Linkage restoration: Interpreting fragmentation theory for the design of a rainforest linkage in the humid Wet Tropics of north-eastern Queensland

By Nigel I. J. Tucker

***Nigel Tucker** is the Manager of the Qld Parks and Wildlife Service, Center for Tropical Rehabilitation, PO Box 21, Yungaburra Qld 4872, Australia. Email: CTR@env.qld.gov.au. This article is based on work undertaken at Donaghy's Corridor as part of the author's MSc programme.*

Summary Studies of forest fragmentation, particularly in the species-rich tropical zone, have contributed significantly to our understanding of its effects and impacts, and allow us to predict a cascade of flow-on effects likely to emerge in the coming decades. Practical management strategies to combat these effects, however, have not been forthcoming, despite intuitive assumptions and a growing body of scientific evidence that maintaining and restoring habitat connectivity is likely to be critical for the long-term persistence of many life forms in these fragmented landscapes. This paper reviews the potential problems involved with linkages, and examines some of the strategies adopted to overcome these issues in a linkage restoration project on the Atherton Tableland, in the Wet Tropics of north-eastern Australia. The paper concludes with the suggestion that restoration projects, such as the Donaghy's Corridor example, offer opportunities for researchers and practitioners to collaboratively observe and validate these strategies, and develop 'real world' techniques to reverse the ecological, social and economic effects of forest fragmentation.

Key words: *connectivity, fragmentation, habitat linkage, rainforest, restoration strategy.*

Introduction

The effects of fragmentation in rainforest ecosystems have been well documented (Laurance & Bierregaard 1997) and the phenomenon is considered the most serious of all the threats to biological diversity (Wilcox & Murphy 1985; Whitmore 1997). Changes in the distribution and abundance of native and exotic species in isolated habitat remnants affects higher order interactions, such as predation (Terborgh & Winter 1980; Wilcove 1985; Harrington *et al*. 1997); parasitism (Wilcove 1985; Rich *et al*. 1994) and seed dispersal (Crome & Bentrupperbaumer 1993; Harrington *et al*. 1997). These changes may favour ecological generalists over specialists (Sarré *et al*. 1995), and can result in rapid species' extinctions at a local, regional or national scale (Lovejoy *et al*. 1984; Bierregaard *et al*. 1992; Shea *et al*. 1997). The maintenance of biodiversity in fragmented landscapes is likely to depend on the ability of resource managers to enhance species persistence by ensuring that a more favourable habitat matrix exists across regional landscapes (Goosem & Tucker 1995; Lamb *et al*. 1997; Laurance & Gascon 1997; Shea *et al*. 1997; Bennett 1999).

The importance of habitat connectivity to enhancing species persistence in fragmented landscapes remains an intuitively appealing concept, rather than a well-tested hypothesis. The paucity of data results largely from difficulties in the application of theoretical principles and testing of hypotheses in landscapes of the 'real world'. However, this is of little comfort to land managers seeking solutions to problems which fragmentation theory continues to expose. This is particularly the case in tropical areas which have high biotic diversity and endemism, and where the ecosystems are themselves poorly studied and rapidly disappearing.

The practical task of restoring connectivity to fragmented ecosystems may offer us a better understanding of the ways linkages may or may not function and their role as part of a regional conservation strategy. Carefully planned restoration of links between previously connected areas provides the opportunity to undertake pre-treatment sampling, to monitor changes over time using a range of bio-indicators, and to make more informed decisions about the way we manage regional ecosystems. In seeking answers to guide these decisions it is important to ensure we ask the right questions.

Because every existing or potential linkage will vary according to its dimension, setting, condition and the target species, the correct question is likely to be 'will this linkage, in this ecological setting, with these habitat features, provide any benefit to species *a*, or community *b*?' This can only be done with significant preplanning, a clear understanding of the species for whom the corridor is intended to function, and gauging whether their needs can be met in the sites available for restoration. Planning should also identify potential problems that may arise as a result of linkage restoration. Strategies can then be developed to deal as effectively as possible with these drawbacks. As an example of this process I detail one such project in north Queensland and discuss the strategies developed to deal with some of the problems identified in previous studies.

Here in the Wet Tropics bioregion of north Queensland, fragmentation threatens the long-term persistence of a number of plant and animal species and the ecological communities in which they occur (Hopkins *et al*. 1996; Laurance 1997a; Goosem *et al*. 1999). The Atherton Tableland is characteristic of much of north Queensland where deforestation for agriculture was initially concentrated in the most productive and easily cleared areas. Many national parks and reserves were selected for a scenic feature only and the surrounding landscape cleared for other land uses. Such is the fate of the Lake Barrine section of the Crater Lakes National Park, an isolated fragment of type 1b rainforest (Complex Mesophyll Vine Forest on basalt) as described by Tracey (1982), which encompasses an area of 491 ha, including 220 ha of water surface (Fig. 1). The park has been isolated in a sea of pasture grasses since the last clearing event in 1913 (N. Kingston, pers. comm., 1997) when surrounding forest was felled and burnt to facilitate pasture establishment. The volcanic crater lake is a popular tourist attraction and while it has tremendous scenic appeal, the park's isolation and the effects of internal fragmentation are significant management issues.

Around 1 km east of Lake Barrine is Gadgarra State Forest, contiguous with an 80 000 ha rainforest massif including the peaks of Bellenden Ker (1528 m) and Bartle Frere (1615 m), within the Wet Tropics World Heritage Area. The catchment of Toohey Creek, a permanent stream flowing from Lake Barrine is largely intact and forest cover has only been removed over that portion of the stream which traverses private land between Barrine and Gadgarra. Restoring native vegetation along Toohey Creek offered the opportunity to reconnect Barrine to the larger block, and monitor the effects of this restoration on a range of life forms within the replanted linkage and in the formerly isolated Barrine reserve. The Barrine–Gadgarra linkage, known colloquially as Donaghy's Corridor, is approximately 1 km long, varies between 70 m and 120 m in width and follows the course of Toohey Creek. More than 20 000 plants of around 100 type 1b rainforest species were established to form the linkage, in four yearly plantings of approximately 5000 stems. Plantings were conducted in late January of 1995, 1996 and 1997, with the final link planting established in 1998, and an adjacent windbreak/agroforestry zone established in 1997.

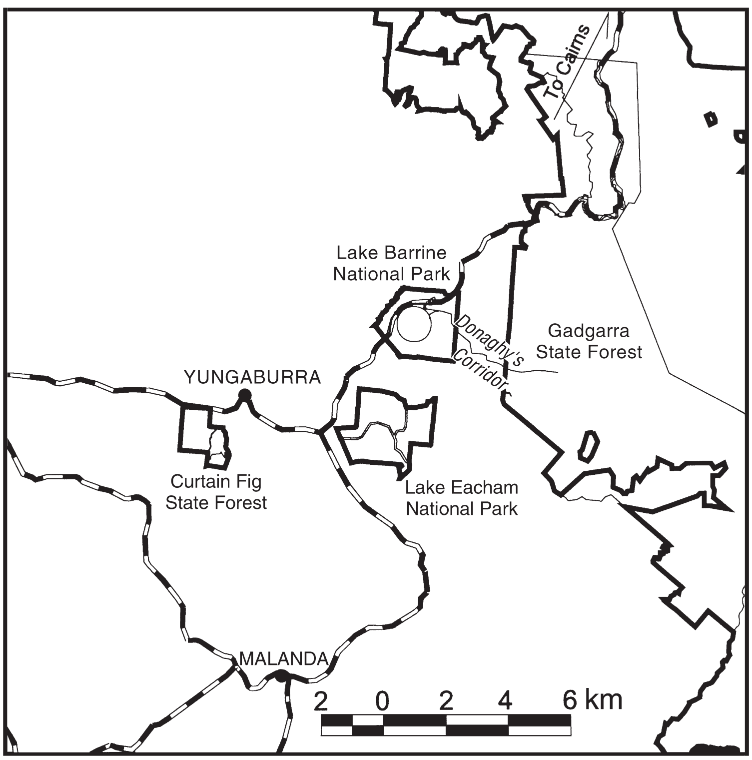

Figure 1. Location of Donaghy's Corridor between Lake Barrine National Park and Gadgarra State Forest, north Queensland.

Problems and strategies

There are a number of reasons why linkages, including the Barrine–Gadgarra example, may be problematic, including catastrophic contagious effects; exposure to humans; exposure to domestic animal disease; invasion of exotic plant species; increased road deaths; introduction of different genotypes and the financial cost of linkages in relation to other conservation strategies (Simberloff & Cox 1987). Linkages may function for habitat generalists only (Hobbs 1992), and with high edge : area ratios may act as 'linear predator magnets', exposing organisms to higher rates of predation and mortality.

These problems are ecological, social and economic in nature and strategies to overcome them will almost always be site specific and involve many stakeholders. It is important to recognize that the strategies put in place at Donaghy's are essentially unique to this linkage and may not be applicable across all tropical sites. They may, however, provide some insight into the broad issues likely to arise in many linkage restorations, especially in the tropics and subtropics.

Catastrophic contagions

Catastrophic contagious effects may include fire, introduced predators and virus or disease. Rainforests are intolerant of fire (Adam 1992) and, in the Wet Tropics, the response to this intolerance has been evolution of the tall, open, ecotonal forests of the western rainforest margin and mosaic patches of sclerophyll vegetation caused by cultural burning or edaphic factors in other areas. However, in the absence of a combustible ground strata of vegetation, standing rainforest is unlikely to burn in all but the most extreme drought years. In this area, fire control is undertaken by the volunteer Lake Barrine Bush Fire Brigade in rural residential areas and by government land management agencies within protected areas. At Donaghy's, three concreted vehicle crossings on the stream can act as water and break points for fire control in an unlikely fire event.

There are introduced predators throughout the Wet Tropics including feral cats, dogs and pigs (Wet Tropics Management Authority 1995). These three species are habitat generalists and their responses to changes in habitat structure are sufficiently flexible to allow them access to the whole landscape, regardless of linkage availability. Feral cats may be a significant predator of terrestrial/arboreal mammals, reptiles and birds. This pest may establish territories in and adjacent to a restored linkage in response to an easily obtained, reliable food source; although trapping could be undertaken if there was any indication of their presence. Elevated predation by edge-favouring raptors, pythons and other native carnivores, is also possible.

The creation of cover resources which provide a range of escape options similar to those in natural forests should be incorporated into the initial linkage design. By restoring microhabitat features such as hollow logs and rock piles (Goosem & Tucker 1995) and a complex vegetation structure with elements such as vines and lianas, escape from predators may be more rapidly provided to a range of smaller animals. At Donaghy's we placed logs of varying girth (with and without hollow cores and in varying stages of decay) throughout each planting area. In restored forest the appearance of these features would normally take many decades. The dead wood requirements of saproxylic and other insects as habitat per se is discussed elsewhere in this volume (Grove & Tucker 2000). Artificial dens and nest boxes are likely to be essential for arboreal species including flying and non-flying mammals. At Donaghy's Corridor the installation of these features will be undertaken over the next 3–5 years as vegetation height increases.

Exposure to humans and roads

Human exposure is likely to be a factor in some linkage sites, particularly those close to rural residential subdivisions or near protected areas. Linkages located away from houses, roads and other infrastructure, however, can be assumed to be safer. Unlike some tropical countries, wildlife poaching or hunting is not a significant problem in Australia. More significant in north Queensland is the negative interaction between Southern Cassowaries (*Casuarius casuarius*) entering remnant protected areas and the large numbers of tourists visiting these areas on a daily basis. A seed disperser that facilitates some long-range dispersal of large-fruited rainforest plants, Southern Cassowaries are only occasional visitors to the park. They tend to associate roads, vehicles and people with food after inappropriate hand feeding. The most recent resident bird was euthenased as a result of injuries received in an incident with a truck in a visitor area. This incompatability presents real challenges to park managers attempting to encourage the bird's presence for its dispersal attributes, while at the same time trying to restrict its negative interaction with visitors.

Strategies to overcome potential Southern Cassowary mortality are limited to public education (which has not worked to date), or relocating birds as they appear (clearly a strategy at odds with the overall intent of linkage restoration). Increased intervention programmes aimed at slowing traffic on the highway through the park; stopping hand feeding; and educating the public on the bird's important ecological role, are clearly needed to ensure the corridor does not indirectly cause unnecessary Southern Cassowary mortality. While site selection has ensured traffic is not a problem in or adjacent to the Donaghy's linkage, the problem of cassowaries, people and traffic is very real (Crome & Bentrupperbaumer 1993), particularly if new immigrants were hand-fed in picnic areas or from cars on the highway. The increased road deaths alluded to by Simberloff and Cox (1987) are also seen as a threatening process here in north Queensland for many other wildlife species (Goosem 1997).

Disease transmission

There are no local records of disease transmission through natural or restored habitat linkages.

There is also little information in the scientific literature, or anecdotally, reporting exotic animal diseases in Wet Tropics species — and overseas examples of other species (Simberloff & Cox 1987) relate to small populations of less than 100 individuals. For populations of small size, a different conservation strategy is clearly warranted, given that restoring habitat linkages is unlikely to mitigate against an immediate extinction outcome for very small populations. However, introduction of exotic diseases by feral/domestic species can occur (Hess 1996), particularly in mixed agricultural areas. This suggests that regular management would be required to eliminate or detect these occurrences at an early stage. If disease transmission was identified at Donaghy's, it would be possible to mechanically clear a large enough break in the vegetation. However, the possibility of disease transmission (or any stochastic disturbance causing local extinctions) must be weighed against the role of linkages in facilitating re-colonization after an extinction event, a variation on the 'rescue effect' (Brown & Kodric-Brown 1977).

Facilitating weed invasion

A range of exotic plant species is present at Barrine and Gadgarra and the possibility of weeds extending their range through the new linkage is possible. Coffee Bush (*Coffea arabica*) is a serious weed in some remnants of the Wet Tropics and is present at Lake Barrine (N. I. J. Tucker, pers. obs., 1997; Humphries & Stanton 1992). This species has not been recorded from Gadgarra and linkage provision may facilitate further undesirable extension of the infestation. Similarly, the shade-tolerant, ground-storey shrub, Coral Berry (*Rivina humilis*) is present in the disturbed remnants that are now incorporated into the corridor. It is likely, then, that this species could also invade reserves at either end through restored linkages. Control at the source point is the most appropriate weed strategy and this is regularly undertaken for all agricultural and environmental weeds in the linkage and environs. Regular monitoring of weed cover is also an important component of the strategy and this is undertaken systematically every 6 months.

In restoring linkages with nursery grown plants, there was also a risk of introducing new weeds into both areas via potted plants. This is a particular issue in shaded riparian ecosystems such as Toohey Creek where the abundance of water is similar to a nursery environment. This artificial moisture abundance selects for weeds with this ecological tolerance, allowing establishment of new wild populations in restored areas (N. I. J. Tucker, pers. obs., 1995). Nursery practices suggest that quality control procedures in plant production areas can limit, if not completely eliminate, this risk. Quality control also assists in limiting the spread of soil pathogens such as Cinnamon Fungus (*Phytophthora cinnamomi*), which may cause serious damage to native vegetation if introduced via infected plant stock (Goosem & Tucker 1998). Potting media, nursery plants and water are regularly tested in production areas for pathogens by using a lupin-baiting technique, and weeds are excluded through nursery management systems.

Disruption to gene flow

Inbreeding has been shown to be a threat to reduced populations (Ralls & Ballou 1982), including dwindling populations of higher order predators such as the Florida Panther (*Felis concolor coryi*; see Simberloff & Cox 1987). Relocating individual animals is one possible way to overcome the problem of inbreeding (Simberloff & Cox 1987), although the autecological studies required under this strategy may be cost-prohibitive for only a small subset of extant species (Hess 1996), and the ethics of this approach have been questioned (Noss 1987).

There is clearly a need to deduce the relative risk or benefit in maintaining isolated populations as an overall conservation strategy. The question seems to have little relevance in the Wet Tropics landscape, however, where isolation has been caused by recent fragmentation of previously connected populations, with prefragmentation rates of gene flow. For example, Campbell (1995) has documented a loss of genetic variation in the White-tailed Rat (*Uromys caudimaculatus*) population at Lake Barrine compared to adjacent populations in relatively intact forests, despite its abundance in small- to medium-sized remnants on the Atherton Tableland (Laurance 1991; Crome *et al*. 1994; Laurance & Laurance 1996). For species with similar autecological profiles the effect may be similar. The same situation might be presumed to exist for plant species, although plants established in the linkage were propagated from seeds and cuttings collected as close as possible to the restoration site (generally a 1–2 km radius) to maintain local genotypes and their site suitability.

Linkage costs

The costs of establishing new linkages or acquiring existing links may preclude other options for what are limited conservation dollars. In north Queensland there are several significant areas of habitat on private land which would represent major contributions to biodiversity conservation if added to the Protected Area Reserves System. These are existing habitats with little legislative protection, often containing species and communities underrepresented or absent from the reserves system. The most appropriate strategy is likely to be a mixture of approaches. There are a number of ways the cost of establishing new corridors can be reduced, including using community resources and support.

The community can assist in management of the landscape matrix in a number of ways. First, the lands needed for re-establishing linkages will almost always be on the cleared private lands intervening between forest fragments, and legislated resumptions are unlikely to be socially or politically acceptable. Encouraging landowners to voluntarily provide lands for linkages may bring other benefits in addition to wildlife conservation, including a wider appreciation of off-park nature conservation issues. Second, the community can also lower costs by assisting with other aspects of linkage restoration including assistance with plant production/establishment and monitoring programmes. These are labour-intensive tasks often not requiring technical expertise and represent major savings in labour costs.

In the case of Donaghy's Corridor, land was donated by the owners (the Donaghy family) and the linkage proper is now protected by legislation through a Nature Refuge Agreement which is binding on title. Members of the community tree planting group TREAT Inc (Trees for the Evelyn and Atherton Tableland) provided all labour for plant production and establishment, and continue to assist with some monitoring tasks. In this way, agency costs have been limited to fencing and hardened stock-watering points, weed control and most monitoring tasks.

Edge effects

The high edge : area ratio of a linear vegetation strip may increase the suitability of restored linkages to weed establishment along the margin, symptomatic of an edge effect (Saunders *et al*. 1991; Murcia 1995) likely to permeate throughout narrow linkage areas (Hobbs 1992). Laurance (1997b), in a survey of forest within Lake Barrine, found elevated numbers of treefalls and vine/liana tangles, indicative of a strong edge effect. Reducing some edge effects is possible, although complete elimination is unlikely. At Donaghy's an attempt is being made to reduce edge-induced microclimatic changes and weed establishment by planting fast-growing, thickly crowned plant species just inside the stock-proof fence on the link edge, buffering the abrupt changes in soil and atmospheric moisture and wind penetration that favour weed establishment. Brown Salwood (*Acacia aulacocarpa*), a moderate- to long-lived pioneer species, has been established on the pasture-linkage edge, and this species has been interplanted with different fig species (*Ficus* spp.), long-lived species more typical of climax forests.

There is a dual function in this strategy. First, Brown Salwood is planted to perform an important role in sealing the edge of the margin during the first 10–15 years when a weed community is most likely to establish and prevail. During this time its canopy and competitive root system limits weed establishment but appears not to inhibit regeneration of native species (Tucker & Murphy 1997). After this period, a likely strategy would be to ring-bark or selectively cut these Brown Salwoods. This should allow dense fig canopies to develop, and in the long term provide a keystone frugivore resource along the forest margin to attract seed dispersers and seeds from adjacent forests. This regular input of seed may assist in the long-term domination of the margin by native species and act to reduce weed establishment. As Brown salwoods decay and fall they contribute structural complexity to the ground storey, providing habitat for a wide range of species, both vertebrates and invertebrates.

Edge effects could be further reduced by establishing an agroforestry zone adjacent to a habitat linkage, which acts as a windbreak and reduces light penetration along the pasture–linkage interface, reducing the establishment of light-demanding weeds on the margin. An agroforestry zone also provides extra shade to stock; a source of farm timber; diversified farm income; reduces evaporation on pastures and provides a nesting, foraging and cover resource for pasture-based granivorous birds. At Donaghy's, three rows of the native plantation species, Hoop Pine (*Araucaria cunninghamiana*), have been established in a windbreak/agroforestry zone alongside the linkage. Stock are temporarily excluded from these rows until trees average 1.5 m tall, at around 18–24 months of age. Stems were spaced 3 m apart and there was 5 m between rows. This should allow sufficient light penetration to permit year-round pasture growth and adds 30 m to the overall linkage width.

As noted, provision of natural cover features may be one way to reduce edge-elevated predation, and feral cat trapping will be undertaken if this predation becomes obvious and significant. Nest predation is another edge-induced effect (Andren & Anglestam 1988) that may be exacerbated by a thin, linear configuration. The absolute effect of this predation in the linkage proper may be difficult to counter and it is hoped that the Hoop Pine rows may assist by providing a long-term reduction in biotic and abiotic edge effects.

Linkage width

The question of optimum width has been widely discussed in relation to linkage suitability for various life forms (see Bennett 1999). Laurance and Gascon (1997) suggest 300-m wide strips of vegetation be retained along watercourses in the tropics, and most authors agree that the wider the strip, the more effective it is likely to be. For most farms on the Atherton Tableland, however, 300-m wide strips would resume significant areas of productive land and no farmer would commit to this without compensation for loss of income. Despite this, it is clear that strips 5–20-m wide would provide minimal value at best, and function as predator magnets at worst. Donaghy's Corridor should provide some data on the potential viability of a linkage where width averages 10 per cent of the overall length, excluding the adjacent agroforestry zone. However, it should again be emphasized that questions of width need addressing in terms of the ecosystem type and the target species for which the linkage is intended to function.

Dispersal ability

Rosenberg *et al*. (1997) and Simberloff *et al*. (1992) assert that animal use of a linkage does not show a linkage is necessary, nor demonstrates how animals might move in the absence of linkages. This is a weakness if animals do move through a hostile matrix, independent of linkages. The narrow habitat tolerances of ecological specialists in Wet Tropics rainforests mean they are unlikely to traverse distances > 200 m through pasture to reach another habitat patch. For species such as the Lemuroid Ringtail (*Hemibelideus lemuroides*), an arboreal marsupial which rarely forages below 5 m in height (Laurance 1990), this traversal seems virtually impossible. The issue of independent movement can only be partially addressed by regular sampling of open habitats between forest patches and the effect of successful chance crossings can probably never be fully assessed. However, our knowledge of rainforest obligates' intolerance of fragmentation suggests that the successful movement of such species through open pasture must be assumed to be an extremely rare event.

In a study of fragmentation tolerance in north Queensland's arboreal marsupials, Laurance (1990) found ability to disperse through a matrix could be 'a critical determinant' in some species' persistence in fragmented landscapes. The structural and resource similarity of restored vegetation here in north Queensland, to the regrowth (secondary vegetation) discussed in Laurance's study, suggests regrowth-tolerant species such as Green Ringtails (*Pseudochirops archeri*) and possibly Lumholtz Tree Kangaroos (*Dendrolagus lumholtzi*) would be likely to use restored habitat linkages. However, this study detected regrowth avoidance by Lemuroid Ringtails and, in a later review (Laurance 1997a), by Spotted-tailed Quolls (*Dasyurus maculatus*). This suggests that, for these latter species, restored habitat linkages may not function for many years, if at all.

The construction of artificial dens may hasten colonization by some arboreal species. For the regrowth-intolerant species, a bias toward preferred food plants in the initial planting phase may be an option. This would ensure that in the long term, such reconstructed habitats possess at least the required dietary resources to sustain dispersing subadults, using a linkage to locate vacant territory that contains a full range of niche requirements. At Donaghy's, food plants of the arboreal, leaf-eating possums, and fruit-eating birds (including Southern Cassowaries) and flying foxes (*Pteropus* spp.), are prominent.

Rescuing endangered communities

The value of linkages extends beyond their utility for movement through their value as habitat per se (Rosenberg *et al*. 1997; Bennett 1999). This is a major consideration in an area such as the Wet Tropics which has been subjected to large-scale, non-random deforestation, resulting in many plant communities being listed as endangered or vulnerable (Goosem *et al*. 1999). Tracey's (1982) forest type 1b (Complex Mesophyll Vine Forest on basalt) is one such community; with Winter *et al*. (1987) documenting the loss of 76 000 ha of this type from the Atherton Tableland, including the area surrounding the Lake Barrine reserve. The type now contains a number of rare/vulnerable plants and animals (Hopkins *et al*. 1996), which could benefit from re-establishment into areas of their former range. Restoration can facilitate immediate re-introduction of rare or vulnerable plants onto the landscape, establishing them as a part of habitat plantings advantageous to faunal utilization and persistence across regional landscapes. Rare plants occurring in type 1b forest, including Fern-leaf Tamarind (*Sarcotoechia serrata*), Bull Kauri (*Agathis microstachya*) and Atherton Quandong (*Elaeocarpus coorangooloo*), have been incorporated into plantings in the Donaghy's linkage.

Conclusion

Laurance and Gascon's (1997) pre-emptive approach to fragmentation accepts the reality that clearing will continue (in most cases, regardless of policy or management) and suggests that maintaining habitat connectivity would be an important component of a less destructive approach to clearing. However, restoring habitat connectivity can be seen as a defragmentary action for existing problem areas, seeking as it does, to break up disturbed and degraded lands with new habitat areas, so-called 'bandages for wounded landscapes' (Soulé & Gilpin 1991). Concomitant to this concept, though, is the recognition that the gap existing between science and management must quickly close if 'real world' strategies to overcome fragmentation effects are to be developed and implemented, and their effects validated. Only with close collaboration between government, communities, scientists and landowners can the role of linkages in regional ecosystem management be examined and evaluated.

The Donaghy's Corridor project is one linkage on one landscape and its capacity to provide managers with generic techniques should not be considered as a goal or a possible outcome. It may, however, demonstrate that by bringing together scientists and practitioners in cooperative partnerships, the value of these works, and our understanding of the restoration process, can be enhanced to the benefit of both natural and human communities.

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