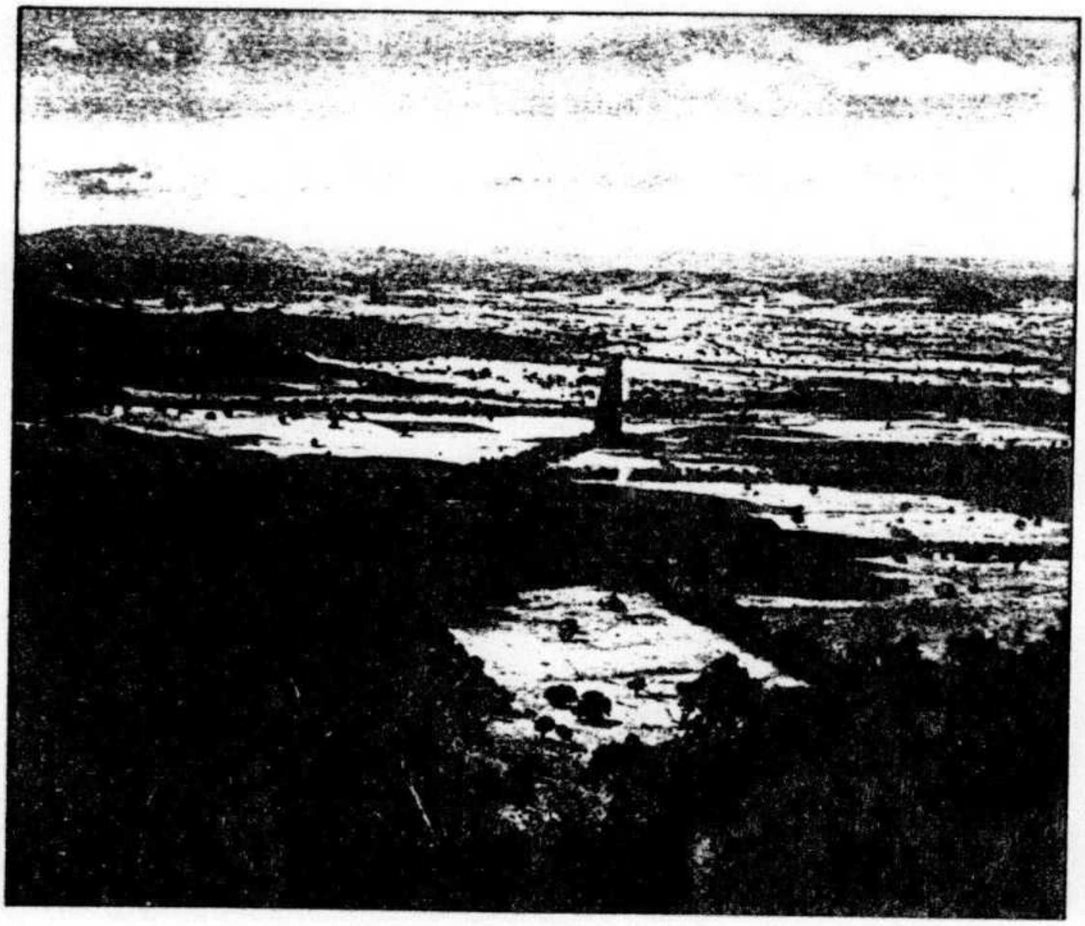
Habitat Corridors

Their Role in Wildlife Management and Conservation



Andrew F. Bennett

Conservation & Environment

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Arthur Rylah Institute for Environmental Research
1990

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Summary

The loss and fragmentation of natural habitats is one of the major issues in wildlife management and conservation throughout the world. This is particularly true of most rural areas in southern Australia, where little remains of the natural environment after less than 150 years of agricultural settlement. The consequences of habitat fragmentation for the native fauna include: changes in the number of species present in remnants compared with extensive habitats; changes to the composition of faunal assemblages in remnants; and, changes to ecological processes in remnants. For single species, fragmentation leads to smaller population sizes, greater isolation of local populations, and an increased vulnerability to the process of decline and local extinction.

Habitat corridors, linear strips of habitat that differ from the surrounding environment, are present in most landscapes, especially in those extensively modified by humans. The preservation of existing corridors, or the establishment of new corridors to link isolated habitats, have been widely proposed as practical conservation measures that can ameliorate the effects on wildlife of habitat loss and fragmentation. Where corridors provide a pathway for the movement and interchange of individuals between populations, they may reduce the vulnerability of small populations to extinction from chance demographic, genetic or environmental processes; or they may facilitate recolonisation should local population extinction occur.

Examples are presented of the use by wildlife of corridor habitats from around the world, including: riparian habitats, hedges, shelterbelts and plantations, fencerows, roads and roadsides, tunnels and underpasses, and planned corridors or corridor systems. These studies provide a wide range of evidence for the value of corridors as habitats in their own right, and as a conduit for animal movements. However, there is little empirical data that demonstrates unequivocally the conservation benefits that are gained from known movements through corridors.

Few data are available that address practical questions that are relevant to the design and management of corridors for conservation. However, principles that are relevant to these issues include: the ecology and behaviour of animal species; the structural connectivity of the corridor system; the quality of habitat in the corridor; edge effects; corridor width; and the location of corridors.

In southern Australia, the major emphasis in wildlife conservation has been to select, set aside and manage certain areas as National Parks or other nature reserves. While these areas are of great importance, it is suggested that on their own they are unlikely to be sufficient for the long-term conservation of all species. We must expand our vision and develop broader regional perspectives that include the management of wildlife and their habitats in other areas also. The potential role of corridors in developing such strategies in rural and forested regions of south-eastern Australia is discussed, and recommendations are made for research and management actions that will contribute to a better understanding of the values of corridors and their contribution to wildlife conservation.

Introduction

The concept of incorporating habitat corridors into plans for the management and conservation of wildlife has recently received increased attention throughout the world. It is a response to growing concern among wildlife managers, scientists and the community about the clearing and fragmentation of wildlife habitats, and the consequent isolation and extinction of animal populations. There is widespread recognition that we must take practical steps towards restoring continuity to wildlife populations that have become fragmented and isolated through the clearing or development of their habitats.

This document presents a comprehensive review of the role of habitat corridors in wildlife management and conservation. The objectives of the review are:

- *to discuss the scientific basis for the functions and values of habitat corridors in wildlife management and conservation;*
- *to document examples of habitat corridors from throughout the world, to illustrate their practical value in wildlife conservation;*
- *to discuss the role and contribution of habitat corridors in a regional approach to conservation planning; and,*
- *to identify research requirements and management actions that will facilitate the development of effective corridor systems for wildlife conservation.*

The focus of this review is the wildlife and environments of southern Australia, particularly south-eastern Australia. However, scientific literature from throughout the world that is relevant to habitat fragmentation and corridors has been extensively quoted, both to document the value of corridors and to provide an information resource for wildlife scientists, planners and managers.

What are Corridors?

In almost any landscape we can recognise linear corridor habitats: a roadside strip of trees passing through an expanse of cleared farmland, a creek winding through a developed urban area, a railway reserve crossing an open plain, streamside strips of eucalypt forest amidst a pine plantation, stone fences lining the edge of a farm paddock, or a thin line of cool-temperate rainforest along a moist gully in the ranges. In this review, these are all regarded as corridors. Essentially, corridors are linear habitats that differ from a more extensive, surrounding matrix (Forman 1983; Forman and Godron 1986). Frequently, they link one or more patches of habitat in the landscape and may be a pathway for animal movement, but they may also occur as isolated lines of habitat.

Origins of corridors

Habitat corridors may originate in a number of ways (Forman and Godron 1986).

Natural corridors, such as streams and their associated riparian vegetation, usually follow topographic or environmental contours and are the result of natural environmental processes.

Remnant corridors, such as strips of eucalypt forest in pine plantations or along roadsides, result from clearing, alteration, or disturbance to the surrounding environment.

Regenerated corridors occur as the result of regrowth of a strip of vegetation that was formerly cleared or disturbed.

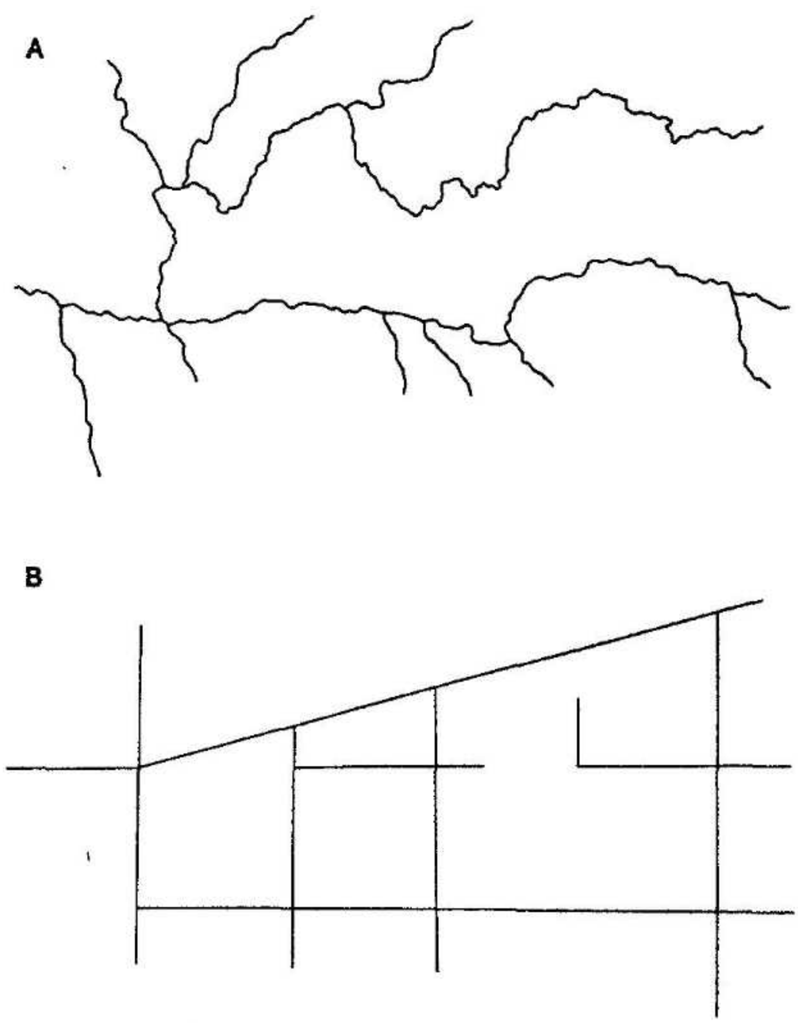

Figure 1. *Characteristic patterns of a natural stream corridor (A) and a network of remnant vegetation on roadsides (B).*

Natural vegetation on roadsides is an example of remnant corridors in the landscape.

Planted corridors, such as farm plantations, windbreaks, and some urban greenbelts, have been established by humans.

Disturbance corridors, including railway reserves, roads, and cleared transmission lines, result from disturbance within the corridor strip.

Corridors are a typical element that is present both in natural landscapes and in landscapes severely altered by humans. However, there are some major differences between natural corridors and those resulting from human activities in the landscape. For example, streams and their associated riparian vegetation are typically meandering in their pathway, forming dendritic branching patterns as they join to form increasingly larger waterways (Fig. 1). They follow the line of lowest topography in the landscape, they are relatively permanent in structure, and they are maintained by the natural distribution of environmental resources. In contrast, corridors of human origin frequently follow straight lines and cross environmental contours, they often form rectangular grids (e.g. road systems, farm plantations), and their maintenance requires continued management effort, either within the corridor or in the surrounding matrix. For example, a cleared transmission line corridor will regenerate with time if it is not deliberately maintained, and a corridor of mature forest in a clear-felled stand will gradually disappear as the surrounding forest regenerates and ages.

Connectivity

The connectivity of a corridor, or system of corridors, is an important attribute that influences its effectiveness for conservation. Two components of connectivity can be defined.

Structural connectivity describes the mappable spatial continuity of the corridor. The distance over which the corridor extends, the number and length of gaps, the number of junctions with other corridors, and the presence of "nodes" of habitat along the corridor, all influence the level of structural connectivity.

Functional connectivity (cf. 'connectivity' of Merriam 1984) is a measure of the ability of a species to move between two habitats. The functional connectivity of a corridor depends not only on its spatial continuity, but also on factors such as the behaviour of the species utilising the corridor, the scale of the species' movements, and its response to the width and quality of habitat in the corridor.

Corridors as a conservation measure

In the last decade there has been increasing concern at the loss and fragmentation of wildlife habitats throughout the world, and the effects that this is having on wildlife populations (e.g. Soule and Wilcox 1980; Burgess and Sharpe 1981; Soule 1986; Saunders *et al.* 1987). The establishment of corridors to link isolated populations of wildlife has been widely advocated as a practical conservation measure to enhance wildlife conservation in disturbed environments. Before considering the ways in which corridors can enhance conservation strategies, it is pertinent to briefly consider the effects of habitat loss and fragmentation on wildlife.

Habitat Fragmentation and the Consequences for Wildlife

Habitat fragmentation in southern Australia

Clearing and fragmentation of natural areas has occurred, and continues to occur, in every continent throughout the world (Curtis 1956; Darby 1956; Asahina 1973; Ranjitsinh 1979; Brown 1981; Burgess and Sharpe 1981; Wells *et al.* 1983). It is one of the major issues confronting wildlife conservation on a global scale. In Australia, clearing and fragmentation of natural vegetation is also of major importance, and it is having a profound effect on our native fauna. The greatest loss of natural vegetation has been in those areas used intensively for agriculture, including the slopes and plains inland of the Great Dividing Range (Marlow 1958), the plains of western and northern Victoria (Willis 1964; Paine 1982; Wells *et al.* 1983), the southern half of South Australia (Interdepartmental Committee on Vegetation Clearance 1976; Williams and Goodwin 1988), and the wheatbelt region of Western Australia (Gentilli 1961; Kitchener *et al.* 1980a).

These changes to our natural environments are immense, and have profound implications for wildlife conservation. Several examples serve to illustrate both the overall decline in total cover of natural vegetation and the increasing fragmentation and isolation of the remaining blocks. In South Australia, 75% of the wooded areas in the southern agricultural regions of the state have been cleared (Interdepartmental Committee on Vegetation Clearance 1976). Clearing has been most extensive in those areas that have been settled and farmed for the longest time; for example, 92% of vegetation on the Yorke Peninsula, 93% in the lower south-east, and 95% on the Mt. Lofty Ranges and Adelaide Plain. An intensive study of the Fleurieu Peninsula, South Australia, found that only 9% of the total area of 1500 km² now supports native vegetation (Williams and Goodwin 1988): of the 540 remaining patches, 67% (360/540) are less than 10 ha, and only three are larger than 500 ha.

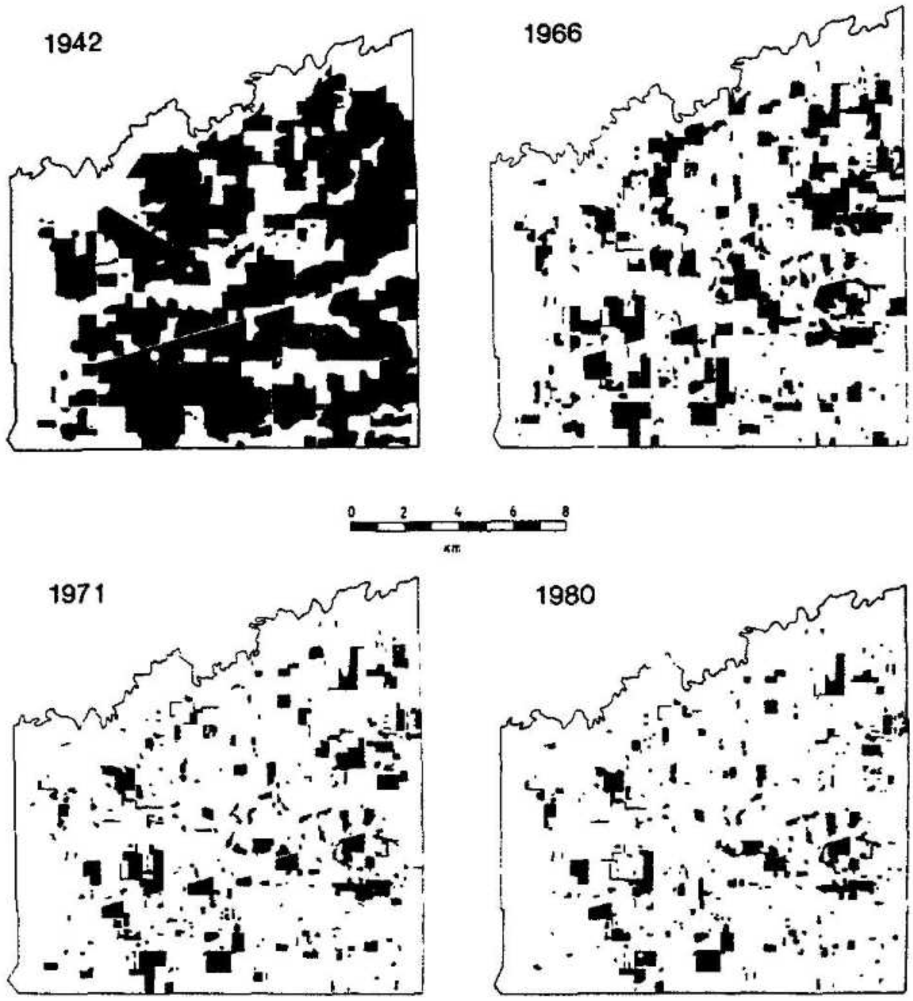

Figure 2. *Loss and fragmentation of forest at Naringal, south-western Victoria (from Bennett 1990a). Forest vegetation (shaded) has been increasingly cleared and the remnant patches have become more isolated with time.*

In Victoria, forest and wooded cover has declined by some 60% between 1869 and 1972, and it continues to decline as forests on private land are cleared (Woodgate and Black 1988). The greatest loss and fragmentation has been in central and western Victoria, where more than three quarters of the original cover has been cleared from some regions: for example, Horsham region (of the Department of Conservation and Environment) 76% cleared, Portland 82%, Ballarat 76%, Bendigo 85%, and Benalla 84% cleared (Woodgate and Black 1988). The remaining tracts in these regions have been extensively fragmented and in many cases further modified by grazing of domestic stock, altered fire regimes and timber extraction. At a 200 km² study area in south-western Victoria, examination of aerial photographs revealed that forest cover declined from some 50% of the area in 1947, to 16% in 1966, to less than 9% in 1980 (Fig. 2) (Bennett 1990a). By 1980, 92% of the remaining forest patches were less than 20 ha in size. Many other examples of the dramatic decline and fragmentation of forests and woodlands in southern Australia are also available (Gentilli 1961; Suckling 1980; Wells *et al.* 1983; Smith 1987).

It is important to note that agricultural settlement in southern Australia is recent (< 150 years) in comparison with many other countries. Thus, it is not uncommon for canopy trees to pre-date European settlement, particularly those trees in small remnants or scattered through farmland. However, there is often an obvious lack of successful regeneration, due to grazing by stock, to replace these ageing individuals. As the remnant stands age and senesce we can expect even further depletion of forests and woodlands in the rural landscape, unless active measures are taken to promote regeneration.

Fragmentation of wildlife habitats can also occur in large, seemingly intact, tracts of vegetation. Timber harvesting, for example, leaves isolates or loosely-connected patches of mature forest (old-growth forest) amid stands of regenerating forest. With the increasing intensity and scope of forestry activities in south-eastern Australia, areas of mature forest outside reserves are becoming fewer in number, smaller in size, and more and more isolated. For the fauna that is dependent upon mature forests, the degree of isolation of populations in these patches is related to their ability to pass through or utilise forests of earlier successional stage. Fires, both natural and of human origin, can also create patches of differing successional stages within extensive natural areas, and so isolate faunal populations that may depend upon a particular seral stage.

Effects of fragmentation on wildlife communities

Throughout the world, concern at the effects of fragmentation and isolation of habitat on wildlife has stimulated a large number of studies of wildlife communities in remnant habitats and isolated nature reserves (e.g. Moore and Hooper 1975; Leck 1979; Soule *et al.* 1979; Shreeve and Mason 1980; Whitcomb *et al.* 1981; Blake and Karr 1984; Lovejoy *et al.* 1984; Lynch and Whigham 1984; Opdam *et al.* 1984; Freemark and Merriam 1986; Askins *et al.* 1987; Diamond *et al.* 1987; Lynch 1987; Soule *et al.* 1988). In Australia, the effects of habitat fragmentation have been studied for birds (Bosworth *et al.* 1977; McLaren 1979; Howe *et al.* 1981; Kitchener *et al.* 1982; Howe 1984; Naismith 1984; Gell 1985; Loyn 1985, 1987), mammals (Kitchener *et al.* 1980b; Suckling 1982; Bennett 1987, 1990 a,b; Pahl *et al.* 1988), and reptiles (Kitchener *et al.* 1980a; Kitchener and How 1982; Caughley and Gall 1985).

Three main consequences of habitat loss and fragmentation for wildlife can be identified.

(i) Changes to the number of species in fragments

Fragmentation and isolation of natural areas results in a reduced number of species in a fragment compared with that in the original area. Usually there is a highly significant relationship between the area of a fragment and the number of species that are present; with increasing area an increasing number of species is usually present. The relationship between habitat area and species richness has been explained in three ways (see Connor and McCoy 1979). Firstly, a larger area of remnant habitat contains a greater 'sample' of the original habitat, and consequently it is likely to have sampled a greater variety of fauna than a smaller area. Secondly, because a larger area supports a greater population size, more species are able to maintain viable populations there than in a smaller area. Thirdly, with increasing area there is usually a greater diversity of habitats for animals to occupy, and consequently the number of species reflects the diversity of habitats that are available.

In addition to area and diversity of habitats, other factors such as the spatial and temporal isolation of the remnant, and the degree of disturbance, also influence the number of species that are present (Opdam *et al.* 1984; Askins *et al.* 1987; Loyn 1987).

An emphasis solely on species diversity or the number of species in remnants can be misleading, as it does not consider what *kinds* of species are present, and how large or small the population of each species may be.

Size class (ha)	<2	3-7	8-15	16-40	41-100
Number of patches	8	8	8	8	7
European Rabbit	63	100	100	100	100
Bush Rat	38	75	100	100	100
Common Ringtail Possum	25	88	100	88	100
Fox	0	63	100	100	100
Short-beaked Echidna	13	50	100	100	100
Brown Antechinus	13	50	100	100	86
Swamp Wallaby	13	13	75	63	86
Long-nosed Potoroo	0	13	50	63	100
Eastern Grey Kangaroo	13	50	13	63	57
House Mouse	25	25	38	38	57
Cat	25	38	50	38	50
Swamp Rat	0	13	13	25	29
Long-nosed Bandicoot	0	13	13	0	43
Red-necked Wallaby	0	0	0	38	29
Sugar Glider	0	0	13	25	29
Southern Brown Bandicoot	0	0	13	13	14
Common Brushtail Possum	0	0	13	0	14
Black Rat	13	25	0	0	0
Brown Hare	13	0	0	13	0

Figure 3. *Nested pattern of occurrence of species of mammals in south-western Victoria (after Bennett 1987). Values are the percentage occurrence of each species in five size classes of patches. Blocks enclose species that occurred in more than 50% of patches.*

(ii) Changes to the composition of faunal assemblages

Species respond to fragmentation in different ways, and this results in the relative composition of faunal assemblages changing as a result of fragmentation. For example, in western Victoria the composition of mammal assemblages in forest fragments displayed a nested pattern, with species added to the assemblage in a relatively ordered sequence with increasing size-class of forest patch (Fig. 3). The smallest patches supported the most widespread and common species (e.g. Bush Rat, Common Ringtail Possum) and only in the larger size classes did the uncommon species regularly occur (e.g. Red-necked Wallaby, Long-nosed Bandicoot) (Bennett 1987, 1990 a,b). Similar patterns in the composition of birds in forest fragments have been described in Europe and North America (e.g. Moore and Hooper 1975; Lynch 1987)

Studies of the fauna of isolated nature reserves in Western Australia (Humphreys and Kitchener 1982), found that an important change to the composition of wildlife communities was the increased proportion of "edge" species and species with wide habitat tolerances, in fragmented habitats. The percentage of species that are able to utilise disturbed environments increased disproportionately as the size of the nature reserve decreased: species that require undisturbed vegetation were most numerous in large reserves. These results parallel observations on the forest avifauna in North America, where many studies have pointed to the need for large tracts of habitat to support a suite of "forest-interior" birds that seldom occur in small fragments (Whitcomb *et al.* 1981; Lynch and Whigham 1984; Askins *et al.* 1987).

Species that are most susceptible to habitat fragmentation, and are among the first to disappear as habitats are subdivided, are usually those that naturally occur at low densities (Terborgh and Winter 1980; Diamond 1984). These include large animals; species that are high on the food chain (e.g. owls, falcons, carnivorous mammals); and species that have specialised food or habitat requirements. Because of their low population density, a remnant may not be sufficiently large to support a viable population. In addition, human activities accompanying or following fragmentation may accelerate, or be wholly responsible for, the elimination of certain species (e.g. carnivorous mammals perceived to be pests).

(iii) *Changes to ecological processes in fragments*

The loss of native species, or the introduction of exotic species, to habitat patches disrupts or modifies ecological processes such as food chains, predator-prey interactions, plant-animal pollination and dispersal associations, and nutrient cycling pathways, because important elements of these processes disappear. These changes are often difficult to detect immediately, or to attribute directly to fragmentation processes. Gilbert (1980) used the term "mobile links" to describe animals that are significant factors in the persistence of a number of plant species, that in turn support otherwise separate food webs. Animals that are pollinators, or seed dispersers, are examples of such links between food webs. "Keystone mutualists" are those organisms, usually plants, that are critical to the survival of "mobile link" species (Gilbert 1980). The loss of either of these types of organisms, for example, may have profound far-reaching effects on the rest of the biota in a remnant.

Introduction of exotic animals has its most severe impact on smaller remnants and strips. Grazing by domestic stock in remnant vegetation has marked effects on the composition and structure of wildlife habitats through selective browsing of plants, an overall decline in understorey biomass, trampling and soil compaction, and altered soil nutrient levels (e.g. Suckling 1980). Foxes, efficient introduced predators in Australia, have been associated with the declining status of medium-sized marsupials (e.g Brush-tailed Bettong, Parma Wallaby, rock wallabies) (Christensen 1980; Kinnear *et al.* 1988).

A reduced abundance of insectivorous birds because of habitat changes (e.g. loss of understorey vegetation), or from territorial exclusion by other species, can lead to increased abundance of phytophagous insects and reduced tree health (Loyn *et al.* 1983; Loyn 1987). This appears to be one of a suite of factors that is associated with rural tree decline (dieback) in eastern Australia.

We have much to learn of the interactions between plants and animals, of the critical elements and regulatory mechanisms in ecological systems in southern Australia, and of how these are affected when they are disturbed.

Problems faced by small populations

The primary effect of fragmentation and accompanying human disturbance to wildlife populations is a reduction in their size, and increased isolation from other populations. These smaller and isolated populations are more vulnerable to decline than are large populations. Documented examples of species' extinctions have frequently shown an initial pattern of major range reduction and fragmentation followed by successive extinctions of local populations (e.g. Petterson 1985).

Why are small populations vulnerable to decline and extinction? Firstly, both small and large populations are subject to on-going disturbance processes in the landscape (e.g. continued deforestation, increased predation from introduced predators, habitat disturbance, reduced food supply). A large population size and a widespread distribution are likely to provide a better buffer against these deterministic processes.

Secondly, small populations are more sensitive than large populations to at least four sources of chance variation (Shaffer 1981; Soule 1986; Simberloff 1988).

Demographic stochasticity refers to random variation in population parameters such as birth rate, death rate and sex ratio. For example, if a small population of a short-lived species by chance experienced a low birth rate in two successive years, the immediate probability of survival of the population may be greatly reduced.

Genetic stochasticity refers to random genetic processes that can lead to a loss of genetic variation and a reduced capacity for a population to resist recessive lethal alleles, or to respond to changing environmental conditions. Inbreeding depression, genetic drift, and a founder effect, can all contribute to a loss of genetic variation in small populations (Brown 1983 discusses these issues with respect to Victorian fauna; also see Soule 1986; Simberloff 1988).

Environmental stochasticity is the random variation in environmental processes that can affect a population (e.g. fluctuations in temperature, rainfall, food resources, populations of predators and competitors).

Natural catastrophes, such as floods, fire, drought and earthquakes, occur at irregular intervals and can have a major effect on population survival. Wildfire, for example, is a natural but irregular event in Australian ecosystems. Localized populations of animals can be eliminated, but in extensive tracts of forest there are always small refuges that are not burned (Newsome *et al.* 1975; Christensen and Kimber 1975). However, in fragmented environments, single remnants can be totally burned and the entire population of a species can be eliminated.

How Do Corridors Enhance Wildlife Conservation?

It is only recently that the contribution of corridors to understanding the dynamics of animal populations has been recognised and discussed in ecological theory. Theoretical approaches that recognise the importance of corridors are briefly reviewed here, and in the following section numerous examples of habitat corridors and their practical use by wildlife are presented.

Island biogeography and corridors

The equilibrium theory of island biogeography was developed by MacArthur and Wilson (1967) to explain the frequent observation that islands contained fewer species than mainland areas of comparable size. The equilibrium theory proposed that the number of species occurring on an island tends towards an equilibrium determined by a dynamic balance between the rate of colonisation of new species to the island and the rate of extinction of species resident on the island. The rate of colonisation is determined primarily by the degree of isolation of the island from the mainland, while the rate of extinction was postulated to be determined primarily by area. The number of species on the island should remain approximately constant, but the composition of the faunal assemblage would change with time.

It was quickly realized that isolates of habitat on the mainland, such as mountain tops, lakes, forest fragments and nature reserves, could also be viewed as "islands" surrounded by a "sea" of unfavourable habitat. Thus, the equilibrium theory became the first theoretical framework for interpreting and discussing the distribution and dynamics of fauna in patches of habitat. It stimulated a large body of research into the consequences for animals of habitat fragmentation and isolation (for reviews see Simberloff 1974; Gilbert 1980), and became the initial foundation for a new ecological discipline termed "conservation biology".

The important influence of isolation on the predicted number of species that an isolate might support at equilibrium, suggested that any measures that would reduce isolation and increase the rate of colonisation would have a significant conservation benefit. Accordingly, stepping stones or preferably continuous corridors of habitat to link isolates, were recommended in design strategies for nature conservation (Diamond 1975; Wilson and Willis 1975). Further, the presence of corridors facilitating colonization of animals could supplement declining populations before they actually reached extinction, in this way slowing down the rate of species extinction. This has been termed the "rescue effect" (Brown and Kodric-Brown 1977).

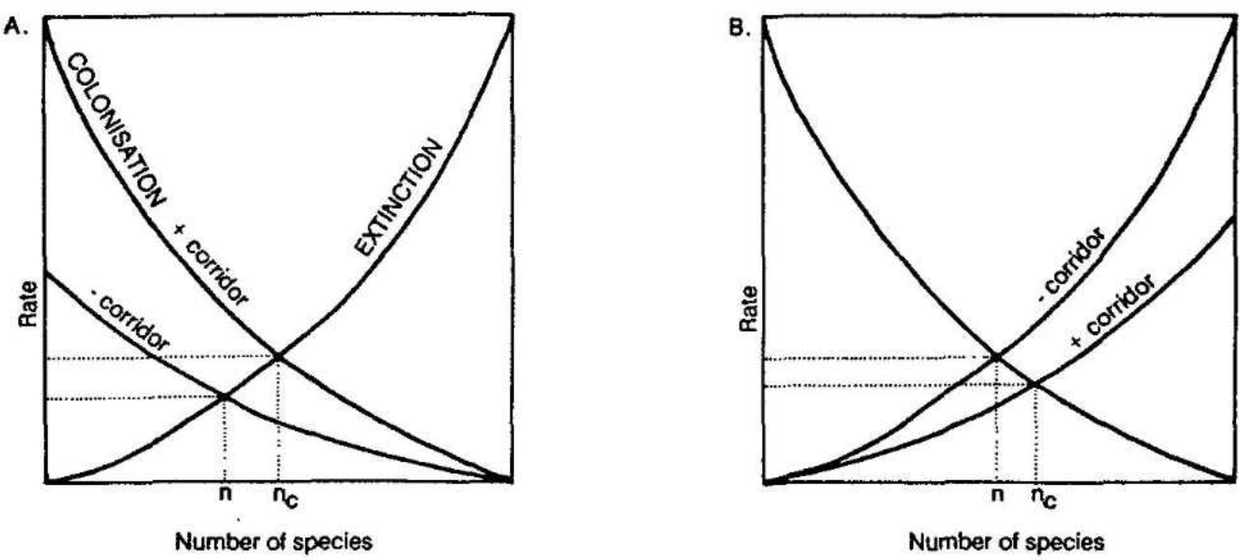

Figure 4. *The contribution of corridors to the species richness of an isolate, as predicted by the theory of island biogeography. The number of species at equilibrium, n, is a balance between the rates of colonisation of species to an isolate and the rate of species' extinctions. The presence of a corridor link increases the species richness at equilibrium, n_c, by increasing the rate of colonisation (A) and decreasing the rate of extinction (B).*

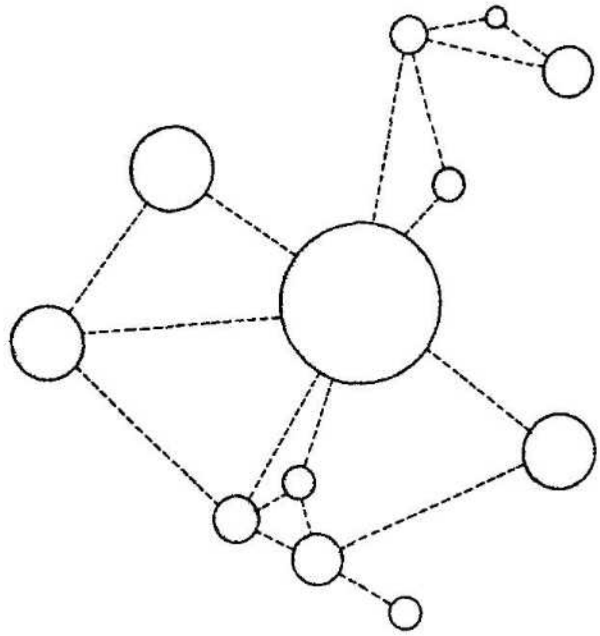

Figure 5. Diagrammatic representation of a metapopulation: a group of populations, large or small, that have some level of interaction (dashed lines) between them.

Thus, island biogeographic theory predicts that corridors will increase the conservation status of habitat isolates by maintaining a higher level of species richness at equilibrium (Fig 4). This is achieved by (i) increasing the rate of colonisation of species to the isolate, and (ii) supplementing declining populations, and reducing the rate of species' extinctions.

Metapopulation dynamics and corridors

In recent years, ecologists have increasingly recognised that natural environments are not homogeneous, but rather that they are composed of heterogeneous habitats that vary spatially and temporally in their quality and suitability for animal species (Wiens 1976; Cockburn 1981; Cockburn *et al.* 1981; den Boer 1981). Many species naturally occur in populations that are separated to varying degrees by poorer quality habitat. Small populations are particularly sensitive to chance variation in population change, genetic change and environmental fluctuation, and local extinctions may be a regular occurrence. For these populations, survival can depend upon interaction with other nearby populations. The level of interaction between adjacent populations is determined by the degree of isolation between them. If isolation is not absolute, the interchange that takes place between populations may be sufficient to recolonise any local population extinctions that occur, and thus prevent regional extinction in the entire group of populations. This model of a group of interacting animal populations has been termed a "metapopulation" (Fig. 5).

Populations of animals living in remnant habitat patches can also be viewed as metapopulations when there is some level of interchange between them (Fahrig and Merriam 1985; Henderson *et al.* 1985; Harrison *et al.* 1988; Opdam 1988; Hanski 1989). The metapopulation model is now replacing equilibrium island biogeography as the theoretical framework for understanding processes in habitat fragments. This model focusses on changes to populations of a species, rather than on the number of species in an isolate.

The ability of animals to move between isolated populations is crucial to the way a metapopulation will function. For example, when the level of isolation between populations is reduced, local extinctions should be less frequent and recolonisation more rapid, thus tending to increase the stability of the species in the regional landscape (e.g. Fahrig and Merriam 1985). The metapopulation model, therefore, recognises the importance of corridors as their ability to facilitate movements of animals between patches of habitat in order to: (i) recolonize populations that have become locally extinct; and (ii) supplement local populations that are declining. This is a species level approach and the conservation benefit of corridors is measured in terms of the persistence and status of viable populations of the target species in the regional landscape.

Landscape ecology and corridors

The development of landscape ecology has provided a more comprehensive understanding of the function of corridors in the environment (Forman and Godron 1981, 1986; Forman 1983; Noss 1983; Merriam 1984; Noss and Harris 1986). All landscapes, both those that are natural and those extensively modified by humans, are heterogeneous in space and time. Corridor habitats, together with patches of varying kinds and a background matrix, can be viewed as fundamental structural elements in the landscape. For example, in a rural landscape, corridor habitats may include streamside and roadside strips of forest, there may be small and large patches of forest, and all set amidst a background matrix of cleared farm paddocks. To understand ecological processes in the landscape, we must understand the dynamic functions of each of these elements and their interrelationships.

Corridors can fulfil four main functions in the landscape (Fig. 6) (Forman 1983; Forman and Godron 1986).

(i) They are a habitat for certain species.

The value of corridors as habitats is often overlooked. There is abundant evidence that wildlife utilise corridors of riparian vegetation, fencerows, hedges, plantations, roadsides, ditches, urban greenbelts, rail reserves, and other linear elements as habitats (see next section). In undisturbed environments, natural corridors (e.g. riparian vegetation) are frequently of high value as a habitat for wildlife and often support species that do not occur in adjacent habitats (e.g. Redford and de Fonseca 1986).

(ii) They facilitate the movement of plants and animals along the corridor.

Corridors frequently link habitat patches in the landscape and can be a pathway of favourable habitat along which animals move between patches in order to forage, for dispersal or to undertake nomadic or seasonal migratory movements. As landscapes become increasingly more disturbed, and the environment between patches becomes more isolating, the role of coridors is increasingly important if animals are to be allowed to maintain their normal movement patterns.

(iii) They are a filter or barrier to the movement of certain species through the landscape.

Natural corridors such as streams can act as a boundary to home ranges, to populations, and even to genetic units where there is total genetic isolation between animals on either side of the corridor. Because they are a part of natural landscape processes, the isolating effect of natural corridors is not of concern. In contrast, disturbance corridors of human origin (highways, canals, pipelines, railway lines, transmission clearings) are imposing an ever-growing network of partial or complete barriers through the landscape (Klein 1971; Oxley *et al.* 1974; Singer 1975; Barnett *et al.* 1978; Campbell 1981; Mader 1984, 1988). The isolating effect on wildlife populations that results from these disturbance corridors can be of major conservation concern (Harris and Gallagher 1989; Mansergh and Scotts 1989).

(iv) They are a source of environmental and biotic effects on the surrounding landscape.

Corridors do not occur in isolation, but interact in numerous ways with the surrounding environment. Corridor vegetation may provide shelter, nesting sites or refuge for biota in the surrounding environment, and animals from the corridor may move out to forage in adjacent habitats. Road systems, for example, are a source of chemical and physical pollutants and they may introduce invasive plants and animals into environments that the road corridor passes through (Bennett in press.).

In summary, landscape ecology views corridors as a fundamental structural unit in the landscape that fulfils at least four major functions.

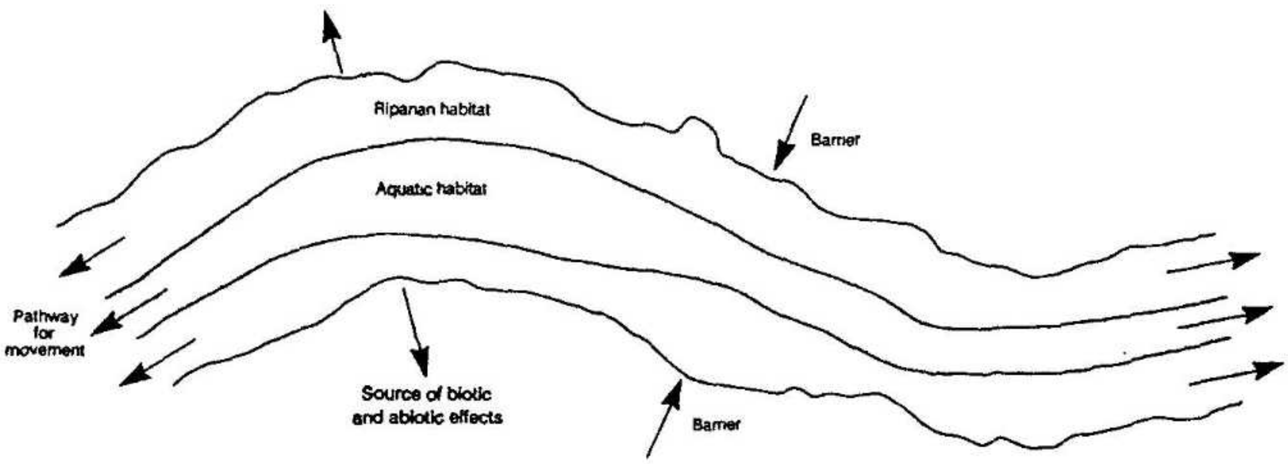

Figure 6. *Diagrammatic representation of a stream corridor illustrating four main functions of a corridor. The riparian and aquatic zones: (i) provide a habitat for fauna; (ii) provide a pathway for movement of animals through the surrounding environment; (iii) pose a barrier or filter to the movements of certain animals; and, (iv) are a source of biotic and abiotic effects on the surrounding environment.*

Habitat Corridors and Their Use by Wildlife Throughout the World

The following examples are presented to illustrate the use of habitat corridors by wildlife throughout the world. Firstly, examples of the use of five main types of corridors are documented; riparian habitats, hedges and plantations, fencerows, roadsides, and tunnels and underpasses. Secondly, selected examples are presented of corridors and corridor systems that have been designated by land-use planning processes to create ecological links in the landscape.

Riparian habitats

Streamside riparian habitats are natural corridors; the mesic streamside environment supports a band of vegetation that usually is structurally and floristically distinct from adjacent habitats. There is usually a gradient in the composition of the riparian vegetation as it merges with adjacent vegetation communities. Stream corridors may be wide, extending across a broad floodplain, or they may comprise a narrow band in a steeply-sloping gully. In south-eastern Australia, stream corridors generally have distinctive vegetation and they are readily recognised and mapped (Land Conservation Council 1987; Parkes *et al.* 1985; Earl and Bennett 1986).

Riparian habitats are well known for their rich faunas (Stauffer and Best 1980; Emmerich and Vohs 1982; Redford and de Fonseca 1986; Harris 1984, 1988c; Coles *et al.* 1989). In southern Australia, surveys of birds (Loyn *et al.* 1980; Norris *et al.* 1983; Friend 1982b; Smith 1984), mammals (Loyn *et al.* 1980; Friend 1982a), and reptiles and amphibians (Land Conservation Council 1985; Yugovic *et al.* 1987) have revealed the wide range of fauna that occur in these habitats. Frequently, the riparian corridor supports species that do not occur in adjacent environments. Aquatic species or semi-aquatic species (e.g. Platypus, Water-rat, Gippsland Water Dragon, Spotted Tree Frog), and species that forage in, or use other resources of, the aquatic habitat (e.g. Azure Kingfisher, Large-footed Myotis) are obvious examples. Other species favour the riparian vegetation as a habitat and seldom occur elsewhere (e.g. Brown Gerygone, Black-faced Monarch, in eastern Victoria).

The Murray River, where it passes through semi-arid parts of northern Victoria, is an interesting example of a natural riparian corridor. Many species, such as the Feather-tailed Glider, Blue-faced Honeyeater, Yellow Rosella, Little Friarbird, Tree Goanna, Tiger Snake, Eastern Water Skink, Peron's Tree Frog and Barking Frog, are almost entirely restricted to the mesic riverine habitats (Land Conservation Council 1987), and for many of these species the riverine habitat clearly has been the pathway along which they have extended and maintained their ranges in the semi-arid environment. A similar example has been described from Brazil, where narrow mesophytic gallery forests along watercourses are crucial in maintaining a high diversity of native mammals in the dry cerrado vegetation formation (exceeding 1.4 million km^2) (Redford and de Fonseca 1986). The gallery forests provide corridors of moist vegetation that allow many forest-dwelling animals to expand their ranges into the drier environment of the cerrado. Some 86% of the genera of mammals recorded from the cerrado (total of 65 genera and 100 species presently known) use the gallery forests either obligately or opportunistically (Redford and de Fonseca 1986).

Riparian habitats often survive, or are retained, as remnant corridors in developed landscapes such as plantations, farmland and urban environments (Suckling *et al.* 1976; Friend 1980, 1982a; Emmerich and Vohs 1982; Brooker 1983; Dobbyns 1983; Fowler and Howe 1987; Recher *et al.* 1987; Coles *et al.* 1989). In these environments they can make an important contribution to maintaining a wide range of forest-dependent species in the landscape. For example, Recher *et al.* (1987) censused birds and arboreal mammals in remnant riparian corridors of eucalypt forest amongst pine plantations in the Eden area, New South Wales. Of the 113 species of terrestrial birds known from the Bombala district, 81 (72%) were recorded in six riparian corridors, and 41 were found nesting. All seven species of arboreal mammal known from the area were recorded during censuses of 20 riparian corridors, although the Yellow-bellied Glider was only present in the widest strip (247m).

Corridors of riparian vegetation to be reserved from timber harvesting have consistently been proposed by biologists following surveys of the fauna and flora in forest blocks in Victoria (e.g. Carr *et al.* 1984; Brown *et al.* 1987; Horrocks *et al.* 1987; Lunt *et al.* 1987; Schulz *et al.* 1987). These proposed corridors have been identified as links between sites of biological significance, as habitat for rare species of plants and animals (e.g. Sooty Owl, Powerful Owl, Blue Mountains Tree Frog, Spotted Tree Frog), and as rich faunal habitats in their own right.

Hedges, shelterbelts and plantations

Hedges, shelterbelts and plantations are corridors of vegetation that have been planted by humans, usually along the boundaries of farm paddocks. Hedges are widespread in Great Britain and Europe where they have traditionally served as a barrier to the movement of stock between fields (Pollard *et al.* 1974; Forman and Baudry 1984; Dowdeswell 1987). Shelterbelts and plantations have been established in many countries for various purposes, including: as windbreaks; to reduce soil erosion; as a source of timber; as wildlife habitat; and for their aesthetic qualities.

The ecology of hedges in Great Britain and Europe has been much studied (for a review see Forman and Baudry 1984), and they are well known as a habitat for wildlife (Lewis 1969; Pollard and Relton 1970; Eldridge 1971; Pollard *et al.* 1974; Arnold 1983; Osborne 1984; Rands 1986; Lack 1988). The persistence and abundance of many animals traditionally present in British and European farm landscapes depends upon the availability of hedges as shelter, breeding sites, refuge, and habitat (Pollard *et al.* 1974). Arnold (1983) surveyed birds in farmland in Cambridgeshire and found that census sites (5 ha) that included hedges, ditches or linear woods, had a greater number of species than sites comprising arable land only. Osborne (1984) censused birds in hedges in Dorset, and found that hedge area was the best predictor of bird species richness. Bird-rich hedges were those that had a large area, many species of trees, dead timber, and were close to scrub areas. Intersections of hedges are favoured by many breeding birds in comparison to straight stretches (Lack 1988), probably because a greater area of habitat is available within a shorter distance.

Pollard *et al.* (1974) noted that almost all British mammals make use of hedges at varying times. Small terrestrial mammals have been most studied (Pollard and Relton 1970; Eldridge 1971). Some species depend on the hedge habitat for persistence in farmland (Bank Vole), while others (Wood Mice, Short-tailed Vole) also occur in agricultural fields.

Clearing of hedges in rural areas in recent decades (e.g. Conyers 1986) has raised concern at the loss of habitat and habitat continuity for wildlife. Several studies (Bull *et al.* 1976; Watnough 1973 in Arnold 1983) indicate that following reduction in the extent and continuity of hedges, the total number of bird species in farmland remains similar, but species typical of open fields increase in abundance at the expense of other species. In the Netherlands, van Dorp and Opdam (1987) found that the species richness of woodland birds in small remnant forests was best predicted by forest area; but that the extent of hedge corridors in the landscape made a further significant contribution to species richness. Thus, a forest remnant in a landscape with numerous hedge corridors is likely to have more resident woodland birds than a remnant of similar size in a landscape lacking corridors.

Hedges have been described as movement corridors for the Viper in Great Britain (Presst in Pollard *et al.* 1974). During winter, Vipers hibernated in a hedge on a raised sandy bank. After emergence in spring, they initially dispersed along the hedge where they remained until they sloughed their skins. Subsequently, individuals of both sexes moved along the network of hedged banks and ditches to a wet marshy area where they remained over summer. In mid-August pregnant females migrated back to the hedge where they gave birth: later the males also moved back to the hedge for winter hibernation (Pollard *et al.* 1974).

The establishment of planted borders and shelterbelts, and regrowth of brushy fencerows in North American farmland was advocated by early wildlife managers as a strategy to increase wildlife, especially game species, in rural areas (Davison 1941; Dambach 1945). Recent studies (Martin 1980; Emmerich and Vohs 1982; Yahner 1983a,b) have documented the large variety of wildlife that can use plantations. For example, during two breeding seasons in southern Minnesota, USA, Yahner (1983a) recorded 87 species of birds in shelterbelts. To maximise their value for the avifauna, he recommended that shelterbelt corridors should be at least eight rows in width, that a diversity of plantings be used, that mowing and cultivation not occur, and that dead trees be retained as nesting and foraging sites. In five of these shelterbelts, a total of 11 species of small mammals were trapped (Yahner 1983b). It was concluded that small mammals would benefit by establishing shelterbelts that are as large as possible within the economic constraints of farming.

Linear plantations and shelterbelts are common in farmland of southern Australia, but there has been little documentation of the wildlife that use them. Many plantations are of exotic species of conifers, or eucalypts from other regions; but planting of indigenous trees and shrubs is increasing in popularity. In Western Australia, Biddiscombe (1985) recorded the avifauna of four experimental eucalypt plantations established around salt seeps. Thirty-five species of birds were recorded during fixed transects and a further 26 species were sighted at other times. This total included a wide range of woodland and open farmland birds. The number of birds increased each year (1976-1983) as the trees grew in height and foliage cover increased (Biddiscombe 1985).

Fencerows

Fencerows are narrow strips of vegetation along field boundaries. In contrast to hedges and shelterbelts that have been deliberately planted, fencerows have developed by the regeneration and dispersal of plants in a strip of neglected land between agricultural fields. Fencerows are widespread in the eastern United States and southern Canada where they form an extensive corridor network of wildlife habitat through farmland. Fencerow vegetation ranges from scattered shrubs amid long grass, to narrow lines of shrubs, to broad strips with a mature tree canopy and a woodland interior.

Studies of the fauna of fencerows (Petrides 1942; Dambach 1945; Ogilvie and Furman 1959; Wegner and Merriam 1979; Best 1983; Asher and Thomas 1985; Henderson *et al.* 1985) show that they are used by many species and have an important role in maintaining wildlife within the agricultural zone. For example, Petrides (1942) noted that 92 species of birds had been observed in fencerows in his study area in New York State, and Best (1984) recorded 62 species as using fencerows among farmland in Iowa. Asher and Thomas (1985) trapped nine species of small mammal in fencerows among farmland in southern Ontario, Canada.

Fencerows provide pathways for the movement of animals between forest patches within the agricultural mosaic. Wegner and Merriam (1979) found that the White-footed Mouse and Eastern Chipmunk seldom moved between forest patches and grassy fields, but they frequently moved between forest patches and fencerows. Similarly, birds seldom flew directly across fields in their study area, but more commonly moved from forest patches to fencerows (Wegner and Merriam 1979). Johnson and Adkisson (1985) described Blue Jays following fencerows on flights of up to 4 km, while carrying beech nuts from the forest to their winter caches. Of the birds observed, 91% followed the fencerow closely and only 9% flew over fields. The fencerows provide a travel pathway along which shelter from avian predators was readily obtained (Johnson and Adkisson 1985).

A modelling study, verified by field data, demonstrated that populations of the White-footed Mouse in forest patches that are linked by fencerows are less likely to become locally extinct, and are likely to attain a faster population growth rate in spring and summer (following over-winter mortality) than are populations in isolated patches (Fahrig and Merriam 1985). Radiotelemetry of tagged mice (Merriam and Lanoue 1990) showed that they preferred to move in fencerows rather than in more open landscape elements, and that they favoured fencerows with structurally-complex vegetation.

Fencerows are commonly used by squirrels for movement through the farmland mosaic. Baumgartner (1943) identified the importance of fencerows as "travel lanes" for Fox Squirrels (a game species) to recolonise forest patches when the patch had been "shot out". Movements of Eastern Chipmunks in a farmland-forest mosaic were documented by Henderson *et al.* (1985). Numerous movements of animals along fencerows, from fencerows to forest patches, and between forest patches, were recorded. When local extinctions were simulated by removing chipmunks from forest patches, the patch was rapidly recolonized by dispersing individuals.

Roads and roadsides

There is growing evidence that animals can use road reserves as a habitat in which to live, and as a movement corridor that facilitates local movements, dispersal and migration: road systems can also act as barriers to animals and as a source of biotic and abiotic effects on the surrounding landscape (for a review see Bennett in press).

The survival of remnant patches and strips of natural forest, woodland or shrubland vegetation on roadsides is a distinctive feature of rural landscapes in southern Australia. In the Wimmera region of Victoria, Middleton (1980) noted that he had observed more than 130 species of birds in roadside vegetation. In a single strip of roadside woodland, 2.5 km in length and 70 m wide, he recorded a total of 85 species of birds from regular transects, of which 30 species bred there. At least 25 species were migratory or nomadic, and used the roadside strip for short periods only: nectarivorous honeyeaters and lorikeets, for example, passed through the roadside vegetation when the eucalypts were flowering. Flocks of up to 60 White-naped Honeyeaters were also observed using the roadside corridor as a pathway for migratory movements through cleared farmland (Middleton 1980).

Roadsides with mallee shrubland vegetation in north-western Victoria are a valuable remnant habitat for birds among the extensive wheat farms. Krohn (1981) reported 40 species from a road reserve with narrow (<10m) strips of mallee vegetation. Silveira and Bennett (unpublished data) recorded 43 species from brief censuses at 34 roadside sites where mallee vegetation ranged from 9 to 50 m in width. These species included open farmland birds (e.g. Australian Magpie-Lark, Crested Pigeon), common birds of dry woodlands and shrublands (e.g. Weebill, Red-capped Robin, White-browed Babbler), and also birds typical of mallee shrubland (Yellow-plumed Honeyeater, Yellow-rumped Pardalote). In South Australia, a 10 km segment of a former travelling stock reserve, 400 m in width, is now designated as Ridley Conservation Park (Anon. 1983). Forty-nine species of birds have been recorded from this long corridor, and an incomplete list of three native mammals (including the Southern Hairy-nosed Wombat), and two reptiles is also recorded.

Bird populations on road reserves in Western Australia have been studied at several localities. Newbey and Newbey (1987) documented the birds of a 2.0 km length of road reserve, 20 m in width, in farmland at Ongerup. Forty-four species were recorded from the roadside vegetation, and for 22 species the roadside was considered to be an important part of their local range. Eight species bred in the reserve, and nine species (e.g. Regent Parrot, Western Rosella, Varied Sitella, Silvereye) were considered to use the reserve as a movement corridor between larger tracts of woodland in the area (Newbey and Newbey 1987). In the Kellerberrin district, censuses of the avifauna at 22 road reserves listed 52 of the 64 recorded landbird species of the area (Arnold *et al.* 1987; Arnold and Weeldenburg 1990). Roadside vegetation plays an important part in the local and regional conservation of the avifauna of the wheatbelt by providing: permanent or seasonal habitat for numerous species; foraging areas for locally nomadic species; shelter and nesting sites for species that forage in farmland; and pathways for dispersal of young between remnants (Arnold and Weeldenburg 1990).

Long-term studies of the population dynamics of Carnaby's Cockatoo in Western Australia (Saunders 1980, 1982; Saunders and Ingram 1987) have illustrated the importance of roadside corridors in the local survival and persistence of this species. This cockatoo nests in woodlands where tree hollows are available, and forages in mallee and heathland vegetation. In the fragmented landscape, cockatoos must move large distances between remnants to obtain these dual requirements. Saunders and Ingram (1987) showed that breeding success was higher in landscapes with broad vegetated roadsides that provide clear links between remnants of heathland and shrubland. At one study site, where roadside linkages are narrow and incomplete, the population had a low breeding success and subsequently declined to extinction.

Reports of birds utilising roadside corridors are also available from other countries, including Great Britain (Way 1977), Denmark (Laursen 1981), India (Dhindsa *et al.* 1988), and the United States (Oetting and Cassel 1971; Ferris 1979; Michael 1986).

In south-western Victoria, Bennett (1988, 1990b) documented the mammals that occurred in forested roadside corridors, 5 to 40 m in width, that form a network of linkages through a forest-farmland mosaic. Eighteen species, 78% of the local mammalian fauna (excluding bats), were recorded using the roadside as a refuge, foraging area, movement corridor, or as a resident habitat. Studies of the population dynamics and movements of six species of small terrestrial mammal showed that the roadside corridors facilitate continuity between forest patches for these species by the movement of single animals along the corridor, and by gene flow resulting from the movements of animals to and from populations resident within the corridor.

Dispersal of the arboreal Sugar Glider along a forested roadside in eastern Victoria was documented by Suckling (1984). He studied populations of gliders living in several forest fragments and a roadside strip, and found that all known dispersal movements, of up to 1.9 km, involved movement along the roadside corridor. Four other arboreal marsupials, the Common Ringtail Possum, Common Brushtail Possum, Koala, and Feathertail Glider, were recorded in the roadside corridor and probably also use it as a pathway for dispersal.

Roadsides and median strips adjacent to main highways in the United States were found to support 40 species of small terrestrial mammal (Adams 1984; Adams and Geis 1983). The grassy habitat on many roadsides was favoured by grassland rodents, and higher densities were present there than in adjacent habitat. Getz *et al.* (1978) described how one grassland rodent, the Meadow Vole, expanded it's geographic range in Illinois, by dispersing along the dense grassy corridors of interstate highways. Huey (1941) described the range expansion of pocket gophers across desert terrain in California by their use of a narrow corridor of mesic microhabitat at the edge of the road where it received runoff from the road surface.

Lightly-trafficked roads are commonly used by predatory mammals as a clear pathway for movement and hunting, unimpeded by vegetation and other obstructions (e.g. Pienaar 1968). In south-western Tasmania, the marsupial predators Tiger Quoll, Eastern Quoll and Tasmanian Devil were recorded only along forest tracks despite a greater survey effort away from tracks (Taylor *et al.* 1985). The introduced predators, Fox and Cat, also use roads extensively as movement pathways through forests. The proliferation of roads and tracks in forests facilitate their spread. The open space above forest roads provides a corridor along which bats can forage and move freely through the forest vegetation. Crome and Richards (1988) suggest that forestry roads through rainforest in Queensland assist a group of 'gap-specialist' bats to locate and move between the gaps in the forest where they forage.

Martin and Tyler (1978) reported the dispersal and range expansion of the Spotted Grass Frog along a roadside ditch in northern Australia, where a population of this eastern Australian frog had accidentally been introduced.

Tunnels and underpasses

Tunnels and underpasses are a distinctive example of corridors that have been constructed and installed to facilitate the movements of wildlife across potential barriers. Roads, in particular, pose a barrier to wildlife movements due to the expanse of cleared and altered habitat; the noise, movements and flashing lights from passing traffic; and the risk of death from passing vehicles.

Highway underpasses are regularly used for the management of large game species such as Elk, Mule Deer and Mountain Goat in North America (Reed *et al.* 1975; Reed 1981; Ward 1982; Singer *et al.* 1985; Harris 1988b). They have proved to be effective in facilitating animals crossing highways at migration pathways, or where busy highways bisect their habitats. For example, in Montana, USA, where a highway crossed the pathway of Mountain Goats travelling to a natural salt lick, the animals were inhibited, but not prevented, from crossing the road (Singer 1975). However, the effects of the road included increased stress for the animals, the risk of separation of mother and young, and increased mortality from road kills. When an underpass was subsequently constructed, less stress was observed in animals crossing, and the number of visits and the seasonal duration of visits increased (Singer *et al.* 1985).

Underpasses or tunnels have also been used to facilitate movements of smaller animals such as Badgers (Ratcliffe 1974, in Mansergh and Scotts 1989), Toads (van Leeuwen 1982) and, in Australia, the Mountain Pygmy-possum (Mansergh and Scotts 1989). For this latter species, a road and other structures bisecting its alpine habitat, appeared to be disrupting social organisation within the population by preventing dispersal of males. When a rock-scree corridor and tunnels were installed to restore habitat continuity, dispersal of males occurred and the survival of resident females within the breeding habitat was significantly increased (Mansergh and Scotts 1989).

Tunnels may also be used under railway lines (e.g. Hunt *et al.* 1987) and other structures; and in Alaska, oil pipelines have been elevated above the ground to provide underpasses for Caribou populations (Klein 1971; Curatolo and Murphy 1986).

Planned corridors and corridor systems

The following selected examples illustrate a range of situations in which particular corridors, or corridor systems, have been identified and managed for conservation purposes.

(i) Zona Protectora La Selva, Costa Rica.

A recent acquisition by a consortium of conservation agencies has created a corridor that links two important reserves in Costa Rica, the upper elevation Braulio Carillo National Park and the lower elevation La Selva Biological Station (Wilcove and May 1986). The corridor encompasses a 7700 ha expanse of forest, 3-6 km wide and some 24 km in length. The combined reserve can now protect larger populations of many species, and the corridor should assist the seasonal altitudinal migration of at least 35 species of birds.

(ii) Queet River corridor, Olympic National Park, USA.

Olympic National Park, Washington, USA, was designed to include an 80 km riparian corridor linking the mostly high elevation park with the Pacific Ocean. The purpose of this river valley corridor is to facilitate the seasonal migrations of Steelhead, Salmon, Roosevelt Elk, Columbia Black-tailed Deer and other wildlife species (Harris and Gallagher 1989).

(iii) Pinhook Swamp corridor, Florida, USA.

The Osceola National Forest in Florida and the Okefenokee Wildlife Refuge in Georgia, two large natural areas in south-eastern USA with a combined area of some 400,000 ha, are separated by 16 km. In 1989 they will have a protected linkage when the purchase of Pinhook Swamp corridor is completed (Harris and Gallagher 1989). This strategic linkage will create a natural area of sufficient size for viable populations of a number of endangered species (e.g. Red-cockaded Woodpecker), and which has potential for the re-introduction of other endangered species such as the Florida Panther, Whooping Crane, and Red Wolf (Harris and Gallagher 1989).

(iv) Hedge networks and the "remembrement", France.

In parts of rural France, restructuring of farm properties ('remembrement') is being carried out to rationalise the distribution of parcels of land that each farmer operates (Baudry and Burel 1984). Over a number of generations, inheritance customs have resulted in many farms becoming a scatter of fields that may be up to 5 km apart. The restructuring is done on a municipality basis, and at the request of the majority of owners. In those landscapes with extensive hedge networks ('bocages'), initial attempts at re-distribution involved much destruction of natural features and led to environmental problems. Subsequently, environmental survey and evaluation have been carried out prior to any changes. This has resulted in recommendations for the preservation of a selected network of hedges and other linear features to provide windbreaks, prevent erosion, and to maintain ecological links between forests and throughout the farm landscape. Additional hedgerows can be planted to complete the planned corridor network, where necessary. This ecological planning appears to be worthwhile, even though the recommended strategy is not necessarily adopted in entirety (Baudry and Burel 1984).

(v) Experimental corridor, Brazil.

An experimental project on the effects of clearing and fragmenting rainforests in Brazil (Lovejoy *et al.* 1984) includes a study of the effects of a corridor on the dynamics of fauna in forest isolates. Harper (in Simberloff and Cox 1987) monitored the ant birds in a 100 ha isolate connected to extensive rainforest by a 2 km riparian corridor at least 100m wide. When 300 m of the corridor was destroyed, three species of ant birds disappeared from the isolate within four weeks. After a year of regeneration in the corridor, one of the three species is beginning to recolonize.

(vi) Network of 'old growth' forest, north-western USA.

The Douglas Fir-Western Hemlock forests in Washington and Oregon States, USA, originally spanned a distance of 800 km and occupied some 11 million ha. These forests have the most expansive tracts of interconnected, unlogged forest in the United States. They are the habitat of a wide range of forest fauna, with the presence of large carnivores (e.g. Cougar, Lynx, Black Bear, Wolverine, Spotted Owl, Great Horned Owl) being an outstanding characteristic of the fauna. These forests are also in great demand for timber production. Harris (1984) described the forest ecosystem and the value of old-growth forests to wildlife communities, and outlined a strategy for the preservation of a network of corridors and stepping-stone reserves of old growth forest to preserve biotic diversity. This is a good example of a reasoned ecological analysis for the importance of preserving a regional system of corridors; its implementation, however, is not assured.

(vii) Network of reserved forest, Eden, New South Wales.

At Eden, New South Wales, eucalypt forests are managed for the integrated production of pulpwood and hardwood sawlogs. When logging commenced in 1968, large blocks of forest (800 ha) were cleared with little knowledge of the effects on forest wildlife. This region subsequently became the location of intensive studies into the effects of timber harvesting on forest fauna (Recher et al. 1980; Braithwaite 1983; Braithwaite et al. 1983, 1984; Kavanagh et al. 1985; Smith 1985; Recher et al. 1987), and the preliminary results from these studies have contributed to the development of a planned network of reserved forest as part of the management of this area (Dobbyns 1983). The network of reserved forest includes nature reserves, swamps, areas of rocky or steep terrain, and a system of corridors along rivers and creeks. Forest types that support the richest communities of forest-dependent wildlife have been recognised, and these can be preferentially included in the reserve system (e.g. the expansion of riparian corridors in gullies and creek flats where *Eucalyptus cypellocarpa* is present). Importantly, the network of interconnecting corridors has been recognised as essential to wildlife management in the forests, and it is planned at a regional scale. Clearly, such planning is a dynamic process and further modification of the reserved forest network will be required in the light of further knowledge of forest wildlife (e.g. Recher et al. 1987).

(viii) Annuello corridor, Victoria.

In 1985, following public concern at the clearing of "mallee" shrubland between the Annuello block (some 35,000 ha) and the extensive Sunset Country in semi-arid north-western Victoria, the Government acquired land to establish a wildlife corridor between these areas. The corridor, some 6 km long and 0.5 km wide, presently consists of patches of mature mallee, regenerating mallee and cleared farmland. Regeneration and restoration of the natural mallee shrubland is presently being undertaken, and a fauna monitoring programme to assess the effectiveness of the corridor began in 1988. Preliminary results (Bennett and Silveira unpublished) indicate that a large proportion of the local mallee fauna is present in the corridor (e.g. 29 species of reptiles, 56 species of birds), but several species typical of mallee shrubland have not yet been recorded (e.g. Malleefowl, Striated Grasswren, Mallee Emu-wren).

What do these examples reveal about the use of corridors by wildlife?

The examples discussed illustrate and provide evidence for two main ways in which corridors can enhance the conservation status of wildlife.

Firstly, there is abundant evidence that corridors of all types serve as habitats in which animals can live. Thus, they function as linear reserves, adding to the total amount of suitable habitat available in the environment. They can also provide a source of colonists to move into surrounding environments when other suitable habitat becomes available. In extensively modified agricultural environments, corridor habitats such as those discussed, and others such as railway lines, water channels, drainage lines and edges of lakes, together may comprise a substantial proportion of remaining natural areas in the landscape. Many of the species that utilise these linear habitats are widespread or relatively common species. However, rare and forest-dependent species can also occur in corridors. For example, in rural areas of north-eastern Victoria, three threatened species, Grey-crowned Babbler, Squirrel Glider and Brush-tailed Phascogale, can utilise vegetated roadside corridors. There is a need, however, for quantitative research to investigate whether some corridors are "sink" habitats in which reproduction is insufficient to balance mortality, or whether they are "source" habitats for populations (Pulliam 1988).

Secondly, there is ample evidence that a wide variety of wildlife species move along corridors, and can use corridor habitats to travel and maintain population continuity through otherwise unsuitable habitats. Corridors facilitate a variety of types of animal movements, and these occur at a range of spatial scales. They include:

- foraging or local movements within a home range area (e.g. Johnson and Adkisson 1985; Saunders and Ingram 1987);
- dispersal between populations (e.g. Suckling 1984; Henderson *et al.* 1985; Bennett 1990b);
- seasonal migratory or nomadic movements (Middleton 1980; Newbey and Newbey 1987); and,
- geographical range expansion (e.g. Getz *et al.* 1978).

It is important to note, however, that few empirical field studies have specifically addressed the issues of animal use of corridors. Consequently, although it is clear that animals can move along corridors, and that population continuity can be achieved through populations resident within corridors, there is little empirical data to demonstrate unequivocally the conservation benefits that are gained from such movements (e.g. the prevention of local extinction, gene flow between populations, recolonisation following local extinction) (for further discussion of this point, see Simberloff and Cox 1987; Noss 1987; Nicholls and Margules in press). These gaps in our knowledge highlight the need for studies to specifically address the conservation role of habitat corridors in a quantitative manner. Clear objectives and careful design of such studies will be essential.

River systems in arid environments, such as the Murray River in north-western Victoria, are natural corridors of mesic vegetation.

Fencerow vegetation along the margins of fields in North America provide a system of regenerated corridors for wildlife in farmland.

Considerations in the Design and Management of Corridors for Conservation

Much of the evidence for the use of corridors by wildlife is observational and concerns remnant corridors that have survived by default rather than by good management (e.g. roadsides, fencerows). There are few planned systems of corridors, and there is little empirical data that addresses practical questions to which wildlife managers and planners require answers in order for ecologically sound corridors to be established. In this section, some of the major issues in the design and management of corridors are discussed. Clearly there is an urgent need for quantitative, process-oriented research to provide a more satisfactory basis for such planning.

How do corridors provide continuity for animal populations?

Facilitating the continuity of wildlife populations through an unfavourable environment is one of the main contributions of habitat corridors to wildlife conservation. But how do corridors facilitate continuity of populations? What types of movements do animals undertake in corridors? How does the type of movement affect the design of corridors?

Population continuity between patches of habitat can be achieved by three types of movement along corridors (Fig. 7).

(i) Direct movement by single individuals

Direct movements by single animals along the entire length of the corridor are most likely to be made by large animals, or those whose regular movements are at a greater spatial scale than the length of the corridor. For example, a predator foraging within a forest-farmland mosaic may move along remnant corridors between forest patches within a few minutes. Birds that fly along corridors on foraging expeditions or on migratory movements, may also do so in single direct movements.

(ii) Movement by a single individual, punctuated by pauses in the corridor

The movements of animals along corridors are commonly punctuated by one or more pauses within the corridor. Individuals that forage as they traverse the corridor may pause for an hour or less (e.g. lorikeets feeding on flowering eucalypts along a roadside). Migrating birds or mammals may pause for hours or days, using the corridor as a shelter or feeding area before moving further. Small mammals dispersing between isolated populations in forest patches may pause in the corridor for days, weeks or months before completing the dispersal movement.

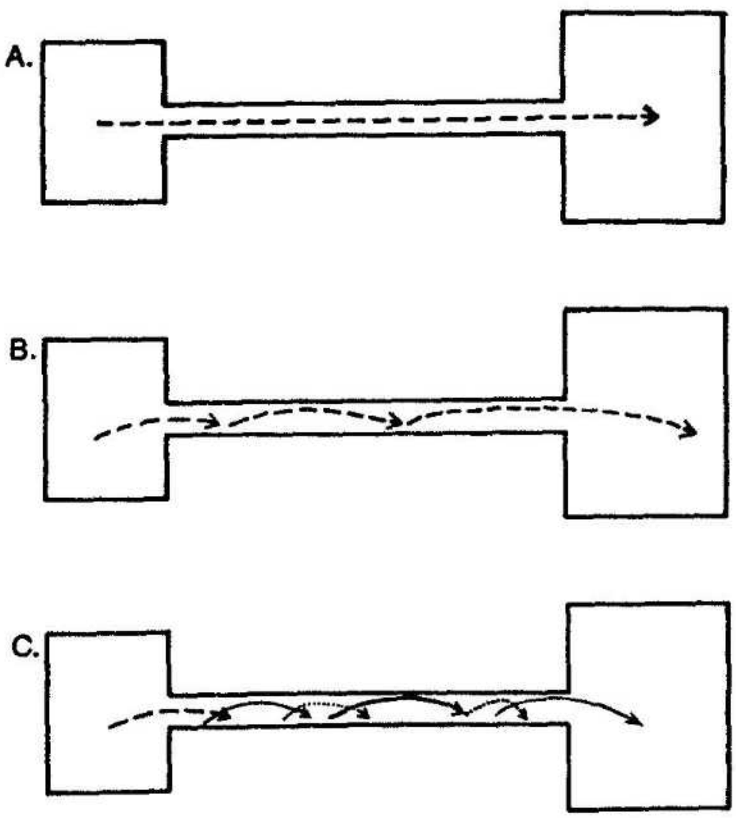

Figure 7. Diagrammatic representation of three ways in which corridors facilitate continuity between populations in habitat patches: (A) direct movement by single individuals; (B) movement by a single animal punctuated by pauses in the corridor; and, (C) gene flow through a population resident within the corridor.

(iii) Gene flow through a population resident within the corridor

The most effective way for corridors to provide continuity between populations is by the presence of an interconnecting corridor that is of sufficient size and habitat quality to support a resident population of the target species. The combined movements of animals to and from a resident population in the corridor, plus movements and reproduction within the corridor, can result in gene flow and effective continuity between populations that are linked in this way. Reproduction within the corridor provides an additional source of dispersing animals and increases the overall population size in the landscape. This type of corridor will also facilitate direct movements of animals, and will assist them by the reliable presence of food and shelter within the corridor.

Ecology and behaviour of species

Identification of the species or species assemblage for which a corridor is required, and a basic knowledge of their ecology is a first requirement for corridor design. Knowledge of the spatial scale of a species' movements is of particular value. How large is the home range? How far do animals disperse? Do they undertake seasonal or nomadic movements? Clearly, the optimum dimensions of a corridor will differ between small terrestrial animals whose scale of movements can be measured in metres, and larger animals that regularly move hundreds of metres.

Information concerning the habitat requirements, diet, and other necessary resources, will assist in optimizing the habitat within the corridor. Other behavioural and ecological attributes, such as the ability to cross gaps, the role of dispersal in the life-history, the age of dispersing individuals, social organisation, and behavioural spacing mechanisms within the population, will also influence the ability of species to effectively utilise corridors.

In most situations, corridors are intended to benefit a community or assemblage of animals rather than a single selected species. Design of corridors to provide habitat and effective population continuity for those species with the largest movement patterns and more-specialized habitat and foraging requirements should also encompass the requirements of many other species. For example, in the forests of south-eastern Australia, corridors designed to maintain the Yellow-bellied Glider and Sooty Owl within the forest ecosystem should also be effective for the Brown Antechinus, Water Skink, Golden Whistler and a host of other forest wildlife.

Structural connectivity of the corridor system

Variables that can influence the structural connectivity of a corridor system include; the presence, number and length of gaps; the presence of alternative pathways, or networks; and the presence of habitat nodes in the system (Fig. 8) (Forman 1983; Forman and Godron 1986; Baudry and Merriam 1988).

Gaps in a corridor can severely disrupt animal movements along the corridor, or the continuity of a resident population within the corridor. What constitutes a gap, and how effective it is as a barrier, will depend upon the habitat specificity, the scale of movements and the behaviour of a species. For a forest animal, a gap in a forested corridor could be a stream, a road, a strip of grassy vegetation, a burned patch of forest, a break in the canopy, or even a different forest community. The severity of the gap will depend upon the extent of contrast between the gap habitat and the corridor habitat. A narrow gap of unsuitable habitat may be a more effective barrier than a broad gap of poor quality habitat (or vice versa). A gap in a forest corridor that is an effective barrier to a small mammal or beetle is unlikely to inhibit the movements of most forest birds. Similarly, a gap in the tree canopy of a forested corridor may pose a formidable barrier to an arboreal mammal, but not to a terrestrial mammal.

There is very little empirical information on the effects of gaps on the movement of animals. Studies of the effects of roads that bisect the habitats of small terrestrial mammals indicate that relatively narrow gaps of < 10 m, can inhibit, but not necessarily prevent, their movement (Barnett *et al.* 1978; Kozel and Fleharty 1979; Wilkins 1982; Mader 1984; Merriam *et al.* 1989). In eastern Australia, Barnett *et al.* (1978) reported that a narrow forest road (< 5 m wide), and even an overgrown fire trail (3 m), appeared to inhibit movements of the Brown Antechinus and Bush Rat. In Canada, Oxley *et al.* (1974) found that the White-footed Mouse and Eastern Chipmunk were able to cross roads that had a clearance of up to 30 m, but no road crossings were recorded for roads that had more than 100 m clearance. Studies of invertebrates (Mader 1984, 1988) have shown that bare road surfaces as narrow as 6 m in width can pose an almost total barrier to beetles and spiders.

The length of a corridor can influence its effectiveness in several ways. With increasing distance there is a reduced likelihood of single animals (particularly small terrestrial animals) traversing the length of the corridor, and an increased reliance on self-sustaining populations in the corridor to provide population continuity. Increased length also exposes animals in the corridor to a greater cumulative impact of edge

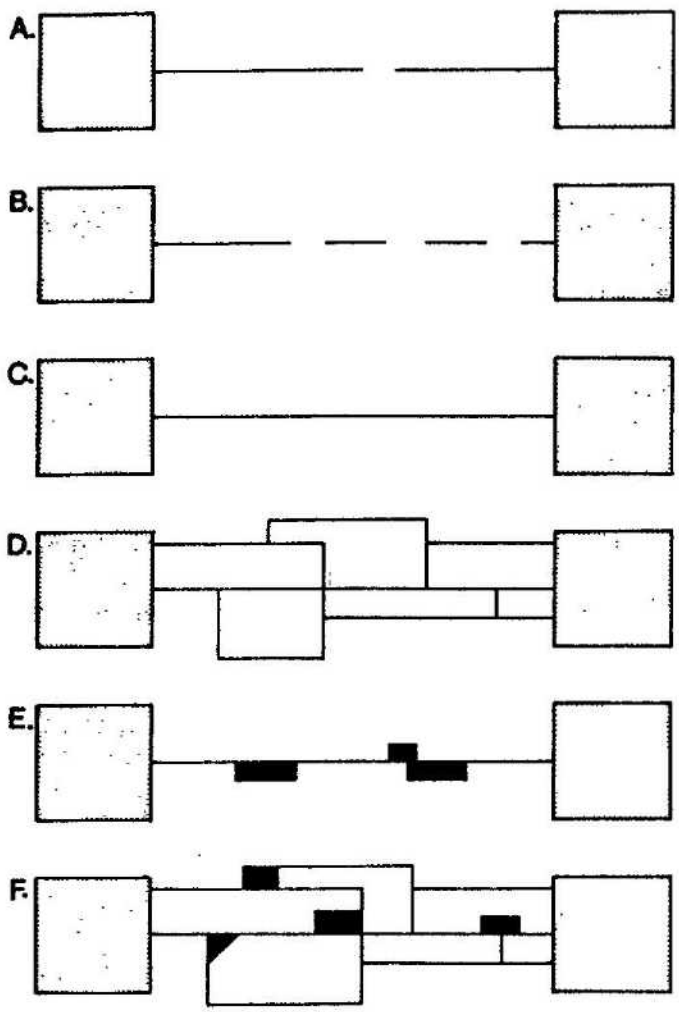

Figure 8. The structural connectivity of a corridor system is influenced by a number of factors: the number and length of gaps (A and B) or whether the corridor is continuous (C); whether a network or multiple pathways are are available (D); and whether there are nodes or patches of habitat along the corridor (E). A corridor system that provides continuity, multiple pathways and nodes of habitat along the way (F) is likely to be the most effective way of linking animal populations in remnant habitats.

effects (e.g. risk of predation) from adjacent habitats,and there is a greater vulnerability to sudden disturbance or catastrophe that can cut the corridor (e.g. fire, grazing by stock). Corridor length is obviously determined by the distance between habitat isolates, but several measures that may reduce the risks associated with corridor length include: duplication of the corridor; creating a network of corridors; and increasing the width of the corridor to reduce edge effects.

Incorporation of nodes of habitat along the corridor can increase its effectiveness by providing additional habitat in which animals can pause during lengthy movements, or maintain a larger breeding population, thus introducing more dispersers into the system. Examples of nodes include: floodplain expansions along riparian corridors (Dobbyns 1983; Recher *et al.* 1987); additional vegetation at T and + junctions along hedgerow networks (Forman and Godron 1986; Lack 1988); small forest patches adjacent to roadside corridors; and nature reserves linked along a broad, regional corridor system (Noss and Harris 1986).

Intuitively, it is obvious that corridors will be most effective when there is a high level of structural connectivity, created by alternative and network pathways, nodes along the corridor, and an absence of gaps or breaks. However, much more empirical data is required to gain a better understanding of how important are each of these aspects of connectivity.

Quality of habitat in the corridor

The availability and reliability of essential resources (e.g. food, shelter, nest sites) are critical if animals are to live in corridors and use them as pathways for movement. A number of studies have shown relationships between relative abundance of animals in corridors and the availability of certain habitat components (e.g. Pollard *et al.* 1974; Yahner 1983a, b; Arnold 1983; Osborne 1984; Recher *et al.* 1987). The provision of high-quality habitat raises several issues in the design and management of corridors.

(i) The retention of existing natural vegetation to create a corridor is more effective than attempting to reconstruct or revegetate a corridor. A high quality habitat for wildlife requires the full diversity of natural vegetation, and it is maintained by the functioning of natural ecological processes. Resources such as litter, tree hollows, dead trees, hypogeal fungi, and diverse invertebrate communities cannot be created simply by planting trees and shrubs in rows. They require the operation of natural ecosystem processes. There is an urgency, therefore, to retain and protect corridors and natural links that are still present in the landscape before they are lost.

(ii) Wildlife habitats are not static but change with time. Some resources (e.g. tree hollows) only develop after long periods of time, whereas others (e.g. dense shrub cover) may only occur in early successional stages. In the longer term it may be necessary to actively manage corridors to ensure that the habitat resources required by wildlife are continually available.

(iii) Corridor habitats are particularly vulnerable to "edge effects" (see below), and consequently a greater level of management may be required than for a comparable area within an extensive natural habitat.

(iv) When corridors link large tracts that include several contrasting habitats (e.g. ridges and gullies in mountainous forest, dunes and swales in arid environments), the corridor must be suitable for species that occur in all habitats. This can be achieved by a broad corridor that encompasses the range of habitats, by duplication of corridors, or by placement of the corridor in a habitat that all species can utilise.

Edge effects

The linear shape of corridors means that the ratio of edge to area is high (Fig. 9). Consequently, corridors are particularly vulnerable to "edge effects". There has been little research in Australia concerning edge effects, but a growing body of research in North America and Europe indicates a range of biotic and physical effects that occur along edges (e.g. Harris 1988a; Yahner 1988). Some of these effects are summarised below.

(i) Micro-climatic changes occur at the edge of a habitat, including changes in solar radiation, incident light, humidity, temperature, and wind speed (Forman and Baudry 1984; Forman and Godron 1986; Young 1988).

(ii) Changes in the composition and structure of plant communities occur at the edge of a habitat, so that edges are characteristically different to the interior of the habitat (e.g. Wales 1972; Gates and Mosher 1980; Ranney *et al.* 1981). Micro-climatic changes are an

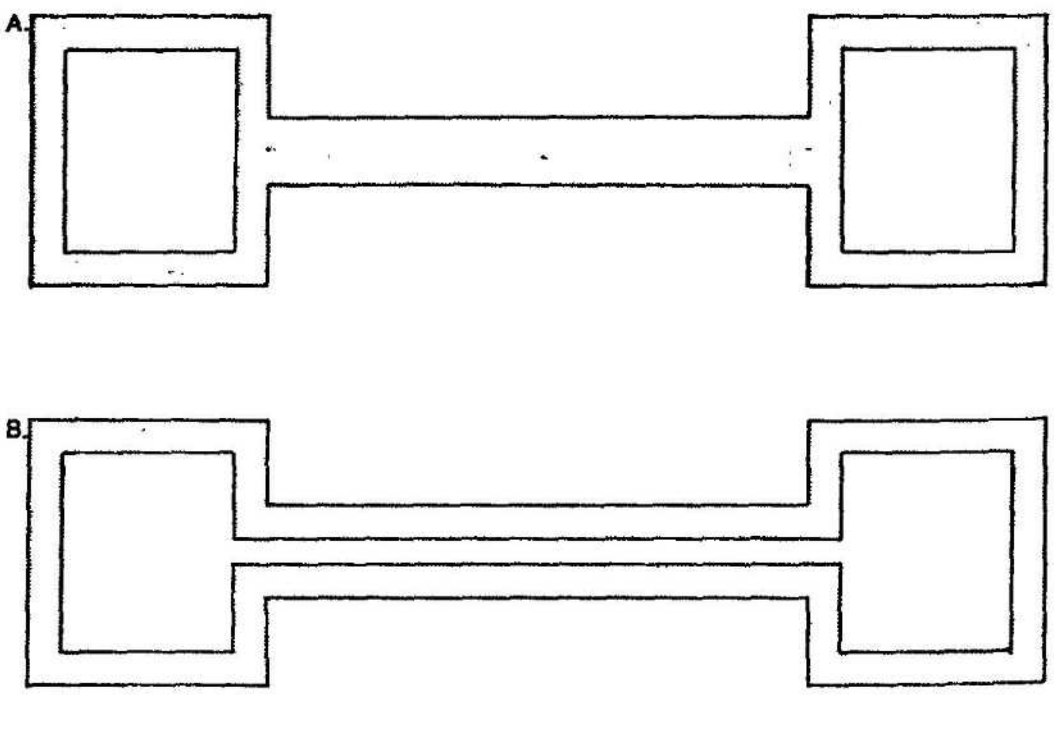

Figure 9. *The linear shape of corridors makes them especially vulnerable to edge effects. A particular disturbance (shaded) may not penetrate far into a large block of habitat, but the same disturbance may affect the entire corridor (A). Increasing corridor width (B) is the most effective way to reduce edge effects in a corridor.*

important influence on vegetation, and plant species from the adjacent habitat can invade and compete with forest plants. In disturbed and cleared environments there is usually a large array of weedy and pioneer species that are available to colonise, displace native plants, and alter the habitat.

(iii) Wildlife species that are edge specialists and those typical of adjacent developed habitats (e.g. farmland) can invade the corridor and become predators, competitors, or parasites of "interior" species (Yahner 1988). In edge habitats, the original suite of predators may be supplemented by those from the adjacent habitat. Experimental and observational studies have shown a significantly greater level of predation (of birds nests) in edge habitats compared with interior habitats (Gates and Gysel 1985; Wilcove 1985; Andren and Angelstam 1988; Small and Hunter 1988; Yahner and Scott 1988). Edge species can also compete with "interior" species for food and other resources. For example, the Noisy Miner utilises forest edge habitats in southern Australia and displays territorial aggression to small insectivorous birds. Loyn (1985, 1987) found that small forest fragments in Gippsland where Noisy Miners were present had a low species richness compared with other fragments where they were not present. Noisy Miners are common along forested roadsides and may affect the use of these corridors by other birds by actively displacing them (e.g. as has been described for Bell Miners, Loyn *et al.* 1983). In North America, the Brown-headed Cowbird, an open-country species and a nest parasite, has been found to reduce the breeding success of small forest birds along forest edges (Brittingham and Temple 1983).

(iv) Edges are prone to a range of disturbance effects, often the result of activities in the adjacent developed land. These include the drift of fertilizers and chemicals from farmland, trampling and grazing by farm animals, fires escaping into forest edges or riparian buffer zones, the placement of access tracks and control burns along edges, and recreational disturbance and littering.

How far do edge effects extend? How wide is an edge? How wide must a corridor be to include interior habitat? These are difficult questions of direct relevance to wildlife management. The solutions must be considered in relation to a particular process or parameter. For example, Gates and Mosher (1980) showed that in terms of vegetation structure the width of a forest edge was less than 13 m, but based upon the distribution of birds nests the functional width of the edge ranged from 9 - 64 m for three sites studied. In Sweden, elevated levels of predation on birds nests at the forest-farmland edge declined with increasing distance into the forest, but at distances of 100 m they were still higher than at 200 - 500 m into the forest (Andren and Angelstam 1988). Changes to the forest microclimate in forest patches adjacent to cleared farmland in New Zealand extended from 30 m to more than 100 m into the forest, depending on the aspect of the edge (Young 1988). Disturbances such as grazing by domestic stock, fires, and fertilizer drift can also extend many metres inside the apparent forest edge.

It appears that the width of edge processes will be greatest where there is a sharp contrast between the two types of habitat. Narrow corridors within farmland, such as roadsides, hedges, and narrow riparian strips, may effectively be entirely edge habitat. In contrast, a mature forest corridor surrounded by earlier successional stages of the same forest type is more likely to have an interior habitat and support interior species.

Width of corridors

The width of a corridor is a particularly important consideration in corridor design as it influences most aspects of corridor function. Maximising the width of corridors is one of the most effective options that wildlife managers can exercise to increase the effectiveness of corridors for wildlife conservation. Available information is limited, but it indicates that increasing corridor width has two main results.

(i) Increased width incorporates a greater area and thus provides the opportunity for a greater diversity of habitat and greater abundance and diversity of wildlife. Several studies have shown an increased species richness with increased corridor width. Recher *et al.* (1987) censused birds in remnant corridors of eucalypt forest, ranging in width from 69-247 m, retained within pine plantations at Eden, New South Wales. Their results showed a trend of increasing relative abundance and increasing species richness as the width of the corridor increased. Similarly, Stauffer and Best (1980) reported that bird species richness increased with the width of wooded riparian habitat in Iowa, USA. Arnold *et al.* (1987) censused birds in roadside strips ranging from 5 - 52 m in width in the wheatbelt of Western Australia, and found that the number of species observed in the roadside corridors was significantly correlated with width of the roadside vegetation.

(ii) Increased width can make a corridor more suitable for 'sensitive' species - those with greater spatial requirements or specialized feeding and habitat requirements. Studies of fauna in remnant patches of forest have shown that there is often a clear pattern of occurrence of species in relation to patch area; a species will only occur in patches larger than a certain minimum area (Moore and Hooper 1975; Lynch 1987; Patterson 1987; Van Dorp and Opdam 1987). A similar trend may occur in relation to the width of corridors, although data are scant at present.

Forest-dependent birds at Eden, New South Wales, occurred as a lower proportion of the total avifauna in narrow corridors, compared with wider corridors (Recher *et al.* 1987). Those bird species that declined in abundance in the corridor reserves over the years studied were forest birds with large foraging areas or more specialized feeding and nesting requirements (e.g. Gang-gang Cockatoo, Crested Shrike-tit). In contrast, those species that increased in abundance were all widespread and common forest birds (e.g. Grey Fantail, White-browed Scrub-wren, Rufous Whistler). In Iowa, USA, Stauffer and Best (1980) identified six species of birds in wooded riparian strips that only occurred when the mean width of the strip exceeded 40 m, and for three of these only for widths of 150 m or greater. They predicted that if the vegetation was reduced to narrow strips (<15m) along the streams, six of the 41 species recorded during the study would disappear from riparian corridors, and a further 16 species would decline in numbers.

In the riparian corridors at Eden (Recher *et al.* 1987), the Greater Glider was present in all of the corridors surveyed for arboreal mammals, but the Yellow-bellied Glider was present only in the widest reserve. The Greater Glider is a solitary folivorous marsupial that occupies a small home range, whereas the Yellow-bellied Glider is social, occupies a large home range and has more specialized feeding requirements. Dickson and Huntley (1987) investigated the value of retained riparian corridors for squirrels within hardwood forests of southern USA. Observations of animals and counts of nests in trees both showed that animals were not present in the narrowest strips (< 25 m), rarely present in medium strips (30 - 40 m), and regularly present in the widest corridors (> 50 m).

How wide should corridors be? There is no simple answer. The optimum width depends upon the objective of the corridor, the ecology and movements of the target species, and the structure of the landscape in which the corridor is located. Systematic study of the ecology of wildlife in corridors of varying width is the first step to a solution. Long-term changes in the integrity of the corridor habitat, and the intensity of edge effects on fauna must also be considered.

Location of corridors

Several considerations are relevant to the location of corridors.

(i) A primary purpose for establishing habitat corridors is to maintain or restore continuity to populations and habitats that were continuous before the intervention of human development. Corridors should not be used to link populations or habitats that naturally are biogeographically separated. Care should also be taken when re-establishing continuity, not to facilitate the spread of disease that may have established in an isolated population.

(ii) Corridors should be located along natural environmental or topographic contours, whenever possible, to ensure continuity of habitats. Exceptions to this rule include corridors that are deliberately designed to cross ecological contours (e.g. a corridor across a ridgetop to link two adjacent forested catchments, or a regional linkage to restore continuity between lowland and highland environments.

(iii) The designation of buffer areas may assist to protect sensitive habitats within corridors (e.g. a buffer of eucalypt forest on either side of rainforest corridors to protect against micro-climatic changes).

(iv) Whenever possible, either corridors should be located away from sources of disturbance or disturbance sources located away from the designated corridor. Where a source of disturbance is unavoidable, it should be located to one side, not within the corridor. For example, it is preferable to locate a wide strip of roadside vegetation to one side of the road rather than having narrow strips on either side.

(v) Whenever possible, corridors should be located to complement and enhance other resource conservation strategies, or rural land management plans. For example, in addition to serving as wildlife corridors, strips of native vegetation can contribute to the protection of water quality, the reduction of soil erosion, protection against salinity from rising watertables, the conservation of rare plant species and communities, and the retention of indigenous plant stock and seed sources.

Corridors and the Development of a Regional Approach to Conservation in Southern Australia

The importance of a regional approach

The traditional approach to nature conservation in Australia has been to identify areas of high conservation value (e.g. high species diversity, presence of rare or threatened species, representation of biotic communities) and to set them aside as reserved areas (National Parks, Conservation Parks, State Parks, Wildlife Resrves, Flora and Fauna Reserves, etc.). Resource extraction (timber, minerals) and other uses that conflict with nature conservation objectives, generally are not permitted in nature reserves. Wildlife management resources have primarily been devoted to these areas, particularly to National Parks and Wildlife Reserves (including Game Reserves). Less attention has been given (except for endangered species) to wildlife in the large areas not reserved for nature conservation, particularly the agricultural and pastoral lands.

Reserved areas are vitally important for nature conservation, and it is essential that a representative set of natural ecosystems be protected with nature conservation as the primary objective. Nevertheless, this intensive approach by itself is insufficient. We cannot rely on nature conservation reserves alone for the long-term protection and preservation of wildlife communities. We must develop a broader perspective and manage fauna at a regional, statewide and national scale, that includes lands used for a range of other purposes.

(i) Firstly, the size of many nature reserves (e.g. National Parks) is too small to support long-term viable populations of many species of wildlife. Large predators are a particular test case, but species with specialized foraging requirements (e.g. Yellow-bellied Glider, Purple-crowned Lorikeet, Bandy-bandy) or specialized habitats (e.g. Black-eared Miner, Spotted Tree Frog), and large-bodied animals (e.g. Red Kangaroo, Emu), also require relatively larger areas to sustain viable populations. Little information is available on the home range requirements, spacing behaviour and densities of predators at the top of the food chain in southern Australia; species such as the Tiger Quoll, Dingo, Powerful Owl, Masked Owl, Sooty Owl, Tree Goanna, Grey Goshawk, and Carpet Python. For any of these species the area required to support a population of 500 breeding pairs, for example, is likely to be greater than the area of suitable habitat available in any nature reserve in Victoria.

(ii) The movement patterns of many animals regularly cross the boundaries of nature reserves. Migratory patterns of birds are well known and involve movements within reserves as well as beyond reserves. In southern Australia, these include: altitudinal migrations (e.g. Flame Robin, Pied Currawong), north-south seasonal migrations (e.g. White-winged Triller, Sacred Kingfisher, Rainbow Bee-eater, Rufous Songlark, Shining Bronze-cuckoo), trans-Bass Strait migration (e.g. Orange-bellied Parrot, Swift Parrot), and international migration (Latham's Snipe, Curlew Sandpiper, Greenshank). Other species of birds are semi-nomadic and their presence and relative abundance may coincide with the local abundance of food resources (e.g. Musk Lorikeet, New Holland Honeyeater, Regent Honeyeater, White-fronted Honeyeater), or with climatic conditions in other parts of their ranges (e.g. Budgerigar, Black Kite, Grey Teal, Freckled Duck).

(iii) Some animals utilise resources that occur in markedly different habitats. The Regent Parrot, for example, nests in large tree hollows in riverine Red Gum forests, but it feeds in mallee shrublands that may be kilometres distant (Burbidge 1985). Common Bent-wing Bats are widespread in southern Australia and have been recorded from numerous nature reserves, but all breeding activity in Victoria, for example, is confined to two known maternity caves that have a suitable micro-climate.

(iv) Ecological, environmental and disturbance processes operate at scales that may be much greater than the size of nature reserves. Wildfires, for example, can burn many thousands of hectares, and have a dramatic effect on the fauna of reserves (e.g. Nadgee National Park, New South Wales; Newsome *et al.* 1975). The effects of a rise in saline groundwater in the Murray-Darling Basin of south-eastern Australia extends across a vast area. Nature reserves are also affected by this rising salinity, although the origin of this ecological problem mainly lies outside the reserves in recharge areas that have been cleared of vegetation.

(v) Finally, there are numerous species whose populations occur mainly outside nature reserves (e.g. Eastern Barred Bandicoot, Blue Bonnet, Long-billed Corella, Brolga, Bush Thick-knee, Striped Legless Lizard). Small remnants of habitat can be purchased and managed for these species, but the persistence of these 'unprotected' populations largely depends upon their survival outside of the reserve system. Management and conservation actions must also extend onto non-reserved lands if the needs of these species are to be adequately met.

The role of habitat corridors in a regional conservation strategy

Habitat corridors have the potential to make a major contribution to regional conservation strategies by ameliorating the detrimental effects that habitat fragmentation and isolation have on wildlife populations. Corridors can maintain and restore natural linkages between isolated habitats that formerly were continuous, thus "tying together" the patchy habitats in the landscape. This can assist animals in their movements through the landscape; it can promote gene flow between otherwise isolated populations; and, by increasing the effective size of populations, reduce their vulnerability to local extinction. Corridors also have an important role as habitats for wildlife, assisting to maintain populations within developed areas and serving as a source to recolonise surrounding environments when suitable habitats are available.

The delineation of regional corridor networks has also been proposed as a measure to ameliorate the potential impacts of global climate change (Greenhouse effect) (e.g. Mansergh and Bennett 1989). Detailed treatment of this issue and the role and potential of corridors in such circumstances is not within the scope of this review.

Corridors must not be viewed as a universal panacea for the ecological problems of habitat fragmentation. There is still much to be understood concerning their function and effectiveness, and concerning the optimum dimensions and habitat quality to meet the requirements of certain wildlife species. Further, corridors can not be expected to solve the dilemma of habitat fragmentation when there are other underlying problems such as the lack of sufficient total area of habitat, poor quality of habitat, or persistent sources of disturbance to populations and habitats. These problems require alternative management actions to respond to the particular problem.

Corridors in forest landscapes

Two main functions of corridors in forest landscapes can be identified.

Firstly, where large forest blocks are isolated by developed land, broad regional corridors are required as links to re-establish continuity between populations of forest dependent fauna. For example, Robinson (1977) outlined the need for regional corridors to restore continuity between wilderness areas and conservation reserves in the Illawarra region of New South Wales. There are numerous other locations where large blocks of public land, including nature reserves, are isolated from adjacent blocks by developed land.

Secondly, in forests used for timber harvesting, corridors must form a part of a linked system of retained habitat that will sustain, throughout the forest landscape, populations of species that are sensitive to harvesting. The system of retained habitats will include nature reserves and other existing reserves (e.g. water catchments); areas excepted from harvesting because of steep slopes, or because they are uneconomic for production; filter strips and buffer strips retained to protect water quality; designated sites of floral or faunal significance; rainforests and their associated buffer strips; and, a hierarchy of wildlife corridors. Initial planning and location of corridors may be most appropriately carried out on a forest block basis, but it is important that the system of retained habitat be co-ordinated and developed from a broader regional perspective.

The function of corridors in the system of retained forest habitat is to provide continuity between populations in other reserved areas to prevent their isolation and decline; and to serve as a source of colonists that can move into the regenerating forests when suitable habitat is available. Thus, the corridors are required to function as linear reserves that will support resident populations of most sensitive species.

Species that have been identified as being sensitive to forest changes resulting from timber harvesting are primarily those that are dependent upon some aspect of a mature, or old-growth, forest environment (Recher *et al.* 1980; Loyn *et al.* 1980). Animals that use tree hollows, such as forest owls, parrots, cockatoos, gliders, possums and bats, are prominent examples. Of particular importance are those forest-dependent species that naturally occur in low densities; predators (e.g. Masked Owl, Powerful Owl), species with large body size (e.g. Yellow-tailed Black Cockatoo), and those that are social, or have specialised foraging or habitat requirements (e.g. Leadbeater's Possum, Yellow-bellied Glider). For these species, the effect of broad-scale habitat changes are compounded by the need for larger areas to sustain viable populations.

Riparian vegetation is ideally suited to be the basis for a corridor system in forest landscapes for several reasons.

(i) Gullies, drainage lines, streams and rivers form a hierarchy of natural corridors that are distributed throughout most forest landscapes.

(ii) Riparian habitats support rich faunal communities. They are the interface between aquatic and terrestrial food chains and nutrient cycling processes; and they usually have a high level of structural habitat diversity.

(iii) Most forest-dependent species utilise riparian vegetation, and for many it is a preferred habitat.

(iv) Buffer strips are presently retained along streams to protect water quality (Clinnick 1985; Victorian Government 1989). A wildlife corridor system superimposed on the buffer system will minimise the area of productive timber to be forfeited.

Riparian corridors will need to be supplemented by corridors passing over ridges to create links between adjacent catchments, and to link with nature reserves. These corridors can be achieved by extending a riparian corridor upstream, over the ridge, and linking it with a riparian corridor in the adjacent catchment.

A hierarchy of corridors, scaled to meet the requirements of fauna and fitted to the forest landscape, is envisaged.

(i) *Regional corridors* are required to restore natural links between formerly continuous large blocks that are isolated by developed land. The length of these corridors will depend upon the degree of isolation, and their width must be sufficient to provide a continuous and diverse forest habitat between the blocks. Because they are generally surrounded by farmland or other developed land, they are likely to experience greater levels of disturbance and consequently a broad swathe of forest will be required to maintain the integrity of the corridor habitat.

(ii) *Major wildlife corridors* within production forests can provide primary links extending from nature reserves into the centre of the production zone, or between important reserved areas within the zone. These major corridors could follow the larger river systems.

(iii) *Wildlife corridors* forming common linkages in the system of retained habitat will extend in a co-ordinated network through the forests. The optimum width of these corridors to enhance continuity of forest-dependent wildlife is a high priority for research. However, until such recommendations are forthcoming, a minimum width of 100 m with no logging within the corridor, as recommended by the most comprehensive research to date (Recher *et al.* 1987), should be adopted as the standard in forests of south-eastern Australia.

The spatial pattern and frequency of wildlife corridors must be scaled to the landscape. In steeply-dissected terrain where there are many streams and rivers and substantial areas of forest are retained on steep slopes, wildlife corridors may not need to be located along every stream. Conversely, in gently sloping lowlands or plateaux, where the harvestable area of forest is large and streams are fewer, all riparian areas may need to be reserved as wildlife corridors. This issue of scale, pattern and landscape structure must also receive further attention in planning and research.

Corridors in rural landscapes

Rural landscapes are where the greatest loss and fragmentation of natural vegetation (forests, woodlands, shrublands and grasslands) has taken place in southern Australia, and where the greatest changes to wildlife populations have occurred. In every rural district in southern Australia, species of wildlife have disappeared since settlement and numerous other species have declined in regional abundance and conservation status. A co-ordinated network of corridors to link together remnant natural areas, both large and small, into a system of remnant habitat has great potential benefit for wildlife. It will enhance the movements of animals throughout the system, and effectively increase the sizes of species' populations.

The objectives of a corridor network in rural landscapes are two-fold. Firstly a system of corridors is required to restore natural linkages between remnants of native vegetation that were formerly continuous. Important priorities include: restoration or enhancement of linkages between existing nature reserves and other large tracts of natural vegetation; linkages within fragmented systems that are known to have high conservation value for wildlife, or are known to support threatened species; and connections between large tracts and adjacent satellite areas of natural vegetation.

Secondly, a network of corridors can be envisaged throughout the large expanses of cleared farmland to serve as linear reserves of wildlife habitat and help to sustain many species within the agricultural zone. These corridors will also facilitate the immigration of new species (particularly birds) into agricultural areas to take advantage of remnant habitats and revegetated lands.

How can a corridor network be created? A number of approaches are available.

(i) Maximum advantage should be taken of existing corridor networks, such as road reserves, rail reserves, travelling stock reserves, and streamside reserves. These existing corridors have great potential as wildlife corridors because they are extensive in distribution, they often form intersecting networks, they are public land, and in many instances remnant strips and patches of native vegetation are still present along them. Restoration and revegetation of these corridors in an ecologically sensitive manner will have value for many species of wildlife. Clearly, not all species will be able to use them, and there are management issues such as adequate protection of vegetation from farm stock, control of vermin and noxious weeds, and fire prevention, that require consideration.

(ii) In some locations acquisition of land, or sympathetic management by private landowners, is required to restore linkages between large natural areas. These major links must be of sufficient width to buffer the corridor from disturbance processes in adjacent farmland, and from other detrimental edge effects. The Annuello wildlife corridor in north-western Victoria is one example of a restored link. Extending some 6 km in length and 0.5 km in width, it links the Annuello block of public land (approx. 35,000 ha) with the extensive Sunset Country. Identification of other links, especially those where remnant vegetation is still present, is an important priority before they are cleared and the opportunity is lost.

(iii) There is growing interest in revegetation in rural areas (Breckwoldt 1983, 1986; Burke and Youl 1990), and many landowners are choosing to plant native trees and shrubs as shelterbelts, for agroforestry, and to restore natural environments. In western Victoria, for example, a group of landowners are working together to revegetate a corridor between the Black and Dundas Ranges, by co-ordinated planting of trees and shrubs across their properties. Encouragement, support and incentives to landowners to revegetate corridors within their properties, or to widen or extend existing corridors, may have long term benefits for wildlife conservation within the rural community. However, in practical terms, revegetation on a scale sufficient to create networks of rural corridors is an enormous challenge, and will require continuing change in community attitudes and in recognition of the value of restoring and retaining native vegetation in farmlands.

Revegetation along gullies and drainage lines can provide corridors for wildlife while also serving to reduce erosion and combat salinity.

Recommendations for Research and Management

Research

Process oriented, ecological research

Major research initiatives are required to investigate ecological processes in corridors as a basis for developing sound management recommendations. This research must be carried out from a landscape perspective, by studying wildlife populations and ecological processes in corridors in relation to their ecology in the surrounding landscape. Investigation of these processes in corridors of varying width is important, as a fundamental requirement of managers is information on the optimum widths and design of corridors.

Issues that require further investigation include the following.

(i) The conservation value of corridors for wildlife on a "landscape scale". Are remnant patches of habitat linked by corridors of greater value to wildlife than are isolated blocks? Do "linked" landscapes support a greater diversity of wildlife than fragmented landscapes? Can gene flow and the benefits of gene flow to isolated populations be demonstrated? Can corridors be demonstrated to significantly increase the likelihood of recolonisation following local extinction of a patch population?

(ii) The values of corridors of different structural types (e.g. roadside vegetation, riparian vegetation, plantations) and of different forest types. For example, how valuable are roadside strips as regional corridors, and for what type of species are they useful? Which species of wildlife can use planted corridors? What are the optimum dimensions and planting requirements to create corridors that are of value to wildlife in farmland?

(iii) The composition and dynamics of faunal communities in corridors, in comparison with the adjacent habitats. Are wildlife communities in corridors different to those in adjacent habitats? Why are they different? Which species are more abundant, and which less abundant? What are the most important factors influencing the composition and persistence of wildlife communities in corridors?

(iv) The density, population dynamics and movements of selected species in corridors, and their interactions with adjacent habitats. Are corridor habitats "sinks" in which reproduction is insufficient to balance mortality, or can they be "source" habitats (Pulliam 1988)?

(v) The importance of edge effects and disturbance on species and communities in corridors. What are the effects of micro-climatic changes and plant invasion on animal habitats? What are the effects of predators and competitors on wildlife that use corridors? Are these effects greater or less than in adjacent habitats? Are particular species more sensitive to predators and competitors? How does corridor width influence the intensity of edge effects?

(vi) The effects of gaps and habitat nodes on the performance of corridors. What constitutes a gap for different species? How do gaps affect use of the corridor?

(vii) The effects of isolation on corridors and their fauna. Does spatial isolation of a corridor influence its use by wildlife? Does the use of a corridor change with time?

(viii) The scale of movements that a range of species of wildlife undertake, and their ability to move through sub-optimal habitats of differing composition or successional stages.

(ix) The "non-conservation" values of corridor habitats in rural environments. What is the contribution of linear habitats to improved farm productivity through shelter for stock and improved pasture growth? How does the presence of native vegetation affect property valuations? Can it be demonstrated quantitatively that wildlife contribute to the health of agro-ecosystems? These and other issues will be important in encouraging landowners to retain or establish linear habitats.

Research projects are required to investigate the conservation of wildlife in remnant systems of habitat, both in production forest landscapes and in rural landscapes. Research in forest landscapes, especially to provide and refine management guidelines in timber production forests, should be carried out in conjunction with other studies of forest ecology and forest processes. Research concerning corridors in rural and developed landscapes should be carried out in conjunction with studies of ecological processes and wildlife communities in remnant systems of habitat in rural environments. This research would provide an information base for expanding wildlife management and extension programmes, and conservation planning, in rural environments.

Inventory and monitoring

(i) An inventory of the distribution, composition and quality of existing corridor vegetation (e.g. stream reserves, roadsides, broad natural links) is required on a regional basis. These results should be mapped and published, and the data contribute to management of these reserves as part of a regional corridor network. Techniques for regular inventory of remnant vegetation to detect changes in cover and continuity, should also be investigated (e.g. Landsat imagery, aerial photography).

(ii) Development of a simple procedure for monitoring fauna in linear habitats is required, that can be implemented in regional monitoring programmes by wildlife managers and interested community members. Objectives of the monitoring could include:

- to monitor and assess the value to wildlife of newly regenerated or planted corridors;
- to monitor the wildlife of a range of corridors on a long-term low-intensity basis;
- to monitor regional changes to the fauna following the establishment of corridor linkages.

Planning and management

There are many issues concerning corridors that affect wildlife planning and management activities. Several important issues are outlined below.

(i) It is important that wildlife managers, environmental planners and landowners recognise the variety of functions of corridors, particularly that corridors have value as a habitat in their own right. It must also be recognised that corridors facilitate continuity of populations in several ways - the most effective way being by the provision of habitat that is suitable for resident populations along the length of the corridor.

(ii) There is an urgent need to implement effective procedures to protect and manage existing corridors of natural vegetation along roadsides, rail reserves and stream reserves. Tracts of natural habitat on public or private land that form critical links between existing reserves or large natural areas, should also be identified, protected and managed before the opportunity to retain these links is foregone. Existing and future leasehold arrangements for linear reserves on public land should be carefully reviewed to ensure that environmental values are maximised.

(iii) Plans, methodologies and practices for effective long term management, revegetation, and rehabilitation of corridor vegetation are required. These must address some current practices (e.g. grazing, destruction of harbour for vermin, fire prevention measures) that can degrade the quality of remnant habitats for wildlife.

(iv) Strategic planning is required to establish co-ordinated regional systems of linkages and corridor networks. Planning on a regional basis must first map existing nature reserves and natural areas, and then identify locations for major corridors and secondary corridor networks to be developed or preserved. In forested areas, this should include the delineation of a corridor network within production forests to enhance the persistence of forest-dependent wildlife. Geographic Information Systems can provide an important tool for the most efficient planning and identification of suitable corridors.

(v) Further support for existing schemes (e.g. Land Care, Land for Wildlife, in Victoria) will help to encourage landholders and groups of landholders to revegetate corridors across their properties, or to establish nodes of vegetation adjacent to existing corridors. Whenever possible, these activities should be a part of a regional corridor strategy, and also complement other resource conservation strategies. Practical evidence for the "non-conservation" values to be gained from the retention or establishment of native vegetation may be the most effective incentives for private landowners. However, financial assistance through grants or taxation relief also have a role, especially towards the cost of fencing corridors. The linear nature of corridors and their vulnerability to disturbance and edge effects means that fencing is one of the most important management actions required to maintain natural vegetation.

(vi) Extension activities, in conjunction with research and management initiatives, are required to "feed back" to local communities and landowners the value to wildlife of existing corridors, or those being restored; and to report on the value of habitat restoration projects in local communities.

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Appendix 1.

Common and scientific names for species mentioned in the text. Species are listed in alphabetical order of common names for each class.

Mammals

Bank Vole	*Clethrionomys glareolus*
Black Bear	*Ursus americanus*
Black Rat	*Rattus rattus*
Brown Antechinus	*Antechinus stuartii*
Brush-tailed Bettong	*Bettongia penicillata*
Brush-tailed Phascogale	*Phascogale tapoatafa*
Bush Rat	*Rattus fuscipes*
Caribou	*Rangifer tarandus*
Cat	*Felis catus*
Cougar	*Felis concolor*
Common Bent-wing Bat	*Miniopterus schreibersii*
Common Brush-tailed Possum	*Trichosurus vulpecula*
Common Ring-tailed Possum	*Pseudocheirus peregrinus*
Dingo	*Canis familiaris dingo*
Eastern Chipmunk	*Tamias striatus*
Eastern Quoll	*Dasyurus viverrinus*
Eastern Barred Bandicoot	*Perameles gunnii*
Elk	*Cervus elaphas*
Feather-tailed Glider	*Acrobates pygmaeus*
Florida Panther	*Felis concolor coryi*
Fox	*Vulpes vulpes*
Fox Squirrel	*Sciurus niger*
Greater Glider	*Petauroides volans*
Hare	*Lepus capensis*
House Mouse	*Mus musculus*
Koala	*Phascolarctos cinereus*
Large-footed Myotis	*Myotis adversus*
Leadbeater's Possum	*Gymnobelideus leadbeateri*
Long-nosed Bandicoot	*Perameles nasuta*
Long-nosed Potoroo	*Potorous tridactylus*
Lynx	*Felis lynx*
Meadow Vole	*Microtus pennsylvanicus*
Mountain Goat	*Oreamnos americanus*
Mountain Pygmy-possum	*Burramys parvus*
Mule Deer	*Odocoileus hemionus*
Parma Wallaby	*Macropus parma*
Platypus	*Ornithorhynchus anatinus*
Rabbit	*Oryctolagus cuniculus*
Red Kangaroo	*Macropus rufus*
Red-necked Wallaby	*Macropus rufogriseus*
Red Wolf	*Canis rufus*
Short-beaked Echidna	*Tachyglossus aculeatus*
Short-tailed Vole	*Microtis agrestis*
Southern Brown Bandicoot	*Isoodon obesulus*
Southern Hairy-nosed Wombat	*Lasiorhinus latifrons*
Squirrel Glider	*Petaurus norfolcensis*
Sugar Glider	*Petaurus breviceps*
Swamp Rat	*Rattus lutreolus*
Swamp Wallaby	*Wallabia bicolor*
Tasmanian Devil	*Sarcophilus harrisii*
Tiger Quoll	*Dasyurus maculatus*
Water-rat	*Hydromys chrysogaster*
White-footed Mouse	*Peromyscus leucopus*
Wood Mouse	*Apodemus sylvaticus*
Wolverine	*Gulo gulo*
Yellow-bellied Glider	*Petaurus australis*

Birds

Australian Magpie-lark	*Grallina cyanoleuca*
Azure Kingfisher	*Ceyx azurea*
Black-eared Miner	*Manorina flavigula melanotis*
Black-faced Monarch	*Monarcha melanopsis*
Black Kite	*Milvus migrans*
Blue Bonnet	*Northiella haematogaster*
Blue-faced Honeyeater	*Entomyzon cyanotis*
Blue Jay	*Cyanocitta cristata*
Brolga	*Grus rubicundis*
Brown Gerygone	*Gerygone mouki*
Brown-headed Cowbird	*Molothrus ater*
Budgerigar	*Melopsittacus undulatus*
Bush Thick-knee	*Burhinus magnirostris*
Carnaby's Cockatoo	*Calyptorhynchus latirostris*
Crested Pigeon	*Ocyphaps lophotes*
Crested Shriketit	*Falcunculus frontatus*
Curlew Sandpiper	*Calidris ferruginea*
Emu	*Dromaius novaehollandiae*
Flame Robin	*Petroica phoenicia*
Freckled Duck	*Stictonetta naevosa*
Gang Gang Cockatoo	*Callocephalon fimbriatum*
Great Horned Owl	*Bubo virginianus*
Greenshank	*Tringa nebularia*
Grey-crowned Babbler	*Pomatostomus temporalis*
Grey Fantail	*Rhipidura fuliginosa*
Grey Goshawk	*Accipiter novaehollandiae*
Grey Teal	*Anas gibberifrons*
Latham's Snipe	*Gallinago hardwickii*

Little Friarbird .... *Philemon citreogularis*
Long-billed Corella .... *Cacatua tenuirostris*
Mallee Emu-wren .... *Stipiturus ruficeps*
Malleefowl .... *Leipoa ocellata*
Masked Owl .... *Tyto novaehollandiae*
Musk Lorikeet .... *Glossopsitta concinna*
New Holland Honeyeater .... *Phylidonyris novaehollandiae*
Noisy Miner .... *Manorina melanocephala*
Orange-bellied Parrot .... *Neophema chrysogaster*
Pied Currawong .... *Strepera graculina*
Powerful Owl .... *Ninox strenua*
Purple-crowned Lorikeet .... *Glossopsitta porphyrocephala*
Rainbow Bee-eater .... *Merops ornatus*
Red-capped Robin .... *Petroica goodenovii*
Red-cockaded Woodpecker .... *Picoides borealis*
Regent Honeyeater .... *Xanthomyza phrygia*
Regent Parrot .... *Polytelis anthopeplus*
Rufous Songlark .... *Cincloramphus mathewsi*
Rufous Whistler .... *Pachycephala rufiventris*
Sacred Kingfisher .... *Halycon sancta*
Shining Bronze-Cuckoo .... *Chrysococcyx lucidus*
Silvereye .... *Zosterops lateralis*
Sooty Owl .... *Tyto tenebricosa*
Spotted Owl .... *Strix occidentalis*
Striated Grasswren .... *Amytornis striatus*
Swift Parrot .... *Lathamus discolor*
Varied Sitella .... *Daphoenositta chrysoptera*
Weebill .... *Smicrornis brevirostris*
Western Rosella .... *Platycercus icterotis*
White-browed Babbler .... *Pomatostomus superciliosus*
White-browed Scrubwren .... *Sericornis frontalis*
White-fronted Honeyeater .... *Phylidonyris albifrons*
White-naped Honeyeater .... *Melithreptus lunatus*
White-winged Triller .... *Lalage sueurii*
Whooping Crane .... *Grus americana*
Yellow-plumed Honeyeater .... *Lichenostomus ornatus*
Yellow Rosella .... *Platycercus elegans flaveolus*
Yello-rumped Pardalote .... *Pardalotus xanthopygus*
Yellow-tailed Black Cockatoo .... *Calyptoryhnchus funereus*

Reptiles

Bandy Bandy .... *Vermicella annulata*
Carpet Python .... *Morelia spilota*
Eastern Water Skink .... *Sphenomorphus quoyii*
Gippsland Water Dragon .... *Physiognathus lesueurii*
Striped Legless Lizard .... *Delma impar*
Tiger Snake .... *Notechis scutc*
Tree Goanna .... *Varanus va*
Viper .... *Vipera be*

Amphibians

Barking Frog .... *Limnodynastes fletcl*
Blue Mountains Tree Frog .... *Litoria citr*
Peron's Tree Frog .... *Litoria perc*
Spotted Grass Frog .... *Limnodynastes tasmanier*
Spotted Tree Frog .... *Litoria spens*