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LANDSCAPE ECOLOGY AND LANDSCAPE CHANGE

Modification of the landscape by humans for agricultural and other purposes has led to the immense loss of native vegetation, fragmentation and degradation of habitat, factors implicated in the global decline of biodiversity (see box, right).[9,10] Many landscapes throughout the world are now highly modified with only scattered fragments of native vegetation remaining.[11]

The modification of landscapes influences ecosystem processes, species richness and distribution, as well as altering physical attributes of the environment, ultimately leading to a poorer environment in which all species, including humans, live. Maintaining the integrity of ecosystems is vital if they are to adapt to climate change, if biodiversity is to flourish, and if humans are to continue to receive the ecological goods and services on which we depend for our existence. Services provided by functional ecosystems include clean air and water, carbon sequestration, pollination, biological pest control, raw resources, the prevention of soil erosion and degradation, and recreational opportunities.

Landscape ecology is the study of patterns and processes of species assemblages and their interactions within landscapes.

Classifying the elements and patterns that make up landscapes, and understanding the complex biophysical interactions within the context of whole landscapes, enables scientists and land managers to make informed decisions about effective conservation and land management. The study of landscape patterns, species assemblages and ecological processes is known as landscape ecology. Landscape ecology has its roots in geography and ecology.[13] Landscape ecology is central to effective conservation ecology and the mitigation of adverse environmental effects arising from vegetation loss and degradation caused by human modification to the landscape.[14]

Biodiversity

The term 'biodiversity' is often defined as the variety of all forms of life, encompassing genes, species, ecosystems and their interactions. Biodiversity has three main components: composition, structure and function.

- Composition includes the identity and variety of elements within a system. The three levels at which biological variety has been identified are:
  - genetic diversity – the total number of genetic components that make up a species. This includes populations, significant taxonomic units and individuals. At the level of biological populations, genetic variation among individual organisms is a signature of their evolutionary and ecological past, but also a basis of future adaptive evolutionary potential. Species that lack genetic variation are thought to be more vulnerable to extinction from natural and human-induced environmental changes.
  - species diversity – the number of species and their relative abundance.
  - ecosystem diversity – the diversity of ecosystems.
- Structure is the physical organisation or pattern of a system and includes habitat complexity, patch patterns and the elements within a landscape.
- Function involves physical, ecological and evolutionary processes including nutrient cycling, disturbances and gene flow.[12]

2.1 Landscape patterns and processes

Scientists distinguish between pattern and process in conservation ecology. Pattern refers to the spatial arrangement of species and habitats, and process refers to their interactions with each other and the environment.[4] Existing approaches to biodiversity conservation and management have focused on pattern, but recently emphasis has also been given to understanding and protecting ecological processes and a recognition that these processes operate at multiple geographic scales.[15] The emphasis on ecological processes arises from, or has coincided with, an acknowledgement that building ecological resilience will be necessary so that ecosystems have the best change of adapting to climate change as it occurs. A healthy and resilient ecosystem will be better able to cope with environmental fluctuations (including climate change) outside normal ranges.

Removal of large areas of vegetation alters physical processes, including those related to water flux, radiation, wind and erosion. The greatest effect of these changes on vegetation fragments occurs at the boundaries of the fragments. The microclimate at the boundaries differs from the interior of fragments in terms of light, temperature, humidity, and wind speed. In turn, these physical changes affect biophysical processes such as litter decomposition and nutrient cycling, and the structure and composition of vegetation. Land uses in the surrounding environment, such as the use of fertilisers, alterations to drainage patterns and water flows, also have adverse effects on fragments. In particular, grazing by domestic stock markedly alters vegetation fragments by changing the structure and nutrient cycles.[16]

One of the most detrimental impacts on the landscape caused by wide-scale land clearing in southern Australia is dryland salinity. The wide-scale removal of trees has resulted in the rise of groundwater, bringing salts from ancient seas to the surface. Where the brackish water discharges in the landscape it degrades agricultural productivity and native vegetation.[17]

2.1.1 FRAGMENTATION, PATCHES AND THE MATRIX

Vegetation fragmentation is the ‘breaking apart’ of continuous vegetation (figures 2.1 and 2.2). Fragmentation results in the reduction of the total amount of vegetation (habitat loss), the sub-division of vegetation into patches and fragments (fragmentation) and the replacement of removed vegetation with new forms of land use.[11] The intervening land and its associated land use are referred to as the landscape matrix.

Landscape change is not random. The type of land use influences the spatial patterns of landscape change, underlying ecological processes and species distributions in different ways. For example, areas of fertile, low lying land suitable for agriculture are typically targeted for extensive clearing. Remnant vegetation in these areas, if it exists at all, tends to be in small and isolated patches. Steep terrain such as highland slopes or low fertile soils such as mallee shrublands are less suitable for agriculture and tend to support more substantial patches of native vegetation.[10]

Figure 2.1
An agricultural landscape along the Murray River, illustrating large remnants in areas prone to flooding.

Figure 2.2
A modified landscape extensively cleared, containing few remnants. Linear remnant vegetation follows road reserves and drainage lines.

McIntyre and Hobbs (1999) conceptualised a model of landscape change represented by four major stages of landscape condition (figure 2.3).[18] Landscapes can be:

- **intact** – in which landscapes contain most original vegetation with limited clearing;
- **variegated** – in which landscapes are dominated by original vegetation, but include gradients and buffers of modified habitat;
- **fragmented** – contains discrete patches of vegetation in a modified matrix; or
- **relictual** – with little (less than 10%) of the original vegetation remaining, surrounded by highly modified landscape.

Landscape change is a dynamic process. Landscapes are comprised of innumerable configurations along a continuum and consist of a variety of elements such as riparian, granite or wetland areas (figures 2.1 and 2.2). Landscape modification changes the spatial configuration of native vegetation. The extent of modification influences the proportion of edges, size and shape of a fragment. With increasing clearing, the distance between patches increases and landscape connectivity decreases. Furthermore, the quality of the remaining vegetation decreases because of changes in water fluxes, solar radiation and susceptibility to invasion by weeds, grazing by domestic stock and a loss of native biodiversity.

2.1.2 EFFECTS OF LANDSCAPE CHANGE ON SPECIES AND POPULATIONS

Different organisms display diverse and individual responses to landscape modification depending on the scale at which they normally operate and the scale at which they perceive the environment.[19,20,21] For example, a large bird of prey with a large home range and able to fly many tens of kilometres has a radically different response to a plant. The ability to utilise highly modified landscapes (e.g. agricultural pastures), in addition to native habitat, has enabled some generalist species, like galahs, to prosper and expand their ranges. Some species are known as 'edge specialists'; they inhabit the matrix-vegetation boundary and benefit from highly fragmented landscapes.[10] Several species that have flourished in an agricultural matrix have become overabundant and in certain landscapes are considered pests requiring active control measures. In contrast, many other species have specific habitat requirements that restrict them to certain elements of the landscape (e.g. native grasslands or wooded areas), and their ranges have contracted within modified landscapes or have become locally extinct.

Generally the number of species found within an area is proportional to the size of the area and how isolated it is from other core areas. This concept is known as the species-area relationship and is derived from the

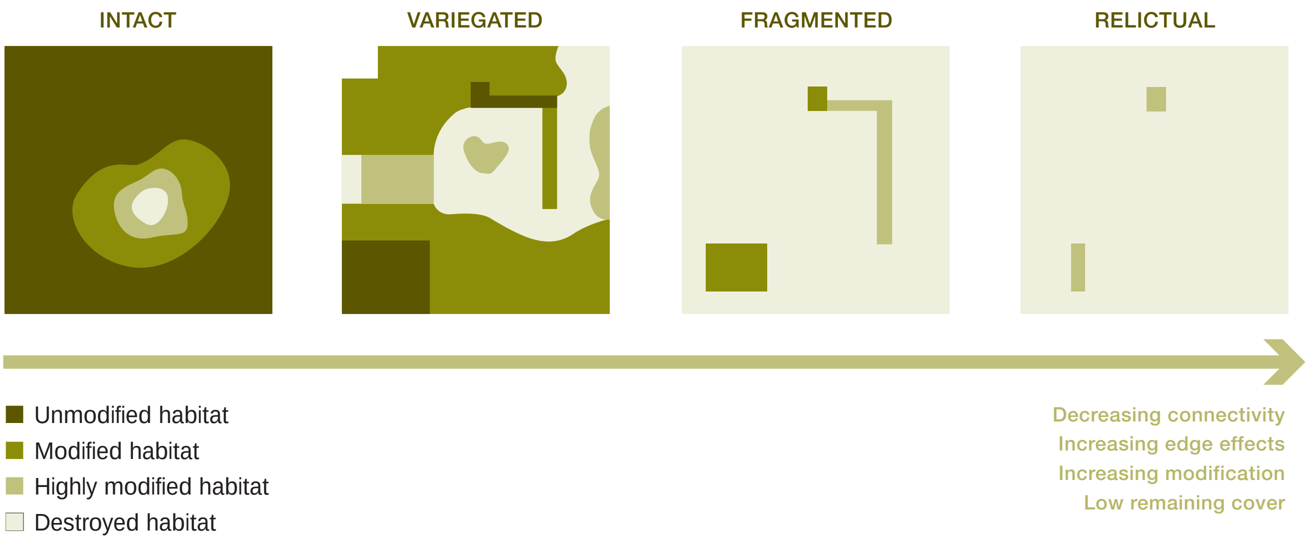

Figure 2.3
Four landscape alteration states (intact, variegated, fragmented and relictual) showing modification of remaining habitat (from McIntyre and Hobbs 1999).[18]

equilibrium theory of island biogeography.[22] The theory postulates a relationship between the number of species found on an island and the island's area and isolation. The theory predicts that the number of species on an island represents a dynamic balance between the rate of colonisation of new species to the island and the rate of extinction of species already present. The analogy between islands in the ocean and vegetation patches in a matrix has formed the basis of landscape ecology. For terrestrial systems, the theory predicts that as the size of a patch decreases, the number of species found will generally also decrease. In other words, as patches become smaller, and more isolated from other patches, the progression of habitat loss eventually leads to species loss.

Landscape change affects animal and plant species distributions and abundance – frequently with adverse consequences.

Within unmodified landscapes, a given species may occur as spatially discrete populations that are functionally connected via the interchange of dispersing individuals. Collectively, such connected populations are known as a 'meta-population'.[23] The characteristic process that defines a meta-population is extinction and re-colonisation of populations. In a meta-population model, local populations are vulnerable to extinction from random processes. However the movement of individuals between local populations 'rescues' failing populations or permits the re-colonisation of patches in which the species previously declined to extinction. A species will thus persist in the regional landscape as long as local population extinction does not exceed re-colonisation.[23, 24]

Within modified landscapes, habitat loss and fragmentation has resulted in populations of a species existing as a series of spatially discrete entities, where previously they may have been substantially connected. In many cases, the spatial isolation of patches and the nature of the intervening matrix restrict the capacity of an organism to move through the landscape. In the absence of landscape connectivity, populations in small patches are vulnerable to extinction.

For species dependent on native vegetation, the clearance of vegetation and replacement with alternative land uses represents habitat loss. Smaller patches become unsuitable for many species because they do not support sufficient resources; for example, suitable nest sites, food and shelter.[25] Smaller patches support smaller populations that are vulnerable to extinction because of natural fluctuations in resources, random changes in population demographics, adverse genetic processes and disturbance events (e.g. fire).[26,27,28]

The presence of a species within a patch does not necessarily equate to a locally viable population. Species may persist within vegetation patches because of immigration of individuals from resource-rich areas outside the patch or locality. These populations are considered 'sink' populations as they are unable to sustain their numbers in the absence of immigration.[29] Such populations are likely to be prevalent throughout highly modified landscapes and mask the true status of populations or species.[24]

Evidence suggests that species loss may take many decades to manifest following fragmentation.[30,31] Local extinction of a species can occur after a substantial delay following habitat loss, fragmentation or disturbance. That a species can initially survive environmental perturbations, but later become extinct despite no additional change to the habitat, is known as 'extinction debt'. Extinction debt can refer to a proportion of populations of a single species or the proportion of all species subject to the given environmental perturbation.[32]

As long as species still persist following environmental perturbations, then there is time to implement counter measures, such as habitat restoration, to prevent extinction. However, extinction debt poses a significant but under-recognised challenge for biodiversity conservation, because the delay between the perturbation event and the demise of a species may take many decades and go unrecognised until near extinction.[33]

Some ecological consequences of past landscape modification have yet to occur. The existence of mature non-reproducing individuals may give the impression of healthy population sizes using assessments based on occurrence or abundance, but in the absence of recruitment they will decline.[34]

2.1.3 DISPERSAL, LANDSCAPE CONNECTIVITY AND CORRIDORS

Landscapes that maintain or enhance connectivity are thought to be more likely to maintain populations of the various species that once occupied the original landscape.[35] Connectivity prevents and reverses local extinctions by enabling the re-colonisation of empty patches. Connectivity promotes the exchange of genes between populations, and prevents the extinction of local populations due to inbreeding depression and random shifts in the demographics of a population (e.g. over-abundance of a single sex).[36]

The ability of a species to disperse between isolated fragments depends on the intrinsic behaviour of the species, its habitat requirements and the nature of the intervening matrix. From the perspective of an individual species, what may constitute connectivity varies greatly. Highly mobile species such as parrots can traverse open areas of agricultural land to feed on patches of suitable flowering eucalypts. However, the same landscape may be impermeable to a small native rodent or ground-dwelling bird that requires dense vegetation as protection against predators. Such species may be unwilling, or unable, to successfully traverse open land to re-colonise new patches of suitable habitat.

Connectivity can be considered in three ways. From the perspective of a single species, connectivity is connectedness between patches of suitable habitat. From a human perspective, connectivity refers to patterns of vegetation. Finally, from an ecological perspective, connectivity may be considered as being made up of ecological processes at multiple scales.[20]

Figure 2.4 illustrates three major types of landscape connectivity.

- **Corridors –** Linear or linear-like features that connect core areas of habitat. The effectiveness of vegetation corridors will be dependent on their width and quality, and is species-specific.
- **Stepping stones –** Like corridors, stepping stones can provide additional habitat to those species that are not area sensitive. Although a small patch may not support the diversity of larger patches, the cumulative conservation value of small patches in the landscape is substantial and studies show that up to three-quarters of native bird species may use patches of less than 1 hectare in some way. [20]
- **Matrix –** In modified landscapes many species use the matrix as habitat. Scattered trees in the matrix are used by bats, woodland birds and reptiles.[20,37] Despite the potential value of the matrix for some species, the matrix will be inhospitable to many other organisms.

Connectivity may also have detrimental effects. Animals carry out an important role in ecosystem processes by carrying and dispersing seeds and facilitating pollination. However, undesirable species can also be dispersed within native vegetation systems by the same mechanisms. Connectivity via vegetation corridors may also facilitate the movement of fire and other abiotic disturbances through the landscape.[38] The design of corridors should also consider the intrinsic characteristics of species and their susceptibility to predation or other inhospitable attributes of the corridor. Furthermore, inappropriately placed corridors may establish new routes for dispersal in previously isolated systems, disrupting local adaptation.[39]

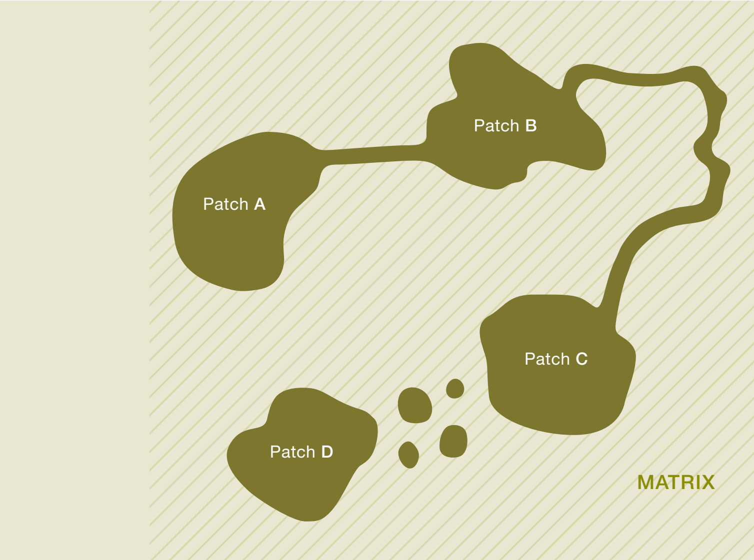

Figure 2.4
Schematic representation of corridor attributes. Corridors may be direct between two patches [A-B], a non-direct route such as along a riparian zone [B-C] or a series of structurally non-connected stepping stone corridors [C-D].

Figure 2.5
Connectivity operates at all spatial scales, from the transcontinental to this lace monitor crossing the Hume Freeway using a bridge provided principally for squirrel gliders.

2.2 Habitat restoration

For the reasons already discussed above, vegetation loss and fragmentation undermine the resilience of ecosystems. Where ecosystems are degraded, improving and restoring vegetation will improve ecosystem function and contribute to resilience.

Given the relationship between vegetation decline and loss of biodiversity it follows that conservation in fragmented landscapes can be enhanced by vegetation restoration. Ecological restoration can be carried out by:

- protecting and improving the quality of existing habitat – particularly core habitat or refugia;
- increasing the amount of habitat and connectivity between fragments. This includes the reduction or elimination of landscape discontinuities so as to reduce edge effects and provide dispersal and migration opportunities for species;
- the restoration of buffer or transitional zones in critical sensitive places such as riparian areas;
- the restoration of wildlife corridors and stepping stone habitat to ensure adequate migration flows within the wider landscape matrix; and
- prevention of further habitat loss.[16,20,40]

Ecological restoration is undertaken at a variety of scales and, for example, may include small areas of less than one hectare, strips of roadside reserves, or large-scale plantings of many thousands of hectares. The importance of restoration and increasing connectivity for landscape-scale ecosystem function has lead many community groups in Australia to working towards rebuilding connectivity on large spatial scales (e.g. Habitat 141 and WildCountry).[41] These projects are frequently referred to as ‘biolinks’. Biolinks are defined as “broad geographic areas identified for targeted for action to increase ecological function and connectivity, improving the potential of plants and animals to disperse, recolonise, evolve and adapt naturally”.[7] Biolinks do not necessarily aim to establish structurally contiguous corridors of native vegetation, but also involve projects which improve the quality of existing habitat by domestic stock exclusion, weed removal, facilitation of water flows, re-establishment of native vegetation patches, and wetlands restoration.

Detrimental effects of land degradation can be mitigated by habitat restoration.

A key issue for conservation (and hence habitat restoration) is the relative importance of habitat loss versus habitat fragmentation.[42,43] That is, what is the relative importance of *how much* habitat remains in the landscape versus *how fragmented* it is?[10,43] Theoretical modelling and empirical studies suggest that the effects of fragmentation on biodiversity become apparent at about 10-30% of remaining vegetation,[42,43] though species responses are individualistic.[21] Restoration of landscapes containing remnants of native vegetation at these thresholds would need to strategically consider if restoration effort would be best targeted at increasing the size of individual remnants or enhancing connectivity.

Several recent scientific studies into landscape scale restoration of woodland habitats in the heavily fragmented systems of southern Australia has provided insights into how species (particularly birds) respond to spatial and structural aspects of original and restored native vegetation in modified landscapes.[44] The size of patches, total woody cover and structural complexity of vegetation are important elements in local species diversity. Crucially, landscapes comprised of remnant native vegetation are found to support a higher diversity of species, than those with revegetation alone.[45] This work emphasises the importance of protecting extant stands of remnant native vegetation if conservation of a range of species is a restoration goal.

2.3 Climate change

2.3.1 MAGNITUDE

Since 1960 the mean temperature in Australia has increased by about 0.7°C. The summer of 2009-10 was Australia's hottest on record, at 0.2°C above the long-term summer average.[46] The decade 1998-2007 was globally the warmest on record with 2007 being the warmest year on record in Victoria with a mean annual temperature 1.2°C above the long-term average. Predictions on climate change estimate Victoria will warm at a slightly faster rate than the global average, especially in the north and east of the state. By 2030, annual temperatures are predicted to increase by at least 0.8°C with much warmer summers and springs. Inland areas will experience more frequent and intense hot days. Rainfall patterns are expected to change with drier winters and springs and increased intensity in rainfall during summer and autumn. In addition to overall lower rainfall totals, evaporation is expected to increase, exacerbating the overall drying trend.[47,1] These changes will result in an increase in the fire index and a likely increase in the frequency of fires.[48]

Climate change poses complex challenges for conservation of biodiversity.

2.3.2 THE IMPACT ON BIODIVERSITY

Biodiversity has been identified as the most vulnerable global sector to be affected by climate change reflecting the very low adaptive capacity of ecosystems.[49] The threats to biodiversity arise because of changes in the physical and chemical environment which underpin all ecosystem processes; especially CO_2 concentrations, temperature, rainfall and acidity. Individual species will be affected in different ways by these changes, leading to flow-on effects to the structure and composition of present-day communities, and then potentially to changes in ecological processes.

How species may respond to climate change will vary greatly and probably in unpredictable ways because of the complexity of biological systems. Organisms experiencing climate change may disperse from their original location (find a better place) or tolerate the change and remain in their original location (genetic or physiological adaptation). The rate of climate change, the ability of species to disperse, the nature of dispersal routes and the intervening matrix, and the ability of a species to adapt will determine the success of the response by a given species. Individualistic responses by species will mean that communities and ecosystems are likely to change with novel combinations of species almost certainly appearing in the future.[1]

Observed changes in Australian species and communities that are consistent with species responding to a climate change signal include changes in geographic ranges, life cycles, populations, ecotonal boundaries, mass bleaching of coral, and changes in fire regimes. Most of these changes are related to temperature and rainfall, but are difficult to separate from other natural and human drivers of change.[1] Australia's biota is already under considerable stress from factors such as landscape degradation and modification, and introduced species. The legacy of past actions has had a devastating influence on species distributions and abundance. Climate change adds a further degree of complexity to the effects of landscape modification and is likely to exacerbate those stresses.

2.3.3 CONNECTIVITY

A global analysis of biodiversity distributions shows a profound shift in species ranges over a wide range of taxa with movement on average of 6.1 km per decade toward the poles.[50] Predictions of shifts in species ranges to different elevations and latitudes in response to climate change suggest that landscape connectivity will aid conservation of biodiversity. Indeed, the general perception from many participants of the stakeholder meetings and submissions and a review of the scientific literature[51] suggest increased connectivity as a key conservation strategy. However, knowledge of how species will respond to climate change is minimal. For example, it is not known if genetic adaptation or dispersal will be the most important factor in determining the success of a species adapting to climate change. Scientists have also pointed out that, ultimately, conservation is a multi-species enterprise and multi-species responses are not a simple function each individual species' response.[1]

Unfortunately in many cases, improving habitat connectivity will not be sufficient to buffer against climate change. The climate envelope in which species currently exist will either cease to exist at all or shift to regions with unsuitable geomorphology prohibiting the establishment of identical (or suitable) vegetation communities. On the other hand, some species may be able to expand their range by extending into areas where competition is decreased or diseases cannot follow.[41]

2.3.4 MANAGEMENT CHALLENGES

Given the uncertain but inevitable changes to biodiversity from climate change there is a growing awareness that management of biodiversity needs to be reorientated towards an overarching goal of minimising biodiversity loss, rather than concentrating on single species approaches. In this context, two key principles to minimise biodiversity loss are maintaining well-functioning ecosystems and protecting an array of ecological systems.[1] Central to this strategy is to enhance robustness of remaining ecosystems to give them a chance to adapt. Approaches would include (but are not limited to):

- addressing key threatening process leading to habitat degradation
- enhancing protection of an array of ecosystems
- building appropriate connectivity
- developing appropriate fire and other disturbance regimes
- translocating species (assisted migration)
- re-engineering ecosystems
- developing new tools in modelling of climate, vegetation responses, animal movements and genetic adaptation, particularly the need to develop more robust and certain models
- developing policy, decision making processes and adaptive management approaches that incorporate uncertainty.

As the current trajectories for sea level rises are at the upper limit of the projection of the Third Assessment Report of the Intergovernmental Panel on Climate Change,[52] and global temperatures are expected to rise given the current rate of greenhouse gas emission production,[53] the need for planning and implementation for future biodiversity requirements is urgent.