doi: 10.1111/j.1442-8903.2009.00471.x

Restoring a rainforest habitat linkage in north Queensland: Donaghy's Corridor

By Nigel I. J. Tucker and Tania Simmons

Re-instating habitat connectivity at the Donaghy's site has allowed many plants, vertebrates and invertebrates to colonise newly created niches and has improved local community understanding of the value of 'defragmenting' landscapes.

Figure 1. Southern Cassowary (Casuarius casuarius johnsonii), a locally iconic restoration target species (Source: Lars Kazmeier).

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Introduction

From 1995 to 1998, restoration plantings were undertaken to establish Donaghy's Habitat Linkage, a 1.2-km × 100-m planting of rain forest species along Toohey Creek, on the Atherton Tablelands, Queensland. The project was designed to link two large habitat areas (Crater Lakes National Park, and the Wooronooran National Park) to provide passage and habitat for a range of fauna species potentially affected by isolation. These particularly included the Endangered Southern Cassowary (*Casuarius casuarius johnsonii*) (Fig. 1) (Tucker 2000a) and the locally endemic Musky-rat

Box 1. Establishing a linkage

Aerial photography from 1943 (Fig. 2) demonstrates the long history of clearing in the region. In 1995, a few isolated fragments of forest cover remained along Toohey Creek, the largest being only 0.25 ha and all were compromised by edge effects and stock trampling pressure. Figures 3 and 4 depict the progress towards canopy closure and establishment of the linkage over 8 years from final planting.

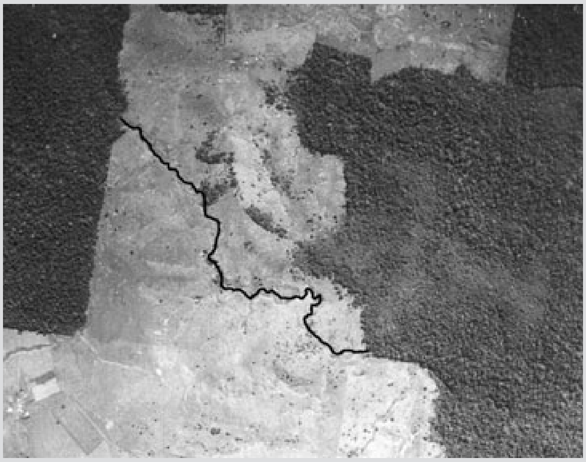

Figure 2. In 1943, the banks of Toohey Creek were largely devoid of vegetation Lake Barinne NP is to the left of this view and Toohey Creek is indicated in black.

Figure 3. In 1998, the final planting can be seen in the middle of the linkage. The 1995 planting to the left (Gadgarra end) and 1996/97 plantings to the right (Lake Barrine end) are more established.

Figure 4. Looking towards Gadgarra State Forest in 2006, Donoghy's Linkage appears to be a well-established part of the landscape.

Kangaroo (*Hypsiprimnodon moschatus*). The project was managed by Queensland Parks and Wildlife (QPW), and involved substantial community participation through the partner group Trees for the Evelyn and Atherton Tablelands (TREAT Inc.).

Toohey Creek springs from Lake Barrine, a volcanic maar contained within a 498 ha section of the Crater Lakes National Park and flows across farmland into the Gadgarra section of the 80 000 ha Wooroonooran National Park. The Lake Barrine section of Crater Lakes National Park and the Gadgarra section of Wooroonooran National Park are both contained within the Wet Tropics World Heritage Area. The Lake Barrine reserve had been isolated from the Wooroonooran massif since the 1930s when agricultural expansion resulted in the clearing of forest surrounding the reserve (see Box 1, Fig. 2).

Fragmentation and potential for linkage

Fragmentation and isolation have resulted in a number of ecological effects within the Barrine reserve.

Campbell (1995) documented a decline in the genetic diversity of some small mammals at Lake Barrine when compared with adjacent intact populations at Gadgarra. Edge effects are prominent, including the mortality of large trees along the exposed margins and dense clumps of rattan or Lawyer Cane (*Calamus spp*.), indicative of edge related disturbance (Laurance 1997). The Southern Cassowary is extinct within Barrine, so its critical role in seed dispersal no longer occurs in the reserve. The Barrine reserve is internally fragmented by roads and powerlines and various weeds are typical in these disturbed areas. Moreover, patches of rain forest isolated in a sea of pasture are a common feature of the Atherton Tablelands landscape and management solutions are required, which can potentially reduce isolation effects in a number of other reserves.

The project managers commenced planning the restoration of the linkage habitat to alleviate these effects, encouraged by a review of the literature on the requirements of linkages (Tucker 2000b) and the cooperative attitudes of the landholders and other stakeholders associated with the site. The majority (85%) of the land to be replanted was privately owned by graziers John and Therese Donaghy and the linkage became colloquially known as Donaghy's Corridor.

Habitat linkages

Rosenberg *et al.* (1997) highlight two key aspects of wildlife corridor function: (i) species habitat; and (ii) conduits for movement. To reinforce this, we refer to corridors as 'habitat linkages', which we define here as naturally discrete areas that provide habitat for a subset of local species and a linkage between habitat patches for mobile species with larger home ranges. The size and habitat suitability of linkages will determine their usage because what constitutes habitat for one species may only ever provide a movement conduit for others. This suggests caution in assuming that linkages will work for all species in all locations and their value may in fact be site and species specific. Therefore,

Table 1. Criteria for the selection of planting stock

Selection criteria	Justification	Donaghy's example
Target species food plants	Provide food resources to sustain dispersing juveniles (especially arboreal folivores) Provide food resources to attract frugivorous seed dispersers	Rhamnaceae, Lauraceae, Myrtaceae, Rutaceae Ficus spp, Lauraceae, Euphorbiaceae, Elaeocarpaceae, Araliaceae
Rapid provision of perches, flowers and fruits	Encourage seed-dispersing wildlife Encourage early colonisation	Pioneers eg. Bleeding Heart (*Homalanthus novo-guineensis*), Sarsparilla (Alphitonia whitei) Species producing good nectar resources at early age e.g. Weeping Bottlebrush (*Melaleuca viminalis*)
Contribution to structural complexity	Even aged plantings of limited life forms lack structural complexity and are less likely to produce levels of mortality required to promote natural disturbance	Fast growing, short lived pioneers eg. Bleeding Heart, Sarsaparilla Vines e.g. *Faradaya splendida* for extra structural complexity
Provide a year round supply of fruit resources	Sustain within linkage populations Encourage 'lean time' visits from seed dispersers	*Ficus* spp.
Niche specialists	Site heterogeneity	Riparian species eg. Water Fig (*Ficus congesta*), Weeping Bottlebrush
Tolerance of open, degraded conditions	Post disturbance condition of lands to be restored	Framework species (Goosem & Tucker 1995) (Group 9)
Families of known importance to frugivorous species	Majority of local rain forest plants are fleshy fruited and require zoochorous dispersal	Lauraceae, Elaeocarpaceae, Euphorbiaceae, Moraceae, Myrtaceae, Sapindaceae
Large fruited taxa	Loss of key dispersers from small fragments Inability of most species to germinate and persist in degraded areas	Water Gum (*Syzygium gustavioides*), Bumpy Satinash (*S. cormiflorum*)
Rare / Threatened Species	Increases population size Allows study of establishment techniques	Bull Kauri (*Agathis microstachya*), Coorangooloo Quandong (*Elaeocarpus coorangooloo*)

to maximise the functional value of the linkage area available for restoration, significant pre-planning was undertaken (Tucker 2000a). This included the establishment of a carefully chosen range of plants (Table 1), and a range of other strategies, to ensure that organisms with varying habitat needs could be accommodated to the greatest possible extent.

Planning the Linkage and the Monitoring

Queensland Parks and Wildlife (QPW), which manages both Lake Barrine and Wooroonooran for conservation purposes, operates the QPW Restoration Services unit based at Lake Eacham. This unit planned and implemented the restoration and monitoring components of the project in collaboration with the project's key partner (Trees for the Evelyn and Atherton Tablelands, TREAT Inc.). Other project stakeholders included the Eggers and Morgan families, whose properties are within the restored area, the Wet Tropics Management Authority who assisted with funding, and a number of other groups including researchers from James Cook University, Qld University of Technology, Griffith University and the University of Queensland. TREAT members and community volunteers were responsible for all the plant production and maintenance tasks and established all plant stock in the linkage area. TREAT volunteers also assisted QPW staff with field monitoring tasks (see Tables 2,3).

Monitoring design and baseline sampling

At the outset, it was decided that the project should be monitored. Monitoring was based around the development of a framework of adaptive management to inform the project specifically, rather than hypothesis testing. The monitoring program sought to observe and document any changes taking place within the linkage, and to ascertain whether these changes were beneficial within the local landscape context. Monitoring was undertaken by QPW staff with assistance from specialist research institutions as required. Full details of the monitoring design are detailed in Tucker (2000b).

For the baseline monitoring, all native and exotic plants occurring within the area to be restored were identified to species level prior to the commencement of works and the position of individual trees and clumps was mapped (Box 3, Fig. 7). Survey showed a diverse group of species from a range of life forms and successional stages, although the 1943 aerial photograph (see Fig. 2) shows an absence of any native vegetation along the creek, indicating that this native vegetation had regenerated since that time. The establishment of transects to capture baseline conditions prior to any natural recruitment was delayed till immediately after the planting also capture baseline planting data.

Mammmal surveys were undertaken at the commencement of the project to examine the potential effects of the restoration works on small terrestrial animals using Elliot traps (aluminium small mammal traps) and cage traps to sample the pasture and riparian zone habitats to be replanted. Trapping grids were placed at 200 m intervals along the strip using the design described in the 'Post-planting monitoring' section (although pit traps were not used prior to planting). Within the proposed linkage area, baseline sampling indicated one rain forest mammal species present at commencement, the Fawn-footed Melomys (*Melomys cervinipes*). Individuals of this species were trapped in a small patch of regrowth vegetation located between the 1995 and 1998 planting blocks (Fig. 7).

Other small mammal surveys had been carried out in the area by Laurance (1994), Campbell (1995), and Laurance and Laurance (1996), so the mammal fauna were well known. Furthermore, Campbell (1995) had shown that 60 years of isolation meant some small mammal species from Lake Barrine had decreased genetic variability and could be genetically distinguished from the adjacent Gadgarra population. This provided a unique opportunity to use these species for monitoring purposes. Using a genetic approach, it was theoretically possible to document movement through the linkage and potentially to show interbreeding between two anthropogenically divided populations.

The planting and Other Actions

The restoration works were based on accepted ecological principles and practical experience accumulated over years of ecological restoration in the local area (Goosem & Tucker 1995). This practical experience allowed QPW and its partners to use well-tested techniques and standards to plan and implement the project. In addition to ecological restoration works, the project required the construction of hardened creek crossings and installation of pipes and pumps for an off-stream watering system, works also performed by QPW. Over the 4 years of the project, around 20 000 plants from 103 species were planted in the 16 ha area within the linkage. A three-row windbreak of Hoop Pine (*Araucaria cunninghamiana*) was established on either side of the linkage to reduce some of the edge effects. Species selection reflected a range of different criteria, as outlined in Table 1.

All plants were matched to any known microsite preferences. In this case, reflecting species were suitable for riparian (creek-side) habitats and more exposed habitats along the outside (fenced) edge, where selection favoured those that resist weed invasion and provide extra shade. Plants were propagated in a sterile nursery facility and planting stock was required to meet a range of quality standards. Applying high standards to plant stock helped contribute to the 95% success rate for overall plant

Box 2. Involving the community

Community tree planting days resulted in a huge volunteer effort (Table 2). Many stakeholders also contributed to project success (Table 3). Incorporation of all stakeholder knowledge and aspirations, as well as the massive level of commitment shown by agency staff, community groups, landholders and over 400 community volunteers was integral.

Community and stakeholder involvement. A diverse cross-section of volunteers and stakeholders attended community tree planting days (Figs 5,6), providing opportunities for knowledge sharing, and building a framework for future project co-operation. Local iconic species such as the Cassowary (*Casuarius casuarius johnsonii*) were highlighted during community engagement activities, increasing support for habitat and linkage restoration on private lands.

In 1995 volunteers assisted with the hole digging, tree placement and planting. In later years, time and physical exhaustion were avoided by digging holes earlier and trees were placed by specialist staff to maintain heterogeneity.

Community groups. The involvement of local community group Trees for the Evelyn and Atherton Tablelands (TREAT Inc) was pivotal to the success of this project. Established in 1982, TREAT now has over 500 members. TREAT volunteers help propagate and raise native plants through an arrangement with Queensland Parks and Wildlife. Volunteers plant trees as well as design and manage projects, including wildlife monitoring. TREAT co-ordinates school based programs and works with landowners, government and non-government departments and local communities.

Table 2. Volunteer efforts summarised

Year	Number of volunteers	Hours of planting	Total volunteer hours	Number of plants
1995	150	7	1050	4800
1996	150	3	450	5000
1997	125	2.5	313	3155
1998	200	2.5	500	5000
Total		15	2313	17 955

Figure 5. Volunteers of all ages and abilities lent time and skills on planting days.

Figure 6. Community volunteers work together to plant out the 1998 section of Donaghy's Corridor.

Table 3. Stakeholder contributions

Stakeholder	Involvement
Trees for the Evelyn and Atherton Tablelands Inc. (TREAT)	Technical support, plant production, tree planting and monitoring assistance
Queensland Parks and Wildlife: Restoration Services	Technical support, project management, plant supply, preparation, maintenance and site monitoring
Tablelands Regional Council Revegetation Unit	Technical support, site supervision and contract labour
Malanda and Upper Johnstone Landcare Group	Organisational support and coordination
Department of Primary Industries and Forestry	Technical support and labour
UCLA Berkeley Griffith University James Cook University	Monitoring and technical support
Land Holders (Donaghy, Eggers, Morgan families)	Provision of planting sites, assistance with planting and maintenance, covenant agreements
Dugulbara Yidinji	Project endorsement
Wet Tropics Management Authority	Provision of funding, assistance with community engagement
Community	Volunteer tree planters, site preparation

Box 3. Planting strategy

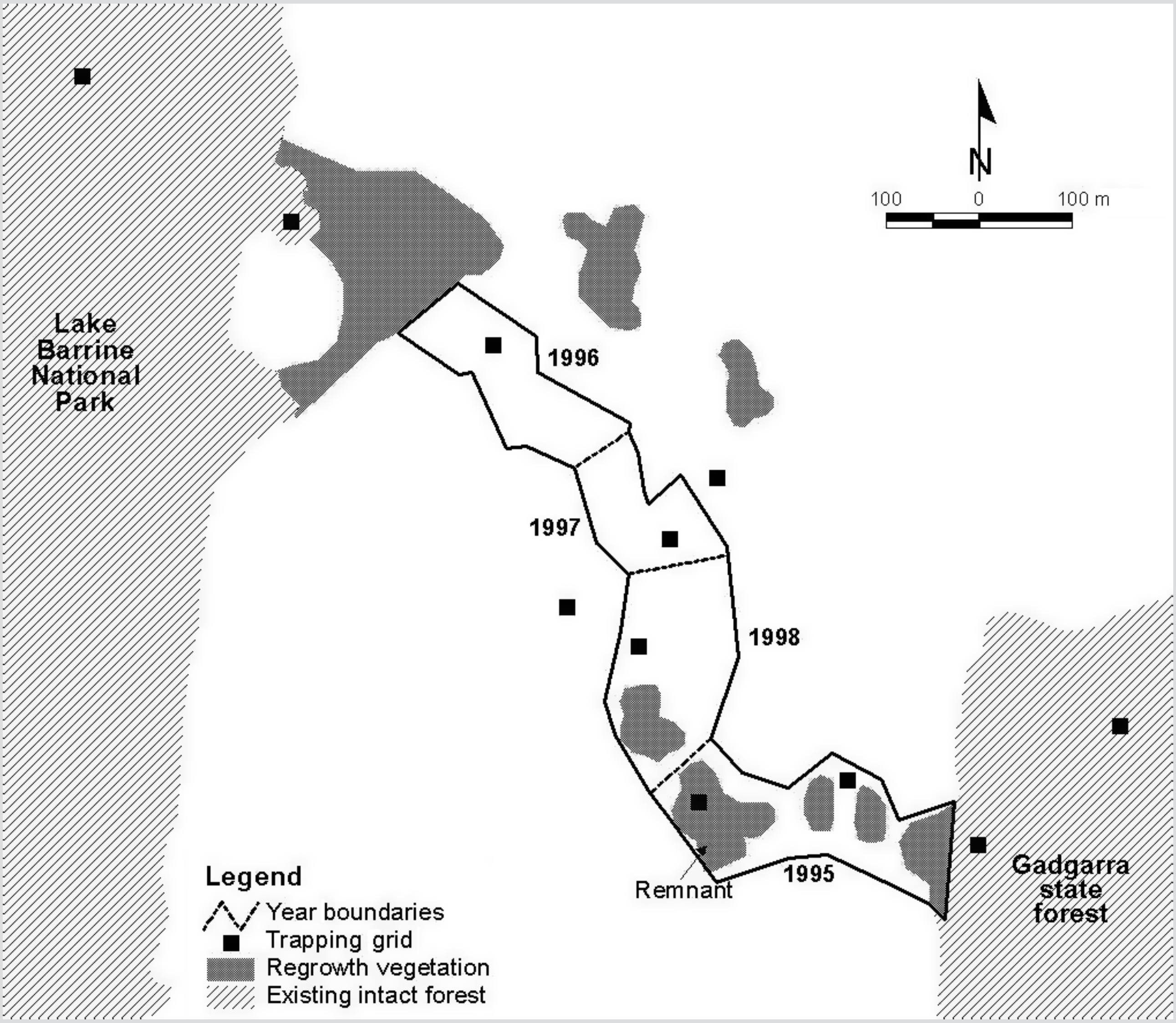

Figure 7. Donaghy's Linkage was divided into four sections to be planted with native tree species. Planting began in 1995 at the eastern end adjoining Gadgarra, to protect existing habitat located in remnants, before establishing new habitat throughout the linkage.

The creek banks were covered by three species of exotic pasture grass: Guinea Grass (*Megathyrsus maximus*), Signal Grass (*Urochloa decumbens*) and Setaria (*Setaria pumila*); while Para Grass (Urochloa mutica) was present in permanently wet areas. Woody weeds including Lantana (*Lantana camara*) and Tobacco Bush (*Solanum mauritianum*) were also present. Cattle activity had led to deterioration of stream banks at watering points, compaction under shade trees (preventing seedling recruitment) and gully erosion, especially along cattle trails.

Weeds present one of the greatest challenges for restoration. Initial site preparation aims to reduce weeds, with ongoing maintenance then focusing on active weed control until a canopy has developed, decreasing the competitive ability of most weeds (Goosem & Tucker 1995). Spraying is preferred over mowing as it more adequately combats competing grasses (whose root grass is only encouraged by mowing) and reduces possible tree damage from trimming too close (Goosem & Tucker).

Table 4. Description of sites and activities for each planting year in Donaghy's Linkage

Year	Site description	Preparation	Planting day	Maintenance
1995	Eastern end, adjoining Gadgarra SF (intact forest) Four exotic pasture grasses & woody weeds Some remnants Soil compacted, no recruitment under remnants	Weeds blanket sprayed twice, approximately 8 and 2 weeks prior Permanent vehicle access installed Anti-foul stock drinking access created Logs placed in gullies and randomly 400 holes dug with augurs at 1.7 m spacing	Plants placed in blocks of 400–500 near planting area Remaining holes dug Volunteers dig out undersize holes 4800 plants established by 150 volunteers Watered in with petrol driven pump All plants fertilised	Follow-up watering 2 days after planting Exclusion fencing installed 95% survival rate Fertilised three times, 4 and 8 weeks after planting and before December monsoons Weeds controlled with glyphosate every 8–10 weeks for 18 months
1996	Western end, adjoining regrowth at Lake Barrine NP Four exotic pasture grasses Intense cattle pressure on steep creek banks	Weeds blanket sprayed twice, as in 1995 Permanent vehicle and stock access installed Logs placed in gullies and randomly All holes dug in two days prior to planting Plants distributed by specialists on morning of planting	5000 plants established by 150 volunteers 10 L of water to each plant, by bucket from Toohey Creek All plants fertilised	Exclusion fencing installed No follow-up water >98% survival rate Fertilised three times; 4 and 8 weeks after planting, and prior to December monsoons Weeds controlled with glyphosate every 8–10 weeks for 18 months
1997	Western middle, adjoining 1996 planting area Four exotic pasture grasses Very few remnant trees	Weeds blanket sprayed twice, as in 1995 Soil ripped to 300 mm with dozer to loosen Logs placed in two eroding channels and randomly across area to plant All holes dug in three days prior to planting Plants distributed by specialists	3155 plants established by 125 volunteers All plants fertilised Mulch from 10 hay bales spread around each stem All watered in on the day	Exclusion fencing installed No follow-up water Survival rate approx 98% Three rows of Hoop Pine (Araucaria cunninghamiana) windbreak planted Fertilised three times; 4 and 8 weeks after planting, and prior to December monsoons Weeds controlled with glyphosate every 8–10 weeks for 18 months
1998	Eastern middle, adjoining 1995 planting area Encompassing farm dam Dam surface covered with Para Grass	Weeds blanket sprayed twice, as in 1995 Cattle entirely excluded from dam and surrounds Excavating reduced Para Grass to one patch covering 15% and deepened southern edge of dam Excavated material spread over adjacent area then ripped with dozer Second water pump installed for stock water Logs placed in gullies and randomly All holes dug in three days prior to planting Plants distributed by specialists	5000 plants established by 200 volunteers 14 bales of hay used to mulch stems Watered in on the day from pump All plants fertilised	Exclusion fencing installed Supplementary watering during week after planting 98% survival rate Fertilised three times, 4 and 8 weeks after planting, and prior to December monsoons Weeds controlled with glyphosate every 8–10 weeks for 18 months

establishment, which was monitored during the first 30 days.

Prior to each yearly planting, the area for treatment was permanently fenced to exclude stock and all exotic plants (mainly pasture grasses) were blanket sprayed with a non-residual herbicide. Salvaged logs and rocks piles were randomly placed through the planting to provide a subset of structural habitat components more rapidly. Permanent, fenced creek crossings were established over Toohey Creek to allow the landholder to access lands on either side of the creek and to exclude stock from all parts of the stream and its banks. Planting was undertaken in the final week of

January in each planting year when wet season rains are reliable. Table 4 provides a summary of the planting and maintenance within each yearly block.

Post-planting Monitoring

Vegetation sampling

At the completion of planting, three transects were established in each of the 4-year blocks (12 transects in total). Transect locations were chosen to reflect the diversity of slope and aspect in each block, but were positioned randomly to avoid biasing information collected. Each transect commences at one fence-line, crosses Toohey Creek and continues to the opposite fence-line. Transects were 3-m wide and were pegged at 5-m intervals from fence edge to creek edge, giving a total of 180 sub-plots, covering 2700 m^2 (<2% of the total linkage area).

Vegetation surveys were conducted twice yearly for 3 years (total six censuses). During surveys, all vascular and non-vascular plants regenerating within each 5-m × 3-m plot were identified to species level and counted.

Data relating to bare soil, weed and litter cover were concurrently collected and evaluated for each plot using the Braun Blanquet Cover Abundance Scale where; >75% cover = 5, 50%–75% = 4, 25%–50% = 3, 5%–25% = 2, <5% = 1, + = a few scattered individuals, and r = rare or absent. Foliage Projective Cover (FPC) of existing/planted stems was assessed using a grading scale of: 0 = nil cover, <5% = 1, 5–25% = 2, 25–50% = 3, 50–75% = 4 and >75% = 5. No plant growth data were collected.

Seedling density per square metre was calculated for each 5 × 3-m subplot in each transect, at the completion of each census. Mean densities from north (3) and south (3) side transects were then combined to provide an overall measure of seedling density, in each year's planting (Fig. 12).

Plant nomenclature follows Census of Queensland Flora (Bostock & Holland 2007).

Mammal sampling

The small mammal trapping programme commenced immediately after the linkage was completed in 1998 and continued from that year until 2000. Trapping grids (30 m × 30 m squares) were established in the linkage (five grids), in the forests at either end (four grids; two at the edge and two in undisturbed forest, 'core' sites) and in the pasture adjacent to the linkage (two grids) (Fig. 7). The two pasture grids were established to ascertain whether any rain forest mammals utilised this habitat. Each grid consisted of 20-Elliot box traps and four (larger) wire cage traps. Traps were baited with a mixture of rolled oats, honey, peanut paste and vanilla essence, and all traps were wrapped in a plastic bag, to avoid climatic extremes. Nesting material was provided for species entering cage traps.

All mammal captures were identified, weighed, sexed, assessed for breeding condition and ear-tagged with a numerical tag. All animals were released at point of capture. While every effort was made to distinguish between two almost identical rodents, the Bush Rat (*Rattus fuscipes*) and the Cape York Rat (*R. leucopus*), some misidentification did occur, although confusion was resolved using *post-hoc* genetic analysis. Genetic analysis indicated identification was correct for *R. fuscipes* in 96% of cases, but only 54% of *R. leucopus* individuals were correctly identified. A limited number (4%) of Grassland Melomys (*Melomys burtoni*) and Fawn-footed Melomys were confused, but were also resolved by genetic analysis. A small fragment of ear tissue was taken from each animal captured for genetic analysis (Paetkau *et al.* 2009) and stored in ethanol.

Pit traps (reptile and invertebrate trapping)

Inside each trapping grid, two pit traps were established using sealable 20-litre plastic buckets with holes drilled for drainage. A 10-metre long drift-line fence (300 mm high) was erected to steer any fauna over each pit. Nest material was provided in each bucket. Pit traps were used to detect reptiles and a number of invertebrates were also recorded in these pits.

All traps were cleared between 600 h and 1030 h each day. Vertebrate captures were identified to species level and released at point of capture. Invertebrates were identified to order or family level only and were also released at point of capture. All trapping was conducted for three nights, every 3 months over 3 years, for a total of 10 010 trap nights (poor weather precluded one autumn trapping round).

Evaluating Outcomes

Vegetation

A total of 4472 native seedlings regenerated naturally within transects during the 3 years of the study. These represented 48 families, 99 genera and 119 species. Eleven seedlings could not be identified to species level. Of the 119 species regenerating in the corridor, 35 were known not to have been planted or to occur within the extant linkage or paddock vegetation prior to the project commencing. Therefore, they were assumed to have been dispersed from the forests at either end of the linkage.

The 10 most common species accounted for 60% of the total seedling pool. Around 20% of species recruited were represented by only one individual and 47% were represented by less than five individuals. Given that the sampled area represented <2% of the total area restored, there appears to have been a very large number of seeds that have been dispersed into

Box 4. Seed dispersal in a restored habitat linkage

Seed dispersal into a newly established linkage is limited by distance from seed resources as well as dispersal vectors. Discrete seed types rely on different dispersal methods, including wind, water, gravity and animal.

Being big. Large seeds (Fig. 8), >30 mm in diameter including fruit circumference, are predominately gravity or animal dispersed. Their size generally restricts animal dispersers to larger bodied, vertebrate species with a large gape width, which excrete viable seed (Stiles 1992). The specialist nature of dispersal method is compounded by the fact that the numbers of many large-bodied dispersers in Australian tropical forests are dwindling, with some listed as vulnerable/endangered.

Figure 8. Atherton Oak (Athertonia diversifolia) fruit on the left and Bumpy Satinash (Syzygium cormiflorum) on the right are both large fruited species that were found among natural recruits in Donaghy's Linkage.

The general physiological and behavioural traits of these species cause the majority to be heavily impacted by fragmentation, restricting their ability to function as large seed dispersers in a fragmented rain forest ecosystem.

Recruiting seeds. In the rain forests of north Queensland large seeds are almost exclusively dispersed by a small number of keystone species, particularly the Southern Cassowary (*Casuarius casuarius johnsonii*), Musky–rat Kangaroo (*Hypsiprimnodon moschatus*) and the Spectacled Flying-Fox (*Pteropus conspicillatus*). Recruitment of large seeded species into a restored area provides an indication that one or more of these animals have utilised the linkage. Taking advantage of fast growing, early fruiting tree species in a restoration planting (Fig. 9) entices animals quickly, accelerates natural recruitment and in turn builds complexity of life forms, increasing the habitat suitability of the site.

Figure 9. Figs, such as the Hairy Fig (Ficus hispida) shown here, bear fruit for much of the year providing food resources for many frugivores. They are eaten by keystone species including the Cassowary and other seed-dispersing birds.

Donaghy's Linkage. Vegetation surveys revealed a dominance of small seeded, primarily bird dispersed species (Figs 10,11). Size classes including fruit circumference, as follows: Small, 30–10 mm; Intermediate, 10–30 mm; Large, >30 mm; and Other, wind/water dispersed. Large fruits were represented by only five species, *Athertonia diversifolia*, *Castanospora alphandii*, *Cerbera inflata*, *Pouteria castanosperma* and *Syzygium cormiflorum*, as summarised in Table 5.

Table 5. Large fruited species represented in natural seedling recruitment at Donaghy's (Table information sourced from Cooper & Cooper 2004)

Scientific name	Common name	Average size	Fruit/seed characteristics	Dispersal vector/s
Athertonia diversifolia	Atherton Oak	36 mm	Drupe; Thin blue or purple flesh over 1 seed with woody endocarp	Musky-rat Kangaroo White-tailed Rat Fawn-footed Melomys
Castanospora alphandii	Brown Tamarind	27 × 45 mm	Berry; pink-brown or red, velvety/hairy cover enclosing 1–2 seeds	Cassowary Musky-rat Kangaroo Spectacled Flying Fox
Cerbera inflata	Cassowary Plum	65 × 28 mm	Drupe; blue/purple thin flesh over fibrous woody endocarp enclosing 1–2 seeds	Cassowary Spectacled Flying Fox
Pouteria castanosperma	Yellow Plum or Milky Plum	56 × 45 mm	Drupe; purple or blackish enclosing 1–3 red-brown woody seeds	Bush Rat Giant White-tailed Rat Spectacled Flying Fox
Syzygium cormiflorum	Bumpy Satinash	50 mm	Berry; white, cream, pink or reddish-pink flesh enclosing 1–2 seeds	Cassowary Spectacled Flying Fox

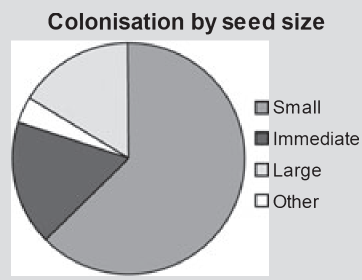

Figure 10. Proportion of each fruit size among natural recruits.

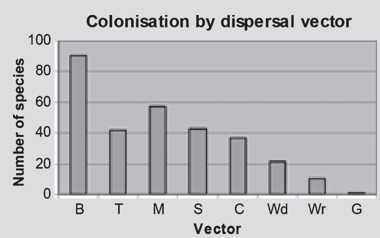

Figure 11. Proportion of naturally regenerating species utilising different dispersal vectors, where B, Bird; C, Insect; G, Gravity; M, Mammal; S, Cassowary; T, Bat; Wd, Wind; and Wr, Water.

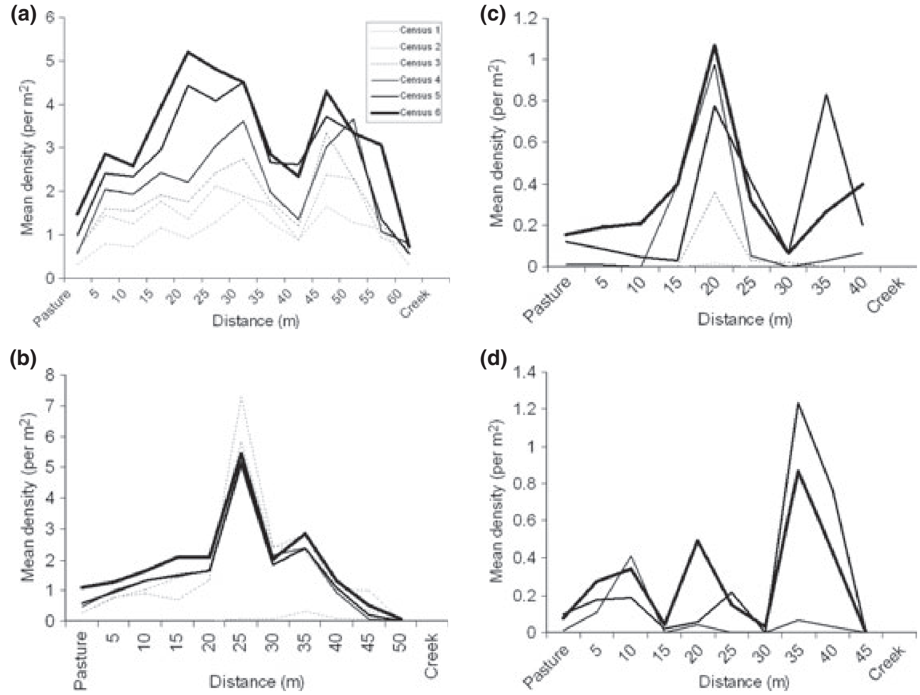

Figure 12. Mean density of naturally regenerating seedlings over time in each planted section of Donaghy's habitat linkage, (a) 1995, (b) 1996, (c) 1997 and (d) 1998. Note that no recruitment was observed in the 1998 section until census 4.

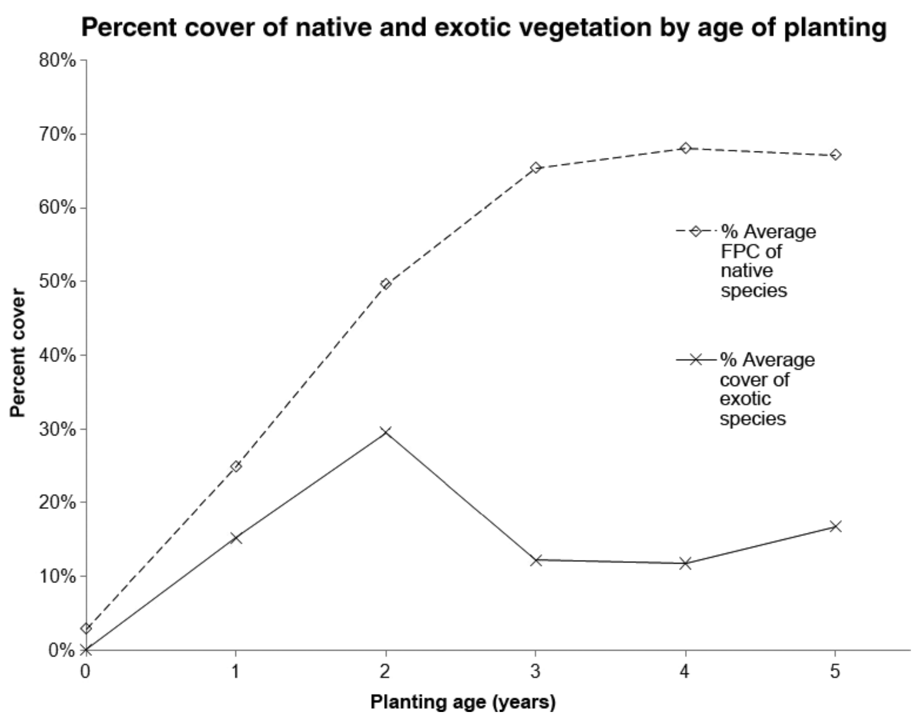

Figure 13. The relationship between increasing Foliage Projective Cover and decreasing weed cover is evident over time. By year 3, exotic species have been almost completely excluded.

the plantings. Newly recruited species were from differing successional stages and a variety of life forms including canopy/sub-canopy trees, vines and lianas, gingers, ferns, scramblers and grasses of the ground stratum (Figs 10, 11, Box 4).

The most diverse plots were located in a 1995 transect where 192 individuals of 30 species were present in one 15-m^2 plot. It is likely that only eight or ten plants would originally have been planted in this sized area. At the final census in 2000, 18 of the 19 sub-plots plots still not colonised by any native plants (around 10% of sub-plots) were in the 1997 (8) and 1998 (10) transects.

Edge effects

The influence of edge on the mean density of plants establishing as seedlings over the six census periods is shown in Fig. 12a–d. These show the increased abundance of regenerating seedlings in the central portions of the plantings and reduced numbers of seedlings along the margins. Maintenance is likely to be required along the margins of plantings such as Donaghy's to ensure that weed competition does not impede regeneration. More information on the nature of colonising vegetation is provided in Box 3.

Age effects

The oldest plantings show evidence of a general trend towards increasing plant density with age (Fig. 12). The trend was generally positive in the 1996/97/98 plantings; however, there are clearly large fluctuations indicative perhaps of fluxes in microclimate and the effect of plot maintenance. Canopy closure was achieved in the 1998 plot in late 1999 (around two years of age) and this is reflected in increased recruitment density after this time, i.e. after censuses five and six. The relationship between weed cover and increasing Foliage Projective Cover of planted stems is shown in Fig. 13.

Table 6. Range of Species captured, depicted by life form location and number of times captured

Species name	Common name	Animal type	ON	OS	BC	BE	96	97	98	R	95	GE	GC
Antechinus flavipes	Yellow-footed Antechinus	Mammal			3		1		1			1	
Antechinus stewarti	-	Mammal										4	4
Hypsiprymnodon moschatus	Musky Rat-kangaroo	Mammal											4
Isoodon macrourus	Northern Brown bandicoot	Mammal				1	1			1	4		
Melomys burtoni	Grassland Melomys	Mammal	42	19			2	6	32	6	15		
Melomys cervinipes	Fawn-footed Melomys	Mammal			27	36	26	6	3	82	74	54	44
Mus musculus	House Mouse	Mammal	3	44			4	16	25	3	4		
Perameles nasuta	Long-nosed Bandicoot	Mammal			3	1	4	4	4		1	5	
Rattus fuscipes	Bush Rat	Mammal			46	35	6	7	7	12	8	41	65
Rattus leucopus	Cape York Rat	Mammal			27	26	5	2	3	1		1	6
Rattus lutreolus lacus	Swamp Rat	Mammal									1		
Rattus sordidus	Canefield Rat	Mammal	16	1				9	5	1	1		
Uromys caudimaculatus	Giant White-tailed Rat	Mammal			8	7	4	2	1	6	6		2
Ailuroedus melanotis	Spotted Cat Bird	Bird						2		1	1		
Alectura lathami	Australian Brush Turkey	Bird					3						
Climacteris affinis	White-browed Treecreeper	Bird											1
Cracticus nigrogularis	Pied Butcherbird	Bird		2					1				1
Dicrurus bracteatus	Spangled Drongo	Bird											1
Grallina cyanoleuca	Magpie-lark	Bird		3					1				
Gymnhorhyna tibicens	Australian Magpie	Bird		2									
Heteromyias cinereifrons	Grey-headed Robin	Bird			1					1		2	
Psophodes olivaceus	Eastern Whipbird	Bird								1			
Rallus philippensis	Buff-banded Rail	Bird						4			1		
Synoicus australis	Brown Quail	Bird						6					
Bufo marinus	Cane Toad	Amphibian	15	44		2	6	8	9	14	8	2	
Limnodynastes peroni	Brown-striped Frog	Amphibian					1			2	3	2	3
Litoria lesueuri	Stony-creek Frog	Amphibian					1						
Litoria rubella	Little Red Frog	Amphibian						2					
Cacophis churchilli	Northern dwarf crowned Snake	Reptile											1
Carlia rubrigularis	Northern Red-throated Skink	Reptile					5	1		4	3		1
Glaphyromorphus fuscicaudis	Grey-tailed skink	Reptile			1	1						1	
Gnepitoscincus queenslandiae	Prickly Forest skink	Reptile			4							7	14
Hypsilurus boydii	Boyd's Forest Dragon	Reptile			3	1							3
Phyllurus cornutus	Northern Leaf-Tailed Gecko	Reptile			2	1						2	
Physignathus lesueurii	Eastern Water Dragon	Reptile					1			3	1		
Ramphotyphlops sp.	Blind Snake	Reptile								2		1	
Saproscincus basiliscus	Basal Shade Skink	Reptile								4			
Saproscincus tetradactylus	4-toed Shade Skink	Reptile				1				1	1	1	
Varanus varanus	Lace Monitor	Reptile											2
Acrididae	Grasshopper	Invertebrate		2	1				1				
Blaberidae	Bush Cockroach	Invertebrate						1					
Carabidae	Ground Beetle	Invertebrate						2				1	
Diplopoda	Millipede	Invertebrate					1			2			
Gryllidae	True Cricket	Invertebrate					1						2
Lycosa sp.	Wolf Spider	Invertebrate		2									
Penalva flavocalceata	White-kneed King Cricket	Invertebrate			6	6	9				1	21	16

95, 1995 planting; 96, 1996 planting; 97, 1997 planting; 98, 1998 planting; BC, Lake Barrine Core; BE, Lake Barrine Edge; GC, Gadgarra Core; GE, Gadgarra Edge; R, Existing Remnant.

Fauna

A total of 46 fauna species were recorded during the study (Table 6). Species recorded from pasture grids were never trapped within core forest sites and vice versa. Although there were only two grids in the pasture, no reptiles were ever recorded from pasture sites and an almost identical trend was evident for invertebrates.

Mammals

Twelve species of mammals were trapped over the 3-year period, within the 11 trapping grids (Table 6). There were differences between the fauna trapped within the restoration areas, the open pasture habitats and the core sites, and these differences (described below) reflect the degree of habitat specialisation attributable to each species and the habitat suitability of linkage vegetation.

Three species associated with rain forest habitats and their adjacent areas only (Crome *et al.* 1994) were trapped in the restoration area. The Bush Rat and the Cape York Rat were relatively common, although numbers trapped fluctuated markedly over the course of the study. The Fawn-footed Melomys was the most frequently trapped small mammal (46% of total captures) and the only rain forest species captured in the linkage area prior to restoration works. At this location, this species appears to be the most tolerant of forest fragmentation, rapidly moving into the restored area with population densities increasing substantially before stabilising.

The Musky Rat–Kangaroo was only trapped four times and only in the Gadgarra core forest grid, despite its presence within Barrine. House Mouse (*Mus musculus*) was the only non-native mammal recorded and were only trapped within restoration areas and open pasture grids. The native grassland rodents, the Grassland Melomys and the Canefield Rat (*Rattus sordidus*) were initially abundant within the linkage and although their numbers declined in the linkage over time, they were consistently trapped within pasture grids. No rain forest species were ever recorded within the two open pasture grids. This may perhaps be attributed to their avoidance of this habitat and/or the proportionately lower numbers of trapping grids in this habitat.

The Swamp Rat (*Rattus lutreolus lacus*), an endemic grassland specialist, was captured only once during the survey period, although the species was trapped in the linkage during baseline sampling at a point very close to the survey capture record.

Small mammal movement

A number of small mammal movement records were generated from mark recapture data (Fig. 14). Movements were over small distances, although one male Fawn-footed Melomys travelled 550 m from the Gadgarra core grid to the 1995 grid. However, this and all the other movements shown in Fig. 14 are within-linkage movements and mark recapture data did not detect any movement through the linkage from one end to another. However, mark recapture data suggests that in time, some species of fauna derived from each end of the linkage are likely to interact and breed, potentially linking populations genetically isolated by human induced disturbance and providing further evidence of the value of the linkage.

A genetic study was conducted in parallel with the mark recapture study described above, which detected a total of 16 movements from one end of the linkage to the opposite end and captured what may have been F1 hybrid *R. fuscipes* within the linkage in the final round of trapping (Paetkau *et al.* 2009). Interestingly, genetic data showed most long distance movements occurred in the 12–24 months immediately after the linkage was completed and afterwards became less frequent. Mark recapture data showed rain forest rodents becoming territorially resident within planted areas after 2 years. These data show that in the early stages of its development the linkage facilitated significant movements in both directions, but as habitat suitability increased, animals began to establish territories and these acted to restrict movements through the linkage.

Reptiles, amphibians and invertebrates

A partly carnivorous scavenger, the White-kneed Giant Cricket (*Penalva flavocalceata*) was recorded from core and edge sites, as well as the 1995 and 1996 grids within the linkage (the two plots proximally closest to edge sites). This endemic species was mostly recorded in pit traps, but individuals were also caught in Elliot traps, reflecting body size. The species is generally known only from forest sites, so its appearance within restored areas suggests increasing habitat suitability. With the exception of Wolf Spiders (*Lycosa sp.*) and grasshoppers from the Acrididae (only associated with grassland habitats), there were no invertebrates recorded in pasture grids.

Grove and Tucker (2000) recorded 18 morphospecies of saproxylic beetles feeding on dead wood placed in the linkage prior to planting. Dead wood was placed immediately prior to planting to provide habitat for vertebrates and invertebrates because this habitat feature takes many years to appear naturally. In addition to the

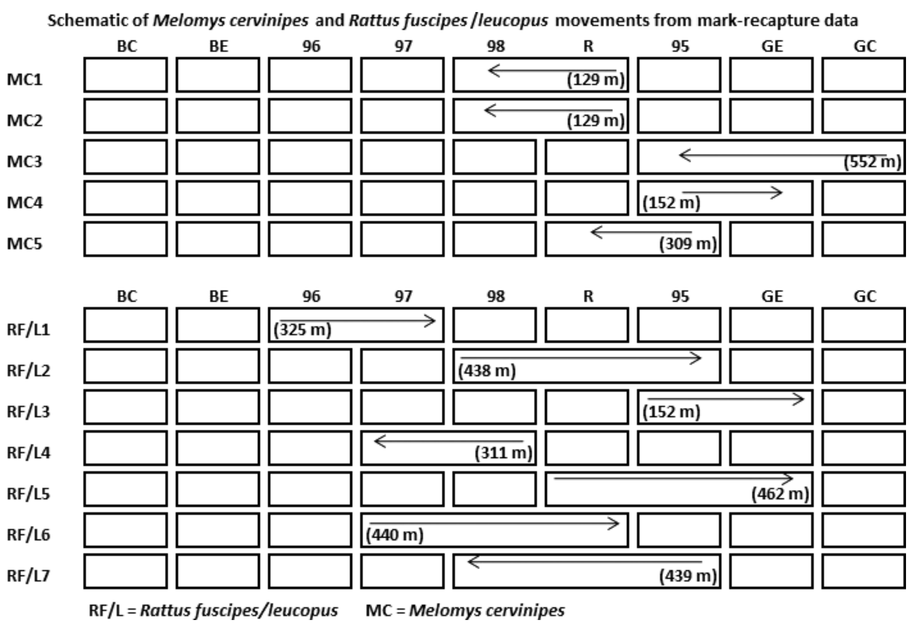

Figure 14. Schematic of small mammal movements between sampling quadrats derived from mark-recapture data. (95, 1995 planting; 96, 1996 planting; 97, 1997 planting; 98, 1998 planting; BC, Lake Barrine Core; BE, Lake Barrine Edge; GC, Gadgarra Core; GE, Gadgarra Edge; R, Existing Remnant).

beetle fauna recorded, samples contained invertebrates from a wide range of other orders.

A variety of litter-dwelling reptiles were trapped in the linkage and there were significant differences between the reptile fauna in the linkage, and in core and edge sites, a similar pattern to that described by Kanowski *et al.* (2006). The exotic Cane Toad (*Bufo marinus*) was consistently pit-trapped in pasture grids, throughout the linkage, and at edge sites, but was never recorded from core sites. This was the only amphibian recorded in pasture habitat and as noted, no reptiles (including land snakes) were ever recorded from the two open pasture sites.

Vegetation and Wildlife Interaction

Changes in mammals with changing vegetation structure

By the time trapping commenced, vegetation was at different stages of development within each yearly block, having significant effect on the diversity and abundance of small mammals over time. A clear relationship exists between the occurrences of the two *Melomys* species in relation to the changing nature of the vegetation structure. From year 1 to year 3, most restored areas contained remnants of the original weedy vegetation and populations of Grassland Melomys persisted in the linkage. By year 3, however, grasses and weeds were almost completely shaded out by the developing plantings and Grassland Melomys had been replaced by the rain forest dwelling Fawn-footed Melomys (Fig. 15). Up until this time, both species were often trapped in the same linkage grid, indicating resources were sufficiently diverse to support these two closely related species.

Dispersal of plants into the linkage

An analysis of the likely vectors of the plant species found that bird dispersal is likely to explain a large proportion of the dispersal and recruitment of rainforest plants into the linkage and shows the value of frugivorous birds in fragmented landscapes (Fig. 11). In a formal study of bird colonisation in the Donaghy's linkage, Jansen (2005) recorded 96 species in 3 years, of which 31 were frugivores. Eight 'rain forest only' species were recorded, along with 29 'mainly rain forest' species, and there was a general trend towards increasing species richness over time. The high proportion of frugivores in Jansen's study is indicative of the guild's diversity in the area, and reflects the dominance of fleshy-fruited and arillate species in the natural regeneration.

The ability of birds to direct the rate and nature of succession through the seed dispersal process is one of the most valuable from a rain forest restoration perspective (Goosem & Tucker 1995; Tucker & Murphy 1997; Wunderle 1997). However, frugivores are also responsible for spreading fleshy-fruited weed species and these species will also colonise if there is a source population close by and conditions within the restoration favour their establishment (Buckley *et al.* 2006; Kanowski *et al.* 2008). The choice of species used in rain forest linkage projects should therefore reflect other framework species attributes (such as weed-suppressing architecture) (Goosem & Tucker 1995), rather than only their attractiveness to vertebrate dispersers. Keystone species such as the figs (*Ficus spp.*) that provide fruit resources outside periods of peak abundance, are also likely to be important to frugivorous dispersers.

Decomposition

Decomposers play critical roles in nutrient cycling and wood-boring beetles assist with nest hollow formation, a critical habitat requirement for many birds, mammals and reptiles. The Grove and Tucker (2000) study showed that the placement of large single logs and log piles immediately

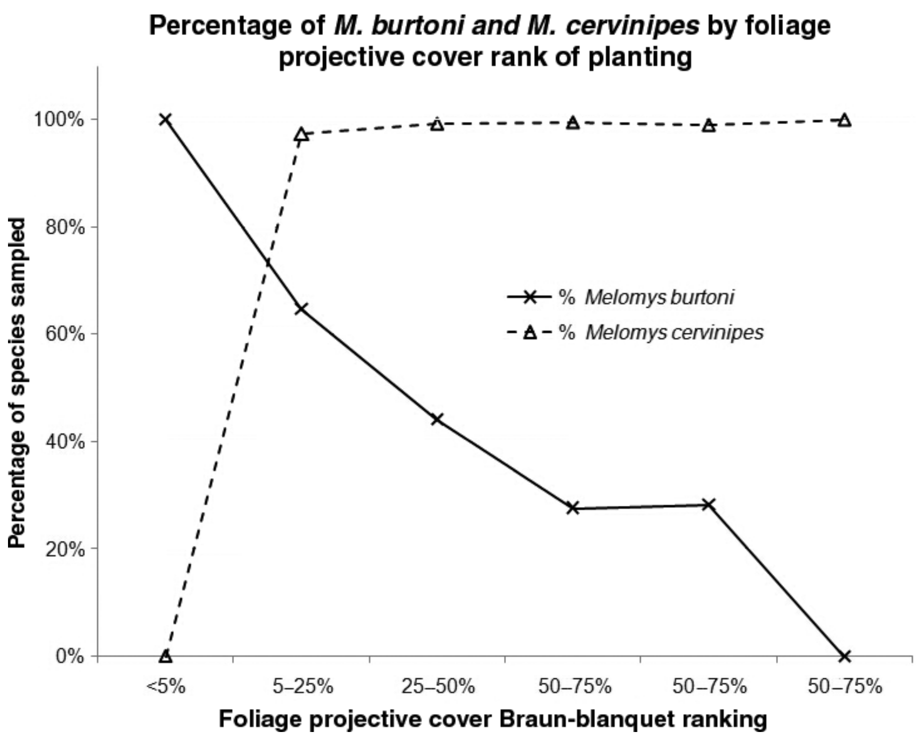

Figure 15. The displacement of Grassland Melomys (Melomys burtoni) by the forest dwelling Fawn-footed Melomys (Melomys cervinipes) is evident as vegetation structure changes to more closely resemble a rain forest ecosystem.

prior to planting appears to have provided habitat for a large number of invertebrates. Most logs had been recently fallen and were unlikely to have been significantly colonised by invertebrates prior to placement. Captured fauna were often observed escaping to these features after release, suggesting such features are also a strategic cover resource for vertebrates.

Pioneer plant species comprised around 25% of the total stems planted in each year, because of their attractiveness to pollinators and seed dispersers as a feeding and perching resource. But pioneers also have the ability to create the disturbance required to generate tree fall gaps and promote species turnover through early mortality, creating dead wood habitat for vertebrate and invertebrate fauna.

Implications of the linkage restoration project

Ecological implications

Re-establishing habitat connectivity has affected dispersal and colonisation within and into the linkage by a variety of life forms. The patterns described above are the result of plants, vertebrates and invertebrates colonising the new niches that have become available. The source of this colonisation is likely to have been a combination of internal radiation from pre-existing populations and an influx of new colonists from the forests at either end. In addition, restoration of a woody native community has resulted in rapid species turnover, as grassland plants and animals are replaced by increasing numbers of species from adjacent rain forest environments. A number of these interactions were established by the end of the third year of plant establishment. This suggests that ongoing maintenance is likely to be an important factor in promoting continued colonisation by rain forest species and such maintenance may be required on a regular basis until weed presence is minor and inconsequential.

At 3 years of age the fauna of the linkage more closely resembled the rain forest edge grids than the adjacent pasture, which previously dominated the area. Although rain forest specialists were not present, there were species more indicative of intact forest beginning to colonise the two ends of the linkage by year three. This 'step-wise' movement would be expected, over time, to result in the re-connection of species populations that had been historically isolated by human-induced disturbance. Only time will demonstrate continued development towards a rain forest structure, if and when rain forest specialists do use linkage habitat, and the effect of this at individual and community levels.

In the discussion of habitat linkages, the danger of assuming a 'one size fits all' approach was highlighted. This article has discussed the process of establishing and monitoring the early effects of linkage restoration at one tropical site, with quite specific spatial habitat configurations. This limitation must be recognised. Differences in the quality and spatial distribution of habitat, within and adjacent to a restored linkage, will influence the rate and nature of plant and animal successions and planning should recognise these differences. For example, linkages that are longer, and traverse a more inhospitable landscape will almost certainly need to be wider, and be comprised of a more diverse species mix.

Social and economic implications

The largest public cost in this linkage was the time investment by QPW staff to implement the project and monitor colonisation. Volunteer labour and donation of the land resulted in direct costs for fencing, stock watering infrastructure and creek crossings only, a total expenditure of <$50 000. There are however, no alternative benchmarks or other intervention techniques (e.g., translocation) against which this cost can be measured.

Aside from the ecological benefits, which have accrued this project as a result of this financial investment, the project also resulted in broader social and environmental outcomes, having stimulated significant interest and increased awareness of the broader ecological connectivity issue in the local community. (See Box 2). It has lead to the establishment of other Atherton Tableland's rain forest linkages (reported on the Society for Ecological Restoration International's Global Restoration Network hub: http://www.globalrestorationnetwork.org/countries/australianew-zealand/australia/) and improved local understanding of the biological outcomes and benefits of ecological connectivity at a range of scales.

In 2001, the Donaghy's Corridor Nature Refuge was declared, placing the linkage area under a perpetual binding-on-title covenant. The Donaghy family were instrumental in this process, emphasising the importance of engaging with landholders in a meaningful way and ensuring landholder contributions and needs are considered. The Nature Refuge agreement is also an appropriate form of covenant to guarantee the public and community investment in such projects.

Take-home message

Fragmentation and isolation are problems facing many tropical and subtropical reserves. Re-instating habitat connectivity can be considered a 'defragmenting' action and at the Donaghy's site, this strategy appears to have been successful for a subset of species. While some caution should be used in interpreting the results for their effectiveness in other situations, monitoring has shown that this habitat linkage has fulfilled both habitat and movement functions for some species. On that basis, the practice of restoring habitat linkages is recommended to land managers and practitioners as a practical measure to assist with managing fragmented landscapes.

Acknowledgements

The authors thank Pete Snodgrass and Nick Stevens and many other QPWS staff for their commitment over the course of the project. Dan Keane and Lana Hepburn assisted with preparation of figures and tables. John Kanowski and one anonymous reviewer provided invaluable comments on a draft of the manuscript. Sue and Bill Laurance identified the gap and deserve the credit for doing so.

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Summary **Donaghy's Corridor is a 1.2 km × 100 m planting of rain forest species on the Atherton Tableland, Queensland, designed to link an isolated fragment (498 ha) to adjacent continuous forest (80 000 ha). Vegetation and fauna monitoring commenced immediately after the linkage was completed. Vegetation surveys showed 119 plant species established in the linkage in 3 years, and 35 of these were not known to occur within the extant linkage either as planted stock or as natural individuals existing prior to project commencement. There were differences between the fauna trapped within the restoration, adjacent open pasture habitats, forest interior sites and forest edge sites. Differences likely reflect variation in species habitat preferences and the habitat suitability of the planted vegetation. Now over 10 years old, Donaghy's Corridor has developed a complex forest structure, with the tallest planted stems exceeding 20 m in height. This feature article provides information about the planning, implementation and monitoring of the linkage, and shows how restoring landscape and ecological connectivity can be a locally effective strategy to counter forest fragmentation.**

Key words: *habitat colonisation, habitat linkage, Queensland, rain forest, restoration.*

