The role of corridors in biodiversity conservation in production forest landscapes: a literature review

M.A. MacDonald
Forestry Tasmania, GPO Box 207, Hobart 7001

Abstract

Habitat loss and fragmentation are major threats to biodiversity conservation. One way of mitigating the negative effects of fragmentation is to improve habitat connectivity. Habitat corridors have been shown to be valuable for the conservation of various groups of wildlife and in various situations (e.g. urban, agricultural, production forest landscapes), although individual species vary in their use of corridors. Retained areas of native forest within plantations are beneficial for wildlife conservation, although their main benefit may be as retained habitat rather than dispersal corridors. Recent research in Tasmania has highlighted the value of wildlife habitat strips for conservation of vegetation and birds. Wildlife habitat strips form an important component of the conservation program in production forest landscapes. However, they cannot stand alone as a conservation measure; complementary measures such as reservation of extensive forested areas are also necessary.

Introduction

Habitat fragmentation is one of the major biodiversity conservation issues facing the world today. This fragmentation may be natural (such as the distribution of alpine habitat) or human-induced, and may occur on many scales. However, when habitat fragmentation is discussed in conservation terms, it is generally regarded as referring to anthropogenic alterations on a landscape scale. The causes of such fragmentation have mostly been land clearance for agriculture, forestry, or urban development. Habitat fragmentation effects may be additional to those that occur from habitat loss, although they are connected (Andren 1994). Saunders *et al.* (1991) summarised the major effects of habitat fragmentation as being increased external influences (such as invasion or predation), altered microclimate (e.g. associated with evapotranspiration, wind and hydrological cycles), and increased isolation from other areas of similar habitat. The importance of fragment area and isolation has been emphasised, largely through the theory of island biogeography (MacArthur and Wilson 1967). While the concepts introduced by this theory remain important, its application to terrestrial ecosystems has been questioned (Rolstad 1991; McIntyre and Barrett 1992). The importance of metapopulation dynamics has been emphasised in several studies (e.g. Howe *et al.* 1991; Fahrig and Merriam 1994), suggesting that habitat patches may not be able to maintain species' populations in isolation but that they may survive indefinitely with some exchange of individuals and genetic material.

It is in this context that corridors have become a significant factor in conservation management systems, in an attempt to reduce the isolation of spatially separated populations and to potentially increase the total area of habitat available. The present review does not intend to be an exhaustive examination of the role of corridors worldwide. Rather, it attempts to provide

e-mail: michael.macdonald@forestrytas.com.au

a general overview of corridors, with an emphasis on their role in Tasmanian production forest landscapes. Soulé and Gilpin (1991) defined a wildlife corridor as 'a two-dimensional landscape element that connects two or more patches of wildlife (animal) habitat that have been connected in historical time...', while Parminter (1998) defined a corridor as '...a narrow strip or linear element that differs from the elements on either side'. There are several other definitions, which generally refer to linearity and connectivity. Classic corridors include riparian zones, hedgerows and road verges (Photo 1).

Theoretical and practical aspects of corridors have been discussed in detail in several publications including Saunders and Hobbs (1991), Wilson and Lindenmayer (1995) and Bennett (1999). The last listed possible advantages of habitat linkages as: assistance to movement of individuals and genetic material through disturbed landscapes; increase of immigration to habitat isolates; facilitation of continuity of

Photo 1. Aerial photograph of a predominantly agricultural landscape. Several linear features that could act as corridors are present in riparian areas and along road lines.

natural ecological processes in developed landscapes; provision of habitat; and provision of ecosystem services such as water quality and stability of hydrological cycles. Merriam (1991) considered that inter-patch dispersal enhanced metapopulation survival by improving individual survival, supplementing population growth and allowing recolonisation following extinction. Possible disadvantages of habitat linkages identified by Bennett (1999) were: increase of immigration rates of pathogens, weeds and inappropriate genetic material; increase in exposure to predation and other mortality sources; creation of sink habitats where mortality exceeds reproduction; facilitation of the spread of fire or other abiotic disturbances; and reduction of resources available for alternative conservation measures.

While connectivity and habitat retention are considered to be the major short-term conservation benefits of corridors, over the longer term they may be valuable to a climatically changing earth (Norton 1999). They may allow species which become unsuited to their current distributions due to climate change, either directly or via resultant habitat changes, to move to appropriate areas. The practical use of corridors in this situation, should it arise, is difficult to determine.

The value of corridors as a conservation measure and the merit of evidence presented in support of corridors have been questioned (Simberloff *et al.* 1992; Rosenberg *et al.* 1997). However, a number of studies has supported the proposal that, on the whole, corridors are beneficial to the conservation of wildlife and / or vegetation. These include studies of small mammals and frogs in Amazonia (de Lima and Gascon 1999), arboreal marsupials in Queensland (Laurance and Laurance 1999), butterflies in North America (Haddad and Baum 1999), and carabid beetles in Scotland (Petit and Usher 1998), although individual species vary in their need for corridors to facilitate movement and / or survival.

Experimental evidence of the benefits of corridors has proved more problematic due to the effort and cost of manipulative studies at a landscape level. One region where experimental work is being undertaken is in the boreal forests of western Canada (Machtans *et al.* 1996; Schmiegelow *et al.* 1997). This is discussed below. By contrast, the value of corridors for plants has been considered to be largely as habitat refuges for endangered species or communities (McDowell *et al.* 1991). Their value for dispersal has been considered in only a few studies (Fritz and Merriam 1993; van Dorp *et al.* 1997). The latter considered that linear landscape elements would not be effective dispersal corridors for plants with short-range seed dispersal due to low migration rates. Their role in aiding gene flow has not been practically assessed.

The value of a corridor depends on its spatial configuration, landscape context, habitat type, scale, the nature of the connected areas, and the species likely to use the corridor. These factors determine corridor ‘quality’, which also varies depending on the taxa concerned (Anderson and Danielson 1997). Conservation aims also determine how valuable a corridor is from a human perspective, and explicit goals are recommended in corridor design (Wilson and Lindenmayer 1995).

Due to their linear nature, corridors tend to be subject to edge effects such as invasion of exotics and altered microclimate (Yahner 1988), although these vary between habitats and between taxa. There may be consequential or coincidental changes in vegetation and animal responses and interactions (Matlack and Litvaitis 1999). Maximising width has been suggested as the most practical way to reduce edge effects (Bennett 1999). Increased corridor width has been associated with increased bird species richness, bird density and frequency of area-dependent bird species in several studies (Keller *et al.* 1993; Spackman and Hughes 1995; Croonquist and Brooks 1993). Similarly, in Queensland, Catterall *et al.*

(1991) considered that narrow corridors were likely to be dominated by aggressive bird species, inhibiting movement of those forest species which are likely to be sensitive to habitat fragmentation. Other taxa, including insects (Hill 1997) and perennial grassland plants (van Dorp *et al.* 1997) have also shown positive relationships with corridor width. Narrow corridors may have significant conservation values, and Andreassen *et al.* (1996) found that wider corridors did not necessarily facilitate movement any more than narrower ones, provided that the corridors were not so narrow that they were avoided as movement pathways. However, in general, there has been no suggestion that reducing corridor width is beneficial to any species targeted for conservation. Other means of reducing edge effects include fencing, management to reduce the 'severity' of the boundary between corridors and surrounding landscapes, and the provision of shelterbelts on adjacent land (Start 1991).

The extent of edge effects is also affected by the nature of the surrounding habitats. Some, such as regrowth forest, may be expected to be more benign than others, such as agricultural land (Taylor 1991). However, Janzen (1983) has suggested that relatively similar surrounding habitat may, in fact, provide more potential invaders than radically different habitat, because the plants and animals are more likely to be suited to the intact vegetation. Conversely, corridor edge effects may involve the penetration of biota from the retained forest into production forest areas. This is generally considered in terms of the economic impacts. These may be positive, as with the control of insect pests by birds from adjacent forest (Holmes *et al.* 1979), or negative, providing a source of browsing mammals such as possums in New Zealand plantations (Gilliam *et al.* 1992).

Other spatial characteristics can be important in determining the value of corridors. Corridor length has not been as thoroughly investigated as corridor width, but optimal corridor length has been considered to be a function of species-specific behaviour and habitat quality. Minimising corridor length, especially when animals do not breed within the corridors, is recommended (Wilson and Lindenmayer 1995). Habitat quality is important in its own right, and has been shown to influence the effective connectivity of corridors (Harrison 1992; Bennett *et al.* 1994).

Another characteristic that influences the value of a corridor is its position in the landscape. Bennett (1999) proposed that, in general, corridors should be located along environmental contours to ensure habitat continuity, and there has been emphasis on riparian corridors. This is partly because they are also important for protection of water catchments and partly because they tend to be species rich and structurally diverse relative to surrounding areas (Brinson and Verhoeven 1999). However, retaining a range of topographies has been shown to be important for mammals in south-eastern Australia (Claridge and Lindenmayer 1994) and for birds in Oregon (McGarigal and McComb 1992). Species that use a range of resources may require a variety of landforms, and it may be necessary to link similar habitats by crossing different habitat (e.g. linking two riparian areas with a corridor across a ridge top). Harrison and Voller (1998) considered that 'corridor location and design should reflect the ecology of an area'.

Corridors in forestry landscapes

The negative impacts of forestry practices on forest flora and fauna have been well documented (e.g. Bull 1981; Heliövaara and Väisänen 1984; Hansen *et al.* 1991). In an effort to minimise these impacts, conservation-oriented forest management practices have been introduced in various parts of the world. Connectivity in general, and corridors in particular, have formed an important part of those practices (Lindenmayer 1994; Moenkkoenen 1999).

It has been suggested that in production forest landscapes the major benefit of corridors may not be as aids to dispersal (Bennett 1999) as has been proposed in agricultural landscapes (e.g. Saunders and de Rebeira 1991) and urban landscapes (e.g. Catterall *et al.* 1991). Rather, they are likely to be important as retained habitat, particularly of oldgrowth elements such as tree hollows (Lindenmayer 1994; Bennett 1999), although the ability of corridors to provide adequate resources has been questioned (Recher 1991).

Bennett (1999) considered several ways in which retained forest strips may enhance forest connectivity: by maintaining resident populations in linked strips of suitable habitat among sub-optimal forest; by providing source populations for recolonisation of the surrounding forest matrix as habitat becomes suitable; by providing resources for species able to forage but not live within the surrounding forest; and by aiding dispersal of species which *are* inhibited from moving through the surrounding forest. The number of species for which this is important is unknown. In Washington, Mech and Hallett (2001) examined genetic distance in two small mammals in a production forest landscape, and concluded that they responded differently to the presence of forest corridors. For one species, corridors between unlogged habitats appeared to maintain higher population connectivity than that found in landscapes without corridors, while forest corridors were unimportant for connectivity of the other species. The attitude of most researchers has been that corridors, once in place, are immutable, but Scotts (1991) considered that over the long term, as long as new corridors of similar ecological character are provided as replacements, harvesting of corridors may be possible. Provision of replacement corridors would be considerably more difficult to achieve in a plantation landscape.

There are differences between agricultural landscapes, where corridors tend to be surrounded by permanently cleared land, and forested ones, where the suitability of surrounding land for wildlife habitat varies as forest regenerates. However, the values of corridors described above still apply, not least the importance of clear conservation aims. A significant difference in production forest landscapes is the ability to plan the location and dimensions of corridors, which is rarely possible in agricultural landscapes where corridors are remnants of native vegetation (Lindenmayer 1994). This ability has also been used as a means to design experiments testing the value of corridors. In Canada, experimental fragmentation of boreal forests in a production forest landscape did not result in a change in bird species richness over a two-year period (Schmiegelow *et al.* 1997). However, there was a change in community structure, which was mitigated when fragments were connected by 100 m wide riparian buffer strips. In the same area, Machtans *et al.* (1996) found that retained riparian buffer strips enhanced the movements of juvenile birds, and maintained movement rates of adults. In Victorian mountain ash forests, retained linear strips within production forest landscapes have been found to support populations of some arboreal marsupial species. However, species richness and tree-hollow occupancy were lower in strips, and an endangered species, Leadbeater's possum, was almost entirely absent, despite the presence of apparently suitable habitat (Lindenmayer *et al.* 1993). Within these retained strips, the rate of tree fall was faster than in contiguous forest, which may affect the future availability of tree hollows, an important resource for arboreal marsupials (Lindenmayer *et al.* 1997).

Corridors in plantation landscapes

Plantation forestry presents different conservation issues from native forest management. The establishment and intensive management of plantations of (mostly) exotic tree species creates a landscape which is relatively hostile to native species and communities (Suckling *et al.* 1976; Smith 1987), although plantation forests are not worthless from a conservation perspective (Spellerberg and Sawyer 1997).

Gilmore (1990) reviewed the effects of plantation forestry on terrestrial vertebrates in Australia. The primary objective of plantation forestry is to maximise wood production but, in the long term, conservation measures improve productivity as well as ecology (Moore and Allen 1999). Most research into the impact of plantations on wildlife has concentrated on pine plantations (e.g. Wall 1983). Woinarski (1979) in Victoria and Bashford (1990) in Tasmania did find differences in the composition of bird and beetle fauna respectively between eucalypt plantations and native forest. Retention of native forest within the plantation landscape has been recommended to improve the habitat value of plantations, along with other conservation mechanisms such as extended harvest rotation (Cruz 1988; SPIS 1990; Norton 1999). This has not necessarily involved the prescription of corridors *per se*. The value of native forest within plantations has been documented for birds in Texas (Dickson *et al.* 1995) and New South Wales (Fisher and Goldney 1998; Lindenmayer *et al.* 2002).

There has been relatively little research into corridors within plantations (although some Tasmanian research is discussed below). In a related area, Lindenmayer (2000) summarised a number of studies from the Tumut Fragmentation Experiment. This major project is still in progress in New South Wales. It seeks to determine the biodiversity values of native forest remnants, many of which are linear features, within stands of radiata pine. These studies found that even small remnants had considerable value for forest vertebrates, and that many species may use the pine matrix for movement, even if they do not reside in it. However, some species, such as the yellow-bellied glider and squirrel glider, may not be conserved within even large and well-connected eucalypt patches. In addition, eucalypt patches were susceptible to invasion by radiata pine wildlings (particularly in dry forest) and blackberry (particularly in wet forest), and their prevalence appeared to increase over time. Lindenmayer (2000) made recommendations to enhance the conservation value of new and existing pine plantations. These included retention of native forest patches, particularly large patches and / or those close to extensive native forest; maintenance, establishment or enhancement of connectivity (e.g. wildlife corridors); retention of 30% native vegetation within the softwood plantation estate; exclusion of stock grazing and firewood collection from native forest patches; control of weeds, especially blackberry and radiata pine; staggered logging schedules for plantations; and limitation of damage to native forest patches during harvesting of the plantations.

Wildlife habitat strips in Tasmania

There has been considerable research into the effects of forestry on Tasmanian wildlife (e.g. Michaels and Bornemissza 1999; Hingston 2000). Corridors within production forests have been prescribed in Tasmania as part of the *Forest Practices Code 2000* (Forest Practices Board 2000), not only for conservation purposes but also to protect water catchments. This Code applies equally to State forest, private land and industrial freehold land. Taylor (1991) considered that the primary value of retained forest strips in Tasmania would not be as conduits for wildlife, and thus he preferred the term ‘wildlife habitat strip’ to ‘corridor’ (Photo 2). He saw their importance as including a means to cater for invertebrate species of restricted distributions that are currently unknown or poorly known; to provide oldgrowth forest in the complete range of environments present within production forests; to act as a source of individuals to recolonise regenerating areas; to reduce isolation of larger forested areas; and to provide specific resources for species which can use regrowth for some purposes.

Wildlife habitat strip guidelines in the *Forest Practices Code 2000* are as follows:

> Wildlife habitat strips should be retained to maintain habitat diversity. As a guide, strips of uncut forest up to 100 m in width, based on streamside reserves but including links up slopes and across ridges to connect streams in adjoining catchments, should be provided every 3–5 km. These strips should connect any large patches of forest which will not be logged.

The above definition also appeared in an earlier edition of the *Forest Practices Code* in 1993. However, prior to this, habitat retention was less strictly prescribed, and therefore some production forest areas in Tasmania either do not have wildlife habitat strips in place, or have strips which do not conform to the above description.

Retained strips of mature native forest have been found to be important for the conservation of several species in Tasmania. Riparian buffer strips (of adequate width) reduce the negative impacts of logging on stream quality and macroinvertebrate abundance (Davies and Nelson 1994), and retained mature forest strips act as habitat for carabid beetles (Taylor *et al.* 2000). Current research being undertaken by Forestry Tasmania includes pre- and post-logging sampling of a wide range of taxa (including vegetation, birds, mammals, geometrid moths and terrestrial invertebrates) at two sites (in dry forest and wet forest) where logging has left strips of native forest. Results from pre-logging sampling are included in Duncan and Brown (1995), McQuillan *et al.* (1998) and Brereton and Taylor (2000). The first post-logging sampling commenced in 2001 and

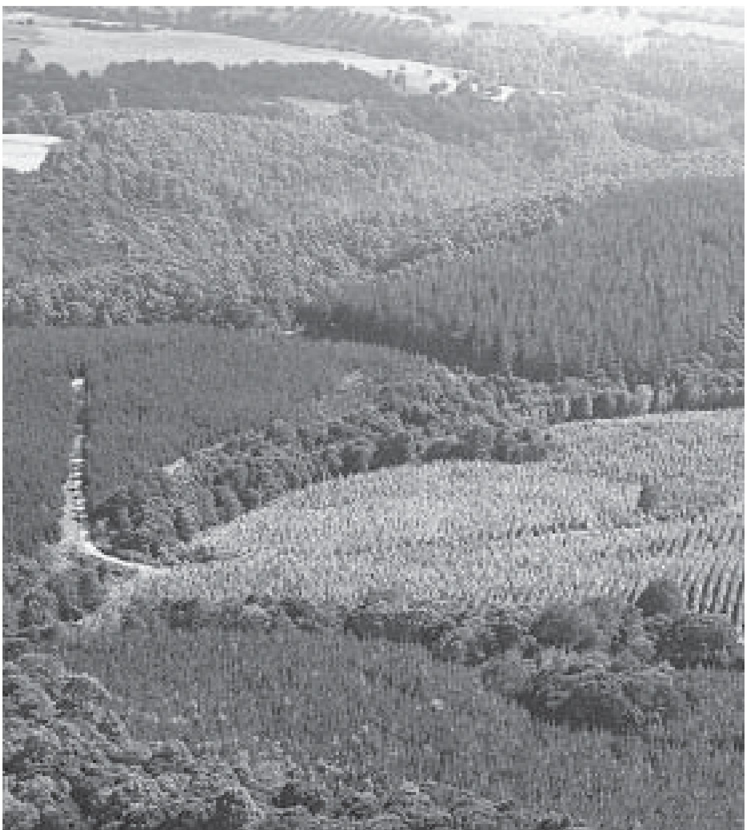

Photo 2. Wildlife habitat strips within a plantation landscape, with extensive native forest in the background.

is ongoing or projected for some taxa (S. Grove, pers. comm.). Publication of results may be expected in the future.

In addition, there has been recent research into the value of wildlife habitat strips for vegetation and birds in a plantation matrix (Loofs *et al.* 2000; MacDonald *et al.* in press). In sclerophyllous forest, wildlife habitat strips were floristically different from continuous native forest, and wildlife habitat strip sites were more likely to have exotic invaders (such as blackberry and radiata pine) and native colonisers (such as *Gahnia*). Bird species composition was similar in wildlife habitat strips and extensive native forest but, outside of riparian zones, bird species richness and total bird abundance were both significantly lower in strips (MacDonald *et al.* in press). Species richness and abundance both increased with wildlife habitat strip *length*. This may indicate that the strips are effectively linear remnants rather than movement corridors, and that there is an area effect.

Both of the above studies concluded that wildlife habitat strips were useful for the conservation of biodiversity. However, management issues were identified. Wildlife habitat strips were predominantly located along riparian corridors, with very few sites available for sampling on upper slopes and ridges in plantations. Almost all of those found away from gullies followed ridgelines rather than crossing slopes to link gullies, as was recommended by Taylor (1991). Claridge and Lindenmayer (1994) found that wildlife corridors in south-eastern Australia were also typically confined to gullies and creeks. They suggested that this was because water catchment protection required protection of riparian zones, and that the placement of wildlife corridors in these ensured that the net loss of commercial timber production forest was minimised. If corridors are to truly reflect the local ecological conditions, as suggested by Harrison and Voller (1998), then consideration needs to be given to the greater inclusion of upper slopes and ridges. In addition, wildlife habitat strips were more susceptible to disturbance than continuous native forest (Loofs *et al.* 2001). Ongoing management of wildlife habitat strips is necessary to maintain their integrity and their value as habitat for fauna. This is also important because wildlife habitat strips, as informal reserves, form part of the comprehensive, adequate and representative reserve system for floristic communities.

Conclusion

Designing and assessing the benefits of corridors for biodiversity conservation is difficult because of the large number of potential influences. Use of corridors by fauna may vary depending on the vegetation type, corridor dimensions, and geographical location. Use of corridors varies markedly between species, even taxonomically close species, and can even vary intraspecifically according to gender or age (Downes *et al.* 1997). Some species do not benefit from retained forest, and these species may require large reserved areas or other conservation measures. The conservation value of corridors for flora has been addressed by relatively few studies. Nevertheless, there is strong evidence to suggest that corridors are an effective supplementary conservation measure—they must accompany other conservation solutions such as reservation of extensive forested areas, manipulation of fire regimes and specific logging prescriptions (Recher 1991). A review of the literature suggests that the findings of studies in agricultural and urban landscapes will not necessarily be applicable to production forest landscapes. Therefore, research in Tasmanian production forest landscapes has been valuable in providing evidence for the benefits of corridors as well as helping to develop and improve prescriptions for their establishment and management. There are still wide gaps in the understanding of the role of corridors, and further research by Forestry Tasmania and other organisations will help to fill these gaps.

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