantations (or intensively-managed natural regrowth) can also contribute significant environmental benefits such as watershed protection and soil conservation.

The concept of 'forest ecosystem management' has been the subject of considerable debate among scientists and forest managers (Swanson and Franklin 1992, Gerlach and Bengston 1994, Irland 1994, Wiant 1995, and Gilmore 1997). It is generally considered to involve managing forests according to sound ecological principles in order to provide a continuing supply of wide range of ecosystem goods, services and benefits. It embodies many components of the traditional forest management concept of 'multiple-use' but also encompasses a more holistic, community-oriented, ecologically and scientifically-based, resource-stewardship philosophy (Kimmins 1997).

The combination of highly-weathered soils, high rainfall, and high temperatures often found in the tropics imposes particular limitations on land management. Traditional land use practices have generally evolved to accommodate these constraints. For example, shifting cultivation and land rotation with bush fallowing is often regarded as an exploitative and destructive practice, but is, in fact a highly-evolved and specialised technique developed by forest dwelling communities in response to the limitations imposed on broad-scale agriculture by the tropical forest environment (Weischet and Caviedes 1993). Similarly, forest scientists and managers working in the tropics for a century or more have developed a considerable body of ecological knowledge that can be used as a basis for ecosystem management in the tropics (Bruenig 1996). However the application of sustainable management systems has been relatively rare for a range of political, economic and social reasons (Poore et al. 1989).

Management of tropical timber plantations is generally based on the single-product output, high-inputs model often using an exotic species, that has been successfully used for plantation timber production in many temperate regions. This intensive model may be appropriate in areas designated solely for wood production although, given the environmental limitations outlined above, it may not be successful in many parts of the tropics (Jordan 1993). Where the aim is to maintain a wider range of ecosystem benefits, alternative plantation management approaches will be required (Bass 1997).

In this paper we describe some alternative management options for tropical forest plantations, incorporating ecosystem management concepts, that can potentially result in a wider range ecosystem benefits from tropical landscapes. Some of these practices have been used by plantation management agencies for some time. Others have been applied on a small scale or are still to be tested operationally. Options include: (1) consideration of the forest landscape and management of the matrix in which the plantation is established, (2) the use of native rather than exotic species, (3) using mixed species plantations rather than monocultures, (4) using the plantation to facilitate natural understorey regeneration, and (5) incorporating more structural and compositional diversity in plantations for wildlife habitat.

LANDSCAPE-LEVEL MANAGEMENT

Plantation development in the tropics is taking place on lands where intact forest is being cleared, or where the previous vegetation has been cleared in the past for another land use. By retaining existing native vegetation, or by restoring natural vegetation on previously-cleared sites, the plantation can be embedded within a matrix of natural vegetation. This results in maintenance of a variety of environmental and conservation functions.

Protection of riparian zones is now a common feature of forest plantation practice. These areas are targeted for retention or restoration of natural vegetation within a production plantation because riparian buffers help maintain water quality and reduce soil erosion, and because they are generally the most productive sites within a landscape and provide habitat for a greater diversity of wildlife. Strips of vegetation can also be retained or established to connect blocks of remnant vegetation within the plantation between areas that are too steep or rocky for plantation development. These bands break large plantation areas into smaller blocks or compartments and the greater floristic and structural diversity of the matrix allows a wider variety of species to persist in the landscape (Gepp 1986, Suckling et al. 1976) and provides for connectivity between different landscape units (Forman 1995) which can signficantly increase the conservation value of a plantation. The maintenance of this matrix of more natural vegetation may result in some loss of plantation production. However, this is generally outweighed by benefits such as clean water and assistance with fire control.

USING NATIVE SPECIES

Tropical plantation projects have largely used a relatively narrow set of exotic species from the genera *Pinus*, *Eucalyptus*, *Acacia* or *Tectona*. Many tropical species in these genera have a range of advantages that make them suited to domestication as plantation species. These include:

- tolerance of a wide range of water and nutrient-limited situations,
- ease of establishment and rapid early growth,
- small, 'orthodox' seeds that can be easily transported and stored,
- ease of propagation by a range of means, and
- utility for a range of products.

Exotic species have been particularly valuable in forest establishment on badly degraded sites where it has often been difficult or impossible to establish native species.

Using native tree species instead of exotic species in plantation monocultures increases the conservation value of a plantation because a local species is more likely to be used as habitat by local wildlife. Using native species can also result in greater natural regeneration in the plantation understorey (see below). Many native species may also have a higher market or social value to the local community and using such species can make a plantation project more socially acceptable.

Testing of tree species for their potential in plantations has been occurring for many years (Streets 1962). For example, teak (*Tectona grandis*) has been successfully grown in plantations within and beyond its range since 1941 (Brown, Nambiar, and Cossalter 1997). High value species from the family Meliaceae (in genera such as *Swietenia*, *Khaya*, *Cedrela* and *Toona*) have also been planted across substantial areas, but have generally only been successful outside the range of native insect pests. However, high-value rainforest timbers have usually been readily and cheaply available from native forests and there has been little incentive to invest capital resources in establishing plantations of these species. These sources are now declining rapidly and there is increased interest in their development in plantations. There is also a growing interest in using a wider range of ecologically-beneficial and socially-acceptable species, and species testing has increased in recent years (Appanah and Weinland 1993, Butterfield and Fisher 1994, Butterfield 1995).

However, the capacity to use many rainforest species in plantation programs has been limited by difficulties with collection, storage and germination of fleshy-fruited seeds and other nursery propagation, pest and disease or silvicultural problems. With appropriate research (e.g., Knowles and Parrotta 1995) these problems are not insurmountable and there is an urgent need to expand our knowledge of plantation production ecology and appropriate silvicultural techniques to a wider range of tropical species.

MIXED SPECIES PLANTATIONS

Planting a mixture of species in a plantation has obvious benefits for increasing plantation diversity. Mixtures have been suggested as a management technique for tropical plantations for some time, but there are few successful operational examples (Wormald 1992). Mixtures can range from simple arrangements, such as alternate rows of two or more species, through to random mixtures of many species. Besides increasing within-stand diversity the potential benefits of mixtures over monocultures include:

Greater production-Species mixtures can potentially produce a greater amount of biomass per unit area by reducing competition between individuals and more fully utilising the site (Montagnini et al. 1995, Kelty and Cameron 1995). Mixing species with differing light requirements can result in canopy partitioning and a greater capture of solar energy, and mixing species with different rooting patterns can more fully exploit soil resources. Species may also have differing phenologies of root or shoot growth resulting in lower competition between individuals for soil water or nutrients (Lamb and Lawrence 1993).

Planting a mixture of faster growing pioneer species with shade tolerant late-successional species may facilitate the establishment of those rainforest species not adapted to establishing in the microclimate of open situations. Mixtures may reduce insect or diseases, for example planting species from the family Meliaceae together with, or under the canopy of, a companion species can reduce the incidence and severity of attack by the tip moth species (*Hypsipyla* spp.).

There has been extensive debate about whether greater diversity results in ecosystems being more stable and resilient to perturbations that has not yet been fully resolved (Peters 1991). Many exotic plantation monocultures have been relatively free of pests and diseases. Monocultures of native species tend to suffer more problems, and there is likely to be less risk of total failure of the plantation as a result of insect pests or diseases if a mixture of tree species is used.

Inclusion of nitrogen-fixing species has been used extensively in agriculture to improve pasture or crop production, and inclusion of a proportion of leguminous tree species can increase production of non-nitrogen fixers in natural and planted stands on N limited sites (Binkley et al. 1992, Binkley and Ryan 1998). Litter decomposition may also be more rapid, and nutrient availability increased when a mixture of litter from different species is present (Simmonds and Buckley 1990).

Using mixtures can increase the production of merchantable timber by improving the form and bole length of the desired species, although the same result may be achieved with close spacing of light demanding species. Planting mixtures could provide greater economic returns than monocultures. Small logs obtained from thinnings for many rainforest species are usually of low value and including other species in the plantation, such as durable eucalypts that have a higher value for small products like posts or poles, could result in increased value from thinnings and higher overall return from the plantation.

Site protection and nature conservation–A mixture of trees and shrubs can maintain a higher ground cover than a monoculture resulting in greater soil protection which may be an advantage on degraded or eroding sites. A mixture of species is the most appropriate method if the objective is to restore the vegetation of a degraded area to something approximating that of the original forest. Ecosystem restoration attempts to mimic the natural successional pathways and processes that enable ecosystems to recover from major perturbations (Jordan, Gilpin, and Aber 1987). By choosing species with fruit consumed by birds or other frugivores and trees with structures suitable for perching the natural regeneration from seed of other species can be enhanced (Guevara et al. 1986, McClanahan and Wolfe 1993, Goosem and Tucker 1995).

Social and aesthetic benefits–Landscape values are becoming increasingly important in many societies and the aesthetic appearance of forestry practices are coming under increasing scrutiny. Many people object to the visual impact of large scale plantations of exotic monocultures on rural landscapes. Planting a mixture of species increases the heterogeneity and improves the appearance of the plantation. This does not necessarily mean planting an intimate mixture of species in a single stand and could include separate smaller plantings of individual species. In general, mixtures of local species are more consistent with the natural landscape and this is likely to result in broader community support for plantation projects. Planting a mixture of species, including those with economic products other than wood, such as fruit, nuts, or medicines, can result in a wider range of products and benefits for the landowner and the local community in developing and developed countries. Inclusion of alternative products that become available from the plantation more quickly than timber products can improve the economic attractiveness of plantation development for private landowners, and result in a greater amount of reforested land. However, more experience is needed in most cases to develop management systems to produce multiple products.

The major disadvantage of mixtures is that they are more difficult and expensive to manage. For example, species in a mixture may grow at different rates and require different harvesting times. This may lead to the possibility that a slower growing species is damaged when the earlier maturing species is removed. Potential production benefits have not always been realised and both production gains as well as losses have been observed (Burkhart and Tham 1992, Wormald 1992, Kelty 1992).

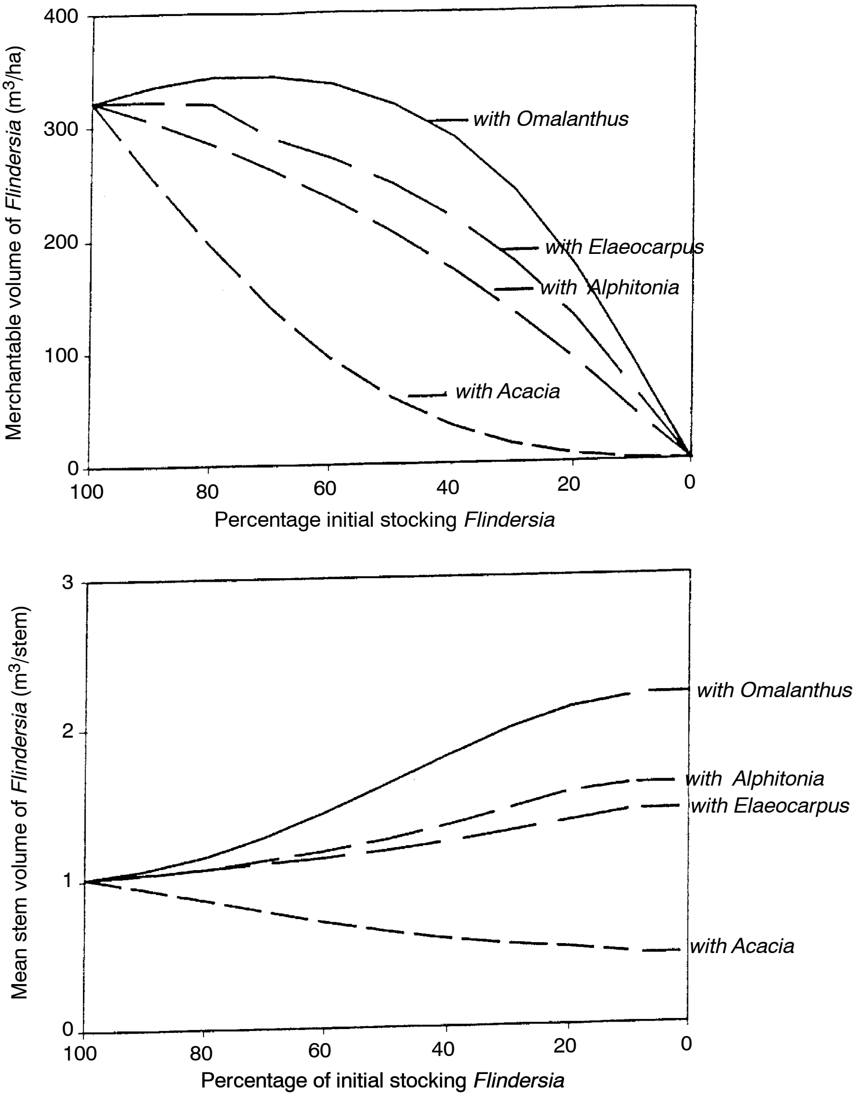
These difficulties are often due to our lack of knowledge about how species are likely to interact. Identifying appropriate plantation mixtures requires a good understanding of the ecology of individual species and comparison of the long-term growth of mixtures and monocultures in replicated, larger-scale experimental or designed operational plantings across a range of sites, however, there are relatively few such experiments.

In the short-term computer modelling may provide an indication of how different species might behave in mixtures. A model with potential for this analysis was developed to predict growth of native rainforests under silvicultural management in north Queensland (Vanclay 1994). Model parameters for recruitment, growth and mortality were derived from measurements of diameter growth on over 200 permanent plots in native forest, some with a measurement history extending over 40 years.

In a recent study this model was used to compare growth of an important rainforest timber species: *Flindersia brayleyana* (Queensland maple), when grown in monoculture and in mixtures with varying proportions of four native pioneer species: *Omalanthus populifolius*, *Elaeocarpus grandis*, *Alphitonia petriei* and *Acacia aulacocarpa*. The modelled plantation regime was to plant 500 stems/ha and grow the stand for 60 years.

The model predicted that *F. brayleyana* growing alone would achieve a merchantable volume (trees > 40 cm dbh) at age 60 years of 321 m^3/ha or a mean annual increment (MAI) in volume of about 5.4 m^3/ha/yr (Figure 1). This is similar to growth rates achieved in 55 year old plantations that had received minimal silvicultural management. Indicating that the predicted yield in the mononculture is similar to field measurements. Increasing the proportion of different companion species had significantly different effects. Predicted merchantable volume when *F. brayleyana* was grown with the short-lived *O. populifolius* was almost identical to that predicted when it was grown in the same numbers alone. In contrast, a mixture with only 20% of *A. aulacocarpa* resulted in a substantial decline in final volume of *F. brayleyana*. This is consistent with other studies of *Acacia-Flindersia* mixtures (Keenan, Lamb, and Sexton 1995). Increasing proportions of *Alphitonia* and *Elaeocarpus* resulted in a less rapid decline in volume than *Acacia*.

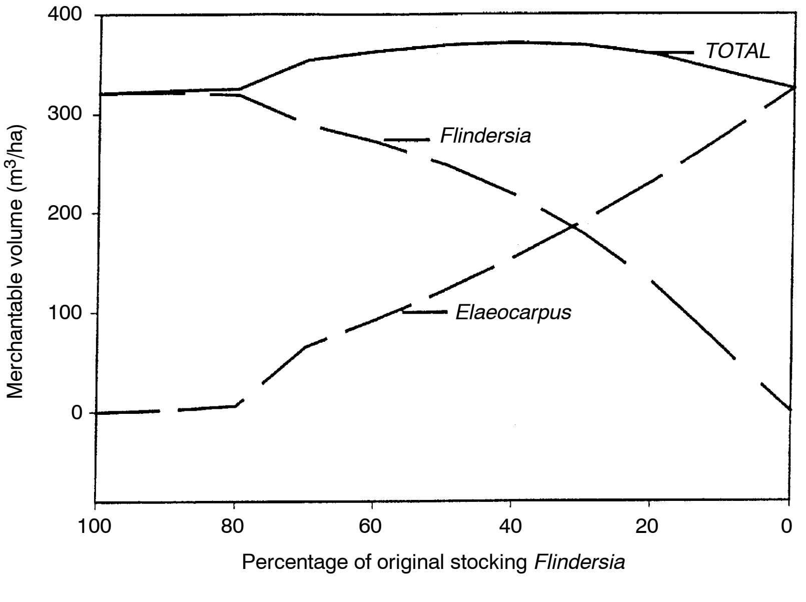
FIGURE 1. Predicted merchantable volume and average stems size of *Flindersia brayleyana* (Queensland maple) at age 60 years using a native forest growth and yield model developed by Vanclay (1994). The model was indicated with 500 stems per ha with an average DBH of 1 cm. Lines show the effect on yield of replacing *F. brayleyana* with 20, 40, 60, 80 and 100% of four rainforest pioneer species: *Omalanthus populifolius*, *Elaeocarpus grandis*, *Alphitonia petriei* and *Acacia aulacocarpa*.



The mix *Elaeocarpus* and *Flindersia* was explored further (Figure 2). Results from this mix indicated that within the range 30 to 70 percent *Elaeocarpus* higher yields could be achieved with the mixture than with either species growing in monoculture.

These results indicate that the growth of target trees in mixtures might vary considerably depending on the nature of the associated species. Species with rapid early growth and dense spreading crowns such as *Acacia aulacocarpa* or *A. mangium* are likely to be unsuited for mixtures with slower growing species. Combining *F. brayleyana* with other species such as *Elaeocarpus grandis* or *Alphitonia petrei* may result in increased production compared with monocultures. While the results are preliminary they indicate that a model based on species behaviour in native forests may be of value in investigating their interactions in plantation mixtures. The model also demonstrates the kind of forest planning tools that will be required to manage more complex plantation designs.

FIGURE 2. Predicted merchantable volume of *Flindersia brayleyana* (Queensland maple) and *Elaeocarpus grandis* (silver quandong) at age 60 years using a native forest growth and yield model developed by Vanclay (1994). The model was initiated with 500 stems per ha with an average of DBH of 1 cm.



FACILITATING UNDERSTOREY REGENERATION

It has been observed for some time that timber plantations established on degraded sites or grasslands may provide more suitable conditions for regeneration of native plant species that cannot establish in exposed microclimatic conditions or under competition from grasses (Lugo 1992, Parrotta 1993).

This phenomenon was recently investigated at a range of sites across the tropics (Parrotta and Turnbull 1997) including four sites in north Queensland (Keenan et al. 1997). Results from the Queensland study indicated there was considerable natural regeneration under plantations of both native (*Araucaria cunninghamii*, *Flindersia brayleyana*, and *Toona ciliata*) and exotic (*Pinus caribaea*) species ranging from 5-63 years in age. In total, 350 vascular plant species were found in the plantations. Tree species dominated recruitment (176 species) in both young and older plantations but most life forms were present in most plantations. Older plantations had appreciably more understorey species overall than younger ones and some of this recruitment had grown to become part of the plantation canopy. Diversity of understorey recruitment was higher in plantations of the native species than the exotic and there was a greater diversity of tree species found under the broadleaved species *F. brayleyana* and *T. ciliata*. Most recolonising tree species were primarily dispersed by birds, with wind dispersal of secondary importance, with mammals only responsible for a small proportion of regenerating species.

In general, understorey recolonisation is dependent on the degree of site degradation, proximity to native forest seed sources, characteristics of the planted species, and the age and management intensity of the plantation (Parrotta and Turnbull 1997). The catalytic effect appears to be stronger on wetter than drier sites, perhaps because of there is less competition for moisture and litter accumulation on wetter sites. Adding species diversity and structural complexity generally promotes more rapid and diverse understorey recolonisation, because of the attractiveness of the plantations to a wider variety of seed dispersers. Larger-seeded species are less likely colonise sites due to dispersal limitations, and direct seeding or planting of these species will be required to facilitate their establishment.

STRUCTURING RAINFOREST PLANTATIONS FOR WILDLIFE

Plantation monocultures often support little wildlife (Bevege 1974, Disney and Stokes 1976, Driscoll 1977, Fisher 1974, Heinekamp and Ramsay 1973). Use of plantations by wildlife might be improved by increasing structural and compositional diversity in the ways described above. Bird species diversity is often related to foliage height diversity (Recher 1969) and diversity in crown height can be created in monocultures by having a mixed age distribution or allowing development of an understorey (Curtis 1974, Gepp 1986). However, regional species diversity is largely determined by the abundance of food resources and shelter and the composition and structure of wildlife populations will be strongly linked to the composition and structure of plantations (Clout 1984). High bird diversity in rainforests of the humid tropical lowlands is made up of many rare species that specialise in utilising relatively scarce and scattered resources (Kikkawa and Dwyer 1992). Consequently, maintaining bird diversity depends on maintaining high plant species diversity. The importance of older tree with hollows and other structural features such as dead standing trees and down woody debris for wildlife habitat has also been recognised for some time (Harmon et al. 1986).

In summary, structural and compositional diversity to maintain wildlife populations in plantations can be developed by (1) creating a complex plantation age structure, keeping some older planted trees and maintaining areas of open space; (2) establishing mixed stands, particularly incorporating preferred food trees; and (3) keeping or creating dying and dead wood within plantations.

CONCLUSIONS

Recent studies in tropical plantations indicate that there are a range of ways that plantations can be managed to produce a wider range of ecosystem goods and services at both the landscape and the site level. Some practices, such as retention or restoration of native vegetation in corridors or riparian zones should be incorporated into all plantation developments. The use of native species is worth encouraging more extensively for a range of reasons. Mixed species plantations can provide a range of benefits (including increased production) but these may come at some cost and more extensive analysis and experimentation is required before they are likely to be widely applied. The role of plantations in fostering understorey development is an additional benefit of tropical plantations that has not been widely recognised but one that may be useful for restoration programs and for development of plantations with multiple values.

Some of the ideas we describe are not new, and are currently incorporated into codes of practice and operational activities of forestry companies (Table 1). 'Ecological purists' may consider that the forests resulting from using such techniques may not fully reflect the structure, composition or functioning of natural forests. However, it is

TABLE 1. Results from a survey of corporate environmental and social practices used in 18 large forest corporations with management responsibility totalling 4 million ha of plantations or intensively managed forests (after Bass 1997).

Use of the land prior to management:
Less than 1% was old-growth forest
33% was farmland/secondary forest
66% was grassland or 'degraded' farmland
2-27% of the area under each company was now indigenous forest, usually in an intricate mosaic with plantations
Company environmental practices:
most used reduced-impact machines
most of those using clonal material had strict clonal replacement strategies (every 2-5 years)
most used few and/or 'safe' chemicals
90% employed soil conservation measures
70% designed-in wildlife corridors
70% monitor the spread of exotic species
25% produce non-timber forest products on a commercial basis
25% use only 1 tree species, and 40% only 2 species
10% monitor soil/water quality
chemicals use rates are decreasing; for a tree rotation they are about the same as for a farm crop over just 1 year
Company social practices:
Most companies have some sort of access agreement with local people
80% support subsistence or non-commercial use of forests for public fishing or recreation
60% either run an outgrower scheme or provide extension services to small landowners who grow trees for them
25% produce wild meat, fish, oils, firewood and/or honey on a commercial basis

important to recognise that human impacts and future global change are likely to result in future forest ecosystems that differ compositionally and functionally from those current or past ecosystems. Ultimately, the aim across a considerable part of the tropical forest landscape will be to implement production systems that are flexible in the goods and services that they provide and that are resilient to future change. Achievement of landscape-level and regional conservation goals will depend on integrating production with conservation objectives on a substantial proportion of the forest landscape, and not simply by zoning lands for either conservation reserves, where production of economic goods is prohibited, or intensive production areas, where little attention is paid to other ecosystem values.

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