

1 Biodiversity

The Avon River basin is part of the South West Botanical Province of Western Australia and one of the world's biodiversity hotspots. The ARB contains 4803 plant taxa, and approximately 10% (416 taxa) are endemic to the region (Richardson et al. 2007, Myers et al. 2000). Sixty per cent of the fauna and flora species of the South West Botanical Province are endemic to the region.

There are 1,197 fauna species to be found in the ARB, including 22 amphibian species, 165 bird species, 19 fish species, 56 mammal species, 121 reptile species and 814 invertebrate species, many of which are endemic to South West Western Australia (Southwest WA) (Richardson et. al. 2007).

The ARB covers approximately 3.4 million hectares of the western part of the Great Western Woodland (GWW), internationally recognised as the world's largest Mediterranean-climate woodland (DEC 2010). Remnant native vegetation within the region is contained within DEC nature reserves, crown land and on private land holdings (refer Table 1).

Table 1. Land Tenure of Native Vegetation

<i>Tenure</i>	<i>Number of units</i>	<i>Area (ha)</i>
<i>DEC Reserves</i>	<i>463</i>	<i>870 000</i>
<i>Private Remnants</i>	<i>50,000</i>	<i>491 000</i>
<i>Crown Land</i>		<i>3 500 000</i>
<i>Roadside / rail reserves</i>	<i>25,000 km</i>	

1.1 Background

The unique nature of South West Western Australian ecosystems resulted from a range of historic and geological factors, including:

- *High degree of endemism resulting from continental isolation and genetic drift*
- *Arid or very dry conditions caused by Australia being located about 30° latitude*
- *Variable climatic and temperature conditions due to the influence of several great ocean currents, resulting in selection for organisms suited to highly variable conditions such as marsupial and eucalyptus species*
- *Selection for organisms tolerant of low soil and water nutrient availability, including dominance of sclerophyll forests, due to low levels of volcanic activity and uplift in recent geological times resulting in a flat topography, leading to a lack of glacial rejuvenation during ice ages*
- *Expanding desert in central Australia resulting from cyclical onslaught of the aridity produced by the sequence of glacial periods.*

1.2 Human Impacts

The arrival of the first humans in Australia approximately 40,000–65,000 years ago changed the landscape through hunting and the use of fire. Around this time many large mammals became extinct throughout Australia. The reshaping of the Australian biotic landscape was primarily influenced by the intensity, time and frequency of the new fire regime and the impact of the new (human) apex predator.

The dingo (*Canis lupus dingo*) was introduced to Australia during another wave of human arrivals approximately 6,000 years ago. The introduction of the dingo is likely to have resulted in the extinction of the thylacine and Tasmanian devil on the mainland, and probably affected the distribution and relative abundance of a range of prey species, further reshaping Australia's biotic landscape.

In the 225 years since their arrival, Europeans have undertaken wholesale clearing of native vegetation for agriculture, reshaping the landscape of the Western Australian Wheatbelt. In addition to clearing native vegetation, European settlers introduced a range of exotic species, changed fire regimes, introduced pathogens, altered landscape hydrology and weather patterns, converted native landscapes to agriculture and initiated or accelerated soil erosion. All these factors have affected ecological function.

1.3 NRM Strategy Goals

The environment provides humans with a range of ecosystem services including food and fibre, fuel, fresh water, a sense of place, shelter, recreation and spiritual and cultural solace, in addition to the more esoteric existence and bequest values. Communities within the ARB are reliant on the natural environment for their social and economic well-being. The overall objective of the community within the ARB, with respect to NRM, is to manage the integrity of the natural resources within the region on which they rely for their continued economic, social and cultural well-being.

Goals and objectives associated with the previous (2005) regional NRM strategy focused strongly on maintaining the extent and integrity of naturally-occurring ecological communities and species within the ARB. A primary objective was to ensure that all native species that occur naturally occur in the Avon region persist in viable populations. The 2005 strategy was predominately focused on a 'threatened species' approach to management of biodiversity; which may have been a reflection the government policy of the day rather than necessarily representing the view of the local and broader community, which may well have preferred a broader approach to conservation management.

In setting goals and objectives it is important to understand the context and underlying trends influencing natural resources within the region. Ecosystems within the ARB have been evolving in response to changes in climatic conditions, fire regimes and the introduction of new species for millions of years.

Current stressors impacting the natural diversity of the system are acute and influence the robustness and resilience of the biotic landscape in multiple and interacting ways. In addition, many

of the stressors, including increasing aridity and feral and invasive species and declining water quality, have not yet reached equilibrium.

The ARB's natural landscape will be influenced by new and emerging stressors in coming decades, in particular increased temperatures and increasing aridity. It is unavoidable that some ecosystems will be impacted by these multiple and overlapping stressors, potentially resulting in cascading effects and possibly tipping ecosystems into unstable and/or alternate states. At the same time, it is inevitable that susceptible individual species will become locally or even regionally extinct. The ecosystems that have emerged from these human induced stressors to date are typically weedy and more open, with few independent relationships among species, and are less stable than those impacted from normal stressors such as slow changes in climate, vegetation cover and natural fire regimes (Hobbs et al. 2006, Lindenmayer & Fischer 2006).

The overwhelming evidence is that a goal of preserving all species are simply not in keeping with current ecosystem trends or the nature of the stressors impacting on the natural environment of the region, and therefore are unlikely to be realistic or achievable. Effective NRM needs to embrace the fact that landscape change is inevitable.

Goals for the management of native vegetation within the region should aim to maintain the resilience of the landscape to absorb shocks and stressors and to limit the impact of current and emerging stressors on our natural ecosystems and landscapes.

1.4 Resource Condition

Current and emerging stressors have reduced native vegetation cover and caused the loss or endangering of some of the regions' biodiversity. According to the Avon Natural Resource Management Strategy report (ACC 2005):

- *Five flora species are now extinct*
- *71 species are endangered and over 450 species of vascular plants are at risk from rising water tables*
- *The ARB has 121 Declared Rare Flora (DRF) and 234 Priority Flora (52 Priority 1, 82 Priority 2, 54 Priority 3 and 47 Priority 4)*
- *Two mammal species are now extinct (twelve are locally extinct within the region) and a further two are endangered*
- *At least three bird species are endangered and many of those remaining have a greatly contracted range.*

1.4.1 Ecosystem Resilience

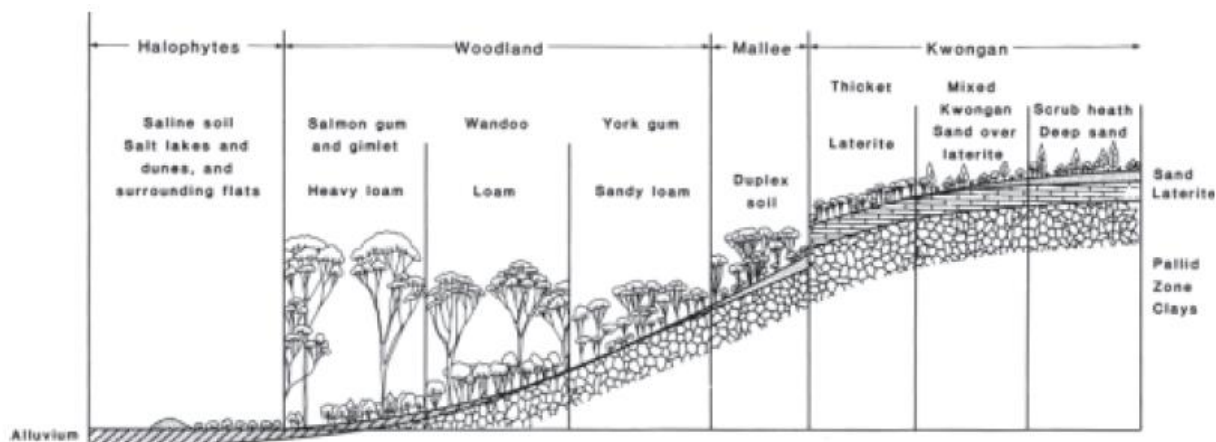
The ecosystems of the Wheatbelt are extremely complex, containing a mosaic of vegetation associations distributed according to landscape position and soil type. Beard's vegetation classification is widely used in mapping and management planning within the region and highlights the complexity of Wheatbelt ecosystems (Beard 1990).

Beard's vegetation description, presented in Figure 1 and Table 2 provides a broad illustration of the vegetation associations underpinning the ecosystems within the Wheatbelt; however, in reality functional ecosystems are stretched across a range of vegetation associations. Pollinators, grazers and predators all move between functional units, with many species requiring multiple habitats to complete their lifecycles.

Ecosystems of the Wheatbelt are made up of a complex, irregular distribution of vegetation associations draped across an ancient dissected landscape, a mosaic of valleys, hill slopes and plateaus, punctuated by creeks, lake systems and numerous granite and lateritic outcrops. Prior to European occupation a fire mosaic was superimposed on this complex vegetation mosaic, adding a further dimension of regeneration and variable age classes to the underlying complex vegetation associations of the regional biome. The species composition of ecosystems is known to change during post-fire successional stages, with plant communities requiring fire for regeneration being more common in early succession stages and becoming less common as time-since-fire increases (Keeley et al. 2005; Keith 1996).

A third dimension of complexity occurs at a more macro scale, reflecting the region's heterogeneous geomorphology with sub-regions differing in landscape composition due to different geology and prehistoric erosion, in addition to variations in current surface water and groundwater characteristics and rainfall patterns (ACC 2008).

Figure 1. Vegetation Associations of the Avon River Basin (Beard 1990)



Beard (1990)

Table 2. Vegetation–Landscape Association (Beard 1990)

	<i>Landscape Position</i>	<i>Veg Association</i>	<i>Soil type</i>
Halophytes	<i>Lake beds, lunettes and surrounds</i>		<i>Clays, gypsums and lunettes</i>
Woodland	<i>Alluvial fans & lower slopes</i>	<i>Salmon gum & gimlet</i>	<i>Heavy loam</i>
	<i>Mid–lower slope</i>	<i>Wandoo</i>	<i>Loam</i>
	<i>Mid slopes</i>	<i>York gum</i>	<i>Sandy loam</i>
Mallee	<i>Upper slopes</i>	<i>Mallee</i>	<i>Duplex</i>
Kwongan	<i>Plateau edge</i>	<i>Thicket</i>	<i>Laterite</i>
	<i>Plateau</i>	<i>Mixed kwongan</i>	<i>Sand over laterite</i>
	<i>Upper plateau</i>	<i>Scrub heath</i>	<i>Deep sand</i>
Other	<i>Various</i>	<i>Mixed</i>	<i>Granite outcrops</i>

In understanding the resilience of an ecosystem it is helpful to consider the underlying attributes of system resilience and the nature of shocks and stressors to which the system is subjected. Shocks and stressors are considered in section 1.4.2.

The key attributes of system resilience (according to Longstaff et al. 2010) are detailed below.

Resource Robustness

- **Performance / fitness** (capacity or fitness of elements of a system to perform their essential role, or the productive capacity of a system expressed as the quality and quantity of output)
- **Diversity** (different types of available resources that perform a particular function; the extent of synergistic interactions between elements of the system)
- **Redundancy** (the extent to which resource elements can perform key functions; the failsafe capacity of a system to cover for losses of individual components).

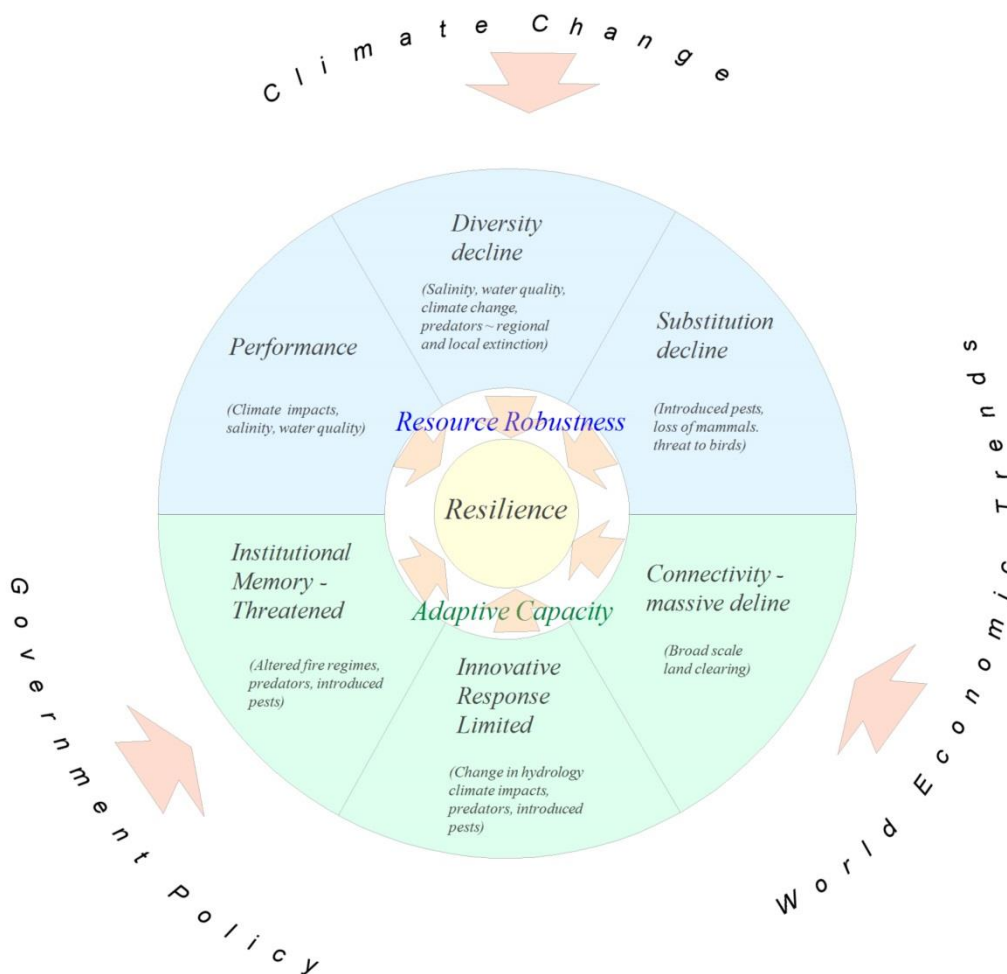
Adaptive Capacity

- **Institutional Memory** (the accumulated knowledge or experience of the community, the knowledge or seed bank contained within the system)
- **Innovative Capacity** (The capacity of the system to utilise the institutional memory, or genetic capacity, to adapt to the altered environment)
- **Connectedness** (the ability of the system to share and transfer institutional memory; the ability of cells within the system to access knowledge/seed banks. Fragmentation can lead to poor connectedness and local extinction of knowledge or genetic material).

Focusing on a narrow range of attributes in managing ecosystems can ultimately cause a reduction in the overall resilience of the system being managed. For instance, an approach that considers only the performance of individual species or an exclusive focus on the diversity or connectedness of the system may result in erosion of other system attributes and ultimately a breakdown in underlying resilience.

The stressors impacting native ecosystems impact the resilience of the regions biodiversity in different ways and many coincide to impact the underlying attributes of resilience (refer Figure 2).

Figure 2. Resilience Attribute Model – Biodiversity



(Adapted from Longstall et. al. 2010)

The resilience attribute model outlined in Figure 2 illustrates the need to manage multiple stressors to increase the resilience of natural ecosystems within the region. The model also highlights that the emerging climate change stressor is likely to impact the resilience of biodiversity across a range of attributes, including declining diversity, performance, institutional memory and capacity to respond. Climate change is also likely to interact with existing landscape fragmentation to place increasing pressure on the ecosystem's overall capacity to respond to mounting stressors.

The model presented in Figure 2 also serves to indicate that single-issue management response programs that focus (for example) on corridors and revegetation but fail to manage fire regimes, predators and grazing pressures will not effectively increase the resilience of our biodiversity.

The resilience attribute model highlights that response strategies need to be multidimensional and will need to be implemented at multiple scales to be effective.

The need for multiple management response was illustrated by *Prober et al. (2011)* in their assessment of the impacts of fencing of York Gum communities intended to manage the impacts of grazing by native mammals. The study concluded that ecosystem vigour improved as a result of fencing to exclude domestic stock, but weed control and appropriate fire management were also essential to stimulate effective regeneration of native remnant vegetation.

1.4.2 Key Stressors

A summary of processes resulting in stressors and shocks impacting native vegetation is outlined in Table 3.

Table 3. *Threatening Processes – Ecosystems (ANRMA 2011, Beecham 2004)*

Threat (Stressor)	Details
Broad-scale vegetation clearing	Clearing within the ARB is extensive and in some areas > 95% of original native veg has been removed, whilst in other areas of the agricultural zone it is ~ 70%. Clearing represents a stress within the GWW sub-region associated with a range of development pressures, including mining and exploration (DEC 2010)
Increasing fragmentation	Passive remnant loss from grazing and vegetation loss is ongoing within the region and may be exacerbated by declining economic returns from agriculture
Grazing pressure	From domestic stock, rabbits and kangaroos
Feral animals	Fox predation mostly impacts mammals in the critical weight range (CWR) of 35-5500 g. The impacts of cat predation and interactions between fox and cat predation activity remain largely unknown.
Exotic weeds	Weeds modify habitat structure, impact on ground-dwelling/feeding birds and mammals, out-compete native plants, and alter fire behaviour and regimes. Notable weeds include bridal creeper, perennial veld grass and various annual grasses
Changed fire regimes	Small remnants may result in localised extinction through single fire event. Linked to weed invasion hazard. Decline in fire frequency in many isolated remnants resulting in modified vegetation structure.
Pathogens	The ARB has a wide range of plant species susceptible to <i>Phytophthora</i>
Salinity and waterlogging	<p>Over 850 species of flora are found only in fresh or naturally saline lowlands directly threatened by rising groundwater and salinity. Over 1,500 plant species occur in low landscape positions and face a salinity hazard.</p> <p>Tall woodlands, mallee and melaleuca shrublands, freshwater and naturally saline wetland systems are most impacted.</p> <p>How salinity and waterlogging will be affected by altered rainfall patterns associated with climate change remains largely unclear.</p> <p>The ARB has a rich endemic aquatic micro-invertebrate fauna that is under threat from the altered hydrology associated with clearing and secondary salinisation. Changes to rainfall–runoff relationships and hydro-period due to clearing present additional stressors for aquatic</p>

	flora and fauna, exacerbated by increased salinity and decreasing pH of surface water. Approx. 40% of fauna are considered vulnerable to salinity (Beecham 2004, Keighery & Lyons 2001)
Increasing aridity	<p>Climate change predictions are for reduced overall rainfall, particularly winter rainfall, longer periods of drought and more frequent and severe episodic events.</p> <p>Drought-sensitive species and those occurring on soils of low water holding capacity are likely to be most affected</p>
Increasing temperature	Increase temperature may impact individual sensitive flora and fauna, likely to significantly impact seed set in sensitive spp. Interaction with increasing aridity and fire regimes may be significant, particularly in the eastern areas of the region where traditional fire regimes are considered to have been less frequent
Sedimentation	<i>Sedimentation is a key stressor impacting habitat in the Avon River and its major tributaries. Large sediment loads occurred as a result of river training scheme and loss of riparian vegetation along the river and major tributaries. Wheatbelt NRM investment in revegetation and fencing to exclude grazing along the Avon in recent years is believed to have stabilised much of the river, but unstable tributaries remain a major source of sediment load</i>
Eutrophication	<p><i>Nutrient loads to aquatic systems within the region from agricultural land, urban and peri-urban environments remain major stressors</i></p> <p><i>Urban environments within the Avon Arc currently contribute 8% of TP load to the Avon River at Toodyay and this contribution is predicted to double in the next 20 years (WNRM 2011)</i></p>
Pollution	<i>Agricultural herbicides and pesticides, hydrocarbons and toxic metals discharging from urban catchments, and low pH discharge containing heavy metals associated with agricultural drainage are potentially lethal stressors to the receiving aquatic environments</i>
Reduced flow	<p><i>Climate change predictions are for reduced overall rainfall, particularly winter rainfall, longer periods of drought and more frequent and severe episodic events</i></p> <p><i>Future conditions are likely to result in decreased frequency of flow, increased variation in frequency and severity of large episodic events and longer periods without flow, further impacting the nutrient and sediment dynamics of aquatic systems</i></p> <p><i>Surface water modelling indicates that a predicted 10% reduction in rainfall will result in a 30%–40% reduction in runoff (WNRM 2008a)</i></p>
Increasing temperature	<i>Increased temperature may negatively affect sensitive aquatic flora and fauna, impacting life cycles and recruitment. Interaction with increasing aridity and fire regimes may have significant impacts on riparian vegetation, particularly in the eastern areas of the ARB where traditional fire regimes have been less frequent</i>

Key stressors impacting native vegetation communities within the region are explored in greater detail below.

1.4.2.1 Exotic Species

Introduced mammals have had such a significant influence over Australian ecosystems because of the interaction between the types of mammals introduced, including top-order predators (red fox and cat) and a range of grazing mammals, and rabbits and sheep. Introduced predators have resulted in considerable reorganisation within vertebrate assemblages of ecosystems, causing very significant fauna attrition within the region. Introduced grazers have changed species composition by changing plant composition assemblages through preferential grazing, influencing the amount of biomass within systems, and displacing a range of smaller native animals (Steffen et al. 2009)..

Fox predation has a particularly pronounced impact on CWR mammals (Short & Smith 1994, Short 1998, Beecham 2000). Modelling suggests several other factors also significantly influence fauna attrition (McKenzie et al. 2007):

- *Rainfall (higher losses experienced in more arid areas)*
- *Environmental change (more losses in areas where habitat has been lost or degraded)*
- *Whether species shelter on the ground or in trees, borrows or rock piles (on ground species most affected)*
- *The length of time since foxes first arrived in the region (the longer the time since arrival the more species lost).*

The impacts of introduced mammals on local biodiversity were noticed in the early days of European settlement in the region. By the 1930s it was clear that populations of mid-sized mammals were in decline, principally due to red fox predation. A further crash of native mammals occurred after the 1970s when a change in rabbit management practice (including the phasing out of one-shot oats for controlling rabbits) caused a dramatic increase in fox populations due to a reduction in secondary kills. Dramatic losses of species from ARB reserves were also experienced during the 1980s and 1990s, including southern brown bandicoot and numbat from the Tutanning Nature Reserve (Friend & Thomas 1994), rock-wallabies from isolated granite outcrops of the central Wheatbelt (Kinnear et al. 2002) and a dramatic reduction in sightings of numbat within the Dryandra nature reserve (located adjacent to the Avon River basin) (Short 2004).

Apex predators are often keystone species, impacting the entire structure of the associated ecosystem. Recent research suggests that dingos suppress smaller predators, including the exotic red fox and feral cats, in open timbered areas such as the GWW. Suppression of fox and feral cat populations can elevate populations of small prey species important in maintaining regional biodiversity. Evidence suggests that artificial control of dingo populations can interrupt their highly structured social networks, leading to increased interbreeding with domestic dogs. In addition, populations of large prey species such as kangaroos increase, as do populations of foxes and cats; the result is a reduction in small mammal populations that can result in changes cascading through the ecosystem (Watson et al. 2008).

1.4.2.2 Land Clearing

Only 13.2% of the 8.3 million hectares of the Avon Arc, Central, Southern and Eastern sub-regions retain natural vegetation cover, of which 7.5% is contained within reserves and the remaining 5.7% in small patches of remnant vegetation on private land (ACC 2005).

Land clearing has caused habitat loss and fragmentation of remnant native vegetation. While the rate of clearing has reduced significantly within agricultural subregions as result of clearing legislation, development of mining interests in the GWW in particular is likely to lead to additional habitat loss around the mineral-rich greenstone belt and banded iron formations. Changes to the management of UCL within the GWW also presents a risk to native vegetation, through increased human activity, weed invasion and changes to fire regimes.

Broad-scale clearing of native vegetation for agriculture remains the most significant environmental legacy of European colonisation. Some shires within the ARB are more than 95% cleared, and nine of the ten most cleared shires in Western Australia lie within the ARB (refer Table 4). Extensive clearing of native vegetation in the region may also have led to regional climate change. Growing scientific evidence suggests that land cover change results in global and regional climatic effects due to changes in solar radiation and evaporation, transpiration, latent and ground heat fluxes and nonlinear feedback through changes in soil moisture surface hydrology (Alpine et al. 2009).

Table 4. Top ten most cleared shires in WA

	LGA	Percentage of Vegetation Remaining
1*	Cunderdin	1.8%
2*	Quairading	3.6%
3*	Dowerin	4.3%
4*	Goomalling	4.6%
5*	Corrigin	4.9%
6*	Wyalkatchem	4.9%
7*	Wongan-Ballidu	5.2%
8*	Tammin	5.5%
9	Mingenew	6.6%
10*	Bruce Rock	7.1%

* within the ARB

Clearing of native vegetation has profoundly influenced the aquatic environment of the ARB, both directly through loss of riparian vegetation and indirectly through clearing leading to reduced water quality due to salinity, increased nutrient load, sedimentation, pollution and hydrological changes.

Resilience attribute assessment suggests that whilst land clearing itself has led to a great reduction in connectedness within the landscape, the interaction of land clearing with a range of other stressors

presents the most significant threat to ecosystems resilience. Connectedness impacts capacity for dispersal and has a major impact on migration, two key strategies for species and ecosystems to respond to stressors including changes to fire regimes and climatic conditions.

Clearing of native vegetation has also provided habitat more suited to the red fox which prefers remnants scattered amongst open country, a keystone exotic predator largely responsible for the decimation of the region's fauna populations.

1.5 Fire Regimes

The frequency, intensity and seasonality of fires within the ARB has changed dramatically since European settlement, with fire management typically focused on fuel reduction activities aimed at preserving human life and constructed assets in large nature reserves. Conversely, small patches of remnant vegetation, including smaller reserves and private remnants, are likely to have experienced much less frequent burning than was the case prior to European settlement, due to isolation and fire suppression activities undertaken in the agricultural landscape.

Fire impacts the structure and function of ecological communities worldwide, and nowhere more so than in Australia where our ecological landscape has evolved in the presence of fire (Bowman et al. 2009). Fire is a definitive natural stressor, shaping species composition and the underlying structure and function of our ecosystems, particularly the mallee and kwongan heath vegetation associations, but also woodlands. As the Australian landscape has become more arid over the last 1–2 million years, fire has become an increasingly important factor in natural selection. The arrival of the first humans in Australia 40,000–65,000 years ago changed the landscape dramatically, primarily through the use of fire. As a result, Australian ecosystems have evolved over millennia in the presence of regular and probably quite specific fire regimes (Gill et al. 1999).

Management of native vegetation requires an intimate understanding of the effects of fire on the structure and function of ecosystems (Watson et al. 2001). This represents a major challenge, particularly considering the largely fragmented nature of the Wheatbelt landscape and the modified environment of the adjacent GWW in the east of the region.

Fire management of native vegetation is critically important to the health and resilience of natural ecosystems. The impacts of fire, both positive and negative, are a function of their frequency, intensity, timing (seasonality) and size. Different vegetation associations throughout the region have different fire behaviour and responses and therefore different fire requirements. Shedley (2007) produced an assessment of fire management requirements within the ARB, including recommended fire regimes for various regional habitats. However, there are many still many gaps in our knowledge of fire history and the ecological response to fire of many ecosystems within the region.

It is a generally held view that many remnants and reserves within the agricultural zone of the region (excluding the GWW) have now experienced a much longer time between fire events than occurred prior to European occupation of the land (Shedley 2007, DEC 2010). There is much less consensus of opinion regarding appropriate or natural fire regimes within the GWW. However, there is some evidence to suggest that the woodland and mallee communities were burnt naturally at intervals of 40–100 years, in contrast to shrublands which were likely to have experienced fire frequency of 15–30 years (Watson et al. 2008). The Department of Environment and Conservation is currently undertaking research in the Lake Johnston district to better determine natural fire regimes for the

GWV. However, much more information is required to understand the relationships between different fire regimes and biodiversity throughout the landscape (Watson et al. 2008).

Even though fire is recognised as a primary factor influencing the structure, function and resilience of natural ecosystems, in reality it does not act as a discrete stressor. Fire interacts with a range of other stressors to influence the health and resilience of our natural landscapes. This is clearly illustrated in the case study of the senescence of kwongan heath undertaken during this review (Chapter X). It is generally accepted that large areas of scrubland heath are senescing and being invaded by *Allocasuarina huegeliana* (rock sheoak), principally due to an interaction between a lack of fire regeneration and changes in grazing patterns. Senescence of kwongan heath within the Avon Region is significant because of the underlying diversity and widespread nature of the vegetation association, representing approximately 25% of all remnant vegetation within the agricultural areas of the ARB.

1.5.1 Climate Change

Modelling indicates that land cover change in Southwest WA has increased average surface temperatures by approximately 0.5°C reduced rainfall by 5%, and increased summer rainfall (Alpine et al. 2009).

Native vegetation and aquatic ecosystems within the region are beginning to show signs of the impacts of climate change (Fitzpatrick et al. 2008). Global climate modelling indicates that Southwest WA will experience more arid and extreme weather over the next century (IOCI 2012).

Climate change is likely to have a substantial negative impact on the extraordinary diversity of the southwest. Projected reductions in rainfall, for example, will dry up groundwater refuges for freshwater animals. Projected hotter and drier conditions will change fire regimes, reducing habitat availability for animals and disadvantaging many plants that reproduce only by seed (Climate Commission 2011).

The impacts of climate change appear to be affecting some plants and animals in Southwest WA. The arrival and departure times of migratory birds has altered, consistent with changes expected under a changing climate (Chambers 2005, 2008), and extreme heatwaves have caused widespread mortality in the already endangered Carnaby's Cockatoo (Saunders et al. 2011).

Climate change is likely to create warmer and more arid conditions, with most plants and animals in the ARB having limited opportunities to adapt or reorganise to rapid climate change, particularly species and ecosystems associated with cooler, wetter habitats. Opportunities for species and ecosystems to migrate southwards and westwards will be limited by previous landscape fragmentation and habitat loss associated with clearing and valley floor salinity (Climate Commission 2011).

Few researchers have modelled the impacts of climate change on habitat. Analysis undertaken to date includes an assessment of the likely impact of predicted climate change on the distribution of Banksia species as an indicator, and suggests that available habitat will be significantly reduced (Fitzpatrick et al. 2008; Yates et al. 2010; Gibson et al. 2010).

Research to date suggests that the ranges of the vast majority of modelled Banksia species will decline due to climate change, with only a few already widespread species responding positively. The ranges of many species are predicted to collapse, suggesting that the impacts on the flora of Southwest WA are likely to be significant even under the most optimistic scenarios (Yates et al. 2010; Gibson et al. 2010).

Native vegetation can respond to climate change in three ways.

- *Phenotypic plasticity*
- *Genetic modification*
- *Migration.*

Previous adaptation to rapid climate change is most likely due to migration, with phenotypic plasticity largely hard-coded within individual species; genetic modifications and development of the capacity to respond to changed environmental conditions require multiple generations to be effective.

The capacity of native vegetation to migrate in response to climate change within the south-west land division of Western Australia will be particularly limited by the pronounced fragmentation of native vegetation caused by agricultural land use. Ecosystem fragmentation reduces the capacity of the landscape to respond to the anticipated increased aridity associated with climate change.

1.5.2 Salinity

Salinity has long had a dramatic impact on valley floor woodland vegetation and aquatic communities throughout the Wheatbelt. Salinity is devastating to native vegetation, often resulting in complete ecosystem collapse. This is because salinity impacts resilience by reducing production, diversity, redundancy and capacity to regenerate. The area of saline land within the Southwest WA is estimated to have grown from 167,000 to approximately 1 M ha between 1975 and 2000 (George 2008).

Approximately 1,500 plant species situated in the broad valleys of the Wheatbelt are vulnerable to the impacts of waterlogging and salinity (ACC 2005). Assuming uncontrolled increases in saline land, then 470 plant species are potentially threatened by salinity within the Wheatbelt (Climate Commission 2011). However, the rate of spread and likely geographic extent of salinity impacts within the region remain unclear. Previous assessments of the probable impact of salinity assumed that the “*valley hazard*” area mapped under the Land Monitor project was likely to be impacted by salinity at some point in the future; this eventuality is now considered unlikely (ACC 2008b).

Salinity trend analysis undertaken for the ARB, which considers a combination of data sources including groundwater trends, land monitor satellite imagery assessment, and stream flow data within the Avon River, confirms that salinity within the older cleared areas of the Avon Arc has largely stabilised (ACC 2008). Monitoring of the Avon River at Northam Weir indicates no increase in salinity in recent decades, suggesting that salinity within the major contributing catchments of the Avon River (notably the Avon Arc) has remained relatively stable (Mayer et al 2005). Nevertheless, an upward trend in baseflow salinity loads in the Yilgran and Lockhart river systems indicates increasing salinity in the Central, Southern and Eastern subregions (ACC 2008).

Salinity trends reported by George (2008) suggest that groundwater levels continue to rise in catchments that are yet to reach hydrologic equilibrium. However, the limited distribution of groundwater bores makes it difficult to assess spatial trends in salinity. George (2008) also reported that the most significant recent driver of salinity in the Avon River basin were the episodic rainfall events of 2000, 2005 and 2006, which resulted in significant inundation of lower landscape areas. This suggests that episodic recharge and surface-groundwater interactions are an important mechanism for salinity development within the low gradient, low permeable catchments of the Central, Southern and Eastern subregions.

How climate change is likely to influence the patterns of development of land salinity within the region, including rate of increase and predicted geographic extent, also remains unclear. Due to a general reduction in funding for salinity and related research in recent years, there is currently very limited work being undertaken in this field.

Understanding the nature of the threat posed by the further development of salinity is essential in planning for and implementing management responses. This understanding is currently hampered by a lack of effective spatial and temporal mapping of salinity, insufficient effective monitoring programs and under-investment in effective management responses.

1.6 References

- ACC 2005 *Avon Natural Resource Management Strategy*. Avon Catchment Council (Wheatbelt NRM), Northam WA.
- ACC 2008 *Salinity Trend Analysis – Avon River basin*. Avon Catchment Council, Northam, Western Australia.
- AJM Hopkins, Shepherd DP, Mazzilli S 2002 *Audit Report of Land-Use and Vegetation*. In Technical report 250: Land-Use and Vegetation in Western Australia. Department of Agriculture, WA.
- Beard JS 1980 A new phytogeographic map of Western Australia. *West Austral. Herb. Res. Notes* Volume 3, pp. 37-58.
- Beard JS 1990 *The Plant Life of Western Australia*. Sydney: Kangaroo Press.
- Beard JS, Chapman AR Gioia P 2000. Species richness and endemism in the Western Australian flora. *Journal of Biogeography* Volume 27, pp. 1257–1268.
- Beecham B 2002 *Avon Wheatbelt IBRA Sub Region Biodiversity Strategy Case Study*. ANRA, Australian Government. www.anra.gov.au/topics/vegetation/pubs
- Bowman DM, et al 2009 *Fire in the Earth System*. Science, Volume 324, pp. 481–484.
- Brown JM, Hopkins AJ 1983 The kwongan (sclerophyllous scrubland) of Tutanning Nature Reserve, Western Australia. *Australian Journal of Ecology* Volume 8, pp. 63–73.
- Chisholm R, Taylor R 2007 Null-hypothesis significance testing and the critical weight range for Australian mammals. *Conservation Biology* Volume 21, Number 6, pp. 1641–5. doi: 10.1111/j.1523-1739.2007.00815.x.
- DEC 2010 A Biodiversity and Cultural Conservation Strategy for the Great Western Woodlands. Department of Environment and Conservation, Kensington, Western Australia.
- Fitzpatrick M, Gove A, Sanders N, Dunn R 2008 Climate change, plant migration and range collapse in a global biodiversity hotspot: the Banksia (Proteaceae) of Western Australia. *Global Change Biology*, Volume 14, Issue 6, pp. 1137–1352.
- Florabank 2012 *Allocasuarina huegeliana*. http://www.florabank.org.au/lucid/key/species%20navigator/media/html/Allocasuarina_huegeliana.htm
- Friend J, Thomas N 1994 Reintroduction and the Numbat Recovery Program. *Reintroduction Biology of Australia and New Zealand Fauna*. Pp. 189–198.
- Gill AM, Allan G 2008 Large fires, fire effects and the fire-regime concept. *International Journal of Wildland Fire*, 17, 688–695.
- Gill AM, Woinarski JCZ York A 1999 *Australia's biodiversity-responses to fire: plants, birds and invertebrates*. Canberra, Australia.

Indian Ocean Climate Initiative 2012 *Western Australia's Weather and Climate: A Synthesis of Indian Ocean Climate Initiative Stage 3 Research*. CSIRO and BoM, Canberra, Australia.

Keeley JE, Fotheringham CJ Baer-Keeley M 2005 Factors affecting plant diversity during post-fire recovery and succession of Mediterranean-climate shrublands in California, USA. *Diversity and Distributions*, Volume 11, pp. 525–537.

Keith D 1996 Fire-driven extinction of plant populations: A synthesis of theory and review of evidence from Australian vegetation. *Proceedings of the Linnean Society of New South Wales*, Volume 116, pp. 37–78.

Kinnear D, Summer N, Onus M 2002 The red Fox in Australia – an exotic predator turned biocontrol agent. *Biological Conservation* Volume 108, pp. 335–339.

Longstaff PH, Armstrong NJ, Perrin KA, Parker WM, Hidek M 2010 *Community Resilience: A function of resources and adaptability*. White Paper, Institute for National Security and Counterterrorism, Syracuse University New York.

Maher 2007 Encroachment of sand plain heathland (kwongan) by *Allocasuarina huegeliana* in the WA Wheatbelt: the role of herbivores, fire and other factors. Thesis for Doctorate of Philosophy, School of Environmental Science, Murdoch University.

Muir BG, 1978. *Introduction to Durolooppin and Koodj Nature Reserves*. Records of Western Australia Museum supplement 7, pp. 9–14.

Myers N, Mittermeier RA, Mittermeier CG, Da Fonseca G, Kent J 2000 Biodiversity Hotspots for Conservation Priorities. *Nature* Volume 403, pp. 853–858.

Prober S, Standish R, Wiehl G 2011 After the fence: vegetation and topsoil condition in grazed, fenced and benchmark eucalyptus woodlands of fragmented agricultural landscapes. *Australian Journal of Botany*, Volume 59, Number 4, pp. 369–381.

Richardson J, Gamblin T, Glossop B, Hogben J 2007 *The Biodiversity of the Avon NRM Region: Towards Privatisation of Conservation*. Avon Catchment Council, Northam, Western Australia.

Shedley E 2007 *Fire and biodiversity guidelines for the Avon basin*. Consultant report to the Avon Catchment Council and the Department of Environment and Conservation.

Saunders et al. 1996 Biodiversity. In *State of the Environment Australia*. Dept. of Environment, Sport and Territories, CSIRO Publishing.

Short J 1998 The extinction of rat-kangaroos in New South Wales, Australia. *Biological Conservation* Volume 86, pp. 365–377.

Short J 2004 Conservation of mallee fowl: are there lessons from the successful conservation of native mammals by intensive fox control? *Proceedings of the National Mallee Fowl Forum*, Mildura, pp. 54–68.

Short J, Smith A 1994 Mammal decline and recovery in Australia. *Journal of Mammalogy*, volume 75, No. 2, (pp. 288–297).

Salmon J et al. 2004 An overview of Valley fire project biodiversity Project. *Proceedings of the fourth National Mallee Fowl Forum*.

Watson A, Judd S, Watson J, Anya L, MacKenzie D 2008 *The Extraordinary Nature of the Great Western Woodlands*. The Wilderness Society of WA Inc., Perth.

Yates C, McNeill A, Elith J, Midgley G 2010 Assessing the impacts of climate change and land transformation on Banksia in the South West Australian floristic region. *Diversity and Distributions*, Volume 16, Issue 1, pp. 187–210.

Yates C, Elith J, Latimer A, le Maitre D, Midgley G, Schurr F, West A 2010 Projecting climate change impacts on species distribution for the mega-diverse South African Cape and South West Australian Floristic Regions: opportunities and challenges. *Australian Ecology*, Volume 35, Issue 4, pp. 374–391.