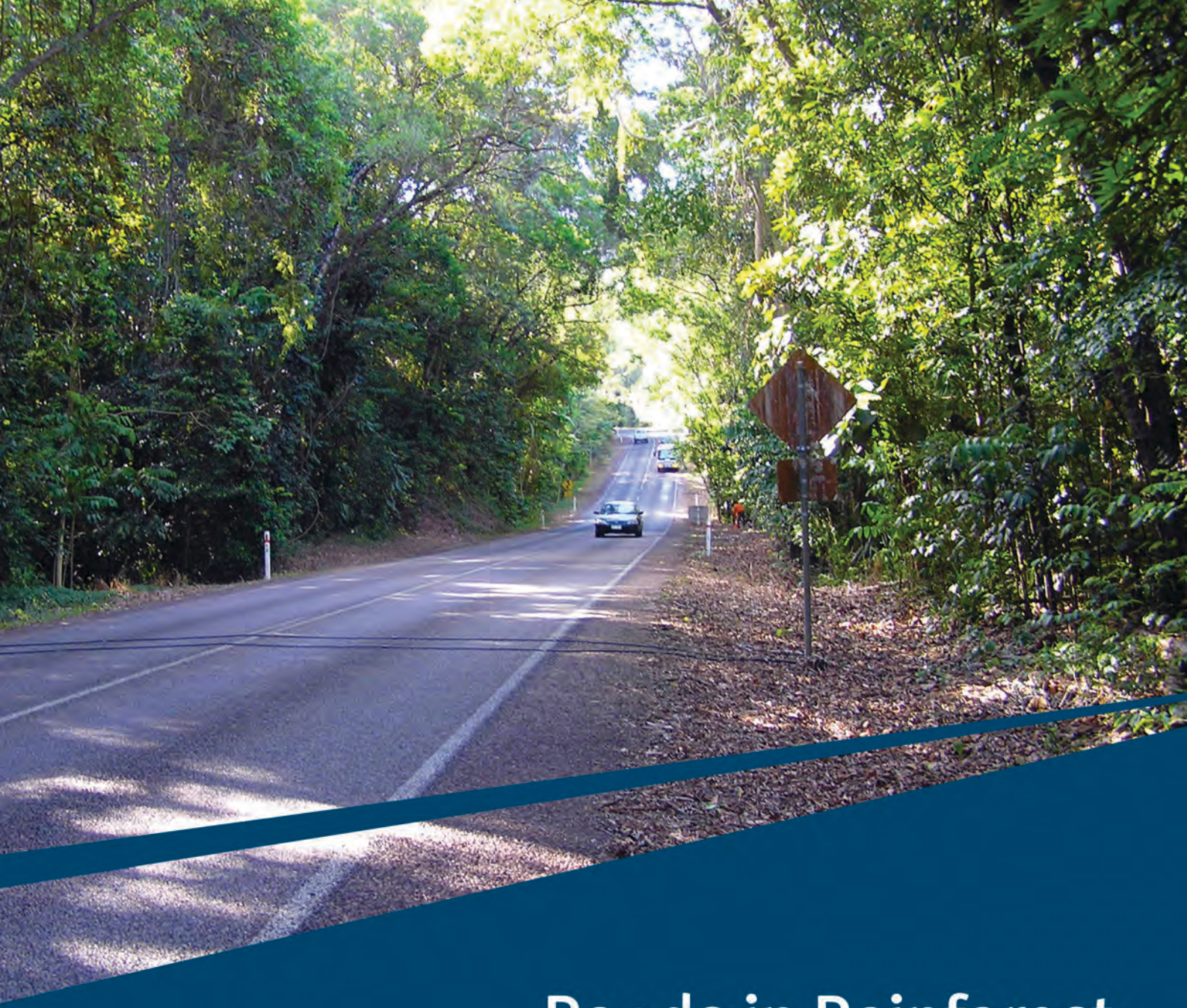


Roads in Rainforest:

Science Behind the Guidelines

M. Goosem, E. K. Harding, G. Chester, N. Tucker and C. Harriss

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Toward Q2 Tomorrow's Queensland

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Introduction

This document summarises scientific findings to date which support the Principles and Guidelines outlined in Part A *Roads in Rainforest: Best Practice Guidelines for planning, design and management* (the Guidelines).

References to Part B (this document) are included throughout the Guidelines and it is recommended that the two documents be read together.

In addition to a comprehensive list of References (page 45) supporting this science background document, further literature is highlighted in 'Further Reading' (page 55) that is relevant to the planning, design and management of roads in the tropical rainforest regions of northern Australia and can provide further information to roads planners, designers and managers.



Photo: Robyn Wilson

1. The Impacts of Roads

In the last few decades a growing awareness of human impacts on our environment and quality of life has forced us to examine all aspects of land use. This includes the variety of ways that the building and use of roads can alter the natural environment.

Roads cover approximately one percent of the United States' land area. Australia has, on a per capita basis, sixty percent greater lengths of roads serving our population than the United States, although the percentage of land area covered is much less (Forman and Alexander 1998).

With respect to road impacts on the functioning of species and their habitats, scientific studies have focused on the following issues:

- Habitat loss and changes in quality;
- Habitat fragmentation and barriers to movement;
- Edge effects and disturbance;
- Road kill (and construction-related mortality);
- Modification of animal behaviour;
- Invasion by weeds, diseases and feral animals;
- Chemical pollutants; and
- Vehicular disturbance.

In addition to these topics, mitigation strategies and revegetation techniques are discussed within this report.

1.1 Habitat Loss and Changes in Habitat Quality

Terrestrial Ecosystems

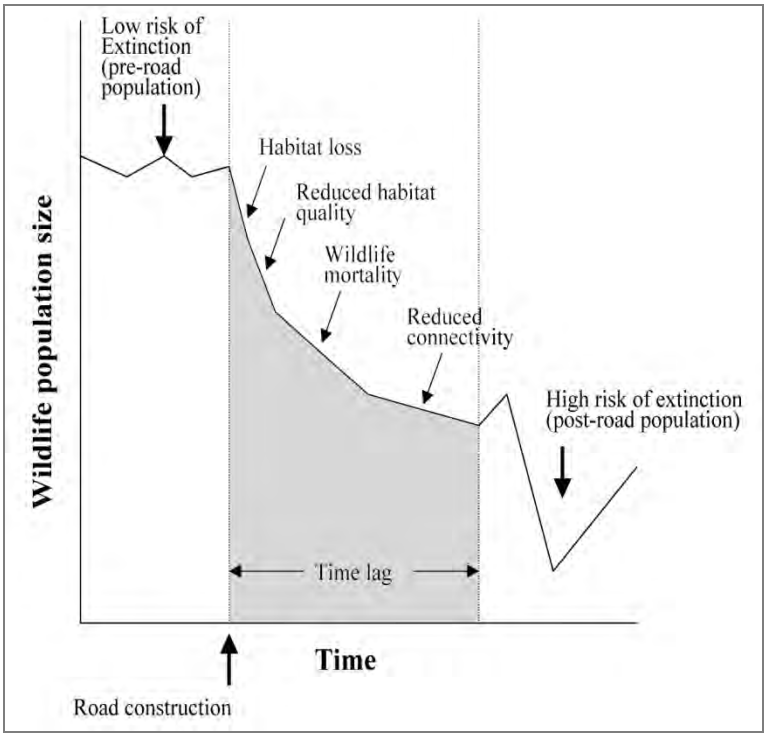
Vegetation clearing associated with road construction can result, either directly or indirectly, in death of animal and plant species. Direct impacts include plant and animal death caused by road construction equipment. Indirect impacts include displacement of individuals that may eventually die from predation or the greater competition and less resources for each animal in the adjacent habitats into which animals are forced. Another indirect impact is genetic alteration due to reduced exchange between populations because the road forms a barrier to individuals.

As an example, the fate of several tree kangaroos was dramatically affected by clearing as described by Newell (1999a). During his study of radio-collared individuals in a rainforest fragment, half of the study area was unexpectedly cleared. All of the individuals returned to their original home range shortly after the clearing and continued to reside amongst the fallen debris for up to a year. In the long-term, only those individuals whose home range was largely unaffected survived, while canine predators gradually killed the others.

Road clearings may appear to be of less impact than other disturbances such as clear-felling for forestry, or rural or urban land uses, however the cumulative extent of road networks within natural areas can result in relatively large areas of habitat loss.

In the Wet Tropics World Heritage Area there are 1,213 km of roads and highways. This network of linear clearings directly impacts 1,610 ha or 0.27% of the total acreage (Wet Tropics Management Authority 2002).

Even within forested conservation areas, road verges are often maintained as grasslands or low weedy shrublands by mowing, grading, burning or spraying with herbicides. This results in a plant community that is floristically and structurally different from the surrounding forest. The area of forest habitat affected by roads (ecological footprint) may be much larger than the actual cleared footprint due to negative edge effects that penetrate the forest to varying distances. Wildlife populations often decline due to the cumulative impacts of roads over time (see Figure).



Impacts of roads on wildlife over time.

Climate change is another factor that may influence the movement patterns of animals. It is likely that some habitats will respond to climate change by altering plant distributions and changing the timing of flowering and fruiting.

Consequently, animal populations may need to disperse into new areas to survive. Roads may prevent these movements. Habitat corridors, which facilitate animal movement across barriers such as roads, will therefore become increasingly important.

Aquatic Ecosystems

Altered stream habitat also extends beyond the immediate cleared area due to changes in erosion, sedimentation, flow patterns and channelisation, with subsequent impacts on aquatic and stream bank life both up- and down-stream from the clearing (Eaglin and Hubert 1993; Brown 1994; Trombulak and Frissell 2000). Most disturbances to rivers are to their structural quality and stream siltation is one of the most widespread degradation processes in Australia. Alteration of stream flow regime is both caused and indicated by stream siltation (Harris 1995). Waterways may also be polluted by storm water runoff from roads (heavy metals and other contaminants: see Section 1.7 – Chemical Pollutants).

A study of erosion on unsealed rainforest roads (Bacon 1998) found that less erosion and road damage occurred where canopy cover was maintained above the road surface. Erosion was probably reduced because rainfall was intercepted by the multilayered canopy and funneled away from the road along branches and trunks (Goosem and Turton 1999).

Run-off from roads also can create turbid water that enters existing waterways. Turbidity reduces the process of photosynthesis in aquatic plants and algae. This, in turn, limits the supply of dissolved oxygen which is essential for fish, tadpoles and other aquatic life. The sediment suspended in turbid water has also been found to irritate the gills of fish. In extreme cases, chronic fine sediment loads can alter the diversity and composition of invertebrate species and dramatically change food web structure within streams (Luce 2002). Runoff from hot rainforest roads can also significantly alter the water temperature in nearby streams (N. Weston, pers. obs.) with an immediate reduction in the amount of dissolved oxygen in receiving waters.

When cut through hillslopes or wetlands, roads can intercept shallow ground water flow, potentially causing death of vegetation upstream through ponding and downstream due to reduced availability of groundwater. Groundwater can be concentrated through the compaction of the road base and fill batters, and by trenching for roadside drainage and stabilisation of cut batters. Water that is redirected into surface streams may potentially remove a source of water that was originally destined for a wetland or a spring. Other associated impacts of roads are the loss of aquatic habitat area and diversity, obstruction of free movement for aquatic life, and degradation of the riparian (stream bank) vegetation.



The platypus can be affected by poor water quality caused by turbid water from erosion or by pollutants on roads.

Altered Patterns of Runoff, Stream Flow and Sedimentation

Roads and bridges can alter natural water flows, with impacts to the natural variation and movements of stream channels and stream bank vegetation (Ian Webb, pers. comm.). Hard bitumen surfaces increase runoff compared to unhardened surfaces, and this additional water can result in channelisation of streambeds and increasing erosion and sedimentation within other sections of the waterway. Further, runoff from one catchment can be funneled to another by road drainage patterns, leading to excessive hydraulic loads in some catchments while reducing the water levels in adjacent systems. These combined changes in hydrology can result in adverse changes to aquatic and riparian habitats.

Construction of roads usually involves removal of topsoil and the compaction of soil for some depth underneath the road base. The compacted soil under the road will restrict the movement of water across the road zone causing accumulation in areas above the road while causing drying in areas below (Trombulak and Frissell 2000).

Logging roads that have been abandoned for more than twenty years in Wet Tropics rainforests show little sign of recovery from compaction, i.e. infiltration properties and soil density are essentially the same as on roads that are used and maintained, although some root penetration had occurred in the top five centimetres (Talbot *et al.* 2003).

Road construction is associated with increased frequency of landslides and other forms of erosion in steep forested landscapes. Road drains divert water from the normal processes of overland runoff and underground seepage which instead passes into the substrate of the road zone perched on the hillslope (Jones *et al.* 2000). Therefore, slopes and verges need to be protected from concentrated flows and erosion, especially near stream crossings, because of the shorter pathways for sediment to enter the stream.



Changes in runoff, stream flow and sedimentation can be of a large scale: the sediment trap constructed as part of this upgrade failed following heavy rainfall during the tropical monsoon period, releasing sediment into nearby streams and waterways.

1.2 Habitat Fragmentation and Barriers to Movement

Roads and their verges can be barriers to the movements and seasonal migration of wildlife (Goosem 2001). The factors contributing to barrier effects are: loss of habitat; avoiding the altered habitat in the road corridor and on the edge of the forest; road clearing width; physical barriers such as fences, cuttings, fill batters and culverts with drop structures; and altered light, temperature and humidity regimes. Many rainforest species are accustomed to the dark, cool, moist climate under the rainforest canopy, and therefore react badly to the bright, hot, drier conditions of road clearings. Although linear clearings for powerlines and pipelines create a barrier effect, roads have the added problem of extra physical barriers and impacts due to road kill (Goosem 2004). The width of a clearing has a large impact on the degree of barrier effects: the wider the clearing, the greater the barrier (Goosem 2000a,b; 2001).



Wider clearings create much greater barrier and edge effects.

Rainforest small mammals have proven a useful 'indicator' group for barrier impacts of road clearings. Studies have shown that smaller species were inhibited from crossing relatively narrow roads (eight metres wide) with canopy cover but managed to cross occasionally (Goosem 2000a, b; 2001). Crossing movements by the same species were further restricted by wider road clearings (twenty metres) with no canopy cover and grassy verges, animals failing to cross during the breeding season. Finally, monitoring of a highway indicated that few small mammals were attempting to cross the wide busy road (Goosem 2000a).

If individuals cannot move easily across these barriers, there may be reductions in home range size and less access to resources, resulting in lowered reproduction and altered genetic flow between divided populations. These short-term effects can lead to long-term changes including reduced genetic diversity and eventual decline in populations due to lowered breeding success. Isolated populations are also more susceptible to extinction when catastrophic events occur due to a lack of recruits from larger populations.

Strips of forest as small as thirty to forty metres in width can function as habitat and movement corridors for some arboreal (tree living) mammals, such as the Herbert River ringtail and striped possums. Other animals, such as the lemuroid ringtail require corridors of primary rainforest of at least two hundred metres wide, making it particularly sensitive to fragmentation. Coppery brushtail possums, green ringtail possums and Lumholtz's tree kangaroos have been found in isolated remnants and regrowth forest as well as continuous forest making them vulnerable to road kill as they move to other fragments (Laurance and Laurance 1999).

1.3 Edge Effects and Disturbance

Changes in Microclimate (Temperature, Humidity and Light) and Vegetation

Edge effects comprise a diverse array of biophysical changes that occur at and near abrupt, artificial margins between natural habitat and clearings. Alterations in microclimatic variables, such as light, humidity, and air and soil temperature occur along the edges of linear clearings (Siegenthaler and Turton 2000; Pohlman *et al.* 2007).

The edges of road clearings have increased wind speeds, increased light penetration to the ground and mid-story vegetation, elevated soil temperatures, drier soils and increased evaporation compared with the humid, relatively dark and windless microclimate found within rainforest. Higher

light levels promote fast growing pioneer plant species (both native and weeds), which can result in a thick ground cover of grasses and weeds on cleared areas while the side of the forest becomes 'sealed' by woody vines (Pohlman *et al.* 2007). To improve the sealing of the forest edge, certain species should be planted depending on the existing light conditions (see Section 3 Revegetation Techniques and Tables 3 and 4).

In northeast Queensland rainforests, a suite of edge effects have been associated with roads and powerline clearings (Pohlman *et al.* 2007). In particular, microclimatic changes can penetrate to distances of 25 metres or more into the surrounding rainforest for factors such as air and soil temperatures and humidity, although increased light levels were only measurable for distances between seven and eleven metres. Such effects were considerably less intense where linear clearings were narrower. The least change in microclimate occurs where the rainforest canopy is completely closed above a narrow road: in this case, changes were only discernible to a distance of three to seven metres (Siegenthaler and Turton 2000).

An unexpected impact of clearing is the dramatic collapse of biomass adjacent to new clearings as shown by research in Amazonian forests (Laurance *et al.* 2000). In this study, many large trees near the forest edges died over a period of months to years. Possible mechanisms for this decline include dehydration from drier air, nutrient stress caused by excessive leaf drop, and shearing by wind. Increased wind speeds can generate greater wind shear damage to trees, especially those which are no longer supported by the canopy interconnections found in intact forest (Laurance *et al.* 2000). Recent research has shown similar reductions in large trees near highway edges in the Wet Tropics (Pohlman 2006).

Changes in rainforest vegetation structure adjacent to clearings have also been demonstrated in the Wet Tropics region. Canopies were more disturbed closer to edges, with increases in 'disturbance' species such as weeds, vines and early successional rainforest trees. Again these changes are less intense where canopy is retained above road surfaces (Siegenthaler *et al.* 2000; Siegenthaler and Turton 2000; Maver 2002; Pohlman 2006).

Changes to Rainforest Faunal Populations

Rainforest specialist fauna (i.e. those that are dependent on rainforest habitats) have been observed to avoid edges, which increases the opportunity for use by gap and edge specialist birds and generalist insects, frogs, reptiles and small mammals (Stevens and Husband 1998; Goosem 2000, 2002; Laurance 2004). The altered species composition resulting from these edge effects may also have consequences for ecological processes such as pollination, dispersal, competition and predation (Murcia 1995).

Australian studies investigating edge effects along rainforest linear clearings have been mainly confined to northeast Queensland. In these studies, changes in the species composition of small mammals and birds have been observed along rainforest road edges (Goosem 2000c, 2002; Dawe and Goosem 2007). Generalist species were more common at edges, while forest interior species decreased in abundance. In locations where canopy closure was maintained over the road, specialised rainforest species may still be restricted to the forest interior (Goosem and Marsh 1997; Goosem 2000a,b,c), although edge effects are likely to be less overall. In contrast, demonstrable edge effects occur along roads through Australian eucalypt forest for birds, but not necessarily for small mammals (Goldingay and Whelan 1997; Baker *et al.* 1998). Certain rainforest frogs also decrease in abundance in some areas adjacent to highways (Hoskin and Goosem, in review).

Bird species can be a sensitive indicator of habitat quality as they utilise the 'vertical' structure of a rainforest. A study examining the relationship between indicators of habitat quality and bird species diversity in rainforest riparian zones in northeastern Queensland found that higher quality areas supported greater numbers of species. In particular, those sites with intact canopy cover and widths greater than fifty metres had an average of sixteen species while sites that were of lower quality (widths less than five metres and less canopy cover) averaged three bird species (Lawson *et al.*

2008). However, some arboreal mammal species that inhabit highland elevation rainforest may require much wider corridors, that is, two hundred metres or more (Laurance and Laurance 1999).

Edge effects associated with unsealed roads in temperate forests include reduced leaf litter depth and decreased abundance and richness of larger invertebrates for up to one hundred metres into the forest (Haskell 2000). Wider roads and roads with more open canopy tend to produce steeper declines in animal species richness and abundance and litter depth, but even narrow roads show an edge effect. Decomposition rates of leaf litter and dung are also affected by changes in insect species composition associated with fragmentation (Didham *et al*. 1996).

Increased Human Disturbance

The road network provides access to forests and their natural resources, enabling collecting of plants and hunting of animals (Laurance *et al.* 2009). Plants, such as orchids and ferns, are often taken from roadsides and road construction sites. Roads also provide off-road vehicles with access to remote areas, creating a risk for sensitive habitats. In dry forest, recreational vehicle use also increases fire risk. Additionally, verges can become dumping grounds for rubbish and litter from cars, with thousands of tons of litter are removed from road corridors every year. Some forms of trash such as bottles, can be a hazard to small animals by acting as death traps.

1.4 Road Kill and Construction Mortality

The death of wildlife through collision with vehicles is one of the most obvious impacts of roads adjacent to rainforest habitat. The magnitude of rainforest road kill is rarely understood because Australian rainforests are home to relatively few animals large enough for victims to be obvious from a moving vehicle. The loss of animals directly and indirectly during construction is also important.

On a two-kilometre stretch of rainforest highway near Cairns that carried between three and four thousand cars per day, more than four thousand road-killed vertebrates were recorded over a three-year period in weekly surveys in the early 1990s. The majority of these animals were amphibians, but mammals and reptiles comprised a significant proportion (>500 each) of the total, with birds being less common (Goosem 2000a). From longevity trials (length of time for a road kill to degrade) these data were extrapolated to indicate that between three and ten thousand vertebrate animals per kilometre per year are being killed on that particular highway. Repeat surveys in 2005/2006 found similar numbers killed although abundance of road kill of many species varied and traffic volume had increased to around six thousand vehicles per day. Similar weekly surveys undertaken over twelve months on a one-kilometre section of a rainforest highway on the Atherton Tablelands, with a traffic volume of six to eight hundred cars per day indicated an annual road kill of 230 vertebrates. The majority were amphibians as well as substantial numbers of mammals and reptiles and a higher proportion of birds than found near Cairns (Goosem *et al.* 2006).



Steep cuttings can trap wildlife on the road – in this location a tree kangaroo was killed by a vehicle because it could not escape. Revegetation can assist, particularly if vines are included.

The rate of roadkill is often higher at gullies and creeks and at the junction between cut and fill embankments because these locations coincide with movement corridors for many species (Goosem 2000a; McKelvey *et al.* 2002). Some frog species are attracted to roadside drains to breed, and are thus regular roadkill victims.

Studies of roadkills near wetlands indicate that roads by wetlands and ponds have very high roadkill rates. One American study recorded more than 625 snakes, and another +1,700 frogs per kilometre per year (Forman and Alexander 1998). A study in Nebraska, USA found that for most animals, speed, and not traffic volume, is the main factor associated with road kills (Spellerberg 2002).

Small mammals such as antechinus and rodents have seasonal breeding or dispersal behaviour that is also obvious in road kill patterns (Goosem 2000a). Dispersing young males form the majority of road-killed tree-kangaroos on the Atherton Tablelands (Kanowski *et al.* 2001). In addition, the presence of cut batters or steep slopes may prevent larger animals from escaping impacts with vehicles (Izumi 2001).

Temperature effects of roads can also affect animal behaviour. Road surfaces store heat and release it at night with the result that wildlife are attracted to roads in cold weather, thus making them more vulnerable to collisions with vehicles (Trombulak and Frissell 2000).



Heavy vehicles have almost no ability to avoid fauna on the road. Roadkill is more likely to occur as the vehicle can take up much of the lane, and cannot swerve nor stop like a car (Photo: David Rivett).

Other factors influencing road kill of rainforest small mammals and frogs include the width of road clearing, presence of road embankments, size of cuttings and traffic speed. Data from studies indicate that as road clearing widths increase, road mortality appears to decrease due to reduced numbers of animals attempting to cross. For small mammals, faster traffic speeds may reduce mortality even further at wide clearings, whereas faster traffic results in greater mortality at narrow clearings. However, reduction in road mortality comes at the cost of greatly increased fragmentation effects if other means of crossing, such as underpasses, are not provided.

Cassowary Fences

Road kill impacts on rare and threatened rainforest species can be substantial. A population of endangered southern cassowaries at Mission Beach suffered road casualties of fourteen percent of known adult individuals over a three-year period (Bentrupperbäumer 1988). Road kill is considered to be one of the main threatening processes for cassowaries due to significant road mortality in proportion to the estimated populations at Mission Beach and the Daintree lowlands (Moore 1998, 1999; Howard and Carberry 2002).

Wire mesh fences may also cause problems for the birds as they may view attractive habitat on the other side of the road through the fence and try to push through, damaging themselves on the wire in the process (J. Bentrupperbäumer, pers. comm.). Therefore any fencing to separate cassowaries from roads should be of a material that prevents direct line of sight to habitat across the road. Shade cloth-covered fencing, constructed along the Kennedy Highway Kuranda Range, appears to have been successful in directing animals away from the road (S. Goosem, pers. comm.). Similar but taller fences have been trialled at Mission Beach, however it is believed design of escape routes from the road and height of shade cloth above the ground are important variables that need further

examination. Cassowaries very seldom use retrofitted culverts or box culverts to cross under roads in comparison to walking across the road surface at grade. It appears that high bridges with vegetated streambanks are preferred over underpasses for road crossings by cassowaries, although the birds also continue to cross the road surface (Moore 2009).

For many other species traffic speed calming or preferably legislated speed reduction and enforcement may be a viable option for reducing mortality near road kill hot spots of many species and is currently being trialled for cassowaries. This may be even more effective if combined with bridges, underpasses, overpasses or reconstruction of some road drainage structures (Newell 1999b).



Shade cloth fencing erected to prevent cassowaries from seeing across the road can be improved by ensuring the gaps beneath the cloth also stop cassowary chicks from entering the roadside area.

1.5 Modification of Animal Behaviour

Birds

Road noise and/or vibration is believed to disrupt communication for many bird species, leading to an avoidance of roads for distances of two hundred metres or more (Reijnen *et al.* 1996). The degree of disruption to communication is dependent on traffic factors (type, volume and speed), vegetation type and topography. Some northeast Queensland rainforest bird species avoid the edges of highways while other species may alter the pitch of their calls as a result of traffic noise, with possible impacts to individual health (Dawe and Goosem 2007).

The disturbance associated with a road, including the canopy gap and the barrier effect, may also restrict the movements of ground dwelling and understory bird species (Laurance 2001). Additionally, those individuals that require a large home range, for example cassowaries, are greatly affected by fragmentation of their habitat. Canopy birds may not be so greatly affected, while some predator species may benefit from enhanced opportunities to hunt on edges and eat carrion (dead animals) on roadsides (if they are not killed by traffic themselves).



The Southern Cassowary (*Casuarius casuarius johnsonii*) (Photo: David Souter).

The southern cassowary is listed as endangered under the *Nature Conservation Act (Wildlife Regulation) 1994* and the *Environment Protection and Biodiversity Conservation Act 1999* and it is estimated that fewer than 1,500 individuals remain. These birds are the only frugivores (fruit eaters) big enough to effectively disperse many large seeded plant species found in the rainforests (Stocker and Irvine 1983). Cassowary populations are seriously affected by road kill (Bentrupperbäumer 1988). However impacts on cassowary populations are difficult to ascertain without long-term intensive observations of individuals (Bentrupperbäumer 1988; Moore 2001) because counts of their droppings along paths do not correlate well with actual bird numbers in some areas (Westcott 1999). Current research is assessing the DNA in droppings to obtain counts of individuals. Cassowary crossings and road kill hotspots have recently been identified in the Mission Beach area (Moore 2009).

Tree Living (Arboreal) Mammals

Road kill of some species of possum can be reduced by maintaining or re-establishing canopy connectivity, i.e. where branches of trees touch above a road (Goosem 2000c). Although canopy connections are preferred as movement routes, barrier effects on arboreal species can be ameliorated by inclusion of arboreal overpasses such as rope ladders, at least for road clearings of fifteen metres or less (Goosem and Weston 2002; Weston 2003). Recent research has demonstrated that longer rope tunnels of 35-40 metres will be crossed but only by some species (Goosem *et al.* 2008). It is currently unknown whether more rainforest-dependent species will cross long clearing distances using rope overpasses (Goosem *et al.* 2008).



Lumholtz's Tree Kangaroo (*Dendrolagus lumholtzi*) (Photo: Jonathan Munro)

Where canopy connectivity does not exist, Green Ringtails, Herbert River Ringtails, Lemuroid Ringtails and Striped Possums will use a rope ladder crossing over a fifteen metre span. Brushtail Possums are very common road kill victims and will also use the rope ladders (Goosem *et al.* 2008; Weston 2003).

Tree-kangaroos often move between remnant patches of forest at ground level making them vulnerable when crossing roads. Most of the individuals killed are juveniles and sub-adult males, which may have been struck while dispersing between patches of habitat (Newell 1999b,c; Izumi 2001; Kanowski *et al.* 2001). Tree-kangaroos have used purpose-built underpasses constructed by the Department of Transport and Main Roads at the East Evelyn Road on the Atherton Tablelands and have been observed traversing through a railway tunnel (J. Munro pers. comm.; J. Kanowski pers. comm.).

Bats

Maintenance of healthy populations of blossom and fruit eating bats is important because of the pollination and dispersal services they provide for rainforest trees. Riparian habitats are important sources of food and are used as commuting corridors for many bat species (Law 2001). However, insect-eating bats (such as freetails) use road gaps as movement corridors while hawking for insects. It is likely that while pursuing their prey by echo-location they are unaware of vehicles and are therefore vulnerable to road mortality (O. Whybird, pers. comm.).

In a study on the movement habits of rainforest hipposiderid bats, three species were found to forage at or below canopy height in rainforest gaps as opposed to undisturbed rainforest (Pavey and Burwell 2000). It is likely that bats which perch to echo-locate prey would not be as susceptible to roadkill as species that forage continuously in gaps by hawking. These latter species have been observed roosting in culverts and under bridges (M. Godwin, pers. comm.). Roadkill on the Kuranda Road section of the Kennedy Highway in northeast Queensland included several common insect eating and blossom feeding bats, as well as several specimens of the less common Golden-tipped bat (Goosem 2000a).

Streetlights attract nocturnal insects, as well as species including bats, frogmouths (bird) and amphibians, and may increase the likelihood of cars killing these fauna. Speed and vehicle size also increase the potential for bat roadkills. Wider roads are not necessarily worse than narrow ones with respect to roadkill of bats unless traffic speeds are greater (S. Clague pers. comm.). Roads that are used intermittently at night or dusk would possibly have a higher mortality rate than roads with constant heavy traffic, because there is less opportunity for a bat to enter the vehicle zone if traffic is constant. On the Kuranda Range, bats have been observed hawking for insects around streetlights, often at a height where collisions with vehicles are probable (Wilson and Goosem 2007).

In the United States, compensation for the effects of road building on wildlife has been provided by bat friendly structures, or bridges designed with appropriately sized crevices in them, to provide roosts for bats (Keeley and Tuttle 1999).

Terrestrial Mammals

As already discussed under 'Edge Effects', small mammals, including many rodents and small dasyurids, are impacted by barrier and edge effects caused by roads (Burnett 1992; Goosem 2001; 2002). These and other species, including bandicoots, are very susceptible to road kill. Fortunately, many small mammals will use under-road culverts and larger underpasses to cross road clearings. However, the musky rat-kangaroo does not seem to use underpasses nor does it appear to cross highways (Goosem 2000a), although it occasionally crosses main roads with less traffic (P. Byrnes, pers. comm.). This species may be avoiding roads due to the noise of highways and/or the large gaps in canopy connectivity (A. Dennis, pers. comm.).

Mammals using purpose-built faunal underpasses at East Evelyn Road include pademelons, bandicoots, rodents and wallabies. Larger macropods of open habitats are very susceptible to road kill and swamp wallabies have been killed near the base of the Kuranda Range, while pademelons were found at all elevations. The musky rat-kangaroo was never observed as road kill on the Kuranda Range road, although it is known to use edges of low use forestry roads (Goosem 2000a).

Reptiles and Frogs

The most obvious impact of roads on reptiles is the high rates of mortality from vehicle impacts (Goosem 2000a). Movement of reptiles is dependent on temperature and food sources. Roads provide a source of stored heat which can attract snakes at night and act as attractive heat sources for lizards during cold weather. In addition, some lizards may be attracted to injured or carrion-feeding insects on the roadsides, putting them at risk of road mortality (Goosem *et al.* 2007).



Prickly forest skinks live in and under moist logs and are badly affected by edge effects and forest fragmentation (Photo: Ulrika Larsson).

One rainforest specialist, the prickly forest skink, has declined in fragmented rainforests because it fails to cross canopy gaps such as those created by roads (Rainforest CRC 1998) and powerline clearings (Larsson 2003).

Road drainage structures that accumulate water are commonly sites of aggregation for amphibians when breeding (R. Alford, pers. comm.; K. McDonald pers. comm.). Due to the close proximity to the road, these impoundments can promote movement onto the wet road surface causing high levels of mortality for amphibians and their predators (Goosem 2000c). Traffic noise may also impact frog species as they rely strongly on hearing for communication (Barass 1985). An endangered frog population was monitored near and away from road edges. The results indicated that smaller animals were found closer to the road, which could mean that noise is causing the larger animals with lower frequency calls to move away from the road (Hoskin and Goosem 2007). The rare Green-Eyed Tree Frog was found in large numbers in the early 1990s as road kill adjacent to two creeks on the Kuranda Range Road (Goosem 2000a). In 2006 it remained a road kill victim, although in lower abundance (Goosem 2006).

Fish

Road crossing structures can impede or prevent fish movement if the:

- Water velocity or turbulence is too great;
- Culvert is too dark, long or narrow;
- Water is too shallow;
- Crossing is full of debris; and/or
- Stream has a drop on the upstream or downstream side of the crossing (Cotterell 1998).

Australian native freshwater fish are generally poor swimmers in comparison to many fish of the northern hemisphere. They are easily impeded by moderate streamflow velocities and are incapable of jumping up small height changes when moving upstream (Kapitzke and Patterson 2002). Road culverts can therefore be permanent barriers to fish movement or, at certain times, restrict breeding season migration (Pusey *et al.* 2004). This can severely affect community composition across the region because culverts are present on most rivers and streams.

Sedimentation can affect the viability of some fish species by smothering their eggs, as well as impacting vegetation and other food sources. A large proportion of freshwater fish species lay eggs on the riverbed or amongst vegetation (Fairfull and Carter 1999). Infilling of gravel beds and deep pools from increased sediment deposition can also reduce available pools for shelter.

The Wet Tropics region contains a very high diversity of the country's freshwater fish species (forty percent of Australia's species and 55% of those in Northern Australia). The Bloomfield River and streams of the Cape Tribulation and Cardwell areas show the most distinctive fauna (Pusey and Kennard 1996).

Australian rainforest freshwater fauna are generally tolerant of low concentrations of oxygen and can withstand broad temperature ranges and high sediment loads. However, if the natural variability in conditions is reduced, for example by construction of dams and weirs or badly-designed culverts, they can be displaced by introduced species better adapted to constant conditions.

Invertebrates

Streams in Queensland's tropical forests support a high diversity of invertebrates, including many endemic and Gondwanan species (Rainforest CRC 2002). Road culverts are often a significant barrier to movement of aquatic invertebrates. Additional impacts can be caused by:

- Artificial substrates;
- Increased leaf litter detritus from road drains;
- Temperature effects due to canopy clearing near culverts;
- Increased light, resulting in more algal and plant growth; and
- Restriction of movement by species on which invertebrates depend, e.g. host fish for parasitic larval stages of mussel (Mace 2002).

In Sweden it has been found that snail populations become isolated from each other by roads, including narrow unpaved tracks (Spellerberg 2002). Studies of beetles in Germany indicate that they also will not cross wide roads (Mader 1984).

Rainforest canopy invertebrates have been found to experience ecological edge effects from linear clearings in the Wet Tropics Region (Foggo *et al.* 2001).

1.6 Invasion by Weeds, Disease and Feral Animals

Road clearings experience increased light levels (Pohlman *et al.* 2007) that, along with heating and drying, produce conditions that favour the establishment of exotic plant species (weeds). A road also provides a movement corridor for the dispersal of weeds. This often results in the development of exotic grasslands or shrubby swathes of woody weeds along verges which enables the penetration of more weeds and animal pests alien to the surrounding forest habitat (Goosem and Turton 2002).

Maintenance practices along road verges such as herbicide spraying, burning, mowing, grading and removal of overhanging branches can act as ongoing habitat disturbance which encourages weed colonisation.

There are major weed infestations along roadsides of the tropical rainforests of Queensland, particularly of exotic grasses such as Guinea grass and molasses grass, and shrubs including lantana and wild raspberry (Goosem and Turton 2002). These weeds add to the other barrier effects and restrict natural recruitment of native plant species.

Roadside weeds may create areas of high fuel loads, resulting in a conduit for fire, which is foreign to rainforest environments. Fire can strongly alter plant composition by allowing greater infestation of species that are more prone to burning (Milberg and Lamont 1995).

The forest dieback disease *Phytophthora cinnamomi* occurs in many regions and its spread can have disastrous effects on biodiversity and the forestry industry. Seven other species of the genus also occur in the Wet Tropics bioregion (Wet Tropics Management Authority 2009). Many dieback patches occur close to roads, implying that road use, and/or road building and maintenance activities may be implicated in the spread of dieback (Gillieson *et al.* 2001). Roads are usually located on flat areas of land that may have impeded drainage which favour the *Phytophthora* pathogen (Worboys and Gadek 2003). Another potential vector is feral pigs, which are documented to move, forage and disturb soil along roads and their verges.

Roads through rainforests also act as dispersal corridors for feral animals. Research on the Kuranda Range Road (Goosem 2000a) indicated that the introduced cane toad comprised a significant proportion of road kill, including on sections of road within rainforest although cane toads are not commonly found inside adjacent rainforest (Hoskin and Goosem 2007). Other feral animals recorded as road kill include the house mouse and the homing pigeon. Feral cats and dogs have also been found to move along rainforest roads from larger clearings and farmlands, with roads providing access for hunting in the forest (Byrnes 2002).

Forest clearings along roads are often invaded by alien grasses which allow the intrusion of grassland habitat fauna including small mammals and feral mice. An example of the strong impacts of alien habitats on rainforest fauna was shown by a study examining a tourist road that bisected weed-infested, abandoned pastures less than five hundred metres wide occurring between two blocks of upland rainforest. Grassland and feral small mammal species dominated the pasture and rainforest species were only able to exist in the rainforest and in large areas of the woody weed lantana (Goosem *et al.* 2001). It is evident from this and other studies that linear clearings in rainforest promote the spread of feral species, as well as encouraging increased populations of non-rainforest native fauna. Alternatively, when canopy closure is retained above narrow roads, the extent of this invasion is reduced or eliminated (Goosem and Turton 2000).

1.7 Chemical Pollutants

The emission of gases, liquids and solids from vehicles may lead to localised pollution of the air, soil and water adjacent to roads. Air pollution from vehicles is not a large problem at present in the rainforests of Queensland due to persistent trade winds at the regional scale. However, roads are the source of numerous pollutants entering the environment after deposition or emission from vehicles. Some pollutants such as heavy metals, hydrocarbons (oils) and rubber particles remain near the road while gaseous emissions and fine particulates disperse widely into the environment.

The impact of pollutants washed from the road surface during rainfall into the surrounding habitat has recently received some study in Australian rainforest areas (Diprose *et al.* 2000; Pratt and Lottermoser 2007a), although more research is needed. In temperate areas, lead, cadmium and zinc have been known to accumulate in roadside vegetation and to move up the invertebrate food chain beginning with insects and earthworms, with increasing levels that may be toxic to vertebrates (Gish and Christiansen 1973). Pesticides and herbicides may be cumulative poisons along road verges due to ongoing maintenance activities. Small mammals near busy U.S highways accumulate significant amounts of lead, placing higher trophic level predators and scavengers at risk of heavy metal toxicity (Quarles *et al.* 1974; Getz *et al.* 1977).

In the Wet Tropics, heavy metals accumulate in the soils and sediments immediately adjacent to highways, occurring in greatest concentrations at road curves where vehicles accelerate or brake. This effect significantly dissipates beyond the rainforest edge where dense edge vegetation acts as a screen for particulates (Diprose *et al.* 2000). Thus, it is possible that rainforest invertebrates such as earthworms occurring near the road edge could accumulate heavy metals, introducing these toxins into the food chain. Bioaccumulation in grasses has been demonstrated in the Wet Tropics (Pratt and Lottermoser 2007a), but how far this extends through the food chain is currently unknown (Lottermoser 2002).

Streams may also be polluted by road and highway runoff that contains contaminants from vehicle emissions. Other pollutants originate from lubricants, tyre and brake wear and transport spillages, as well as herbicides used to control roadside vegetation. Fish living in streams are exposed to these compounds and may bioaccumulate some chemicals. Fish mortality has been linked to high concentrations of aluminium, manganese, copper, iron and zinc.

Research investigating pollutants from northeast Queensland highways has shown that first-flush runoff has very high concentrations of heavy metals. Entry of this first flush directly into waterways may allow the soluble heavy metals to be absorbed into aquatic animal and plants where it can remain active, and potentially concentrate up the food chain. Heavy metal pollutants emanating from roads have been found many kilometres from the road source at the mouth of creeks in the Wet Tropics coastal lowlands (Pratt and Lottermoser 2007b).

For roads within non-rainforest habitats, verges can be specifically revegetated with plants that retain contaminants. These are a preferred alternative to expensive concrete retention basins for reducing the impacts of water-borne contaminants (Forman and Alexander 1998). Unfortunately, this option is generally unviable in rainforest habitats due to the associated habitat loss and increased edge effects from creating vegetated channels.

In the Wet Tropics, forest streams with closed canopies are resistant to adverse changes from increased nutrient loads because low levels of other controlling variables (such as light) restrict primary production (Pearson and Connolly 2000). Up to 95% of incident solar radiation can be blocked by canopies over streams (Mosisch *et al.* 2001). However, once the tree canopy above a stream is cleared, any addition of nutrients into the water will result in increased primary production and the accumulation of bottom living algae. Such changes can result in eutrophication during periods of low flows or in the invasion of weeds throughout the waterway, with further changes in aquatic life subsequently occurring (Stone and Wallace 1998).

1.8 Vehicular Disturbance

Noise, light and vibration from vehicles can disturb animals, causing them to avoid the vicinity of a road when selecting feeding or nesting sites. Traffic noise has the potential to cause stress, hearing loss and altered behaviour particularly when breeding communication is affected (Forman and Alexander 1998). Road noise is likely to affect many species, especially those that rely upon vocalisations and hearing for communication. The ecological effects of road noise may well exceed the direct effects of road kill, and they certainly exacerbate the fragmentation of habitat for some species. Measuring impacts on animal behaviour is not as straightforward as simply counting the number of road kill. Consequently there are few studies that evaluate the effects of noise on wildlife.

In temperate areas, several species of large mammals have been shown to avoid hunters and road traffic resulting in changes to daily movements and the reduction of available habitat (Pienaar 1968; Cole *et al.* 1997). Some bird species have also been found to avoid road edges for distances greater than two hundred metres, with higher levels of traffic volume and speed (i.e. noise) likely forcing the species further into the forest (Reijnen *et al.* 1996).

Studies in the Netherlands have quantified the reduction in bird diversity adjacent to roads of differing traffic density across a variety of landscapes. Songbirds were the most sensitive, but sixty percent of the bird species present had a lower density near a highway (one third lower), and species richness was reduced with proximity to the road. The distance of disturbance was greatest for grasslands and least for coniferous forests. The disturbance effect increased with increasing traffic speed and density (Forman and Alexander 1998).

In Wet Tropics rainforest, vehicular noise is able to penetrate to distances greater than two hundred metres (Marks 1999; Dawe 2005). Noise penetration is affected by type of vehicle, speed, and road topography. Noise was found to travel further uphill on steep slopes, especially from noisier sources such as semi-trailers with exhaust brakes. High levels of noise adjacent to a highway may be the cause of edge avoidance in certain forest animals, particularly birds and amphibians that use auditory communication (Dawe and Goosem 2007; Hoskin and Goosem 2007). Recent evidence from northeast Queensland shows that some rainforest bird species may change the frequency of their song in response to the low frequencies of traffic noise (Dawe and Goosem 2007). Similarly, an endangered species of frog appears to call with higher pitch close to a highway (Hoskin and Goosem 2007).

Traffic volumes of up to 480 vehicles per day on narrow forest roads do not appear to increase edge avoidance in small mammal species (Goosem 2004). Unfortunately no data for small mammals exist on road avoidance at highway traffic volumes (+5,000 cars per day), or where nighttime traffic forms a major component of traffic volume.

2. Mitigation Strategies

In designing effective mitigation strategies that directly address significant impacts to ecosystem values, including species-specific effects, it is important to follow the standard Environmental Impact Assessment processes that seek to:

- First avoid sensitive ecosystems and habitats of sensitive species;
- Then minimise the impacts; and
- Finally, if impacts remain, mitigate.

Approaches for minimising impacts, such as retaining rainforest trees near the road, are useful for reducing the negative consequences of road corridors for a myriad of rainforest ecosystem values. The most effective and common minimisation and mitigation designs are discussed below with the goal of maintaining rainforest function across a range of species and ecological components (i.e. plants and animals in both terrestrial and aquatic environments).

2.1 Canopy Closure and Minimising Clearing Width

Ensuring that a rainforest canopy is maintained over a road is one of the most important minimisation and mitigation strategies that can be employed within the design and road construction phases (Goosem 2007). In particular, clearing width should be minimised with consideration of trade-offs with road safety concerns. Cutting and embankment widths should also be reduced as far as possible. Minimisation of vegetation clearing is the most cost-effective and ecologically advantageous way of achieving the smallest possible road clearing width. However, where clearing is unavoidable, planting of native, fast-growing trees with sturdy branches will ensure that the canopy can be re-established within a reasonable time frame (less than ten years; Catterall *et al*. 2004), even though most habitat values may take extremely long periods to re-establish (see Section 3 Revegetation Techniques).

Together, these approaches to maintaining canopy closure over a road will provide:

- Increased habitat connectivity for arboreal species (Wilson *et al.* 2007);
- Greater likelihood of road crossings by terrestrial species (Goosem and Turton 2000);
- Increased shading along edges, with the effect of limiting weed growth (Goosem and Turton 2002);
- Reduced edge effects (more similar to rainforest interior environment; Goosem 2000b; 2002).
- Limited capacity for non-native fauna species to establish (Goosem and Marsh 1997; Goosem and Turton 2000, 2002).
- Reduced cost of roadside maintenance through less mowing and reduced herbicide applications, which also limits potential pollutants (Goosem 2008).
- Improved road longevity (especially for gravel roads) through reduced erosion (Bacon 1998); and
- Reduced sediment reaching waterways and impacting water quality (Goosem 2007).

The practice of providing canopy closure is especially important for arboreal species which may otherwise attempt to cross on the road surface and thus be possibly killed. However, some species will not even attempt road crossings, with the cumulative effect of isolating individuals and causing populations to become fragmented (Goosem 2007). Limiting invasions by weeds and alien animals is also of great importance in the context of maintaining integrity of the ecosystem (Goosem 2004).

The choice of trees to establish near roadsides is very important. Those that tend to drop branches must be avoided, as should all fruit-bearing species that might attract foraging fauna to the roadside (Tucker *et al.* 2005). Trees which spread their branches at canopy height are preferred as these provide canopy connections that allow arboreal species to cross above a road. Canopy connectivity also helps to maintain rainforest-like conditions near the road surface for ground-dwelling species to safely and quickly move across the road (Goosem 2000c).



Closed canopy above a road will reduce road impacts by limiting weed growth and edge effects and allow more animals to cross the road (Photo: Miriam Goosem).

Providing a closed canopy above the roadside but not above the road surface is recommended for highways which carry high levels of fast-moving traffic (+5,000 vehicles per day approximately). In such instances, employment of engineered mitigation solutions is recommended to provide connectivity above the road surface.

2.2 Bridges

Where highways carry high traffic volumes and canopy closure cannot be maintained throughout the length of a road corridor, then several alternative mitigation approaches can be used, depending on the target species, ecosystem and landscape context.

The most effective means of providing habitat connectivity for fauna and flora, including tree-dwelling, ground-dwelling and aquatic species, is the use of high bridges which span above the rainforest canopy (Goosem *et al.* 2004). High bridges are extremely effective as they can be built using a top-down approach with minimal clearing (only clearing of the pylon footprint). Bridges with long spans can even allow the rainforest canopy to persist underneath, provided sufficient light can reach the leaves and sufficient moisture can reach the ground. This depends on the aspect of the bridge but can be ensured by using divided bridges for wider highways (Turton and Pohlman 2004b; 2008).

Lower bridges can also be useful for movements of ground-dwelling species (Goosem *et al.* 2004) with studies indicating that small and medium-sized mammals will move under such structures (Goosem 2008). There must be areas of dry stream bank under either end of the bridge to allow unimpeded passage for animal movements for the majority of the year and sufficient space above the animal's head and body so that animals do not feel trapped. Cover from predators, preferably in the form of understorey vegetation but also including logs, brush and crevices within rocks will improve effectiveness. Bridges built without disturbing the streambed also have the advantage of providing unimpeded movement of stream-dwelling fauna including fish, frogs and invertebrates (Kapitzke 2003). It is essential to maintain stream bank vegetation which serves several functions: it provides shade over the stream, food in the form of leaf litter and prevents erosion and sedimentation along the stream.

Another alternative is to create a land bridge that provides connectivity of habitat on a bridge over the road. Land bridges are generally wider at the edges than the centre to funnel fauna towards the bridge but should be wide enough not to create a bottleneck at the narrowest point. Fencing is necessary to prevent fauna from jumping down to the road surface. This type of bridge needs sufficient depth of soil to allow planting of native vegetation similar to that found in the habitat adjacent to the road. Inclusion of rocks and logs will help to provide cover from predators for ground-dwelling animals, while poles can provide escape routes from predators for tree-dwelling species

and also allow gliding species to move across the land bridge. In open sclerophyll habitat in Brisbane, a variety of mammals and birds have used a land bridge to cross a wide road (Bond and Jones 2008; D. Jones, pers. comm.). It is unknown whether land bridges would function well in rainforest environments, as the moist microclimate and low-light levels could be more difficult to replicate than open forest habitats, but for species such as cassowaries that appear to mainly avoid underpasses (Moore 2009), such structures should be trialed.



An artist's diagram of a high bridge over the rainforest canopy proposed for the Kuranda Range Road upgrade project. Note, tree canopies below the arch (Diagram: Queensland Department of Main Roads 2005).





(*Left*) Low bridges can provide dry passage for ground-dwelling animals during most of the year. Maintaining vegetation under the bridge, together with rocks and logs, will promote animal use of the area (Photo: Miriam Goosem). (*Right*) Land bridge built at Compton Road, Brisbane. Note, depth of soil for vegetation plantings, fencing to prevent fauna jumping onto the road surface, glider poles for movements of glider possums and escape from predators by arboreal species (Photo: Brisbane City Council).

2.3 Faunal Underpasses

One of the more effective design elements for enhancing wildlife movements and reducing road mortality is the creation of faunal underpasses. These structures can be targeted to either a specific species or to a broad range of local fauna. In a five-year study of four faunal underpasses installed under a new road alignment that traversed rainforest habitat in the Wet Tropics region, it was found that many common rainforest species utilised the large underpasses (Goosem *et al.* 2006). Rare target species were also known to occasionally use the underpasses. As compared with a pre-underpass time period, road mortality was slightly reduced (Goosem *et al.* 2006). The road was not fenced but instead was planted with rainforest corridors that encouraged animals toward the underpasses. It is unclear whether the same individuals moved through the tunnels frequently or if there was a significant population of species of bandicoots, rodents and pademelons that became accustomed to the underpasses.



(*Left*) Faunal underpass constructed at Compton Road, Brisbane, targeted at wallabies, possums, koalas, reptiles and amphibians. Note, the ledges about one metre high for small mammals and logs erected at the same height for koalas and possums. The ledge allows dry passage for animals away from the water carried by the culvert (Photo: Brisbane City Council). (*Right*) Interior of faunal underpass near Millaa Millaa, northern Queensland, with rocks, logs and brush for cover from predators for ground-dwelling animals, and vertical poles erected for escape from predators for tree-dwelling animals (Photo: Miriam Goosem).

To increase the effectiveness of faunal underpasses for a broad range of species, the following design elements should be considered:

- Build the underpass large enough in height and width to allow for movement of the largest target species. Animals require sufficient space above and around them to avoid feeling trapped and they also should have an unobstructed view of attractive habitat at either end of the underpass.
- Ensure that structural elements are placed around the entrances and within the tunnel to provide shelter for the smaller target species. Many species will only move through an underpass if there is sufficient cover (in the form of hollow logs, brush or even large rocks, Goosem *et al.* 2001).
- Ensure the tunnel is adequately drained to avoid having standing water during the wet season as this may impede animal movement.
- Provide a wide (at least thirty to forty metres) vegetation corridor that leads all the way up to each side of the underpass (using appropriate local plant species that provide cover for animals).
- Consider specific threats to target species and provide a means to mitigate these factors. For

example, poles in the form of large tree branches have been erected vertically in underpasses to provide an escape route for tree-kangaroos from domestic dogs (Goosem *et al.* 2001).

Underpasses must be maintained over their lifetime, with appropriate structural elements added if target species are found to avoid using the structures in the initial stages.

2.4 Fencing

Fencing can be an important element of a mitigation strategy that encourages faunal movement away from roads by funneling animals towards bridges and underpasses. This may be especially important for highways which carry large volumes of traffic and where the majority of animals attempting to cross may be killed. For less busy roads, bridges and underpasses should allow safe faunal crossing during peak traffic. Fencing in this case is likely to be unnecessary, as more normal faunal movements may be possible in slow traffic periods. Planting of attractive vegetation to encourage faunal use of bridges and underpasses may be preferable to fencing along low traffic volume roads.

Examples of fauna-specific fencing designs include:

- Shade-cloth fencing for large birds such as cassowaries. The materials should be opaque so that the birds cannot see attractive habitat on the other side of the road and therefore do not damage themselves trying to push through fences in an attempt to get to the other side (Bentrupperbäumer and Goosem 2005).
- Low solid barriers attached to the base of fences for funneling small species, including ground-dwelling frogs and skinks, into culvert underpasses (Goosem 2006).
- Slippery materials, such as plastic or rubber, up to one metre high and attached to the base of fencing to prevent climbing animals from going over the fence (Asari 2007).
- Special fence designs to allow animals trapped on the road surface to return to the forest. Examples include ramps on the inside of the fence or gaps that are only evident from the road surface side of the fence (produced by overlapping sections of fence at slightly different angles resulting in a wide entrance on the road side of the fence which funnels down to a very narrow entrance on the forest side of the overlap).



Fencing on top of land bridge, Compton Road, Brisbane. Note, solid slippery material at base to encourage small animals to follow the fence rather than climb upward (Photo: Brisbane City Council).

2.5 Canopy Bridges

Canopy bridges should be considered as a mitigation strategy for those areas along road corridors where canopy connectivity cannot be maintained and arboreal species are present. Rare ringtail possums, some glider species, striped possums, common ringtail and brushtail possums and semi-arboreal rodents have all used rope canopy bridges (Weston 2003; Bax 2006; Goosem *et al*. 2006; 2008). The length of the bridge span should be as short as practical as some species are less prone to move across wide openings (Goosem *et al.* 2008). The number of canopy connections necessary to allow sufficient movements for a resident population should be based upon the range size of the species with the most restricted home range area. It is suggested that at least seventy percent of the home range span of this species would be ideal (Goosem *et al.* 2008).



Erection of a ladder-style rope canopy bridge strung between two trees over a narrow tourist road near Millaa Millaa, northern Queensland. The rope ladder was made taut after this photo was taken (Photo: Nigel Weston).



Group of canopy bridges across the two-lane Palmerston Highway in northeast Queensland. A rope runnel bridge is in the foreground (Photo: Robyn Wilson).

Canopy bridges can be made from simple rope materials, and should include the following design elements (Goosem *et al.* 2008):

- Rope should be durable – 'silver rope' has been found to be ideal.
- A ladder or tunnel design with 'rungs' provides stability for crossing animals and greater safety for motorists (Weston 2003).

- Tunnel designs may provide crossing animals with enhanced cover from aerial predators, although in practice, animals have been observed to cross on top of a rope tunnel (Weston 2003).
- Attach the bridge to electricity poles with stays to concrete footings as this provides safety for wide and busy roads (Goosem *et al.* 2008). For narrow rainforest roads, rope ladder style bridges can often be attached to sturdy tree trunks by wooden supports, saving on costs (Weston 2003).
- Where poles are used in construction, they should be erected as close as possible to the forest edge and additional ropes should be fed into neighbouring trees to encourage animals to move toward the canopy bridges (Goosem *et al.* 2008).



Lemuroid ringtail possum with back young using a rope ladder bridge over a narrow tourist road (Photo: wildaboutaustralia.com.au).

2.6 Fish Passage Structures

Where roads cross watercourses, inappropriate design of structures such as culverts and causeways can prevent the natural movements of aquatic species. This can cause serious problems for many native Australian freshwater fish and invertebrates and potential problems for other aquatic fauna such as frog tadpoles (Hyde 2007).

Improperly designed, constructed and maintained stream crossings impact fish and their habitat directly or indirectly by blocking migration, causing sedimentation, removing vegetation, and possibly adding chemical pollutants to the water. In severe cases, culverts and causeways can completely inhibit upstream movements of many Australian fish (Kapitzke 2007). Consequently, spawning or the migration of young individuals upstream is affected, particularly where the barriers occur at low elevations in the stream. The majority of Australian fish species need to migrate at some stage of their life cycle (Marsden 2003), with many requiring unimpeded access from the upper reaches of a catchment to the marine zone (Pusey *et al.* 2004). Different species migrate under different flow conditions, so low flow and high flow conditions need to be considered and maintained. Therefore, the design of stream culverts should ensure the safe passage of fish throughout the year.

Potential problems with poorly designed culverts include:

- Increased water velocity and turbulence caused by constriction of flow through unnaturally small openings such as culverts, preventing slow-swimming Australian fish species from moving upstream through the culvert (Kapitzke 2003).
- Increased water velocity causing scouring of the streambed and altered habitat.
- Suspended sediment suffocating fish through coating their gills, altering streambed breeding habitat and hiding potential predators (Marsden 2003).
- Removal of vegetation causing increased stream temperatures and heat stress, lowered oxygen levels and less leaf litter food for aquatic fauna.
- Drop-offs beyond the concrete apron due to stream scouring which prevent fish entry into culverts (Kapitzke 2003).

- Dark conditions that fish may avoid (Hyde 2007).
- Water depth that is too shallow for fish passage.

To achieve safe fish passage at stream crossings, culverts must be appropriately designed and, where necessary, include dedicated fishways that create suitable flow conditions over a range of stream discharges. Unimpeded flow of the stream with no alteration to the streambed (from structures such as aprons and culverts) provides the best mitigation option for important freshwater stream habitats. This is easily achieved when bridges are constructed by avoiding in-stream structures (i.e. single span) or, where multiple spans are required, using minimal bridge piers and circular or oval shaped submerged sections to minimise turbulence. Using driven rather than excavated piles will further minimise habitat disturbance. Within fish habitats, pipe culverts, causeways and energy dissipators should generally be avoided (Hyde 2007).

Where culverts are the only option, the following features should be incorporated:

- Large ridge rocks along the culvert sides.
- Minimum water depth of 0.2-0.3 metres over a minimum width of 1.0 metre and maximum invert gradient of 1:100 (NSW Fisheries 1999; 2002).
- Flow velocities limited to 0.2-0.3 metres/sec and water turbulent energy of 30 W/m^3 (Mallen-Cooper 1992).
- Earth bed channel or gravel, cobbles and small rocks to provide small riffles.
- Retaining natural watercourse width, gradient and cross-sectional area (Hyde 2007).
- A meandering alignment following the natural stream depth and position.
- No vertical drops, within or at either end of culvert.
- Natural light penetration.

Rock ramp fishways are suitable for overcoming water surface drops and provide a good fish passage solution for small-bodied species. Rock ramps can simulate a natural stream environment of riffles, pools and rapids when a gentle slope similar to the existing stream is replicated (Kapitzke 2007).

2.7 Removal of Pollutants, Sediment Traps

Traffic can be a source of heavy metal contamination in sediments and streams. Heavy metals from road, tyres, brake and engine wear, as well as from engine exhaust, are flushed into the storm water drainage network during rainfall. Investigations have demonstrated that road sediment and particles in road runoff waters are important hosts for metals. Consequently, storm water treatment devices are often focused on capturing the suspended particle load. However, the dissolved fraction of metals mobilised from road surfaces is likely to contain the highest proportion of any bio-available metal load.

Road runoff treatment systems commonly have a high retention capability for suspended sediment and therefore for particulate-bound metals. However, the retention capability for dissolved metals is usually no higher than twenty to forty percent at best and some dissolved metalloids such as As (arsenic) and Sb (antimony) are unlikely to be retained at all. For optimal retention, runoff flow rates need to be kept low enough to allow sufficient reaction time. Based on laboratory experiments this time is about two minutes (Pratt 2006).

Rainforest creek systems commonly have low suspended sediment concentrations (e.g. <5mg/L in creeks near a rainforest highway near Cairns) and both particulate and dissolved metal concentrations are very low (dissolved concentrations of metals such as Cd, Cu, Pb and Zn in the parts per billion to parts per trillion range). In comparison, road runoff waters from a rainforest

highway carrying seven thousand vehicles per day had levels of Al, Cu, Zn and Pb in the order of 4-17 times greater than background creek levels (Pratt 2006; Munksgaard and Lottermoser 2006, 2008), while levels in sediments were also elevated even at long distances from the highway source (Pratt and Lottermoser 2007b).

The potential for toxic effects from such concentration increases is unknown, although the ANZECC guideline concentrations provide an indication of potential toxicity. Rainforest highway runoff in late 2006 and early 2007 had concentrations of Al, Cu and Zn that exceeded the ANZECC guideline concentrations by approximately 3, 8 and 4 times respectively, while other metal and metalloid concentrations were below ANZECC guideline concentrations (Munksgaard and Lottermoser 2008). Accordingly, Al, Cu and Zn in road runoff waters were potentially toxic if released untreated or undiluted. However, for high conservation value areas the ANZECC guidelines recommend a precautionary approach that establishes guideline levels based on local background water quality. Therefore, high metal levels in runoff water entering rainforest creeks may be unacceptable even if levels are below ANZECC guideline values (Munksgaard and Lottermoser 2008).



Installation of runoff water treatment system on rainforest highway, northeast Queensland (Photo: Bernd Lottermoser).

While rainforest creek flows and dilution capabilities are likely to be relatively high during the 'wet' season from January to April, during the period from August to December it is very unlikely that creek dilution will be of any significant assistance in reducing metal concentrations in road runoff. Coincidentally, it is during the dry period that an extended build-up of road contaminants is likely to occur. Therefore, the months of August-December have the highest risk of a toxic flush of road runoff entering rainforest creeks.

Any treatment system to be operated in a 'low-metal' environment must be designed, manufactured and operated to stringent criteria in order to provide any significant capability of retaining dissolved metals. This task is much more difficult than treating urban runoff to standards acceptable in an urban environment. Due to the likely modest retention capability for dissolved metals of even a well functioning treatment system, any treated road runoff discharged to rainforest creek systems has to rely on substantial dilution to achieve ANZECC water quality guideline concentrations for dissolved Al, Cu and Zn. Following dilution, the affected creek waters are likely to still contain levels of dissolved metals above natural background levels (Munksgaard and Lottermoser 2008).

In addition to a self-contained treatment system, another potential mitigation option for removing pollutants is to use native wetland vegetation (i.e. sedges and rushes) in channels and sediment ponds. However, in rainforest environments this is generally not recommended due to the potential loss of rainforest habitat and increased barrier effects generated by the clearing necessary for such light-loving vegetation.

3. Revegetation Techniques

See TMR Technical Specifications for Landscape and Revegetation Works for further details.

Revegetation is an integral part of any mitigation strategy that seeks to ameliorate the negative impacts of roads on ecosystem function. The purpose can also be aesthetic or for ensuring geo-technical stability, either temporarily or permanently. In natural areas, it is desirable to always plant species that are native and naturally occurring in the location (a local provenance). The only exception to this rule is the planting of short-term cover crops for immediate soil stabilisation. These species should not be invasive weeds, and should preferably be infertile and have a strong root structure to assist stability until a more permanent species becomes established (Tucker *et al.* 2005).

The goal of revegetation is to ensure that the roadside plantings will respond, in the long-term, to existing environmental conditions and management/maintenance practices in the same way as the surrounding landscape. Timing is an important issue in determining the most appropriate revegetation/rehabilitation techniques. It is essential to establish the final objectives of revegetation in the design phase so that an appropriate lead time of twelve months is scheduled for preparing rainforest seedlings. Preparation includes collection of appropriate species, and propagation and growth to a suitable size for planting (Tucker *et al.* 2005).

Biotropica Australia recently undertook germination trials for two native fern and two native sedge species. It was determined that specialist techniques are required for fern germination, and that the sedge *Gahnia sieberiana* germinated well regardless of treatment but *G. aspera* germination was less successful, with the best results following scarification of seeds.

Revegetation projects should be outlined in the following documents: Environmental Design Report, any construction contract documents and the Environmental Management Plan (Construction)[1].

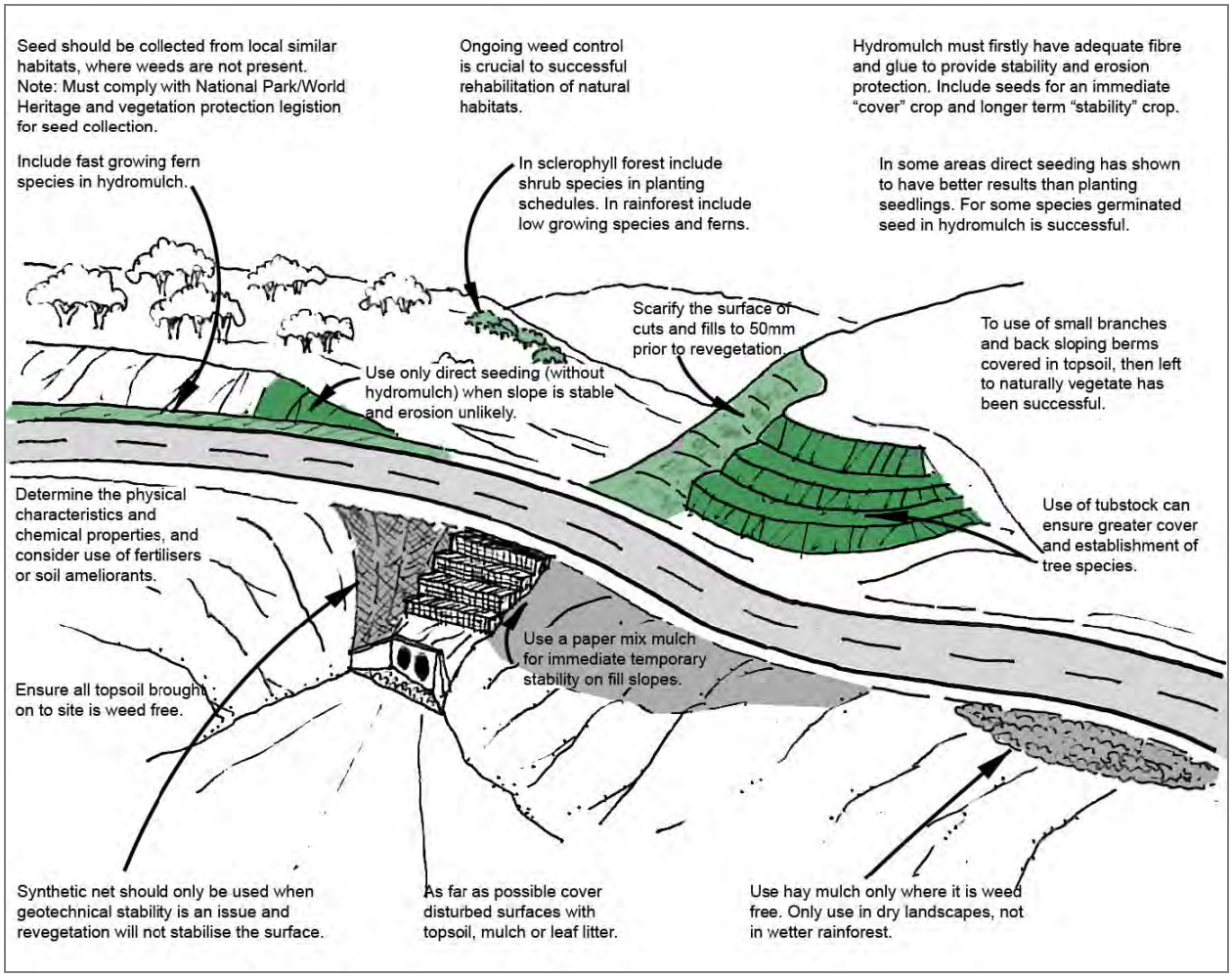
It is important to select the most appropriate rehabilitation, revegetation, soil stabilisation and waste management technique to achieve the desired result. The choice of approach is related to the:

- Conservation values to be protected;
- Ease of application;
- Accessibility;
- Cost;
- Scale (small or large);
- Timing (temporary or permanent stabilisation);
- Maintenance requirements;
- Vegetation type;
- Physical condition of the soil; and
- Stability.

Compost taken from the outside of abandoned turkey nests, (i.e. compost less than six months of age), can provide local provenances of tree species and possibly introduce beneficial fungal spores and other microorganisms to the area being planted (Westermann 2000).

It is necessary to determine whether species are best propagated vegetatively by direct seeding or whether they should be transplanted as small tube stock. Specialist expertise should be sought in determining appropriate techniques.

[1] http://www.mainroads.qld.gov.au/en/business-n-industry/road-builders/technical-publications



Rehabilitation requires proper initial site preparation and ongoing maintenance.

Recent research has shown variable effectiveness of revegetation works:

East Evelyn Road: In 2000 and 2001, cut batters were hydromulched and fill batters manually planted. In 2005 trees on the fill batters were two to four metres high and nutrient-stressed, and little recruitment of native trees had occurred on the grassed (hydromulched) cut batters.

Gillies Highway: Sections near Lake Barrine were planted with *Acacia celsa* from 1988-1994. The oldest plantings are now sixteen metres high with more recent plantings fourteen metres high. Bench planting near Lake Eacham in 1995/1996 had by 2005 resulted in mixed rainforest species growing to between ten and twelve metres.

Palmerston Highway: After twelve years, plantings undertaken in 1992/1993 have achieved eight metres' height, which is a moderate rehabilitation success (Tucker *et al.* 2005).

Some bioengineering techniques that should be considered and are discussed in more detail below include:

- Hydromulching
- Drill seeding
- Mulching
- Rock/tree placement

- Trash blanketing
- Willowing – brush matting
- Stiff grass barriers
- Cover crops and grasses
- Synthetic or organic matting
- Virotube or virocell planting

Hydromulching

Hydromulching is the use of a mixture of seed, fertiliser, mulch and binder to provide a surface that promotes plant growth. The mulch retains moisture and can be applied to areas on steep slopes that cannot be accessed by conventional techniques. Mulches may contain paper or sugar cane – both are used successfully in hydromulching. The seed mixture can be adjusted to suit local conditions and priorities, i.e., for providing temporary cover or permanent plant cover. Hydromulching should be undertaken using application rates which provide adequate fibre and glue for the site conditions. In general, use of higher rates of glue and fibre are required in wet rainforest areas. Hydrotackifiers that are used in rainforest settings include Polyacrylamide and Curasol.

Seeding

Direct seeding is a standard technique. To encourage germination, the native seed should be covered by soil or mulch and treated with an appropriate fertiliser.

Mulching

Mulches, either synthetic, or natural such as wood-chips or hay, can provide a surface that retains moisture, holds seeds and assists in seed germination. If hay is used as mulch it should be weed-free and contain no other contaminants to avoid introduction of exotic species. Straw mulch is generally only applied in dry areas and on shallow slopes where batters are lower than 1:2.5.

Rock/Tree Placement

The strategic placement of rocks, in combination with either newly established plants or vegetative debris can be beneficial for moderating water flow and providing bank stability. Rocks can also provide microhabitats that conserve water and encourage biodiversity. Figs can be used on cut and fill benches to assist with stabilisation of slopes, as well as with the achievement of habitat objectives.

Trash Blanketing

Trash blanketing is the use of cut vegetation strategically placed to protect the soil surface and provide a protected environment for germination. Seed collection from species found in habitats adjacent to road construction should be stockpiled and sown into the trash blanket in suitable weather.

Willowing

This is the technique of placing cut branches and other vegetative parts in either banks or other disturbed sites, with the aim of having the vegetative material take root to stabilise the soil surface or embankment. (Note: There are only a few rainforest plants which can fulfill this function.)

Stiff Grass Barriers

Stiff grass plants can be used along, or just off, the contour to either hold water or direct surface water away from the area. Stiff grass barriers have also been used to repair eroded surfaces by their planting as a weir in either a gully or waterway. The grass currently used for this purpose is Vetiver

grass (*Chrysopogon zizanioides*), which can spread quicker by runners. The use of stiff grass barriers in natural areas should consider the likelihood of introducing the grass as a weed. In all cases, local native species are recommended as the final vegetative cover to be achieved. The native mat rushes (*Lomandra* spp.) are an appropriate alternative to Vetiver grass in rainforest areas.

Cover Crops and Grasses

The planting of a quick cover crop can be used to aid soil stabilization on hillslopes. In areas adjacent to the road pavement, low growing grass species can be used for long-term revegetation. Traditionally, grasses with fast growth rates have been sown in these areas but these require constant mowing. Where low heights are required, the following are recommended: green couch (*Cynodon dactylon*), and broadleaf carpet grass (*Axonopus compressus*).

The use of naturally occurring ferns should also be investigated for covering batters in moist, shady situations, as their appearance and maintenance requirement is preferable to most roadside grasses. Species include: *Dicranopteris linearis*, *Sticherus flabellatus*, *Pteris pacifica*, *Nephrolepis cordifolia*, *Blechnum orientale*, *B. nudum*.

Any introduced grasses/vines that trail or climb are NOT recommended (for example): centro (*Centrosema pubescens*), siratro (*Macroptilium atropurpureum*), singapore daisy (*Sphagneticola trilobata*), molasses grass (*Melinis minutiflora*), para grass (*Urochloa mutica)*. These are all recognized as weeds of rainforest areas.

Introduced erect grasses are also not recommended, e.g. guinea grass (*Megathyrsus maximus*), due to their known or likely propensity to become pests. The only exception is Vetiver hedge grass (which only reproduces vegetatively and is not tolerant of shade, but see above) and Japanese millet (a sterile hybrid commonly used in hydro-mulching).

Matting

Matting can be used to promote regrowth and stabilise exposed earthworks. A number of matting techniques are available which protect the soil surface from erosion whilst decomposing to provide a surface that promotes growth and germination of seeds. Coconut matting is not recommended on fire prone slopes.

Tube planting, virotube, viro cell planting

Installation of viro cells is a proven technique for establishing native plants in harsh conditions. A viro cell is an Australian native grass or tree/shrub grown in an upside down pyramid like cell, which is air trimmed. The viro tube should be a minimum of 50 mm x 50 mm at the top, and a minimum of 90 mm deep with a square profile from both top and bottom views. The hole at the bottom should allow for efficient air trimming of the roots.

Summary

Successful revegetation requires continued care such as weed control and fertiliser application to maintain growth rates, especially on sites with poor soils. Nutrient cycling rates on infertile soils via litter fall are very low in most rainforests; however fast growing pioneer and early secondary species possibly incorporate less calcium and magnesium into structural material to cope with low levels of these nutrients. Fertilisers and supplements to correct soil pH do not last long in high rainfall and poor soils. A slow release mineral supplement such as Minplus has been shown to improve the nutrient status of many soils in the Wet Tropics over several years. However, such products may not always be appropriate, and alternatives such as mulching with organic material should be considered.

The use of figs and other species attractive (as perches or food sources) to fruit eaters (such as pigeons) will facilitate faunal dispersal of seeds in the area. This provides increased plant diversity

and structural complexity in the revegetated sites (Tucker 2000). Figs also provide canopy connectivity with minimal loss of branches and deeper roots that assist in stabilising embankments. However, such species are not recommended in areas where ground-dwelling threatened frugivores such as cassowaries are common, as they may attract these species to the roadside and increase road kill (Goosem 2004).

It is important that cleared areas are protected and successively revegetated as construction proceeds. Areas with no topsoil should be ripped and combed to provide areas suitable for seed germination. Revegetation should begin as soon as practicable and temporary protection be used if areas are to be exposed for more than fourteen days after earthworks cease. Before undertaking revegetation works, factors that cause erosion and sedimentation should be identified and appropriate control techniques determined. This may involve measures to divert, control and reduce the flow velocity of water and runoff. By controlling factors such as these an area may re-establish itself naturally.

Areas that are undergoing revegetation and rehabilitation works should be protected and monitored until the vegetation is self-sustaining. General goals for successful revegetation include sixty percent vegetation cover for slopes less than five percent grade and one hundred percent ground vegetation cover for slopes greater than five percent grade.

Appropriate signage and fencing should be installed to increase public awareness of revegetated areas that are sensitive to disturbance. Use of fencing and other barriers should not impede or restrict wildlife movement and other fauna activities (except in the case of direct browsing on planted tree seedlings). Trees in the work area should be protected from accidental damage by fencing, plastic barricade or fluorescent netting.

Species Selection

The ‘Framework Method’ (Goosem and Tucker 1995) is the best approach for selecting species to plant in various climatic, soil and altitude zones in the Wet Tropics Bioregion. Some of the species may also be appropriate in other rainforest regions of Queensland. For roadsides, consideration should be given to selecting the smaller, hardier species that require minimal maintenance and do not produce fruit attractive to wildlife. They should be local provenances of native species with the following characteristics:

- Easy to propagate;
- Fast growing;
- Protect/bind the soil surface;
- Are not weeds;
- Do not drop branches;
- Do not produce fruit attractive to birds (particularly cassowaries) or other frugivorous fauna;
- Do not have roots that will eventually block roadside drains;
- Are tolerant of edge conditions (sun, shade, dry and wet); and
- Appear natural in the rainforest and require little or no maintenance (mowing or spraying with herbicide).

Table 1 lists species from northeast Queensland suitable for the ‘Framework Method’ and which fulfill the characteristics listed above. Trees known to be a food source of cassowaries or known to drop branches have been deleted. Other low growing plants suitable for road verges and cuttings are suggested in Table 2. Species recommended for margin sealing in maximum and minimum light conditions and batter stabilisation are provided in Tables 3, 4 and 5 respectively.

Table 1: Suggested 'Framework' species for revegetation.
(Note: Local expertise should be sought in each bioregion.)

Species	Family	Common Name
Archirhodomyrtus beckleri	(Myrtaceae)	rose myrtle
Argyrodendron peralatum	(Sterculiaceae)	red tulip oak
Carallia brachiata	(Rhizophoraceae)	corky bark
Claoxylon tenerifolium	(Euphorbiaceae)	Queensland brittlewood
Commersonia bartramia	(Sterculiaceae)	brown kurrajong
Cryptocarya murrayi	(Lauraceae)	Murray's laurel
Cupaniopsis anacardioides	(Sapindaceae)	green-leaved tamarind
Darlingia darlingiana	(Proteaceae)	brown silky oak
Melicope xanthoxyloides	(Rutaceae)	yellow evodia
Euroschinus falcatus	(Anacardiaceae)	pink poplar
Flindersia bourjotiana	(Rutaceae)	Queensland silver ash
Franciscodendron laurifolium	(Sterculiaceae)	tulip sterculia
Glochidion philippicum	(Sapindaceae)	buttonwood
Glochidion sumatranum	(Euphorbiaceae)	buttonwood
Guioa acutifolia	(Sapindaceae)	glossy tamarind
Guioa lasioneura	(Sapindaceae)	silky tamarind
Harpullia pendula	(Sapindaceae)	tulipwood
Helicia nortoniana	(Proteaceae)	Norton's silky oak
Leea indica	(Leeaceae)	bandicoot berry
Litsea fawcettiana	(Lauraceae)	brown beech
Macaranga involucrata	(Euphorbiaceae)	macaranga
Macaranga tanarius	(Euphorbiaceae)	macaranga
Mallotus mollissimus	(Euphorbiaceae)	kamala
Mallotus philippensis	(Euphorbiaceae)	red kamala
Melicope bonwickii	(Rutaceae)	yellow evodia
Mischocarpus lachnocarpus	(Sapindaceae)	woolly pear fruit
Nauclea orientalis	(Rubiaceae)	Leichhardt tree
Homalanthus novo-guineensis	(Euphorbiaceae)	bleeding heart

Species	Family	Common Name
Pilidiostigma tropicum	(Myrtaceae)	apricot myrtle
Pittosporum ferrugineum	(Pittosporaceae)	rusty pittosporum
Pittosporum venulosum	(Pittosporaceae)	brown pittosporum
Pongamia pinnata	(Fabaceae)	pongamia
Pullea stutzeri	(Cunoniaceae)	hard alder
Rhus taitensis	(Anacardiaceae)	sumac
Scolopia braunii	(Flacourtiaceae)	flintwood
Symplocos cochinchinensis	(Symplocaceae)	white hazelwood

Trials undertaken on the Gillies, Captain Cook and Kennedy Highways have shown an orderly and expected progression of establishment of species sown in hydromulch applications. Japanese millet established immediately with couch grass, forest daisy and wattle germination following. Long lasting grasses (carpet grass and forest blue grass) established on some sites. Grasses clearly provide initial stability with subsequent germination of broadleaf natives. The wattle species *Acacia simsii*, *A. holosericea* and *A. flavescens* all had success in germination (long term success has not yet been studied) (O'Brien 2003).

A study involving the planting of fish-bone fern on gabion structures found that successful establishment depended upon the organic content in the gabion rock matrix and on an ongoing supply of water. These results suggest that new bare gabion rocks with no nutrient input from leaf litter or topsoil may have little success for plant establishment unless organic material is added.

Table 2: Suggested low-growing species for roadside revegetation in the Wet Tropics bioregion.

Species	Family
Commelina spp	Commelinaceae
Pollia spp	Commelinaceae
Alpinia modesta	Zingiberaceae
Molineria capitulata	Hypoxidaceae
Pleuranthodium racemigerum	Zingiberaceae
Tapeinochilos ananassae	Zingiberaceae
Oplismenus spp	Poaceae
Lomandra spp	Xanthorrhoeaceae
Dianella spp	Phormiaceae
Cyperus spp	Cyperaceae
Gahnia aspera	Cyperaceae
Blechnum spp	Blechnaceae
Dicranopteris linearis	Gleicheniaceae
Doodia spp	Blechnaceae
Lygodium reticulatum	Schizaeaceae
Pteris tripartite	Pteridaceae
Pteris umbrosa	Pteridaceae
Phyllanthus cuscutiflorus	Euphorbiaceae
Clerodendrum floribundum	Lamiaceae
Grevillea pteridifolia	Proteaceae
Pleomele angustifolia	Dracaenaceae

Table 3: Species suitable for margin sealing where there is maximum available light.

Species	Common Name	Life form
Rhodamnia sessiliflora	mallettwood	shrub
Gossia myrsinocarpa	lignum	shrub
Polyscias australiana	ivory basswood	small tree
Tarenna dallachiana	tarenna	small tree
Macaranga subdentata	needle bark	small tree
Macaranga inamoena	buff macaranga	small tree
Macaranga involucrata var. *mallotoides*		small tree
Mallotus philippensis	red kamala	small tree
Mallotus mollissimus	soft kamala	small tree
Jagera pseudorhus	foambark	small tree
Helicia nortoniana	Norton's oak	small tree
Guioa acutifolia	silky tamarind	small tree
Guioa lasioneura	tamarind	small tree
Pittosporum ferrugineum	rusty pittosporum	shrub
Acacia simsii	Sim's wattle	shrub
Pipturus argenteus	white nettle	small tree
Archirhodomyrtus beckleri	pink myrtle	
Phyllanthus cuscutifolurus	pink phyllanthus	small tree
Cyathea cooperi	Cooper's tree fern	tree fern
Cyathea rebeccae	Rebecca's tree fern	tree fern

Table 4: Species (growing to generally less than four metres) suitable to thicken understorey margins where light is scarce.

Species		
Pandanus monticola	*Dichapetalum papuanum*	*Podocarpus dispermus*
Mackinlaya macrosciadea	*Polyscias australiana*	*Freycinetia scandens*
Bowenia spectabilis	*Lomandra hystrix*	*Sarcotoechia serrata*
Carallia brachiata	*Clerodendrum longiflorum* var. *glabrum*	*Ficus congesta*
Alpinia caerulea	*Austromyrtus dallachiana*	*Decaspermum humile*
Pleomele angustifolia	*Pollia crispata/macrophylla*	*Alpinia modesta*
Molineria capitulata	*Pleuranthodium racemigerum*	*Tapeinochilos ananassae*
Oplismenus spp	*Gahnia sieberiana*	

Table 5: Batter stabilisation species.

Species	Common Name	Life form
Lomandra longifolia	mat rush	grass
Hibbertia scandens	snake vine	vine
Tetracera nordtiana	fire vine	vine
Pullea stutzeri (other Cunoniaceae, i.e. Pseudoweinmannia may also be suitable)	alder	tree
Malaisia scandens	burny vine	scrambler
Maclura cochinchinensis	cockspur thorn	vine
Parsonsia straminea	parsonsia	vine
Breynia cernua	coffee bush	shrub
Schefflera actinophylla	umbrella tree	tree
Acacia simsii	Sims' wattle	shrub
Gahnia aspera	sawsedge	sedge
Cyperacae species	native nut grasses, sedges	sedge
Commelina spp	scurvy weed	scrambler/groundcover
Blechnum spp *(orientales)*	fern	fern
Dicranopteris linearis	jungle brake	fern
Lygodium reticulatum	wine fern	fern

4. Glossary

Bank

A compacted ridge of soil or other material with an upslope channel, used to intercept and divert the flow of water.

Batter

A sloping section of exposed soil usually created through earthmoving and construction operations. May be a cut or fill batter.

Berm

A ledge formed at the bottom of an earth slope or at some level intermediate between the bottom and the top.

Biomass

Total quantity or weight of organisms in a given area.

Bioregion

One in a system of Biogeographic Regionalisations for Australia.

Borrow Pit

A pit from which earth has been excavated for construction operations. Also known as a gravel pit.

Carriageway

That part of a road that carries vehicles.

Catch Drain

A diversion channel constructed above a road or batter to intercept surface water.

Chute (Flume)

An open channel with a steep slope used to convey water to a lower level without erosion occurring.

Community Consultation

The process of seeking community views, aspirations, concerns and comment during a planning or environmental impact assessment process.

Community Participation

The process of involving representatives of stakeholder community groups in decision-making (for example, through advisory committees, etc.).

Conservation

The wise use of natural resources, on a sustainable basis, to meet the needs of both present and future generations.

Corridor

A narrow tract of a natural ecosystem in an area of largely modified ecosystems, or a tract of land through which a road passes (including the road surface plus its maintained roadsides and any parallel vegetated strips, such as a median strip between lanes in a highway).

Cross Section

The transverse profile of a road showing horizontal and vertical dimensions.

Culvert

A covered channel used to carry water under the road surface (usually a pipe but larger watercourses often use one or more box sectioned concrete structures)

Curve Widening

The widening of the travelled way on sharp curves to compensate for the fact that the rear wheels of a vehicle do not follow exactly in the track of the front wheels.

Curvilinear Alignment

A flowing alignment in which the majority of its length is composed of circular and spiral curves.

Cut

Portion of land surface from which earth has been removed by excavation; the depth below original ground surface to excavated surface.

Design Speed

A speed selected for purposes of design and correlation of the physical features of a road that influences vehicle operation. It is the maximum safe speed that can be maintained over a specified section of the road when conditions are favourable.

Design Volume

A volume determined for use in design, representing the traffic expected to use the road.

Design Vehicle

A selected motor vehicle, the weight, dimensions, and operating characteristics of which are used as a control in road design.

Diversion Bank

A bank used to intercept and divert large volumes of water.

Disturbed Area

An area in which the natural vegetation and/or soil cover has been removed or altered, and which is therefore susceptible to erosion.

Drop Structure

A structure that allows water to fall to a lower level without eroding the channel bed.

Ecosystem

A community of organisms interacting with one another and with the environment in which they live.

Embankment

A raised earth structure on which the roadway pavement structure is placed.

Endangered

Species in danger of extinction and unlikely to survive unless threats are removed.

Endemic

A plant or animal species or other taxonomic group restricted to a particular geographic region.

Environmental Management System (EMS)

A comprehensive approach to environmental management that seeks to continually enhance environmental performance.

Erodibility (of soil)

The susceptibility of soil material to detachment and transportation by wind or water.

Erosion

Detachment and movement of soil or rock fragments by water, wind, ice or gravity.

Erosion Risk

The intrinsic susceptibility of a parcel of land to the prevailing agents of erosion. Land management factors are ignored, and erosion risk is dependent on climate, landform and soil factors.

Erosion Hazard

The relative susceptibility of land to the prevailing agents of erosion. Erosion hazard is dependent on climatic factors, landform, soils and land use.

Erosion Control Structure

A structure designed to control erosion. They include banks, hydromulching, fibre blankets, culverts, inverts, stilling ponds and drains.

Fauna

All animal life.

Feral Animal

An animal other than native wildlife.

Fill

Material (usually excavated soil rock, but may be solid waste, etc.) used to raise the surface of an area to a desired level.

Floodplain

Level or nearly level area which adjoins the channel of a natural stream and which is subject to overflow flooding.

Flora

Plant life.

Formed Road

A road that has been constructed and maintained.

Framework Species

Group of tree species with traits including being tough, having fast-growth that can shade out weeds, and regularly providing food or perches which makes them attractive to animals from nearby forests that disperse and deposit seed. Therefore a large range of plant species are brought into the area by natural means and biodiversity increases.

Gabion

A rectangular box made from steel wire mesh that is filled with quarried stone or river shingle. Gabions may be assembled into many types of structures such as revetments, retaining walls, channel liners, and drop structures.

Gravel Outlet

Gravel placed to function as a filter-type outlet for runoff stored behind a perimeter bank or other structure which ponds sediment-laden runoff. The gravel outlet sometimes incorporates a core of weed-free hay bales.

Grade Stabilisation Structure

A structure usually used in a gully that slows water down and encourages the deposition of sediment. Also called a drop structure.

Graded Bank

An earthen bank built slightly off the slope to provide a fall in the channel of the diversion of water.

Gully

An erosion channel, generally more than thirty centimetres deep.

Gully Erosion

The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 300 mm to several metres.

Horizontal Curve

A curve or transitional zone by means of which a road can change direction to the right or left.

Hourly Volume

The number of vehicles passing over a given section of lane or roadway during one hour.

Hydromulching

Pumping of liquid rehabilitation material on to steep slopes, banks, cuts and eroded gullies to provide immediate protective cover.

Impact

Having an effect on the integrity of the natural, cultural or social values.

Integrity

The extent to which the natural heritage values of the Area are in their natural ecological, physical and aesthetic condition, and are capable of sustaining themselves in the long term.

Infiltration (of soil)

Movement of water from the ground surface into a soil.

Median

The portion of a divided roadway separating the travelled ways for traffic in opposite directions.

Mulch

A natural or artificial layer of material placed on the soil surface to provide protection against erosion and to assist the establishment of vegetation. Examples include chipped vegetation, hay and finely woven netting.

Mulching

The application of plant residues or other suitable materials to the land surface to conserve moisture, hold soil in place, aid in establishing plant cover, increase infiltration and minimise temperature fluctuations.

New Jersey Barrier

A concrete barrier used to separate opposing traffic flows. Used in narrow medians.

Provenance

A geographic area in which a species has developed particular characteristics recognisably different from the characteristics of the species from other areas.

Rare

Flora and fauna with small world populations that are not at present endangered or vulnerable but are at risk. Usually localised in restricted geographical areas or habitats.

Recovery Width

The width between the edge of traffic lane and an obstruction eg. tree, that is available for vehicles to recover in before they hit the obstruction. This width is usually 9 m.

Regional Ecosystems

In Queensland, regional ecosystems are broadly defined as a vegetation type and its conservation status. The mapping of ecosystems is based on broad structural and floristic classes, the underlying geomorphology and bioregion, and by additional delineation by elevation and other relevant factors.

Review of Environmental Factors (REF)

A preliminary assessment of likely or potential environmental impacts of a proposal.

Riparian Vegetation

Vegetation occurring along the banks of a river or natural watercourse.

Rill

A small erosion channel that disappears if cultivated.

Ripping

Loosening soil without inverting it to allow improved root and water penetration.

Roadway

The portion of a highway, including shoulders, for vehicular use. A divided highway has two or more roadways.

Sclerophyll

Hard, leathery-leaved plants (eg. eucalypts).

Sediment Basin

A basin used to trap sediment from runoff, often constructed as a barrier or dam on a drainage line.

Sedimentation

Deposition of detached soil particles.

Sheet Erosion

The removal of a fairly uniform layer of soil from the land surface.

Shoulder

The portion of the roadway contiguous with the travelled way for accommodation of stopped vehicles, for emergency use, and for lateral support of base and surface courses.

Sight Distance

The length of roadway ahead visible to a driver.

Silt Trap

Also called a sediment trap. A structure designed to collect and trap sediment carried in runoff.

Slash

Material left on the ground after harvesting operations including tree heads, shrubs and other non-merchantable woody material.

Species

A group of plants or animals with genetic attributes and characteristics in common, which do not generally interbreed with other groups and/or produce fertile offspring.

Soil Structure

The combination or arrangement of primary soil particles (clay, silt, sand and gravel) into aggregates, and their stability. An important property with respect to the erosion resistance of soils.

Table Drain

A drain running along the side of a road or track to collect runoff from the road/track surface.

Threatened

Species, which due to natural or other processes, may be in danger of extinction according to state or commonwealth listing criteria. This includes species of endangered, vulnerable and poorly known status.

Toe (of slope)

Point where a slope stops or levels out. Bottom of the slope.

Topdress (of fertiliser)

Apply fertiliser to established or establishing vegetation to maintain the supply of soil nutrients and to provide a continuing stimulus to plant growth.

Tropical Rainforest

Closed canopy forests growing in tropical areas (excluding mangroves).

Understorey

Forest vegetation growing below the forest canopy.

Undesirable Plant

A plant listed in Appendix 4 of the *Nature Conservation Act 1992.*

Undisturbed

An area in its natural state that has not been altered by human activity.

Vulnerable

Flora or fauna species believed likely to move closer to extinction in the near future if causal factors continue operating.

Wet Tropics Bioregion

The high rainfall tropical region of northeastern Queensland, generally between Townsville and Cooktown.

World Heritage Area

An area internationally recognised as having outstanding universal value and registered on the World Heritage list.

World Heritage Values

Natural (and cultural) heritage that is of outstanding universal value and which enables an area to meet the requirements under the guidelines for listing as a World Heritage site.

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7. Appendix: Rainforest Regional Ecosystems

Regional Ecosystem	Description	Status	Biodiversity Status
CAPE YORK PENINSULA BIOREGION			
3.2.1	Evergreen notophyll vine forest in coastal dunefield systems	Of concern	Of concern
3.2.2	Semi-deciduous vine thicket to vine forest on beach dunes and ridges	Least concern	Of concern
3.2.11	Low microphyll vine forest. Occurs on coastal dunes and beach ridges	Least concern	No concern at present
3.2.12	*Araucarian* microphyll vine forest on coastal dunefields and beach ridges	Least concern	Of concern
3.2.13	Evergreen notophyll vine forest on beach ridges on the east coast	Of concern	Of concern
3.2.28	Evergreen notophyll vine forest on beach ridges on coral atolls, shingle cays and sand cays	Of concern	Of concern
3.2.29	*Pisonia grandis* low closed forest restricted to a few scattered sand cays	Of concern	Endangered
3.2.31	*Premna serratifolia* closed scrub on coral atolls, shingle cays and sand cays	Of concern	Of concern
3.3.1	Closed semi-deciduous mesophyll vine forest on loamy alluvia	Least concern	No concern at present
3.3.2	Semi-deciduous mesophyll/notophyll vine forest on alluvia	Least concern	Of concern
3.3.3	Semi-deciduous notophyll/microphyll vine thicket on slopes of Melville Range	Of concern	Of concern
3.3.4	Evergreen mesophyll vine forest with *Archontophoenix* spp. on stream banks	Of concern	Of concern
3.3.5	Evergreen notophyll vine forest on alluvia on major watercourses	Least concern	No concern at present
3.3.6	Evergreen notophyll vine forest with *Melaleuca leucadendra* on swamps	Of concern	Of concern
3.3.7	Tall semi-deciduous notophyll/microphyll vine thicket on colluvial plains	Of concern	Of concern

Regional Ecosystem	Description	Status	Biodiversity Status
3.3.38	Deciduous microphyll vine thicket ± *Lagerstroemia archeriana* on heavy clay alluvium	Least concern	No concern at present
3.3.39	Semi-deciduous microphyll vine forest ± *Melaleuca* spp. associated with sinkholes	Of concern	Of concern
3.3.40	*Terminalia* sp. deciduous vine thicket in depressions in Lakefield area	Of concern	Of concern
3.3.68	Semi-deciduous notophyll vine forest and thicket on alluvial plains	Of concern	Of concern
3.5.3	Semi-deciduous notophyll vine forest restricted to lateritic Carnegie Tableland	Of concern	Of concern
3.5.4	Semi-deciduous notophyll vine forest in small patches on northern plateaus	Least concern	No concern at present
3.5.20	Simple evergreen notophyll vine forest with *Eucalyptus pellita* on sandstone plateaus	Of concern	Of concern
3.7.1	Semi-deciduous notophyll/microphyll vine thicket on isolated lateritic hillslopes	Of concern	Of concern
3.8.1	Complex mesophyll vine forest on basalt lowlands	Endangered	Endangered
3.8.2	Semi-deciduous notophyll/microphyll vine forest on basalt	Of concern	Of concern
3.8.5	Semi-deciduous and deciduous notophyll vine forest on basaltic islands of Torres Strait	Of concern	Of concern
3.10.1	Evergreen mesophyll/notophyll vine forest restricted to sandstone gullies	Of concern	Of concern
3.10.2	Simple evergreen notophyll vine forest on flat sandstone and ferricrete plateaus	Of concern	Of concern
3.10.3	Simple evergreen notophyll vine forest with *Callitris intratropica* on low hills	Of concern	Of concern
3.10.5	Deciduous notophyll/microphyll vine thicket ± *Gyrocarpus americanus* or *Eucalyptus pellita* emergents on sandstone hills and slopes	Of concern	Of concern
3.11.1	Semi-deciduous mesophyll vine forest on coastal ranges	Of concern	Of concern
3.11.2	Semi-deciduous mesophyll vine forest on metamorphic ranges in the south	Of concern	Of concern

Regional Ecosystem	Description	Status	Biodiversity Status
3.11.3	Simple evergreen notophyll vine forest on exposed metamorphic and granitic slopes	Least concern	No concern at present
3.12.1	Semi-deciduous mesophyll/notophyll vine forest on granite slopes, in the central bioregion	Of concern	Of concern
3.12.2	Araucarian notophyll vine forest on granitic ridges and mountains	Of concern	Of concern
3.12.3	Notophyll vine forest on granitic slopes and plateaus	Least concern	No concern at present
3.12.4	Notophyll vine forest of *Welchiodendron longivalve* and *Acacia polystachya* on low hills and rises on volcanics	Of concern	Of concern
3.12.5	Simple evergreen notophyll vine forest. Upper slopes of mountains and ranges in the south	Of concern	Of concern
3.12.6	Simple evergreen notophyll vine forest ± *Wodyetia bifurcata* on colluvium of granite ranges	Of concern	Of concern
3.12.20	Evergreen notophyll vine forest dominated by *Welchiodendron longivalve* on headlands	Of concern	Of concern
3.12.21	Deciduous vine thicket on granitic slopes	Least concern	No concern at present
3.12.22	Deciduous vine thicket on granitic slopes ± *Wodyetia bifurcate* on granite boulders	Of concern	Of concern
3.12.33	Granite boulders interspersed with vine thicket	Of concern	Of concern
3.12.35	Semi-deciduous mesophyll/notophyll vine forest on granite slopes of Torres Strait Islands	Of concern	Of concern
3.12.36	Evergreen to complex evergreen mesophyll to notophyll vine forest and thicket on mountain ranges of Torres Strait Islands	Of concern	Of concern
CENTRAL QUEENSLAND BIOREGION			
8.2.2	Microphyll vine forest on coastal dunes	Of concern	Endangered
8.2.5	Notophyll feather palm vine forest dominated by *Archontophoenix cunninghamiana* on parabolic dunes	Of concern	Of concern

Regional Ecosystem	Description	Status	Biodiversity Status
8.3.1	Semi-deciduous notophyll/mesophyll vine forest fringing watercourses on alluvial plains	Of concern	Endangered
8.3.9	Complex notophyll vine forest on perched alluvials in valleys of undulating mountain ranges	Of concern	Of concern
8.3.10	Notophyll vine forest with variable dominants, on gently to moderately sloping alluvial fans adjacent to ranges	Of concern	Of concern
8.8.1	Complex notophyll (feather palm) vine forest on Tertiary basalt	Of concern	Of concern
8.11.2	Notophyll/microphyll vine forest ± Araucaria cunninghamiana on low ranges on Permian sediments ± volcanics	Of concern	Of concern
8.12.1	Complex notophyll (feather palm) vine forest often with *Acmena resa* and *Syzygium wesa*, of wet uplands on Mesozoic to Proterozoic igneous rocks	Least concern	No concern at present
8.12.2	Notophyll to complex notophyll vine forest often with *Argyrodendron actinophyllum* subsp. *diversifolium* ± *A. polyandrum*, on drier uplands and coastal ranges on Mesozoic to Proterozoic igneous rocks	Least concern	No concern at present
8.12.3	Notophyll/microphyll rainforest often with *Argyrodendron polyandrum* and *Paraserianthes toona*, ± *Araucaria cunninghamii*, on low to medium ranges on Mesozoic to Proterozoic igneous rocks	Least concern	No concern at present
8.12.11	Semi-deciduous microphyll vine forest/thicket with emergent *Araucaria cunninghamii* in coastal areas including islands, on Mesozoic to Proterozoic igneous rocks and Tertiary acid to intermediate volcanics and granite	Least concern	No concern at present
8.12.16	Low microphyll vine forest to semi-evergreen vine thicket on drier subcoastal hills on Mesozoic to Proterozoic igneous rocks	Of concern	Of concern
8.12.17	Notophyll mossy evergreen vine forest on mountain slopes and summits subject to regular mist cover, on Mesozoic and Proterozoic igneous rocks	Of concern	Of concern

Regional Ecosystem	Description	Status	Biodiversity Status
8.12.18	Notophyll to complex notophyll vine forest with *Argyrodendron polyandrum* ± *Argyrodendron* sp. (Whitsundays W.J. McDonald 5831) ± *Araucaria cunninghamii*, on near-coastal ranges and islands, on Mesozoic to Proterozoic igneous rocks	Least concern	No concern at present
8.12.19	Complex notophyll feather palm vine forest with *Argyrodendron actinophyllum* subsp. *diversifolium* and subcanopy of *Myristica globosa* subsp. *muelleri*, on moist, low to moderate, coastal and subcoastal ranges on Mesozoic to Proterozoic igneous rocks	Least concern	No concern at present
8.12.28	Low microphyll vine forest to semi-evergreen vine thicket with *Acacia fasciculifera*, on foothills of low, near-coastal ranges, on acid to intermediate volcanics	Of concern	Of concern
8.12.30	Notophyll mossy evergreen vine forest dominated by *Ristantia waterhousei*, on upper slopes and summits of mountains on rhyolite	Of concern	Of concern
EINASLEIGH UPLANDS BIOREGION			
9.5.2	Semi-evergreen vine thicket on red kandosols on Tertiary plateaus	Of concern	Of concern
9.8.3	Semi-evergreen vine thicket on Quaternary basalt soils	Of concern	Of concern
9.8.7	Semi-evergreen vine thicket on cones, craters and rocky basalt flows with little soil development	Least concern	Of concern
9.11.8	Semi-deciduous vine thicket on limestone outcrops	Least concern	Of concern
9.11.9	Semi-deciduous vine thicket on metamorphic soils (not limestone)	Of concern	Of concern
9.12.8	Semi-evergreen vine thicket on rocky outcrops and shallow soils of acid volcanic rocks	Least concern	No concern at present
SOUTH EAST QUEENSLAND BIOREGION			
12.2.1	Notophyll vine forest on parabolic high dunes	Of concern	Of concern
12.2.2	Microphyll/notophyll vine forest on beach ridges	Of concern	Endangered
12.2.3	Araucarian vine forest on parabolic high dunes	Of concern	Of concern

Regional Ecosystem	Description	Status	Biodiversity Status
12.3.1	Gallery rainforest (notophyll vine forest) on alluvial plains	Endangered	Endangered
12.5.13	Microphyll to notophyll vine forest ± *Araucaria cunninghamii*	Endangered	Endangered
12.8.3	Complex notophyll vine forest on Cainozoic igneous rocks. Altitude ‹600m	Least concern	No concern at present
12.8.4	Complex notophyll vine forest with *Araucaria* spp. on Cainozoic igneous rocks	Least concern	No concern at present
12.8.5	Complex notophyll vine forest on Cainozoic igneous rocks. Altitude usually ›600m	Least concern	No concern at present
12.8.6	Simple microphyll fern forest with *Nothofagus moorei* on Cainozoic igneous rocks	Of concern	Of concern
12.8.7	Simple microphyll fern thicket with *Acmena smithii* on Cainozoic igneous rocks	Of concern	Of concern
12.8.13	Araucarian complex microphyll vine forest on Cainozoic igneous rocks	Of concern	Of concern
12.8.18	Simple notophyll vine forest with *Ceratopetalum apetalum* on Cainozoic igneous rocks	Of concern	Of concern
12.8.21	Semi-evergreen vine thicket with *Brachychiton rupestris* on Cainozoic igneous rocks. Usually southern half of bioregion	Endangered	Endangered
12.8.22	Semi-evergreen vine thicket with *Brachychiton australis* on Cainozoic igneous rocks. Usually northern half of bioregion.	Endangered	Endangered
12.9-10.15	Semi-evergreen vine thicket with *Brachychiton rupestris* on sedimentary rocks	Endangered	Endangered
12.9-10.16	Araucarian microphyll to notophyll vine forest on sedimentary rocks	Endangered	Endangered
12.11.1	Simple notophyll vine forest often with abundant *Archontophoenix cunninghamiana* (“gully vine forest”) on metamorphics ± interbedded volcanics	Least concern	No concern at present
12.11.4	Semi-evergreen vine thicket on metamorphics ± interbedded volcanics	Of concern	Of concern
12.11.10	Notophyll vine forest ± *Araucaria cunninghamii* on metamorphics ± interbedded volcanics	Least concern	No concern at present

Regional Ecosystem	Description	Status	Biodiversity Status
12.11.11	Araucarian microphyll vine forest on metamorphics ± interbedded volcanics; southern half of bioregion	Least concern	No concern at present
12.11.12	Araucarian microphyll vine forest on metamorphics ± interbedded volcanics; northern half of bioregion	Of concern	Of concern
12.12.1	Simple notophyll vine forest usually with abundant *Archontophoenix cunninghamiana* ('gully vine forest') on Mesozoic to Proterozoic igneous rocks	Of concern	Of concern
12.12.13	Araucarian complex microphyll to notophyll vine forest on Mesozoic to Proterozoic igneous rocks	Least concern	No concern at present
12.12.16	Notophyll vine forest on Mesozoic to Proterozoic igneous rocks	Least concern	No concern at present
12.12.17	Semi-evergreen vine thicket on Mesozoic to Proterozoic igneous rocks; south of bioregion	Endangered	Endangered
12.12.18	Semi-evergreen vine thicket on Mesozoic to Proterozoic igneous rocks; north of bioregion	Of concern	Of concern
WET TROPICS			
7.2.1	Mesophyll vine forest on beach ridges and sand plains of beach origin	Endangered	Endangered
7.2.2	Notophyll to microphyll vine forest on sands of beach origin	Of concern	Endangered
7.2.5	Mesophyll to notophyll vine forest of *Syzygium forte* subsp. *forte* on sands of beach origin	Of concern	Of concern
7.3.3	Mesophyll vine forest with Alexandra palm (*Archontophoenix alexandrae*) on poorly drained alluvial plains	Of concern	Endangered
7.3.4	Mesophyll vine forest with fan palm (*Licuala ramsayi*) on poorly drained alluvial plains, and alluvial areas of uplands	Of concern	Endangered
7.3.7	Red stringybark (*Eucalyptus pellita)* and Pink Bloodwood (*Corymbia intermedia)* open-forest to woodland (or vine forest with emergent *E. pellita* and *C. intermedia*), on poorly drained alluvial plains	Endangered	Endangered
7.3.10	Simple-complex mesophyll to notophyll vine forest, on moderately to poorly-drained alluvial plains, of moderate fertility	Of concern	Endangered

Regional Ecosystem	Description	Status	Biodiversity Status
7.3.11	Mesophyll vine forest with red stringybark (*Eucalyptus pellita*) emergents on very wet to wet, well drained lowland alluvial soils	Of concern	Of concern
7.3.17	Complex mesophyll vine forest on well drained alluvium of high fertility	Endangered	Endangered
7.3.19	*Corymbia intermedia* or *C. tessellaris* +/- *Eucalyptus tereticornis* open-forest (or vine forest with these species as emergents), on well-drained alluvium	Of concern	Of concern
7.3.20	*Corymbia intermedia* and S*yncarpia glomulifera*, or *C. intermedia* and *Eucalyptus pellita*, or *S. glomulifera* and *Allocasuarina* spp., or *E. cloeziana*, or *C. torelliana* open-forest (or vine forest with these emergents, on alluvial fans at the base of ranges	Of concern	Of concern
7.3.23	Simple – complex semi-deciduous notophyll to mesophyll vine forest on lowland alluvium, predominantly riverine levees	Endangered	Endangered
7.3.25	*Melaleuca leucadendra* ± vine forest species, open forest to closed forest, on alluvium fringing streams	Of concern	Of concern
7.3.35	*Acacia mangium* and/or *A. celsa* and/or *A. polystachya* closed-forest on alluvial plains	Endangered	Endangered
7.3.36	Complex mesophyll vine forest or simple notophyll vine forest of high rainfall, cloudy uplands on alluvium	Of concern	Endangered
7.3.37	Complex semi-evergreen notophyll vine forest of uplands on alluvium	Endangered	Endangered
7.3.38	Complex notophyll vine forest with emergent *Agathis robusta* on alluvial fans	Of concern	Of concern
7.3.42	Rose Gum *(Eucalyptus grandis)* open-forest to woodland (or vine forest with emergent *E. grandis*), on alluvium	Of concern	Endangered
7.3.49	Notophyll vine forest on rubble terraces of streams	Of concern	Of concern
7.3.50	*Melaleuca fluviatilis* +/- vine forest species, open-forest to closed-forest, on alluvium fringing streams	Of concern	Endangered

Regional Ecosystem	Description	Status	Biodiversity Status
7.8.1	Complex mesophyll vine forest on well drained basalt lowlands and foothills	Least concern	Endangered
7.8.2	Complex mesophyll vine forest of high rainfall, cloudy uplands on basalt, including small areas of wind-sheared notophyll vine forest on ridgelines	Least concern	Of concern
7.8.3	Complex semi-evergreen notophyll vine forest of uplands on basalt	Endangered	Endangered
7.8.4	Simple to complex notophyll vine forest of cloudy wet highlands on basalt	Least concern	Endangered
7.8.5	Notophyll vine forest dominated by blackwood (*Acacia melanoxylon*) and/or brown salwood (*Acacia* celsa) on cloudy wet basalt uplands and highlands	Of concern	Of concern
7.8.6	Semi-deciduous mesophyll vine forest on moist basalt foothills	Endangered	Endangered
7.8.11	Closed vineland of wind-disturbed vine forest, on basalt foothills and coastal ranges	Of concern	Of concern
7.8.12	Complex notophyll vine forest dominated by *Backhousia bancroftii*, on basaltic terraces and scree slopes of the North Johnstone River	Of concern	Endangered
7.8.13	Simple notophyll vine forest of *Blepharocarya involucrigera* of high rainfall, cloudy uplands on basalt	Of concern	Endangered
7.8.14	Complex notophyll vine forest with emergent *Agathis robusta*, on basalt	Of concern	Endangered
7.8.15	Rose Gum (*Eucalyptus grandis)* open-forest to woodland (or vine forest with *E. grandis* emergents), on basalt	Of concern	Endangered
7.11.1	Simple-complex mesophyll to notophyll vine forest on moderately to poorly drained metamorphics (excluding amphibolites) of moderate fertility of the moist and wet lowlands, foothills and uplands	Least concern	No concern at present
7.11.2	Notophyll or mesophyll vine forest with *Archontophoenix alexandrae* or *Licuala ramsayi*, on metamorphics	Of concern	Of concern
7.11.3	Semi-deciduous mesophyll vine forest on moist and dry metamorphic foothill slopes	Of concern	Of concern

Regional Ecosystem	Description	Status	Biodiversity Status
7.11.5	Red Stringybark (*Eucalyptus pellita*) +/- Pink Bloodwood (*Corymbia intermedia*) open-forest (or vine forest with *E. pellita* and *C. intermedia* emergents) on lowlands and foothills on metamorphics	Least concern	No concern at present
7.11.6	Simple mesophyll vine forest with turpentine (*Syncarpia glomulifera*) emergents on very wet to wet metamorphic lowlands and foothills	Of concern	Of concern
7.11.7	Complex notophyll vine forest with kauri pine (*Agathis robusta*) emergents on foothills and uplands, on metamorphics	Least concern	No concern at present
7.11.8	*Acacia polystachya* woodland to closed-forest, or *Acacia mangium* and *Acacia celsa* open-forest to closed-forest, on metamorphics	Of concern	Of concern
7.11.9	Notophyll semi-evergreen vine forest on moist to dry metamorphic foothills and uplands	Least concern	No concern at present
7.11.10	Brown Salwood (*Acacia celsa*) open-forest to closed-forest on metamorphics	Of concern	Of concern
7.11.11	Notophyll vine forest dominated by *Acacia cincinnata*/*Acacia polystachya* on wet metamorphic foothills and uplands	Of concern	Of concern
7.11.12	Simple notophyll vine forest of moist to very wet metamorphic uplands and highlands	Least concern	No concern at present
7.11.13	Cadaghi *(Corymbia torelliana)* open-forest, usually with a vine forest element, on metamorphics	Of concern	Endangered
7.11.14	Rose Gum (*Eucalyptus grandis*) open-forest to woodland, or Pink Bloodwood (*Corymbia intermedia*), Red Stringybark (*E. pellita*), and *E. grandis*, open-forest to woodland (or vine forest with these species as emergents) on metamorphics	Of concern	Endangered
7.11.15	Simple notophyll vine forest dominated by blackwood (*Acacia melanoxylon*), brown salwood (*Acacia celsa*) on cloudy wet metamorphic uplands and highlands	Least concern	No concern at present

Regional Ecosystem	Description	Status	Biodiversity Status
7.11.18	Pink Bloodwood (*Corymbia intermedia)* and/or Moreton Bay Ash (*C. tessellaris*) +/- Forest Red Gum (*Eucalyptus tereticornis*) open-forest to woodland (or vine forest with these species as emergents) on coastal metamorphic headlands and foothills	Of concern	Of concern
7.11.23	Complex mesophyll vine forest on fertile, well drained metamorphics of very wet and wet footslopes	Of concern	Of concern
7.11.24	Closed vineland of wind-disturbed vine forest of metamorphic slopes, often steep and exposed	Of concern	Of concern
7.11.25	Simple-complex mesophyll to notophyll vine forest on amphibolites of the very wet lowlands and foothills	Of concern	Of concern
7.11.27	Simple microphyll vine-fern forest or microphyll vine-sedge forest of wet metamorphic uplands and highlands	Of concern	Of concern
7.11.28	Wind-sheared notophyll vine forest of exposed metamorphic ridge-crests and steep slopes	Of concern	Of concern
7.11.29	Microphyll to notophyll vine forests with *Ceratopetalum virchowii* and/or *Uromyrtus metrosideros, Flindersia bourjotiana, F. pimenteliana* and *Beilschmiedia oligandra* of moist uplands, on sharply undulating metamorphics	Of concern	Of concern
7.11.30	Simple notophyll vine forest of *Blepharocarya involucrigera* on metamorphics	Of concern	Of concern
7.11.31	Red Mahogany (*Eucalyptus resinifera) +/-* White Mahogany (*Eucalyptus portuensis) +/-* Turpentine (*Syncarpia glomulifera)* open-forest to woodland (or vine forest with these species as emergents) on metamorphics	Of concern	Of concern
7.11.32	Turpentine (*Syncarpia glomulifera*) and/or Allocasuarina spp. +/- heathy understorey, woodland to tall woodland to open-forest (or vine forest with these species as emergents) on steep rocky metamorphic slopes with shallow soils	Of concern	Of concern

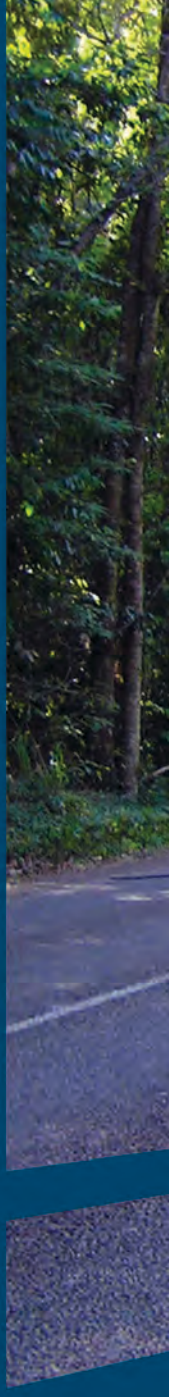
Regional Ecosystem	Description	Status	Biodiversity Status
7.11.38	Brush Box (*Lophostemon confertus*) low woodland to low closed-forest +/- Brown Salwood (*Acacia celsa*), Turpentine (*Syncarpia glomulifera*) and *Allocasuarina* spp. on steep metamorphic slopes	Of concern	Of concern
7.11.40	Complex of sclerophyll communities dominated by Turpentine (*Syncarpia glomulifera*), or Tea Tree (Melaleuca spp)., or sedges, or ferns, or microphyll vine forest with *Trochocarpa bellendenkerensis* on highlands, on quartzite or associated metamorphics	Of concern	Of concern
7.12.1	Simple-complex mesophyll to notophyll vine forest of moderately to poorly-drained granites and rhyolites of moderate fertility of the moist and wet lowlands, foothills and uplands	Least concern	No concern at present
7.12.2	Notophyll or mesophyll vine forest with feather palm (*Archontophoenix alexandrae*) or fan palm (*Licuala ramsayi*), on granites and rhyolites	Of concern	Of concern
7.12.4	Mesophyll vine forest with turpentine (*Syncarpia glomulifera*) emergents on very wet granite and rhyolite lowlands and foothills	Of concern	Of concern
7.12.5	Red Stringybark (*Eucalyptus pellita*) +/- Pink Bloodwood (*Corymbia intermedia*) open-forest, or *Acacia mangium* and Brush Box (*Lophostemon suaveolens*) open-forest, (or vine forest with these species as emergents), on granite and rhyolite	Of concern	Endangered
7.12.6	Semi-deciduous mesophyll vine forest on granites and rhyolites, of the moist and dry lowlands and foothills	Of concern	Of concern
7.12.7	Simple to complex microphyll to notophyll vine forest, often with Kauri Pine (*Agathis robusta*) or *A. microstachya*, on granites and rhyolites of moist foothills and uplands	Least concern	No concern at present
7.12.9	Brown Salwood (*Acacia celsa*) open-forest to closed forest, on granites and rhyolites	Of concern	Of concern
7.12.10	Notophyll vine forest with emergent hoop pine (*Araucaria cunninghamii*) of the moist and dry foothills and uplands on granites and rhyolites of the Seaview and Paluma Ranges	Of concern	Of concern

Regional Ecosystem	Description	Status	Biodiversity Status
7.12.11	Simple to complex notophyll vine forest and semi-evergreen notophyll vine forest of rocky areas and talus, on moist foothills and uplands on granite and rhyolite	Least concern	Of concern
7.12.12	*Acacia mangium* and *A. celsa* open-forest to closed-forest *or A. polystachya* woodland to closed-forest of granite and rhyolite foothills	Of concern	Of concern
7.12.13	Blackwood (*Acacia melanoxylon*) and Brown Salwood (*A. celsa*) closed-forest of cloudy wet uplands and highlands on granites and rhyolites	Of concern	Of concern
7.12.16	Simple to complex notophyll vine forest, including small areas of Bunya Pine (*Araucaria bidwilli*) of cloudy wet and moist uplands and highlands on granites and rhyolites	Least concern	No concern at present
7.12.17	Cadaghi (*Corymbia torelliana*) open-forest usually with a well developed simple notophyll vine forest element, on granites and rhyolites	Of concern	Endangered
7.12.18	Microphyll vine forest often with hoop pine (*Araucaria cunninghamii*) on moist to dry granite foothills and uplands	Of concern	Of concern
7.12.19	Simple microphyll vine-fern forest with *Balanops australiana*, *Elaeocarpus* spp. +/- *Trochocarpa bellendenkerensis* +/- *Uromyrtus* spp. +/- *Agathis atropurpurea* of cloudy wet highlands, on granite and rhyolite	Least concern	No concern at present
7.12.20	Simple microphyll vine-fern thicket of windswept exposed peaks on granite	Of concern	Of concern
7.12.21	Rose Gum (*Eucalyptus grandis*) open-forest to woodland, or Pink Bloodwood (*Corymbia intermedia*), Red Stringybark (*E. pellita*), and *E. grandis*, open-forest to woodland, (or vine forest with these species as emergents) on granite and rhyolite	Least concern	Endangered
7.12.22	Red Mahogany (*Eucalyptus resinifera*) +/- White Mahogany (*E. portuensis*) +/- Turpentine (*Syncarpia glomulifera*) tall open-forest to tall woodland (or vine forest with these species as emergents) of granite and rhyolite uplands and highlands	Least concern	Endangered

Regional Ecosystem	Description	Status	Biodiversity Status
7.12.23	Pink Bloodwood (*Corymbia intermedia*) and/or Moreton Bay Ash (*C. tessellaris*) +/- Forest Red Gum (*Eucalyptus tereticornis*), open-forest to tall open-forest to woodland (or vine forest with these species as emergents) on coastal granite and rhyolite headlands and near-coastal foothills	Of concern	Endangered
7.12.24	White Mahogany (*Eucalyptus portuensis*) and Pink Bloodwood (*Corymbia intermedia*) open-forest to woodland (or vine forest with *E. portuensis* and *C. intermedia* emergents), on foothills and uplands on granite and rhyolite	Least concern	No concern at present
7.12.26	Turpentine (*Syncarpia glomulifera*) +/- Pink Bloodwood (*Corymbia intermedia*) +/- *Allocasuarina* spp. closed forest to woodland, or Brush Box (*Lophostemon suaveolens*), *Allocasuarina littoralis, C. intermedia* shrubland +/- vine forest spp. on exposed ridgelines or steep slopes, on granite and rhyolite	Least concern	No concern at present
7.12.38	Deciduous microphyll vine forest and/or blue-green algae-covered granite and rhyolite boulderfields	Of concern	Endangered
7.12.39	Complex mesophyll vine forest on fertile, well drained granites and rhyolites of very wet and wet lowlands, foothills and uplands	Of concern	Of concern
7.12.40	Closed vineland of wind-disturbed vine forest on granites and rhyolites	Of concern	Of concern
7.12.42	Notophyll vine forest with *Flindersia brayleyana* and *Argyrodendron polyandrum* on granite uplands of Great Palm Island	Of concern	Endangered
7.12.43	Simple notophyll vine forest dominated by *Stockwellia quadrifida*, on granite	Of concern	Of concern
7.12.44	Simple notophyll vine forest dominated by *Blepharocarya involucrigera*, on granite	Of concern	Of concern
7.12.45	Simple notophyll vine forest dominated by *Dryadodaphne* sp. (Mt Lewis B.P. Hyland+ RFK1496), on granite	Of concern	Of concern

Regional Ecosystem	Description	Status	Biodiversity Status
7.12.46	Microphyll vine forest with *Gossia bidwillii* +/- Hoop Pine (*Araucaria cunninghamii)*, on steep granite talus and boulder slopes of the Palm Islands	Of concern	Of concern
7.12.47	Notophyll-microphyll semi-evergreen vine forest with *Argyrodendron polyandrum* emergents, on rhyolite	Of concern	Endangered
7.12.48	Wind-sheared notophyll vine forest on exposed granite and rhyolite ridge-crests and steep slopes	Of concern	Of concern
7.12.49	Notophyll vine forest and thicket with *Pouteria euphlebia* and *Podocarpus grayae*, on granite	Of concern	Of concern
7.12.50	Simple microphyll vine-fern forest of highlands on granite and rhyolite	Of concern	Of concern
7.12.68	Complex notophyll vine forest of cloudy moist to wet highlands on granite	Of concern	Endangered
BRIGALOW BELT BIOREGION			
11.2.3	Microphyll vine forest (“beach scrub”) on sandy beach ridges and dune swales	Of concern	Of concern
11.3.11	Semi-evergreen vine thicket on alluvial plains	Endangered	Endangered
11.4.1	Semi-evergreen vine thicket ± *Casuarina cristata* on Cainozoic clay plains	Endangered	Endangered
11.5.15	Semi-evergreen vine thicket on Cainozoic sand plains/remnant surfaces	Least concern	Endangered
11.8.3	Semi-evergreen vine thicket on Cainozoic igneous rocks	Of concern	Of concern
11.9.4	Semi-evergreen vine thicket or *Acacia harpophylla* with semi-evergreen vine thicket understorey on fine-grained sedimentary rocks	Endangered	Endangered
11.10.8	Semi-evergreen vine thickets in sheltered habitats on medium to coarse-grained sedimentary rocks	Of concern	Of concern
11.11.18	Semi-evergreen vine thicket on old sedimentary rocks with varying degrees of metamorphism and folding	Endangered	Endangered
11.11.21	Semi-evergreen vine thicket on serpentinite	Of concern	Endangered

Regional Ecosystem	Description	Status	Biodiversity Status
11.12.4	Semi-evergreen vine thicket and microphyll vine forest on igneous rocks	Least concern	No concern at present
NEW ENGLAND TABLELAND BIOREGION			
13.11.7	Low microphyll vine forest on metamorphics	Of concern	Endangered



Further Information:
Marine and Tropical Sciences Research Facility
http://www.rrrc.org.au/mtsrf

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Cover Photo: Traffic counter installed near Mission Beach, North Queensland (Miriam Goosem)