Shale Gas Development in Australia

Potential impacts and risks to ecological systems

Final report prepared for
ACOLA Secretariat Limited

11 January 2013

DOCUMENT TRACKING

ITEM	DETAIL
Project Name	Shale Gas Development in Australia: Potential impacts and risks to ecological systems
Project Number	12COFNRM-0019
File location	H:Synergy/Projects/12COFNRM/0019
Project Manager	Dr Julian Wall
Prepared by	Dr Julian Wall, Mark Vile, Katrina Cousins
Approved by	Mark Adams
Status	FINAL
Version Number	1
Last saved on	4 June 2013

This report should be cited as 'Eco Logical Australia 2012. *Shale Gas Development in Australia: Potential Impacts and Risks to Ecological Systems*. Final report prepared for the Australian Council of Learned Academies (ACOLA). January 2013'.

ACKNOWLEDGEMENTS

This document has been prepared by Eco Logical Australia Pty Ltd with support from Dr Lauren Palmer of the Academy of Technological Science and Engineering and Dr John Williams, founding member of the Wentworth Group of Concerned Scientists.

Executive Summary

Shale gas has the potential to become a significant component of domestic energy supply in Australia and is likely to make a major contribution to future export earnings. Shale beds cover about a quarter of mainland Australia and bind about 6% of the estimated global shale gas reserve. Despite this, shale gas development is at an early stage in Australia, with minor exploration and little commercial production. The majority of Australia's shale gas occurs in deep basins spanning vast areas of remote inland Queensland, Northern Territory and Western Australia that support contiguous expanses of relatively intact native arid and semi-arid vegetation. Smaller shale gas beds occur in temperate and sub-tropical parts of Australia that are often highly urbanised or developed for agriculture, including the Sydney, Perth and Maryborough Basins.

The shale gas industry poses a diverse array of potential impacts to natural assets, although the risk to groundwater systems as a result of hydraulic fracturing has been the focus of media coverage over the past decade even though the likelihood and severity of groundwater impacts is not well understood. Other major ecological impacts such as landscape fragmentation go largely unnoticed in the media.

This document provides an objective review of the likely impacts of shale gas exploitation on natural ecosystems (including groundwater dependent ecosystems) and establishes an overall risk rating for predicted impacts in a whole-of-industry context. The risk assessment considers both the likelihood of an event occurring and the consequences of that event, and is underpinned by recent research published in the scientific literature. Mitigation measures are documented based on United States shale gas literature, however it is acknowledged that novel mitigation measures may yet to be developed by the local industry given the unique shale gas landscapes in Australia.

The assessment finds that habitat fragmentation is an unavoidable result of shale gas expansion and poses a high risk in the context of the various adverse impacts on local fauna and flora and landscape function (e.g. loss of intactness, encouragement of foreign species, noise, roadkill, edge effects). It is an area that will require specific mitigation. The assessment also finds a high risk of contamination to terrestrial and riparian ecosystems given the reported frequency with which shale gas chemical spills occur in the United States, and the quantities of chemicals used, number of impoundment ponds and holding tanks required, and volume of traffic needed to service well pad operations.

In contrast, this assessment finds that risk to groundwater ecology and groundwater dependent ecosystems as a result of hydraulic fracturing and well failure is low to moderate, although uncertainty about groundwater impacts is high.

Moderate risk is identified for aquatic impacts associated with reduction in natural surface water flow (as a result of water abstraction and/or groundwater drawdown). Moderate risk is also established for habitat loss and consequent impact on local fauna and flora populations, as a result of vegetation removal for well pad development, roads and other infrastructure. The risk of major fire is low despite a likely increase in frequency of smaller fires arising from accidents and arson.

Given the various impacts and risks of the evolving shale gas industry, assessment of cumulative impacts from an established baseline is recommended. A cumulative impact assessment framework is proposed in this report that could track ongoing approvals and associated impacts as the industry develops and matures in Australia. The framework would require spatial intersection of shale gas footprints (and those of other industries/land uses) over landscape-scale ecological surfaces (e.g. fauna models, vegetation maps, hydrological models) via spatial software, so that a running inventory of cumulative impacts could be generated and reported. Critical resilience thresholds could be generated as part of the framework, to quantify risk as well as impact on a bioregional scale, and translate it to project specific measures.

Such an approach established now, would aid regulatory certainty for the industry and prevent first mover advantages, allowing adequate and timely project assessments in order to secure social licences for operations.

Contents

List of Figures

List of Tables

Abbreviations

ABBREVIATION	DESCRIPTION
ACOLA	Australian Council of Learned Academies
ATSE	Academy of Technological Science and Engineering
CSG	Coal Seam Gas
DSE	Department of Sustainability and Environment (Victoria)
EPBC	Environmental Protection and Biodiversity Conservation
GDE	Groundwater Dependent Ecosystem
GIS	Geographic Information System
IUCN	International Union for the Conservation of Nature
MNES	Matter of National Environmental Significance
PMSEIC	Prime Minister's Science Engineering Innovation Council
SAF	Securing Australia's Future
tcf	Trillion Cubic Feet

1 Introduction

Natural gas is Australia's third largest energy resource following coal and uranium (GA and BREE 2012), with the majority of production currently based on conventional gas reservoirs, mainly off the north west shelf. The primary driver of growth in Australia's gas market is the opportunity to sell on the international market through established liquid natural gas (LNG) facilities (KPMG 2011).

Unconventional gas such as shale gas and coal seam gas (CSG) is stored in more complex systems than conventional gas, and typically requires more capital, energy and technology to extract. With limited infrastructure (pipelines, LNG plants or other infrastructure), remote locations of reserves, and a relatively high cost of extraction, shale gas development in Australia is in an early, immature state and economic viability is uncertain (KPMG 2011). However, four major factors have provided stimulus for consideration of shale gas as a major future industry in Australia:

- increasing global demand for gas;
- emerging technology, such as horizontal drilling and hydraulic fracturing, that makes extraction more cost effective (CSIRO 2012; Kuuskraa *et al*. 2011);
- global requirement for energy with a lower carbon footprint; and
- significant shale gas potential (about 6% of the estimated global reserves – from Kuuskraa *et al*. 2011).

A major challenge with shale gas development will be management of environmental impacts and risks, and the public's perception of those risks following high media coverage of the shale gas industry in the United States (e.g. Hunter 2012), and the coal seam gas industry in Australia (e.g. Sherriff *et al*. 2010). Public concern over groundwater risks associated with hydraulic fracturing or 'fraccing' has been high and will need to be addressed to ensure public acceptance and a smooth transition from more traditional energy supplies. Other issues such as habitat loss and fragmentation have a lower public profile, but may be of equal environmental concern.

This report provides a review of ecological impacts (including groundwater dependent ecosystems) that may occur as a result shale gas extraction. Carbon and fugitive emissions are not included in the report. A risk profile of principal impacts is included together with typical mitigation measures. A simple framework is provided to address potential cumulative impacts of a developing shale gas industry.

2 Project Scope

The Australian Council of Learned Academies (ACOLA) has commenced a multi-disciplinary research program 'Securing Australia's Future' (SAF), under which a series of projects is being undertaken to inform and guide Commonwealth policy. Project 6 of the SAF, entitled "*Engineering Energy: Unconventional Gas Production*' has been approved by the Prime Minister's Science Engineering Innovation Council (PMSEIC) and is being coordinated by the Academy of Technological Science and Engineering (ATSE) on behalf of the ACOLA Secretariat. The aim of this project is to explore the scientific, social, cultural, technological, environmental and economic issues surrounding alternative energy sources, with particular reference to unconventional gas extraction, notably shale oil gas.

The specific scope of this report is to examine potential impact/risk of onshore shale gas field development on ecosystem function (landscape scale) and species habitat (site scale). The report is partitioned into the following sections:

Section 3	Review of the shale gas resource, including a description of ecological landscapes, native biota and other values that coincide with major shale gas reserves in Australia.
Section 4	Summary of the potential impacts on landscape function and biodiversity that need to be examined for shale gas development, drawing on experience from the US and elsewhere.
Section 5	Assessment of potential risk of a major shale gas industry in Australia on terrestrial and aquatic ecosystems and groundwater ecology. A qualitative risk assessment framework is applied to six broad issues based on AS/NZS ISO 31000:2009 (Standards Australia and New Zealand 2004), in which level of risk is expressed as a function of the consequence of an event and the likelihood of it occurring. Various mitigation measures are included.
Section 6	Brief review of cumulative impact and risk assessment, and provision of a simple risk assessment framework that might be adopted for the shale gas industry.

This report does not include carbon risks or groundwater quality risks associated with the shale gas industry. However, information is presented on groundwater contamination as a source of risk to groundwater dependent ecosystems.

3 Shale Gas Resources

3.1 OVERVIEW

3.1.1 What is Shale Gas

Shale gas is natural gas (mostly methane) trapped in fine grained, organic-rich sedimentary rocks (typically made up of clay, quartz and calcite minerals), such as shales (ANU, 2012; Beach Energy 2012); Broderick *et al*. 2011). Shale gas typically occurs 2,000 m to 4,000 m underground and unlike its shallower CSG counterpart, shale gas contains negligible amounts of water (e.g. ANU, 2012). Shale gas is held either in natural fractures and pore spaces in the shale rock, or is adsorbed onto the organic material in the shale rock.

Unlike conventional gas resources, shale gas occurs in source rocks that exhibit very low porosity (ANU, 2012). Thus to extract the gas, wells are drilled vertically to the shale bed then horizontally along the seam, before hydraulic fracture stimulation is employed to generate a network of small cracks in the shale that liberates gas from the rock (Arthur *et al*. 2009b; ANU, 2012; Beach Energy 2012). Horizontal wells may extent up to 6,000 ft (2 km) from the base of the vertical well, draining an area of four times greater than that drained by a vertical well alone (Arthur *et al*. 2009a). These large lateral distances mean that multiple hydraulic fracture treatments are performed on different sections to stimulate its entire length (Arthur *et al*. 2009b).

Fracturing is an important component of shale gas extraction as it enables gas held in fractures and pore spaces of the shale rock to be produced immediately, while gas adsorbed onto organic material in the shale rock is released progressively as the formation pressure is drawn down by the well. Hydraulic fracturing is now industry standard in the United States (Arthur *et al*. 2009a).

3.1.2 Difference between unconventional gas types

There are three types of unconventional gas: shale gas; CSG; and ‘tight’ gas that occurs in sandstone and limestone. There are major differences between the three types which are important in the context of environmental (and social) impacts. Table 1 provides a comparison of the three unconventional gas types (drawn from CSIRO (2012a) and GA (2012)).

Table 1. Major difference between three unconventional gas types

Feature	Shale Gas	Coal Seam Gas	Tight Gas
Location	Remote locations in WA, QLD, NT and SA, as well as Sydney, Bowen and Perth Basins	Mainly QLD and NSW	Onshore WA, SA and Vic. Largest known resources are in Perth, Cooper and Gippsland Basins
Commercial Production	Currently no commercial production; resources are generally poorly understood and quantified. Santos may have some commercial production from northern Cooper Basin	Significant exploration and production. Commercial production commenced in 1996 and contributes about 10% of Australia's, and about 80% of QLD's gas production	Currently no known commercial production in Australia. Known tight gas reserves in existing conventional reservoirs that are well characterised
Source Rock	Low permeability, fine grained sedimentary rocks (also the reservoir rock)	Coal measures (also the reservoir rock)	Various source rocks that have generated gas which has migrated into low permeability sandstone and limestone reservoirs
Typical Depth	1,000 – 5,000 m	300-1,000m	Greater than 1,000m
Total Estimated Resource Volume (Australia)	396 tcf* (discovered and undiscovered)	235 tcf (discovered and undiscovered)	20 tcf (discovered, expected to increase with further exploration)
Technology required	Hydraulic fracturing (always) Horizontal drilling (often)	Hydraulic fracturing (used for less than half of CSG wells, although use may increase as lower permeability coal seams are increasingly sourced)	Large scale hydraulic fracturing and/or horizontal drilling
Water Usage	Relatively large volumes of water required for drilling and hydraulic fracturing	Water use relatively low as water for drilling and hydraulic fracturing sourced from dewatered coal measure aquifer	Relatively large volumes of water required for drilling and hydraulic fracturing
Key extraction issues	Minimising water used for hydraulic fracturing and reducing infrastructure footprint.	Disposal or reuse of produced water and reducing infrastructure footprint.	Minimising water used for hydraulic fracturing and reducing infrastructure footprint.

* tcf = trillion cubic feet

3.2 SHALE GAS POTENTIAL IN AUSTRALIA

Commercial production of shale gas in Australia is presently negligible, however, initial evaluations indicate that Australia's shale gas resources have the potential to contribute significantly to its energy portfolio. The US Energy Information Administration estimates that "technically recoverable" shale gas resources total 396 tfc in Australia (Kuuskraa *et al*. 2011), where one tfc is equivalent to Australia's annual domestic gas usage (CSIRO 2012b). An overview of the location of major geological basins that provide shale gas potential in Australia is shown in Figure 1 (from CSIRO 2012). It includes:

- Amadeus Basin (Northern Territory);
- Beetaloo Sub-basin (Northern Territory);
- Bowen Basin (Queensland);
- Canning Basin (Western Australia);
- Cooper Basin (Queensland and South Australia);
- Galilee Basin (Queensland);
- Georgina Basin (Queensland and Northern Territory);
- Maryborough Basin (Queensland);
- McArthur Basin (Northern Territory);
- Otway Basin (South Australia and Victoria)
- Perth Basin (Western Australia); and
- Sydney Basin (New South Wales).

The characteristics of these landscapes are explored more in Section 3.4.

3.3 OUTLINE OF SHALE GAS OPERATIONS

3.3.1 Shale Gas Field Development

The development of shale gas resources requires three main steps, which are summarised below:

- Exploration and appraisal – geophysical surveys and drilling of exploration wells, and drilling and testing of appraisal wells (also called pilot wells), which may include the use of hydraulic fracturing.
- Development and production – includes drilling and completion of wells (wells drilled to enable gas production), construction of centralised compression facilities and related infrastructure, and production and operation.
- Decommissioning.

A shale gas production field typically includes the following:

- Shale gas wells and associated infrastructure (e.g. telemetry, generator, water transfer tank).
- Gas gathering pipe networks.
- Water management facilities (e.g. storage ponds, re-use facilities, pipeline).

- Gas treatment and compression facilities including filtration, compression, cooling and dehydration process items.
- Power supply networks (above and below ground).
- Field infrastructure such as access roads and tracks, storage warehouses, workers accommodation camps, offices and telecommunications.

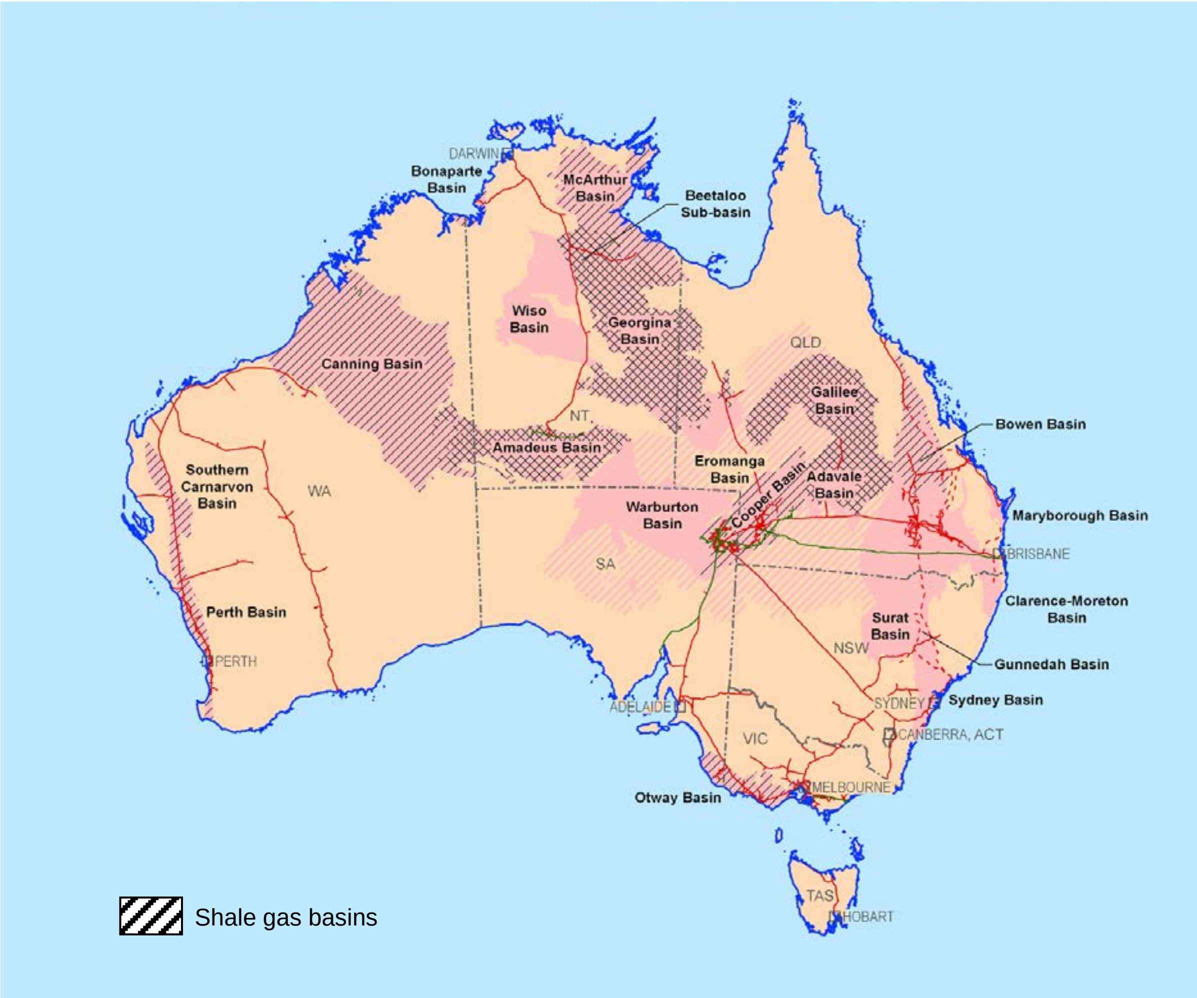


Figure 1. Shale gas potential in Australia (source: CSIRO 2012)

3.3.2 Stages of shale gas extraction

There are three major stages of gas extraction: exploration/appraisal; development/production; and decommissioning (abandonment). These are summarised below (from Royal Society and Royal Academy of Engineering. 2012).

Exploration/Appraisal

A small number of vertical wells (2 to 5) are drilled and fractured to determine if shale gas is present and can be extracted. The exploration stage may include an appraisal phase where more wells (perhaps 10 to 15) are drilled and fractured to characterise the shale; examine how fractures will tend to respond; and establish if the shale could produce gas economically. Further exploration wells may be drilled (perhaps reaching a total of 30) to ascertain the long-term economic viability of the shale.

Development/Production

The development and production stage involves drilling and commercial production of shale gas. Shales with commercial reserves of gas will typically be greater than 100 m thick and will persist laterally over hundreds of square kilometres. These shales will normally have shallow dips, meaning they are almost horizontal. Vertical drilling would tend to pass straight through them and access only a small volume of the shale. Horizontal wells are likely to be drilled and fractured. Once a shale formation is reached by vertical drilling, the drill bit can be deviated to run horizontally or at any angle.

Decommissioning

Like any other well, a shale gas well is decommissioned once it reaches the end of its production life, when extraction is no longer economic. Sections of the well are filled with cement to prevent gas flowing into water-bearing zones or up to the surface. A cap is welded into place and then buried. Decommissioning regulations apply at this stage, and are typically accompanied by site rehabilitation measures that aim to restore areas cleared for well pads and access tracks.

3.3.3 Generation of drilling waste

Drilling involves the establishment of a series of holes ('wellbores') of decreasing diameter and increasing depth that are each lined with steel casing, and joined together to form continuous 'strings' of casing reinforced with cement. Royal Society and Royal Academy of Engineering (2012) provide a detailed summary of drilling procedure that includes the setting of four layers of steel casing sealed with cement: conductor; surface; intermediate; and production, that are designed to maximise the integrity of the well and protect the surrounding rock formations and aquifers from toxic fluids passing up and down the well.

Unconventional gas extraction tends to produce greater surface disturbances and drilling waste in comparison to conventional gas extraction because of tighter well spacing and the need for fracturing. Drilling waste constitutes mud, rock fragments and cuttings from the wellbore, and chemicals added to improve the properties and performance of drilling muds and fluids. Such drilling waste accounts for the second largest amount of waste derived from oil and gas production, the first being waste water (USEPA 2008). Certain methods have been adopted in recent years to reuse and/or reduce drilling waste as well as to diminish the toxicity of various drilling waste, although estimates from the United States suggest that only 10 % of total drilling waste volumes are either reused or recycled (e.g. as levee fill in construction and infrastructure projects), and that current demand for such by-products in other manufacturing sectors is not significant (USEPA 2008).

3.3.4 Water use and management

To assess potential impacts on water resources, aspects of shale gas operation need to be described, particularly in regard to surface disturbance and water use. There are currently no commercial shale gas operations in Australia, however, a review of shale gas operations in the US provide appropriate contextual information.

Water use

Negligible water is produced from shale gas beds, yet substantial water is required for development of a shale gas field, for drilling and hydraulic fracturing. Chesapeake Energy has provided its water use for hydraulic fracturing for each of the shale gas resource areas it operates in the US. Drilling a shale gas well typically requires between 65,000 gallons (0.25 ML) and 600,000 gallons (2.25 ML) of water, and hydraulic fracturing requires an average of 4,500,000 gallons (17 ML) of water per well (Chesapeake Energy 2012a).

Table 2 summarises Chesapeake Energy's water use data for drilling and hydraulic fracturing from a selection of its operating areas in the United States (Chesapeake Energy 2012 b, c, d). This table suggests that 10 – 25 ML of water will be required for each horizontal gas well over the life of the project. This is consistent with the 9 – 29 ML range quoted by Broderick *et al*. (2011). In comparison, research conducted in the United States shows that water requirements for hydraulic fracturing in coal bed methane (i.e. for recovering coal seam gas) is much lower, ranging from 0.19 to 1.33 ML per well (citations in USEPA 2011).

Table 2. Water use data from Chesapeake Energy shale gas operations

	Water use per well – gallons (ML)	
Operation	Drilling	Hydraulic fracturing
Haynesville Shale (Chesapeake Energy, 2012b)	600,000 (2.25)	5,000,000 (19.00)
Barnett Shale (Chesapeake Energy, 2012c)	250,000 (0.95)	2,500,000 (9.50)
Marcellus Shale (Chesapeake Energy, 2012d	100,000 (0.40)	5,500,000 (20.80)

For drilling and fracturing operations carried out within a multi-well pad (typically six horizontal wells along the shale seam from the base of the vertical well), the collective volume of water would be in the vicinity of 54 – 174 ML over the lifetime of the well.

Water Management

According to US shale gas operations, up to 29 ML of water may be required to carry out hydraulic fracturing at each horizontal well over the lifetime of the project. Hydraulic fracturing consists of pumping a fluid and a propping agent ('proppant') such as sand down the wellbore under high pressure to create fractures in the hydrocarbon-bearing shale. These fractures start at the horizontal wellbore and extend as much as a few hundred metres into the reservoir rock. The proppant holds the fractures open, allowing hydrocarbons to flow into the wellbore and to the surface. The composition of fluid used in hydraulic fracturing varies from one operator to another, and is informed by the characteristics of the target formation and operational objectives. However, the fracturing fluid used in modern operations is typically comprised of around 98% water and sand (as a proppant) with chemical additives comprising 2% (GWPC 2009). These additives include acids, breakers, biocides, clay stabilisers, corrosion inhibitors, friction reducers, gelling agents, iron controllers, scale inhibitors and surfactants (Broderick *et al*. 2011).

There are essentially three options available to enable access to sufficient quantities of water for drilling and fracturing:

1. Pumping water directly from a river;
2. Drawing water from a groundwater aquifer; and
3. Piping or transporting water from an external source.

Once on site, water is blended with chemical additives in a truck-mounted blending unit. The blending solution is immediately mixed with the proppant (usually sand) and pumped into the wellbore at high pressure (up to 8,000 PSI), sufficient pressure to fracture the shale formations across distances as much as 300 m (Hunter 2011).

Once the fracturing process is complete, fluid returns to the surface in a process referred to as 'flowback', where it collected into lined pits and/or holding tanks. Flowback waste fluid contains water, methane, fracturing chemicals and sub-surface contaminants mobilised during the process, including toxic organic compounds, heavy metals and naturally occurring radioactive materials (Broderick *et al*. 2012; Rana 2008). Flowback fluid analysed from exploration wells in the UK found notably high levels of sodium, chloride, bromide and iron, as well as higher values of lead, magnesium, zinc, chromium and arsenic compared with the local mains water used for injecting into the shale. The flowback fluid is also very saline, with chloride concentration four times that of seawater (Broderick *et al*. 2011).

According to the US EPA, "estimates of the fluids recovered range from 15% - 80% of the volume injected, depending on the site". It follows that 1 – 23 ML of waste fluid may be recovered per horizontal well, requiring considerable storage and treatment capacity at each multi-well site.

Once the waste water is treated on site, and possibly diluted with additional freshwater, it may be re-injected into the well to facilitate re-fracturing (well production tails off significantly after 5 years), or it may be injected into new wells as they are drilled and fractured. It is not known what level of water reuse is possible and this is likely to vary from one situation to another (Broderick *et al*, 2011). Smith (2012) estimates that reuse water is about 20-25% of total water required to fracture a well.

3.3.5 Gas well network

Well development rate

Because shale gas typically exists in shale deposits that cover huge areas, the number of wells required to access the resource is large and operations are often referred to in the United States as 'gas farming' (Smith 2012). A report by the New York City Department of Environmental Protection (NYC-DEP) on natural gas production in the New York City water supply watershed provides a comparison of shale gas wells in the Barnett, Fayetteville, Haynesville, and Marcellus shale gas development areas of the United States (NYC-DEP 2009). From this comparison it was found that annual well completion rates ranged from 5 to 20 wells initially, accelerating under favourable economic conditions to 100 to 300 wells, and potentially peaking at 500 wells annually.

Well density

Current well densities in the Fayetteville shale beds of the United States range from approximately 200 to 900 wells per 1,000 square miles (2,590 square kilometres) after approximately six years of development, and in the Barnett shale beds they range from approximately 2,400 to 3,250 wells per 1,000 square miles after approximately 13 years of development (NYC-DEP 2009). This translates to a well density ranging from 1 well per 13 km^2 after 6 years, to 1 well per 0.8 km^2 after 13 years. This contrasts with an average density of 1.1 well pads (and 1.6 km of road) per 1 km^2 of land within a CSG development (ELA 2012), and up to 9 pads per square mile (3.5 pads/km^2) in some areas in the United States (Broderick *et al*. 2011).

3.4 ECOLOGICAL CHARACTERISATION OF AUSTRALIA'S SHALE GAS LANDSCAPE

The shale gas landscape covers extensive parts of the Australian continent, intersecting the majority of arid and semi-arid landscapes, and coinciding with a number of temperate and sub-tropical landscapes. An interim biogeographic regionalisation undertaken by Thackway and Cresswell (1995), reviewed by Environment Australia (EA 2000) is used as the basis of a broad ecological characterisation of parts of Australia from which shale gas may be extracted in future. Appendix A lists 26 bioregions that may be affected, and broadly describes their diagnostic characteristics and some specific values. General information in Appendix A has been drawn from Commonwealth Government publications on each of the Bioregions.

The following characteristics are diagnostic of most landscapes that contain potential shale gas reserves, with the exception of the Maryborough, Otway, Perth and Sydney Basins.

- Coincide with vast and remote parts of Australia's inland that support contiguous and extensive areas of arid to semi-arid vegetation.
- Located in dry to very dry regions that experience highly variable rainfall and sporadic flood events. Most rivers and channels are ephemeral, and permanent water is scarce.
- The main land use is cattle grazing (and to a lesser extent sheep grazing), which is practiced across most semi-arid and temperate regions. Domestic grazing in combination with grazing pressure imposed by macropods and feral herbivores, results in a total grazing pressure that is often detrimental to grazing sensitive native flora, including perennial grasses, particular during dry periods, and in association with over-frequent burning.
- Significant populations of feral/invasive animals and infestations of exotic weeds have adversely impacted (and continue to impact) native flora and fauna in many parts of the shale gas region.
- A rich biota of native plants and animals occurs in the shale gas region, including many endemics and threatened species, and various threatened ecological communities.
- Tourism is growing in some regions, particularly those associated with scenically spectacular and beautiful landscapes (e.g. MacDonnell Ranges).
- Biodiversity and ecosystem values in shale gas regions are not well represented in formal conservation reserves (e.g. National Parks).

The following characteristics are diagnostic of the Maryborough, Otway, Perth and Sydney Basins.

- Biodiversity hotspots including many endemic and threatened species, and ecological communities.
- High human population with ongoing pressures from urban expansion and agricultural development, as well as mining.
- Parts of these landscape have been subject to major episodes of land clearing and consequent fragmentation and disturbance.

4 Ecological Impacts

4.1 OVERVIEW

The key risks and impacts of shale gas retrieval and processing to ecological values can be divided as follows (from Broderick *et al*. (2011):

- Impacts to GDEs and sub-surface fauna as a result of contamination of groundwater by fracturing fluids or mobilised contaminants arising from:
  - wellbore/casing failure; and/or
  - subsurface migration;
- Impacts to aquatic ecosystems from contamination of land and surface water, and potentially groundwater via recharge, arising from:
  - Spillage or leakage of fracturing additives; and
  - spillage/tank rupture/storm water overflow from liquid waste storage, lagoons/pits containing cuttings/drilling mud or flowback fluid;
- Reduction in available water for the environment via water consumption/abstraction;
- Loss of vegetation, habitat and landscape function from;
  - drill rig and well pads
  - storage ponds or tanks
  - access roads
- Ongoing impacts arising during construction and pre-production;
  - noise/light pollution during well drilling/completion
  - local traffic impacts

This section describes the potential ecological impacts to ecological features associated with unconventional gas extraction in Australia. Site and landscape impacts are addressed separately.

4.2 SITE IMPACTS

4.2.1 Vegetation clearing

There is a large volume of literature that contends that removal of native vegetation as a result of land use activities associated with agriculture, mining, urban development or recreation results in negative and often irreversible environmental impacts. On a large scale, the permanent loss of vegetation has been shown to result in land degradation (e.g. Standish *et al.* 2006), decline in biodiversity (Johnson *et al*. 2007; Saunders *et al*. 1991) and release of significant volumes of greenhouse CO_2 (International Panel on Climate Change - IPCC 2001).

Broderick *et al*. (2011) cite a US report that estimates the area of average-sized well pads within shale gas networks to be 1.5 - 2.0 ha during the drilling and fracturing phase, with well pads of over 2.0 ha possible. Production pad size following part reclamation is likely to average 0.4 - 1.2 ha. Each pad requires an area sufficient to accommodate fluid storage and equipment associated with the fracturing operations as well as the larger equipment associated with horizontal drilling. Service roads within shale gas developments may total thousands of kilometres depending on gas field size, location and existing road infrastructure, but are typically about 4 - 6 m wide, and can accommodate or be co-located with associated infrastructure (monitoring, communications, pipelines) where it exists.

Local removal of native vegetation may result in:

- potential loss flora species listed as a MNES; and
- potential loss of fauna species listed as a MNES, or its preferred habitat.

As the exact location of wells and associated infrastructure can be flexible, loss of threatened species habitat can be minimised at the project level.

4.2.2 Fauna mortality

In addition to habitat loss (section 4.2.1), direct mortality of native fauna may also arise from drowning and/or poisoning in saline detention ponds, and from vehicle strike (i.e. roadkill).

Mortality in wastewater storages

It has been established that retention ponds that store flowback fluids or freshwater may attract wildlife (e.g. Hein 2012; Ramirez 2009). While quantitative studies do not appear to have been conducted in relation to shale gas or coal seam gas, fauna deaths in treatment dams is not likely to be significant, and should be put in context of the loss of native wildlife in and around rural farms dams as a result of poisoning by algal blooms (e.g. Yiasoumi *et al*. 2009) or from dam inundation and failure (e.g. DSE 2007). Notwithstanding, measures to reduce fauna deaths include exclusion fencing around containment ponds, exclusion netting above the surface of dams, and absence of lighting around ponds that might attract insectivorous fauna species.

Road kill

There is substantial literature available based on wildlife mortality associated with vehicular traffic (henceforth referred to as 'road kill') in Australia and overseas. Most relate to regular traffic flow rather than unconventional gas project areas. The major findings of the literature are that road kill:

- affects a wide diversity of fauna species (Clevenger *et al*. 2003; Dodd *et al*. 2004; Hobday and Minstrell 2008; Taylor and Goldingay 2004);
- can reduce the persistence of local fauna populations and result in local extinctions (Bennett 1991; Clevenger *et al*. 2001; Fahrig *et al*. 1995; Forman and Alexander 1998; Gibbs and Shriver 2002; Jones 2000; Magnus *et al*. 2004), including populations of threatened fauna species (e.g. Dique *et al*. 2003);
- may be more pronounced in particular seasons, especially in relation to breeding and dispersal (Clevenger *et al*. 2003; Dodd *et al*. 2004; Hobday and Minstrell 2008; Taylor and Goldingay 2004), and may be more pronounced during periods of drought (Ramp and Croft 2002);
- is more acute in areas of high animal density (Dique *et al*. 2003), and on roads that are close to wetlands and ponds (Forman and Alexander 1998).
- often occur at fauna 'black spots' (Case 1978; Clevenger *et al*. 2001, 2003; Hobday and Minstrell 2008; Magnus *et al*. 2004), possibly relating to resource availability such as succulent grass or water (Jones 1990; Magnus *et al*. 2004; Smith-Patten and Patten 2008), areas of tree cover within fragmented landscapes (Bennett 1991; Clevenger *et al*. 2003; Hubbard *et al*. 2000; Taylor and Goldingay 2004) and configuration of roads (Clevenger *et al*. 2003; Jones 1990);
- increases in number when vehicles travel faster (Andrews 1990; Clevenger *et al*. 2003; Forman and Alexander 1998; Hobday and Minstrell 2008; Jones 2000; Trombulak and Frissell 2000);
- increases in number as traffic volume increases (Dique *et al*. 2003; Forman and Alexander 1998; Hubbard *et al*. 2000; Jaeger and Fahrig 2004; Trombulak and Frissell 2000), and is influenced by traffic pulses (Dodd *et al*. 2004);
- most commonly occurs at night (Dique *et al*. 2003; Magnus *et al*. 2004) or in early morning and late afternoon (Hubbard *et al*. 2000);
- can cause substantial damage to vehicles and may result in injury or death of occupants (Hobday and Minstrell 2008; Gibson 2008; Magnus *et al*. 2004; Magnus 2006; Ramp and Croft 2002); and
- can be reduced through appropriate mitigation (Clevenger *et al*. 2001; Dodd *et al*. 2004; Jaeger and Fahrig 2004; Jones 2000; Magnus *et al*. 2004).

In relation to unconventional gas networks, the level of vehicular access to each well pad over the mine life will be considerable. Broderick *et al*. (2011) refers to a US study that estimates a total of 4,300 to 6,600 truck visits to a 6-well pad, associated with site clearing and construction, drilling, hydraulic fracturing, flowback water removal and completion. Light vehicle visits associated with project management, safety inspections, internal and external audits, equipment maintenance, environmental surveys, site monitoring, and cleaning would also be substantial. Figure 2 illustrates the level of activity associated with hydraulic fracturing at a single well pad in the United States.

Figure 2. Infrastructure associated with shale gas well fracturing in the USA (from Warner 2011)

4.2.3 Contamination of aquatic ecosystems

Environmental issues identified with produced water management range from potential harm to aquatic life and crops, to streambed erosion from produced water discharges (USEPA 2008). On-site and offsite storage of chemicals used for hydraulic fracturing, and impoundment and treatment of flowback waste water, each presents a risk of spill that could result in impacts to the surrounding ecosystems, and resultant dieback/death of vegetation or contamination of riparian areas. Broderick *et al*. (2011) summarise the various risks associated with handling and storage of toxic materials that may result in an adverse ecological impact:

- spillage, overflow, water ingress or leaching from cutting/mud pits owing:
  - limited storage capacity;
  - operator error;
  - storm water or flood water ingress; or
  - poor construction or failure of pit liner;
- spillage of concentrated fracturing fluids during transfer and final mixing operation (with water) that occurs onsite owing to:
  - pipework failure;
  - operator error;
- spillage of flowback fluid during transfer to storage owing to:
  - pipework or well failure during the operation;
  - insufficient storage capability and overflow;
  - operator error;

- loss of containment of stored flowback fluid owing to:
  - tank rupture;
  - overfilling of lagoons due to operator error or limited storage capacity;
  - water ingress from storm water or floods;
  - poor construction or failure of liner;
- spillage of flowback fluid during transfer from storage to tankers for transport owing to:
  - pipework failure; or
  - operator error
- spillage of flowback fluid during transport to wastewater treatment works

Several incidents have been recorded in the United States that have led to fish kills and wetland contamination. These include on-site spills associated with drilling and waste management, and offsite spills associated with pipeline ruptures or leaks, and road accidents.

Surface ecosystems are also at risk from well failure in the form of blowout, which is a sudden and unplanned escape of fluids to the surface. Blowout is a major health and safety issue that can lead to significant quantities of poor-quality water issuing from the well under high pressure, and in the United States explosions and fires have been reported from unintentional release of methane gas (e.g. Michaels *et al.* 2010). While blowout is relatively uncommon[1], the hazardous nature of methane means that a prolonged leak as a result of rare blowout events can produce acute (immediate) and chronic (long-term) poisoning of living systems (Rana 2008). More routine spills during drilling operations can be controlled effectively (in hours or days) by closing the well with the help of blowout preventers and by altering the density of the drilling fluid (Rana 2008).

[1] On average, 7 out of every 1000 exploratory shale gas wells result in blowout in the United States, although the probability of a catastrophic blowout that causes intense and prolonged hydrocarbon gushing, and requires the drilling of lean holes to tap, is about 1 in 10,000 (Rana 2008).

4.3 LANDSCAPE ECOLOGY IMPACTS

4.3.1 Context

The theory of meta-population biology asserts that a number of small physically isolated populations that are linked by some level of connectedness that facilitates dispersal can collectively function as one larger, more resilient population (Brown and Kodric-Brown 1977; Harrison 1991). Dispersal of individuals among populations is a critical ecological process as it can maintain genetic diversity, rescue declining populations, and re-establish extirpated populations (Calabrese and Fagan 2004). Sufficient movement of individuals between isolated, extinction-prone populations can allow an entire network of populations to persist via meta-population dynamics (Hanski and Gilpin 1991). As areas of natural habitat are reduced in size by human activities, the degree to which the remaining fragments are functionally linked by dispersal (i.e. their connectivity) becomes increasingly important (Calabrese and Fagan 2004). If individual sub-populations are too small to be viable in their own right, and isolation prevents dispersal of individuals, the combination of stochastic and anthropogenic impacts can result in rates of local extinction that exceed the rate of recolonisation (Lambeck 1997). As observed in empirical studies, the extinction probability of a local population is largely determined by its size, which is often approximated by patch area, and the colonization probability of an empty habitat patch is mainly determined by its connectivity to existing local populations (Moilanen and Nieminen 2002).

The majority of landscapes subject to shale gas development in Australia are arid to semi-arid (Appendix A), very large in extent and maintain a reasonably contiguous cover of sparse native vegetation. Past clearing has been limited, although other disturbance factors such as grazing, fire and invasive plants and animals have modified the structure and function of these extensive mosaics to some extent. Notwithstanding, the vast size of these landscapes and their high level of intactness have offered a level of resilience that has ensured survival of the majority of populations of native inland species.

4.3.2 Vegetation fragmentation

The development of shale gas infrastructure involves fragmentation of vegetated landscapes. ELA (2012) calculated that an 'average' CSG footprint in eastern Australia constitutes about 160 km of road and 60 individual 'islands' (parcels of land encompassed by road) for every 100 km^2 developed (Figure 3 shows an aerial view of a typical CSG wellpad and road network, adjacent to an open cut mine in southern Queensland). While the overall proportion of vegetation loss in a CSG or shale gas development is low (less than 2%), the concurrent loss of 'intactness' in the landscape (e.g. Williams *et al.* 2012) is likely to reduce the mobility of many taxa, particularly smaller ground-dwelling fauna species, thus the impact on landscape function as a result of the fragmentation needs to be addressed in the approvals and permitting of shale gas (and CSG) developments.

The intactness of a landscape is its 'naturalness' and is influenced by the proportion of native vegetation remaining and its patchiness[2]. Intact landscapes, including the arid and semi arid regions, possess a continuum of native vegetation cover with little or no degree of roadways, thus a high level of connectivity and relatively low degree of modification (e.g. McIntyre and Hobbs 1999).

[2] Patchiness refers to the number of patches per unit area.

Figure 3. Example of a CSG well network near Dalby, Queensland

Intactness is a reasonable (but not absolute) measure of landscape function as roads and other easements that bisect contiguous areas of native vegetation can act as vectors for movement of invasive species and result in various edge effects (e.g. Forman *et al.* 2003; Hulme 2009; Spellerberg 1998; Trombulak and Frissell 2000). Two primary effects of fragmentation are an alteration of the microclimate within and surrounding the remnant, and the isolation of each area from other remnant patches in the surrounding landscape. Thus, in a fragmented landscape there are changes in the physical environment as well as biogeographic changes. Existing disturbances and other land use practices contribute to loss of intactness.

Physical changes include changes in fluxes across the landscape, including fluxes of radiation, wind, and water which can all have important effects on remnants of native vegetation (Saunders *et al*. 1991). In the bioregional context, establishment of new roads into intact areas has the potential to:

- facilitate establishment of invasive fauna species in remote areas (e.g. Andrews 1990; Brown *et al*. 2006; Mahon *et al*. 1998), including invertebrates that have the potential to significantly disrupt ecological systems (e.g. Lach and Thomas 2008); and
- introduce weeds along roadsides and beyond via vehicles and fauna (e.g. Bergquist *et al*. 2007; Davies and Sheley 2007; Gelbard and Belnap 2003; Hansen and Clevenger 2005).

An intactness index can be generated across any landscape in a geographic information system (GIS) by mapping all extant native vegetation patches and all existing infrastructure easements (road, rail and powerlines) and other non-vegetated areas as a raster layer, then applying the following equation to each raster cell in the landscape that considers all surrounding raster cells within a 5 km radius.

$$Intactness = \left[[(Native\ vegetation)_{Area}] / [(Total)_{Area}] \right]^{[1 + (0.01 * (no.\ patches)]}$$

Where:

$(Native\ vegetation)_{Area}$ = combined area of all true native vegetation [3] within the 5 km buffer

$(Total)_{Area}$ = area of a circle of 5 km radius

No. patches = number of patches in the 5 km radius (including those divided by easements)

The power factor increases with the total number of patches and is used to account for the impact of edge effects. Thus, the more the landscape has been cleared and the greater the number of remnant patches, the greater the relative loss of intactness in the landscape. This is demonstrated in Figure 4 (from ELA 2102).

It is assumed that noise and light pollution and traffic movement will contribute to loss of intactness in the landscape. Broderick *et al*. (2011) estimate that noisy surface activity associated with each well pad will occur on 800 – 2,500 days over the lifetime of the project, with drilling likely to produce the single greatest noise (24 hours continuous noise for 8 – 12 months, for a well pad containing 10 horizontal wells). Loss of intactness resulting from roads is also manifest in death and injury of native fauna that persist in the gas field, as a result of road kill (Section 4.2.2).

Establishment of a fully operational shale gas network within a contiguous landscape would typically reduce intactness from 1.0 (or near 1.0) to less than 0.7. Establishment of a network in a variegated landscape would typically reduce intactness by 0.7 to 0.5. In both cases, the increased level of fragmentation and the increased magnitude of edge effects, together with noise, vehicle traffic and possible proliferation of exotic species, is likely to compromise the long term viability of extant populations of various species. The extent of loss, the specific species potentially impacted and the degree of impact will vary depending on the landscape context, history of disturbance and mitigation or offset measures.

[3] "True' refers to a native vegetation type found *in situ* that is likely to have been *in situ* at the time of European settlement.

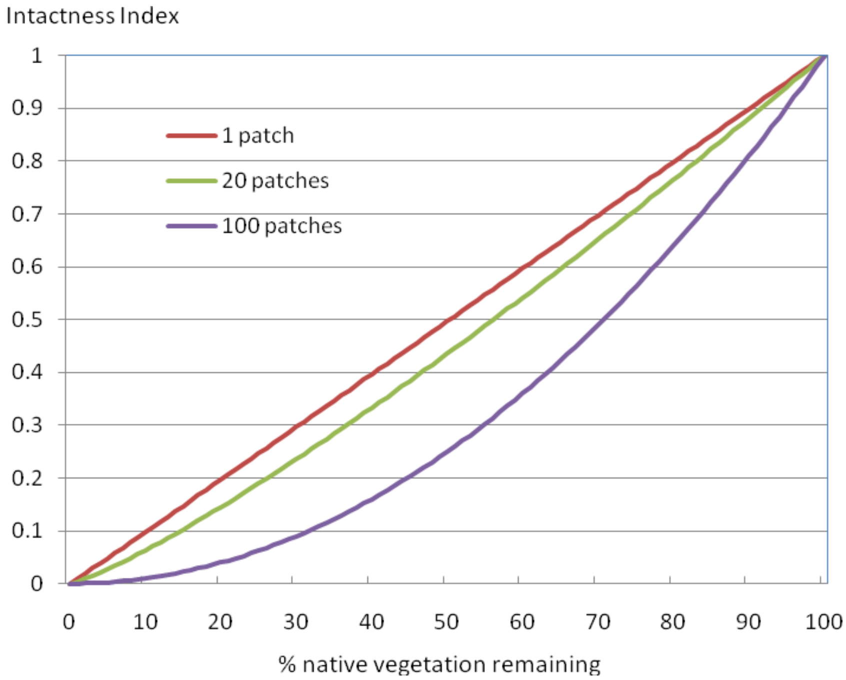


Figure 4. Influence of vegetation cover and patchiness on landscape intactness

4.3.3 Wildfire

Severe or ‘catastrophic’ wildfire has the potential to threaten life and property, and will result in wide scale death of native fauna and flora, and may result in changes to the state or type of native vegetation, to the extent that many species have problems recolonising areas. While the risk of uncontrolled wildfire from a gas project site as a result of an accident or and act of arson is low, the number of wildlife incident is likely to increase. However, the network of roads developed for the shale gas project will act as a means to contain wildfire, and one would expect that emergency response measures are developed on shale gas fields to contain fires effectively and quickly, so that potential for wide scale devastation is very low.

4.4 REGIONAL WATER IMPACTS

4.4.1 Reduction in surface flow

Large volumes of water are required for hydraulic fracturing. In coastal regions, access to permanent river water or domestic/agricultural storage may be an option. In drier regions where surface flow is unreliable, opportunistic water abstraction and on site retention may be possible following good rains, however, this will not be the predominant source. Pumping from groundwater may be possible in some areas, and this may have implications for surface flow if local groundwater is a source of discharge to surface flow. While part of the water demand may also be achieved through water recycling, an alternative supply option for large operations will be piping or transportation of water from an external source, to each well pad for the time in which drilling and hydraulic fracturing take place.

Impacts of water flow restrictions on aquatic ecosystem health as a result of direct abstraction or reduction on groundwater discharge (as are likely to occur from shale gas extraction), are sourced from Brookes *et al*. (2009), Bunn and Arthington (2002), Bunn *et al*. (1999), DECC (2009), Gawne *et al*. (2007), McKay and King (2006), and Read and Brookes (2000).

The major water abstraction impact on general aquatic ecosystem processes is changes in hydrology or altered flow regimes (i.e. the change in frequency, duration, magnitude, timing and variability of flow events). The following principal headings are from Bunn and Arthington (2002), with ecological consequences drawn from additional sources listed above:

1. As natural flows determine physical riparian and floodplain habitat, reduced flows:
   - simplify geomorphology - minimises morphological structure complexity and lead to a more homogenous habitat (Brookes *et al*. 2009);
   - reduce/alter habitat complexity (catchment, reach and patch scales) – a reduction in the transfer of plant material minimises in-stream habitat complexity that is needed for biota (bugs and fish);
   - reduce habitat accessibility i.e. fish movement;
   - reduce food availability/limit food sources, through:
     - reduction in the distribution of allochthonous carbon (logs, leaves, DOC) for temperate/tropical ecosystem (Brookes *et al.* 2009);
     - altered autochthonous inputs from phytoplankton, periphyton and macrophyte productivity (Brookes *et al.* 2009);
     - increased competition between native and invasive species for limited resources (DECC 2009)
   - degrade surface water quality via:
     - increase in nutrient concentrations (nitrogen & phosphorus), leading to higher probability of algal blooms (toxic an non-toxic algal blooms can result in depleted dissolved oxygen levels that can results in fish kills);
     - increase levels of salinity in streams with decreasing water levels, and increased salt loads in soils that impacts riparian vegetation.

2. Aquatic organisms have life strategies that are evolved to natural flow conditions, so that reduced flows:
   - impact flow dependent species e.g. ribbon weed (Georges *et al.* 2003);
   - alter critical ecological processes such as trigger breeding cues for birds and fish (long term impact may be reduced species diversity) (Bunn and Arthington 2002);
   - reduce water available for groundwater dependent ecosystems (GDEs).

3. Natural flows patterns maintain longitudinal and lateral connectivity in aquatic ecosystems, thus reduced flow:
   - restricts connectivity between major habitats (river, wetlands, floodplain, estuaries);
   - changes the ecological character of habitats – increase in salinity concentrations and nutrient loads, reduced native macrophyte distribution and habitat availability, increased distribution of invasive plants, decline in wetland dependent communities (e.g. waterbirds). acidification of soils (DECC 2009);
   - Fragments floodplains and limits riparian vegetation recruitment.

4. The success of invasive species is often facilitated by altered flow regimes.

Another consideration from water extraction associated with shale gas development is the additional or cumulative pressure placed on eco-hydrological systems that are already in poor ecosystem health. For example, the impacts of water extraction may:

- be compounded when associated with the effects of river regulation and other water extraction activities (irrigation), extreme and prolonged drought conditions, climate change and water pollution (DECC 2009);
- cause increased pressure on species/ecological communities already that are already threatened in the landscape.

4.4.2 Disruption to sheet flow

Sheet flow is water movement that occurs in a broad, sheet-like film, typically over a very gentle downhill slope. Such water movement is over relatively smooth rock and soil surfaces and does not concentrate into channels larger than rills (Miller *et al.* 2002). Sheet flow is typically low volume and represents low velocity water dispersal, thus low energy and low potential for erosion (Ludwig *et al,* 1997). Sheet flow is an important source of water in arid and semi-arid zones in Australia and many vegetation formations rely on sheet flows for adequate moisture absorption to support growth.

Linear infrastructure such as rail lines and roads that require raised embankments, sections of cut and fill and water diversion works such as culverts and spillways, have the potential to intercept and divert sheet flow. Key consequences of linear infrastructure works on sheet flow include:

- Water ponding upslope of infrastructure;
- Reduced sheet flow (water starving) down slope of infrastructure;
- Concentrated water flow through diversion infrastructure, with potential to cause erosion and subsequent deposition; and
- Channel formation.

The most widely recognised sheet flow dependent vegetation (SFDV) in Australia is Mulga (*Acacia aneura*) woodland occurring in arid regions. Mulga is well adapted to arid conditions as it possesses thick skinned phylodes that stand erect to minimise sun exposure and sunken stomata, to minimise moisture loss from phylodes. The species is able to grow in poor soils through a symbiotic relationship of nutrient fixing bacteria, *Rhizobium* around its root system. It is a very slow growing and long lived species, up to 200 years. *Acacia aneura* is important in arid ecosystems for nutrient capture and in slowing down surface run off and localised hydrological regimes (Dunkley 2002).

Road and rail construction associated with shale gas exploration and extraction has the potential to impact the Mulga community, and possibly other SFDVs, by disrupting sheet flow through interception, concentration and pooling. Table 3 summarises the impacts.

Table 3: Summary of impacts of linear infrastructure on sheet flow dependent vegetation

IMPACT ON SHEET FLOW	LOCATION	IMPACT ON SHEET FLOW DEPENDENT VEGETATION	TIMESCALE
Water Ponding	Upslope of infrastructure	Excess water leading to change in SFDV - Increased growth and recruitment with increased water - Decreased growth and recruitment with increased water - Invasion of exotic and native plants (weeds) in altered environment	Short to long-term (months to decades)
Water Starving	Down slope of infrastructure	Reduced water leading to decreased growth and recruitment	Long-term (years to decades)
Erosion	Down slope of infrastructure, below culverts	Concentrated flow leading to erosion	Short to medium-term (months to years) following large rainfall events
Deposition	Down slope of infrastructure, below culverts	Erosion and transport of sediment leading to deposition	Short to medium-term (months to years) following large rainfall events
Channel formation	Down slope of infrastructure, below culverts	Concentrated flow leading to erosion and channel formation	Short to medium-term (months to years) following large rainfall events

4.4.3 Groundwater impacts

Primary impacts

The major issue associated with shale gas development and groundwater aquifers is contamination and/or drawdown of groundwater aquifers that overlay the shale strata, and the impact to ecosystem services provided by these aquifers, including provision of drinking water, fresh water for agriculture, recharge of freshwater into river systems, and maintenance of health and function of GDEs and subterranean groundwater communities. This is an area of great uncertainty, as impacts to groundwater may be initially undetectable, and may not be evident for many decades.

Groundwater is at risk from well failure in the form of: blowout; annular leak (vertical movement of contaminants between casings, or between casing and rock formation); or radial leak (movement of contaminants through casing into rock formation). While blowout may cause sudden migration of methane and other toxic substances into groundwater bodies, it is unusual (section 3.3.4). Casing failure is more common as cement is known to shrink over time, causing hairline cracks in the well casing which can result in annular or radial leakage (Royal Society and Royal Academy of Engineering 2012). Unfortunately the short- and long-term effects of repeated fracturing on well components (e.g. cement casing) are not well understood (USEPA 2011), so continuous monitoring of well components over the lifetime of the project will be required to minimise risk of well failure.

Groundwater is also at risk from fluid leakoff, in which methane gas migrates from the shale rock to surrounding aquifers following hydraulic fracturing. Build-up of pressure due to such gasification may lead to tremors or explosions. Aquifer gasification due to shale gas development has been cited in the United Kingdom as a potential cause of elevated seismic activity (KPMG 2011).

Environmental concerns about groundwater contamination as a result of wellbore failure, or land subsidence/seismic activity that may lead to vertical mixing of groundwater bodies, have led to moratoria on hydraulic fracturing for shale gas extraction in parts of the USA and in other countries such as Bulgaria, France and South Africa (Royal Society and Royal Academy of Engineering 2012).

Groundwater dependent ecosystems

GDEs are ecosystems that rely either wholly or partially on groundwater to maintain their species composition and natural ecological processes (SKM 2010). They include terrestrial GDEs[4], wetlands and river baseflow systems, and they may be obligate[5] or episodic (SKM 2010). Cumulative impacts on groundwater aquifers may have implications for GDEs, riparian habitats and aquifer ecosystems, as well as agriculture. Surface ecosystems such as mound springs, river red gum communities and swamps and wetlands, and sub-surface ecosystems that support groundwater invertebrates (stygofauna[6]) may be prone to groundwater loss (e.g. Nevil *et al.* 2010)

Hatton and Evans (1998) outline six types of GDEs, all of which are relevant in the context of shale gas in Australia:

- *Terrestrial vegetation* – vegetation communities and dependent fauna that have seasonal or episodic dependence on groundwater;
- *River base flow systems* – aquatic and riparian ecosystems that exist in or adjacent to streams that are fed by groundwater baseflow;
- *Coastal estuarine and near shore marine systems* –coastal lakes and salt marshes that are fed by groundwater;
- *Aquifer and cave ecosystems* – aquatic ecosystems that occupy free water in caves or aquifers.
- *Wetlands* – aquatic communities and fringing vegetation dependent on groundwater-fed lakes and wetlands (mound spring vegetation of the Great Artesian Basin is included in this category, as are hypersaline lakes);
- *Terrestrial fauna* – a group of groundwater dependent fauna whose reliance on groundwater is based sources of drinking water within springs or pools (particularly important in northern and inland Australia

Artesian springs fed by the Great Artesian Basin (GAB) are examples of important GDEs that could be impacted by shale gas operations, in this case in the Cooper and Galilee Basins. Artesian springs are ecologically significant principally because of the unique and highly restricted vegetation formations that they support (e.g. Fensham and Fairfax 2003), including endemic invertebrate communities (Fensham *et al.* 2007, Ponder 2004). Artesian springs are listed under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) as '*The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin*',

---

[4] Ecosystems in which the root zone (deep or shallow) is connected to the water table.

[5] Continual access to groundwater required.

[6] Stygofauna refers to any fauna that lives within groundwater. There is a growing awareness that aquifers are dynamic ecosystems , containing many species of stygofauna that play an important role in groundwater ecology (e.g. Boulton *et al.*2008; Hancock and Boulton 2008)

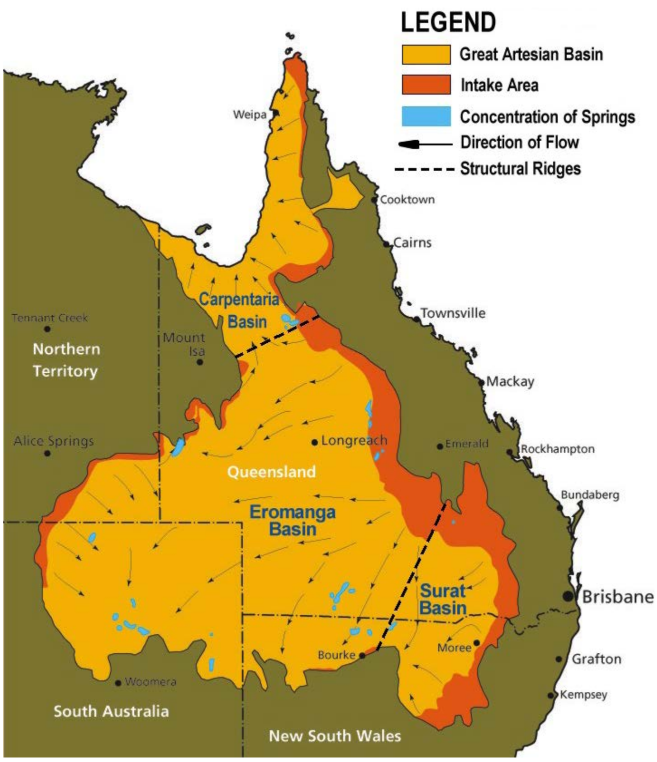


Figure 5. Great Artesian Basin (source: DERM 2011)

Another possible consequence of shale gas extraction to groundwater aquifers and connected spring ecosystems is pollution that can intersect wetland GDEs both from contaminated groundwater and from uncontained flowback. As the GAB is a confined aquifer, water can be up to 1 million years old (Fensham *et al.* 2007), and over that time has been isolated from human-induced pollution. With the increase of shale gas (and coal seam gas) exploration and extraction, there is potential for contamination that might have implications for the mound springs communities. Uncontained flowback of spent fraccing fluid may also impact on wetland GDEs (and other aquatic ecosystems), as has been recently reported in the United States (Michaels *et al.* 2010).

5 Risk Management

5.1 OVERVIEW

A risk level is assigned in this section to six (6) major impacts associated with shale gas development:

1. removal of native vegetation;
2. landscape fragmentation and loss of intactness;
3. increased incidence of bushfire;
4. reduction in surface water;
5. contamination of surface water; and
6. impacts to groundwater ecology.

The risk approach used is based on the Risk Management Principles and Guidelines (AS/NZ ISO 31:000:2009) (Standards Australia and New Zealand 2004). These international guidelines have been developed to assist organisations in dealing with internal/external risk factors in accordance with International Standards. Table 4 shows a generic risk matrix that assigns a level of risk to each combination of event 'likelihood' and impact 'consequence'.

Table 4. Example of a risk matrix

	CONSEQUENCE OF POTENTAL IMPACTS			
LIKELIHOOD	MINOR	MEDIUM	MAJOR	CATASTROPHIC
ALMOST CERTAIN	**M**	**H**	**E**	**E**
LIKELY	**L**	**M**	**H**	**E**
UNLIKELY	**L**	**L**	**M**	**H**
RARE	**VL**	**L**	**L**	**M**

Following application of the above risk matrix to any given ecological impact outlined in Section 4, relevant information was presented in a standard risk assessment table (Table 5). For each potential impact or 'issue' identified, this table provides information about the likelihood that an impact from unconventional gas extraction will occur, the consequence of such an impact, and a description of the associated risk (as drawn from Table 4) in relation to environmental sustainability. A measure of the 'reliability' of event likelihood and impact consequence is provided as a qualitative "high", "medium" or "low", and an outline of risk management and mitigation measures and other comments are provided as necessary.

Table 5. Risk assessment table

ISSUE	LIKELIHOOD	CONSEQUENCE	DESCRIPTION
ASSESSMENT			
RELIABILITY			na
RISK MANAGEMENT/MITIGATION			
COMMENTS			

5.2 ASSUMPTIONS

5.2.1 Scale

The level of risk to an environmental value is largely dependent on the 'resilience' of the natural system within which it is supported. Resilience embodies the system's ability to recover, its ability to adapt, and its ability to transform (PMSEIC 2010). Resilience is also scale-specific as it relates to the magnitude of change – i.e. the more extensive the change, the greater the likelihood that resilience boundaries will be challenged[7]. For shale gas development, the risk tables presented below assume a collective shale gas industry rather than individual shale gas operations.

5.2.2 'Worse case' risk

Landscape diversity

Given the wide diversity of shale gas landscapes in Australia, the level to which they are impacted by shale gas operations is likely to vary considerably. For example, the intactness of Gulf Coast tropical woodlands may be impacted much more than fragmented pastureland of the Otway region. Conversely, the South East Coastal Plain in southern Victoria, with its mosaic of coastal wetlands, would be at considerably higher risk from chemical spill than parts of the arid interior. Accordingly, a level of risk is established below that represents the 'worst case' risk for any part of the shale gas landscape.

Governance

The regulatory environment will be designed to provide consistent protocols on exploration, commercial extraction, and emergency responses to adverse impacts. However, in reality variation in internal petroleum company governance will mean that some organisation's compliance will be exemplary, while others may less so, even if they are well-intentioned. For this assessment, it is assumed that adherence to regulations will vary as a result of individual company circumstances[8].

---

[7] For example, the resilience of a stream reduces for every farm dam that is constructed on it, to a point where downstream aquatic processes are irreversibly changed. The greater the number of dams, the lower the system's resilience.

[8] In the shale gas production region 8 in the United States, various environmental management issues are magnified by estimates that approximately 70 percent of all gas wells nationally are marginal wells – i.e. those producing at the margin of profitability. In addition, they are often owned and operated by smaller producers that may lack the technical expertise or resources to maximise potential pollution prevention and environmental management opportunities (USEPA 2008).

5.2.3 Mitigation

The risk assessments assume that industry best practice measures will be employed to avoid spills, leaks, and other accidents, and to mitigate against erosion, noise, dust and other indirect ecological impacts. Beyond standard measures, there are likely to be a range of other mitigation measures undertaken on a project by project level, including ecosystem offsets, threatened species habitat offsets, habitat augmentation (e.g. placement of nest boxes), invasive species control, land reclamation and ecosystem rehabilitation. Examples of mitigation and offset measures that may be carried out at the project scale are included in the risk tables.

5.3 RISK TABLES

Using the above assumptions, risk tables are presented below for vegetation clearing (Table 6), landscape fragmentation (Table 7), bushfire (Table 8), surface water flow (Table 9), surface water and land contamination (Table 10), and groundwater ecology (Table 11). Given consideration of likelihood and consequence of shale gas impacts, this assessment finds:

- a high risk to landscape function as a result of road construction and associated fragmentation, and a high risk to terrestrial and riparian ecosystems associated with accidental spillage of contaminants into the surface environment;
- a moderate risk to plant communities and species associated with vegetation clearing, and a moderate risk of impacts to aquatic ecology from surface water abstraction and/or groundwater drawdown;
- a low to moderate risk of impact to sub-surface ecological systems as a result of groundwater contamination associated with shale gas operations; and
- a low risk of an increase in destructive bushfires.

Table 6. Vegetation clearing risk table

ISSUE: Loss of habitat as a result of vegetation clearing	LIKELIHOOD	CONSEQUENCE	DESCRIPTION
ASSESSMENT	Almost certain	Minor	Moderate risk of negative impact to a natural asset as a result of removal of native vegetation.
RELIABILITY	High	Moderate	
RISK MANAGEMENT/MITIGATION	Risk management undertaken on a project by project basis, including avoidance of sensitive areas, establishment of offsets, and land site rehabilitation (including top soil management). Implementation of biodiversity management plans that include strategic buffers around rivers, streams, wetlands and other sensitive areas, and timing stipulations for construction activities, can help reduce impacts (e.g. Arthur *et al*. 2010).		
COMMENTS	Flexibility around actual clearing footprints for well pads and roads means that significant features such as MNES, critical habitat, wetlands, and sensitive riparian areas can be largely avoided. However, the overall scale of the shale gas industry suggests that, collectively, there will be a moderate risk of an adverse impact to a significant feature (e.g. MNES) as a result of vegetation loss, although the consequence is likely to be minor.		

Table 7. Vegetation fragmentation risk table

ISSUE: Loss of landscape function	LIKELIHOOD	CONSEQUENCE	DESCRIPTION
ASSESSMENT	Almost certain	Medium	High risk of fragmentation and consequent loss of landscape function
RELIABILITY	High	Medium	na
RISK MANAGEMENT/MITIGATION	The two major issues associated with shale gas transport systems are: fragmentation and road mortality. Measures that may be used to reduce these effects include: - co-location of pipelines; - full utilisation of established roads and tracks; - design of gaswell network that minimises road length and maximises contiguous vegetation areas (i.e. minimises edge effects); - reclamation of temporary service tracks; - feral animal and noxious plant control, onsite and offsite; - speed limits and dawn/dusk driving curfews; - strategic underpasses and overpasses to facilitate movement of fauna.		
COMMENTS	The shale gas industry is likely to introduce a substantial network of new roads to relatively intact landscapes in Australia. These roads will provide a significant number of additional vehicle movements for which road kill will be an unavoidable consequence. Associated fragmentation, edge effects, noise, and encouragement of invasive species is likely to place additional pressure on many native fauna and flora species, and ecological communities, and could change landscape function through local loss of biodiversity, limitation of fauna movement and dispersal, and changes to micro-climate.		

Table 8. Bushfire risk table

ISSUE: Increase incidence of wildfire	LIKELIHOOD	CONSEQUENCE	DESCRIPTION
ASSESSMENT	Likely	Minor	Low risk of destructive bushfires as a result of new shale gas networks
RELIABILITY	Medium	High	na
RISK MANAGEMENT/MITIGATION	Fire emergency response protocols will be in place. They should include establishment of fire breaks the periphery of the production area, to facilitate containment of any fire that burn outwards from the project boundary.		
COMMENTS	While the probability of arson or accident wildfire will increase with shale gas activity (due to escalation in human activity), the risk of destructive fires is low, due to: - industry self-interest in controlling and preventing fires in the shale gas production areas - established network of shale gas roads and access tracks from which to contain fires - many areas in northern Australia are regularly burnt at present		

Table 9. Surface water flow risk table

ISSUE: Reduced surface water flow	LIKELIHOOD	CONSEQUENCE	DESCRIPTION
ASSESSMENT	Likely	Medium	Moderate risk that surface water abstraction will result in local impacts to aquatic ecology, but risk of landscape-scale impacts (e.g. flooding of ephemeral wetlands and waterbird/fish breeding events) is likely to be low.
RELIABILITY	Moderate	Medium	na
RISK MANAGEMENT/MITIGATION	There is concern that water abstraction for shale gas production will reduce the volume of water flowing down major inland rivers and entering basins such as Lake Eyre. Risk management actions include abstraction of surface water only during high-peak flows and metered abstraction of groundwater. Total volumes should be developed in consideration of whole of system environmental requirements, extractable limits and the requirements of other water users.		
COMMENTS	The relatively large volumes of water required for drilling and fracturing shale beds (section 3.3.4) could reduce surface water flow downstream of production areas if water is abstracted directly from natural watercourses and/or if groundwater systems that recharge rivers (e.g. Boulton and Hancock 2006) are drawn down. Transporting water into shale gas areas in remote arid parts of inland Australia is likely to be uneconomic, thus water abstraction from ephemeral rivers (during flow times) and/or pumping from groundwater aquifers is likely to be the standard practice, with some opportunity for water reuse.		

Table 10. Water and land contamination risk table

ISSUE: Water and land contamination	LIKELIHOOD	CONSEQUENCE	DESCRIPTION
ASSESSMENT	Almost Certain	Medium	High risk of chemical contamination to terrestrial and riparian ecosystems.
RELIABILITY	High	Medium	na
RISK MANAGEMENT/MITIGATION	Preventative measures for risk mitigation include avoidance of sensitive areas, and application of best-practice design principles. For example, the possible leakage of liners has led to calls to avoid the use of pits in favour of closed loop steel tanks and piping systems (Groat and Grimshaw 2012).		
COMMENTS	Most incidents are related to accidental leaks and spills during production and distribution, including improper safety procedures and transmission pipeline failures (Rana 2008). Given the potential scale of shale gas operations in Australia, there is likely to be spills of fracturing fluids, flowback fluids, or losses of containment of flowback fluid (e.g. flood overflow or dam wall leakage), or other pipe failure or operator errors. The consequences of a spill will depend on its size, the contaminants of concern, and the sensitivity of the natural environment affected. Given the toxic properties of some fracturing and flowback fluids (and drilling solids), spillage onto land or surface water is likely to be 'of concern' (Broderick *et al*. 2011). Various US studies validate that the number of spills related to fossil fuel production has been significant. For example, one report found there were approximately 924 oil and gas industry spills in Colorado alone over a 4-year period (2002—2006), 20% of which contaminated water to some degree (USEPA 2008).		

Table 11. Groundwater ecology risk table

ISSUE: Impact to sub-surface ecosystems and mound springs	LIKELIHOOD	CONSEQUENCE	DESCRIPTION
ASSESSMENT	Rare-Unlikely	Major	The overall risk of negative impacts to sub-surface ecosystems (e.g. stygofauna communities) or mound springs/recharge areas through contamination of groundwater aquifers by shale gas exploration and production in Australia ranges from low to moderate, although there is uncertainty about the severity of impacts (consequences) on these ecosystems should they occur.
RELIABILITY	Moderate	Low	na
RISK MANAGEMENT/MITIGATION	The design, construction and maintenance of well bores is critical to minimise the risk of well failure and escape of contaminants into freshwater aquifers. Hydraulic stimulation protocols will need to be followed precisely to minimise the risk of blowout. Industry standards need to be adhered to rigorously, and new innovations should be routinely adopted if they minimise the risk of well failure. Decommissioned wells will require ongoing inspection coupled with monitoring wells. Groundwater monitoring will provide long-term data on both the extent and range of impacts to groundwater systems. Shale gas exploration in areas that contain underground caves, feed groundwater springs, or support assemblages of sub-surface fauna should be avoided.		
COMMENTS	A worst case scenario is irreparable toxic contamination to one or more freshwater aquifers (and secondary impacts to groundwater ecology, ground water dependent ecosystems and land use systems) as a result of gas well failure. Fluid leakoff (i.e. migration of contaminants from the shalebed to a freshwater aquifer as a result of fracturing) is not likely as separation distances between shale beds and overlying groundwater bodies is generally high (shale beds are typically 1 km to 4 km deep). Well casing failure and consequent movement of contaminants into the aquifer from the well bore, which intersects the aquifer, is more likely.		

6 Cumulative Impact Assessment

6.1.1 Background

Cumulative effects and cumulative environmental change are used interchangeably throughout the literature to refer generally to the phenomenon of temporal and spatial accumulation of change in environmental systems in an additive or interactive manner (Spaling and Smit 1993). Shoemaker (1994) defines cumulative environmental change as ‘a change in the environment resulting from multiple initiatives of the past, present and reasonably foreseeable future, which combine in an additive, amplifying or discontinuous manner.’ Franks *et al.* (2010) describe cumulative effects as ‘successive, incremental and combined impacts of one, or more, activities on society, the economy or environment’

Sources of environmental change range from simple additions to complex interactions of stressors and are not necessarily brought about by only one activity. For instance, change in vegetation cover across a region is not the result of actions by one industry, but more likely the result of many different types of development interacting in time and space. Types of environmental change and their impacts are summarised by Sadar (1994) and are listed in Table 12.

In the context of the shale gas industry, cumulative environmental effects can be summarised into four similar categories:

1. Space crowding (row 1 - Table 12) is defined by Rees (1995) as “a system being perturbed by several similar agents or activities, or by different activities producing a similar effect, in an area too small to assimilate the combined impacts.” Nibbling is an incremental form of space crowding according to Court *et al.* (1994).

2. Time crowding (row 2 - Table 12) is defined as impacts so close in time that the impacts of one are not dissipated before the next occurs (CEARC 1986).

3. Interactive effects can be additive or synergistic, reflecting the interactive nature of ecosystems. Additive is the simple linear addition of effects, whereas synergism (or compounding – row 3 - Table 12) is when two or more agents have a *greater* effect combined than the sum of the individual agents. Antagonistic effects, where the combined impact of more than one agent is *less than* the sum of the individual impacts (Canter and Kamanth 1995), are unlikely in the mining industry.

4. Indirect effects (row 4 - Table 12) are secondary impacts arising as a result of the direct effect. For example, removal of vegetation leads to various indirect effects (Table 13), including incursion of feral animals and weeds, and fragmentation and degradation of habitat (DEST 1995).

Time lags and space lags (rows 5 and 6 - Table 12) are both synonymous with environmental impact of the shale gas industry. Time lags may be associated with contamination of groundwater. Space lags may be downstream contamination of waterways from an accidental chemical spill. The trigger and threshold category (row 7 - Table 12) is pertinent to thresholds that may inform levels of risk associated with cumulative impacts.

Table 12. Sources of environmental change and their impacts (Sader 1994).

Issue Type	Main Characteristics	Examples
Space crowding	High density of impacts on a single environmental asset	Habitat fragmentation in forests
Time crowding	Frequent and repetitive impacts on a single environmental medium	Wastes sequentially discharged into lakes, rivers and watersheds
Compounding effects	Synergistic effects due to multiple sources on a single environmental medium	Downstream effects of several projects in a single wetland
Indirect	Secondary and tertiary impacts resulting from a primary activity	Roads to resources which reduce intactness
Time lags	Long delays in experiencing impacts	Groundwater contamination
Space lags	Impacts resulting some distance from their sources	Gaseous emissions into the atmosphere
Triggers and thresholds	Impacts to biological systems that fundamentally change system behaviour	Effects of changes in forest structure on forest fauna

In terms of cumulative impact assessment of the gas extraction industry, two of four pathways identified by Spaling and Smit (1993) are important:

- Multiple actions that induce environmental change in a additive but non-synergistic manner (e.g. multiple greenhouse gases that all contribute to global warming, or overall area of vegetation cleared); and
- Multiple actions with synergistic interaction. As previously stated, synergism occurs when the total effect of an interaction between two or more processes is greater than the sum of the effects of each individual process. An example is landscape fragmentation.

It is important to note that these pathways are not mutually exclusive in time and space as several pathways may function simultaneously, or thresholds and time lags in one pathway may activate another in a complex environmental system (Spaling and Smit 1993; Cocklin *et al.* 1992).

It would be prudent of approval authorities to identify such trigger and threshold values in the bioregions in which shale gas is likely to operate, and then set commensurate triggers and thresholds for individual project assessments. The strategic assessment approaches embedded in the EPBC Act would appear well suited for this purpose.

Indirect impacts are typically captured in most environmental assessment approaches.

Table 13. Indirect effects resulting from the vegetation loss.

Direct Effect	Indirect Effects
Vegetation Loss	Fragmentation of communities, leads to isolation of gene pools and long term loss of population viability, increased edge effects and weeds/feral encroachment.
	Decrease in energy fixation with impacts on soil, vegetation and fauna.
	Loss of diversity over the long term.
	Loss of varied age structure and reduced habitat niches.
	Change in infiltration rates with impacts on water table levels and soil erosion.
	Salt intrusion in coastal environments where dunal vegetation serves to fix salt levels in geographic space, allowing for succession plant communities in land.
	Weed invasion with potential to gradually take over the whole ecosystem beyond the original impact site.
	Carbon emissions from direct release of greenhouse gases on clearing and subsequent lower carbon fixation rates from less regrowth.
	Increased wind erosion from destabilised exposed soil.
	Domestic and feral animal invasion often associated with human settlements in cleared areas.
	Altered fire regimes that may lead to reduced reproduction of native flora species.

6.1.2 Cumulative impact assessment and shale gas

Addressing the cumulative impact of shale gas exploration and production to ecological values is important if projects approvals are to be granted in the context of prior shale gas exploration and production impacts. As the shale gas industry is relatively new, it is opportune for Australia to develop and initiate a cumulative impact package that:

1. Establishes 2013 as the baseline;
2. Is spatially based (using GIS);
3. Utilises best data available (this will invariably require industry support);
4. Considers MNES, nationally significant wetlands, vegetation representativeness, landscape intactness and connectivity, surface water and groundwater;
5. Addresses linear impacts (e.g. net cover change) and compounding impacts (e.g. loss of connectivity)
6. Analyses risk in the context of critical thresholds.

A GIS-based cumulative assessment/risk tool similar to that developed for the Namoi Catchment Management Authority in northern inland NSW (ELA 2012) could provide an opportunity to establish a nation wide 'shale gas scenario'. This is effectively a temporal sequence of exploration/production shale gas footprints (captured as project areas and habitat clearing footprints within Australia, or within individual bioregions in Australia) and possibly other activities (mining and non-mining) as they are developed, that capture cumulative impacts. On approval of each additional development, the scenario would be updated by appending that development then simulating all footprints against key landscape layers to report cumulative impacts across the major shale gas basins. Each run would use the standard sequence of developments, ordered according to the time in which the impact occurred (or is predicted to occur).

A benefit of this type of impact assessment tool is that it enables users to forecast the likely impact of *future* shale gas developments (informed by those already established), and may be useful in guiding approvals, or adjusting proposed position/orientation of future proposals. The tool would require compilation of a number of key environmental layers (many of which are available, or which could be completed by identifying and filling gaps, or could be generated via simple modelling):

1. MNES distribution models/maps
2. Vegetation type maps (including wetlands, GDEs and sheet-flow sensitive vegetation)
3. Landscape intactness and corridor layers
4. Median surface flow of major rivers/channels
5. Groundwater aquifer data

6.1.3 Thresholds and risk

On completion of a cumulative impact simulation, risk can be readily assessed using expertly agreed criteria that consider critical thresholds across which major and possibly irreversible state changes may occur. The following are examples of thresholds that could be adopted as part of a cumulative impact assessment framework for shale gas:

1. International Union for the Conservation of Nature (IUCN) threat categories for vegetation communities and species, where highest risk is associated with entities that are *critically endangered*, and lowest risk is associated with entities of *least concern* (see Appendix B).
2. Vegetation cover thresholds that classify landscapes into intact, variegated, fragmented and relictual – each having different degrees of vegetation removal, connectivity, modification, and pattern of modification. The four levels are defined by McIntyre and Hobbs (1999) and may be expressed spatially using the intactness index algorithm (Figure 4).
3. Critical habitat areas based on population viability analysis.
4. Proportion of shale gas development within catchments or micro-catchments that contribute surface water flow to nationally important wetlands.
5. Groundwater extraction for shale gas, as a proportion of total groundwater extraction.

Areas of potential extreme risk (e.g. key threatened species population, place of scenic beauty or cultural significance, iconic wetlands) could be avoided. Other areas or strategies may be used to mitigate or offset cumulative impacts, thus reducing risk (e.g. feral animal control, strategic restoration, purchase of water rights). Thresholds at landscape scale can also be applied per project.

6.1.4 Summary of a proposed assessment framework

A simple framework for assessing impact and risk is shown in Figure 6, and is based on a similar model developed for the Namoi CMA (ELA 2012). It requires the generation of a single impact report for each development in the scenario, a cumulative impact report for all developments in the scenario, a critical threshold assessment report for all developments in the scenario, and an overall risk report based on assessment of impacts in relation to critical thresholds.

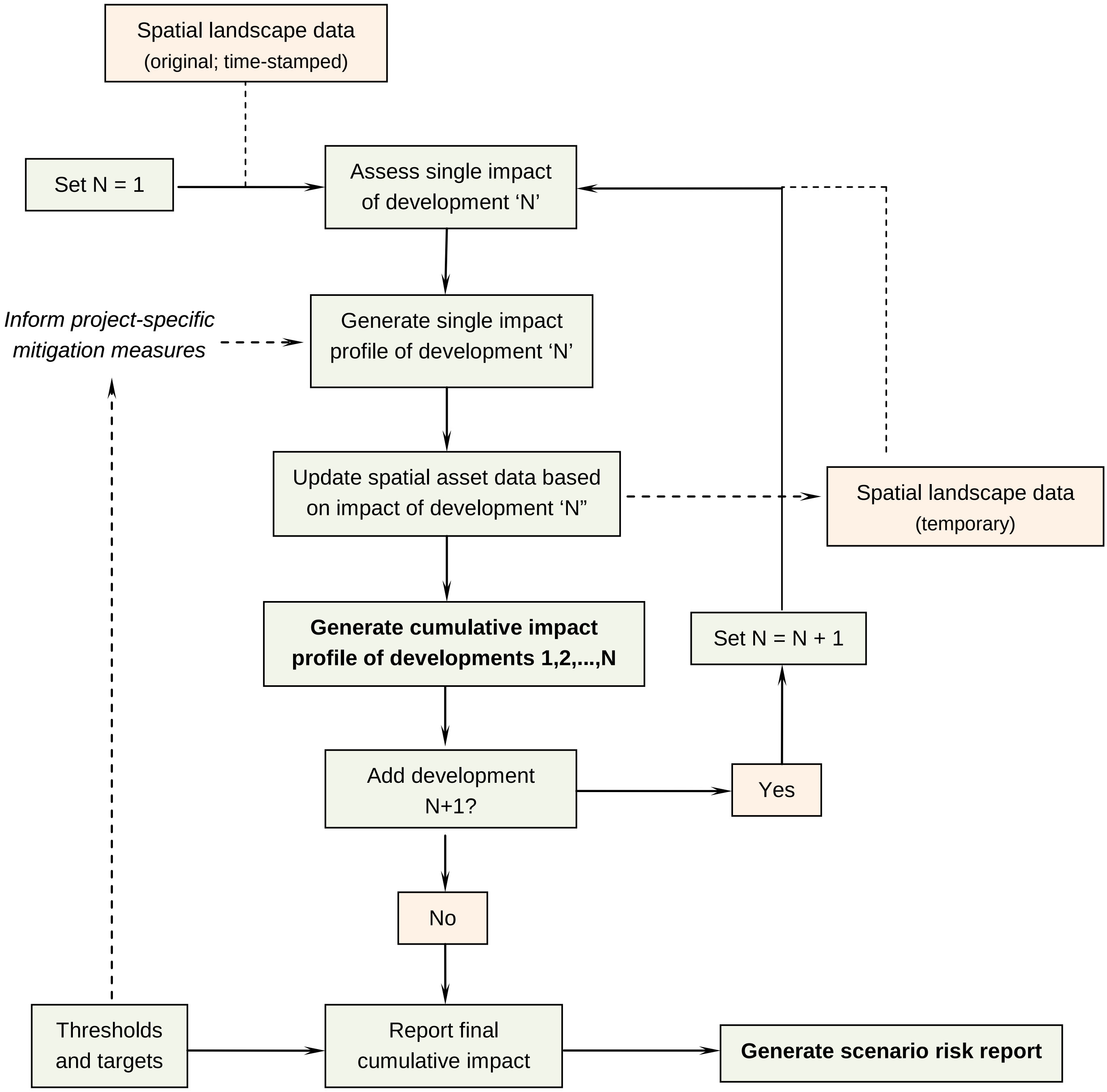


Figure 6. Potential framework for assessing cumulative impacts and risk

(Note: N = shale gas footprint (or other footprint) in the scenario)

7 Conclusions

While the impacts of shale gas extraction on environmental assets may be limited on a project by project basis, the collective impacts of multiple operations across all the major petroleum basins could be significant, and must be carefully managed if the industry expands. In particular, the risk of significant adverse effects arising from landscape fragmentation and water and land contamination is likely to be high.

Mitigation measures are predicted to minimise impacts at a local scale, but not at a landscape scale. In this regard, it is recommended that a strategic framework be developed at the bioregional level that seeks to avoid, mitigate and offset potential impacts prior to shale gas approvals. This framework would act to provide an over-arching level of mitigation to address major landscape issues and be underpinned by agreed and scientifically robust thresholds and targets transferable to project-by-project measures.

The strategic assessment process available in the EPBC Act would appear well suited for such a purpose and provide companies with regulatory certainty and align natural resource management (NRM) goals for catchments, and embrace other landscape initiatives such as the National Reserve System (NRMMC 2009) and the National Wildlife Corridors Plan (DSEWPAC 2012). The cumulative impact assessment approach outlined in Section 6 offers the industry and government a mechanism within the existing approvals framework to operate in tandem with standard industry mitigation measures to protect ecological values.

References

Andrews, A. 1990. Fragmentation of habitat by roads and utility corridors: a review. *Australian Zoologist*. 26: 130–141.

Arthur, J.D., Bohm, B. and Cornue, D. 2009a. *Environmental Considerations of Modern Shale Gas Development*. Society of Petroleum Engineers. SPE 122931.

Arthur, J.D., Bohm, B., Coughlin, B.J. and Layne, M. 2009b. *Evaluating Implications of Hydraulic Fracturing in Shale Gas Reserves*. Society of Petroleum Engineers. SPE 121038.

Arthur, J.D., Coughlin, B.J and Bohm, B. 2010. *Summary of Environmental Issues, Mitigation Strategies, and Regulatory Challenges Associated with Shale Gas Development in the United States and Applicability to Development and Operations in Canada*. Canadian Society for Unconventional Gas and Society of Petroleum Engineers. CSUG/SPE 138977.

Australian National University (ANU) 2012. *Unconventional Gas Production and Water Resources: Lessons from the United States on better governance – a workshop for Australian government officials*.

Australian Petroleum Production and Exploration Association (APPEA) undated. *WA Onshore Gas*.

Bennett, A.F. 1991. Roads, roadsides and wildlife conservation: a review. In: Saunders, D.A. and Hobbs, R.J. (Eds.), *Nature Conservation 2: the Role of Corridors.* R.J. Surrey Beatty, Chipping Norton, Australia, pp. 99–117.

Benson, J.S. 2006. New South Wales Vegetation Classification and Assessment: Introduction - the classification, database, assessment of protected areas and threat status of plant communities. *Cunninghamia.* 9: 329-381.

Bergquist, E, Evangelista, P., Stohlgren, T.J. and Alley, N. 2007. Invasive species and coal bed methane development in the Powder River Basin, Wyoming. *Environmental Monitoring and Assessment*. 128: 381-394.

Boulton, A.J., Fenwick, G. D., Hancock, P.J., and Harvey, M.S. 2008. Biodiversity, functional roles and ecosystem services of groundwater invertebrates. *Invertebrate Systematics* 22: 103-116.

Boulton, A.J. and Hancock, P.J. 2006. Rivers as groundwater dependent ecosystems: degrees of dependency, riverine processes, and management implications. *Australian Journal of Botany* 54: 133-144.

Broderick. J., Anderson, K., Wood, R., Gilbert, P. Sharmina, M. Footitt, A., Glynn, S. and Nicholls, F. 2011. *Shale Gas: An Updated Assessment of Environmental and Climate Change Impacts*. A report commissioned by The Co-operative and undertaken by researchers at the Tyndall Centre, University of Manchester.

Brookes, J., Aldridge, K., Ganf, G., Paton, P., Shiel, R. and Wedderburn, S. 2009. *Environmental Watering for Food Webs in The Living Murray Icon Sites.* Project Number MD1253. Murray Darling Basin Authority.

Brown, G.P., Phillip, B.L., Webb, J.K. and Shine, R. 2006. Toad on the road: Use of roads as dispersal corridors by cane toads (*Bufo marinus*) at an invasion front in tropical Australia. *Biological Conservation*. 133: 88-94.

Brown, J.H., and Kodric-Brown, A. 1977. Turnover rates in insular biogeography: effect of immigration on extinction. *Ecology.* **58**: 445-449.

Bunn, S.E. and Arthington, A.H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Ecological Management*, 30: 492-507.

Bunn, S. E., Davies, P. M. and Mosisch, T.D. 1999. Ecosystem measures of river health and their response to riparian and catchment degradation. *Freshwater Biology* 41: 333–345.

Calabrese, J.M. and Fagan, W.F. 2004. A comparison-shopper's guide to connectivity metrics. *Frontiers in Ecology and the Environment*. **2**: 529-536.

Campbell, I. 2009. An overview of tight gas resources in Australia. *PESA News*. June/July 2009.

Canter, LW and Kamath, J. 1995. Questionnaire checklist for cumulative impacts. Environmental Impact Assessment Review. Vol 15 No 4:312-39.

Case, R.M. 1978. Interstate highway roadkilled animals: a data source for biologists. *Wildlife Society* Bulletin. 6:8-13.

CEARC 1986. *Cumulative Environmental Effects: A Binational Perspective, Ottawa, ON*. Canadian Environmental Assessment Research Council and the US National Research Council Board on Basic Biology.

Chesapeake Energy 2012a. *Factsheet: Water Use in Deep Shale Gas Exploration*.

Chesapeake Energy 2012b. *Factsheet: Water Use in Haynesville Deep Shale Gas Exploration*.

Chesapeake Energy 2012c. *Factsheet: Water Use in Barnett Deep Shale Gas Exploration*.

Chesapeake Energy 2012d. *Factsheet: Water Use in Marcellus Deep Shale Gas Exploration*.

Clevenger, A.P., Chruszcz, B. and Gunson, K.E. 2003. Spatial patterns and factors influencing small vertebrate fauna roadkill aggregations. *Biological Conservation.* 109: 15-26.

Clevenger, A.P., Chruszcz, B. and Gunson, K.E. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin*. 29: 646-653.

Court, J.D., Wright, C.J. and Guthrie, A.C. 1994. Assess*ment of Cumulative Impacts and Strategic Assessment in Environmental Impact Assessment.* Commonwealth Environment Protection Agency.

CSIRO 2012a. *Unconventional Gas Facts*.

CSIRO 2012b. *Australia's shale gas resources*. CESREfs017-12.

Davies, K.W. and Sheley, R.L. 2007. A conceptual framework for preventing the spatial dispersal of invasive plants. *Weed Science*. 55: 178-184.

DECC 2009. State of the Environment. Chapter 6. http://www.environment.nsw.gov.au/soe/soe2009/chapter6/chp_6.1.htm.

DERM. 2011b. *The Great Artesian Basin*. Queensland Government Brochure. February 2011, W68.

DEST. 1995. *Native Vegetation Clearance, Habitat loss and Biodiversity Decline: An Overview of Recent Native Vegetation Clearance in Australia and its Implications for Biodiversity*. Biodiversity Series Paper No. 6. Department of Environment, Sport and Territories, Commonwealth of Australia.

Dique, D. S., Thompson, J., Preece, H. J., Penfold, G. C., de Villiers, D. L., and Leslie, R. S. 2003. Koala mortality on roads in south-east Queensland: the koala speed-zone trial. *Wildlife Research*. 30: 419–426.

Dodd, C.K., Barichivich, W.J. and Smith, L.L. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily travelled highway in Florida. *Biological Conservation*. 118: 619-631.

DSE. 2007. *Your Dam Your Responsibility*: *A Guide to Managing the Safety of Farm Dams*. Department of Sustainability and Environment, Melbourne.

DSEWPAC. 2012. *National Wildlife Corridors Plan: A Framework for Landscape-scale Conservation*. Department of Sustainability, Environment, Water, Population and Communities.

Eco Logical Australia 2012. *Assessing the cumulative risk of mining scenarios on bioregional assets in the Namoi Catchment: Development and trial of an interactive GIS tool.* Prepared for Namoi Catchment Management Authority. August 2012.

Environment Australia. 2000. *Revision of the Interim Biogeographic Regionalisation for Australia (IBRA) and Development of Version 5.1.* November 2000.

Fahrig, L., Pedlar, J. H., Pope, S. E., Taylor, P. D., and Wegner, J. F. 1995. Effect of road traffic on amphibian density. *Biological Conservation*. 73: 177–182.

Fensham R., Ponder, W. and Fairfax, R. 2007. *Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin*. Report to Department of the Environment, Water, Heritage and the Arts, Canberra. Queensland Parks and Wildlife Service, Brisbane.

Fensham, R.J. and Fairfax, R.J. 2003. 'Spring wetlands of the Great Artesian Basin, Queensland, Australia'. *Wetland Ecology and Management*. 11: 343–362.

Forman, R.T.T. and Alexander, L.E. 1998. Roads and their major ecological impacts. *Annual Review of Ecology and Systematics*. 29: 207-231.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T. and Winter, T.C. 2003. *Road Ecology: Science and Solutions*. Island Press. Washington.

Franks, D. M., Brereton, D., Moran, C. J., Sarker, T. and Cohen, T. (2010). *Cumulative Impacts - A Good Practice Guide for the Australian Coal Mining Industry*. Centre for Social Responsibility in Mining and Centre for Water in the Minerals Industry, Sustainable Minerals Institute, The University of Queensland. Australian Coal Association Research Program. Brisbane.

Gawne, B., Merrick, C. and Williams, D.G. 2007. Patterns of primary and heterotrophic productivity in an arid lowland river. *River Research and Applications* 23: 1070–1087.

Gelbard, J.L and Belnap, J. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. *Conservation Biology*. 17: 420-432.

GA and BREE. 2012. *Australian Gas Resource Assessment 2012*. Geoscience Australia and Bureau of Resources and Energy Economics. Canberra.

Gibbs, J. P., and W. G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. *Conservation Biology*. 16:1647–1652.

Gibson, C.G. 2008. *An Assessment of Animal Repellents in the Management of Vehicle-Macropod Collisions in New South Wales*. PhD Thesis. Australian Catholic University. September 2008.

Groat, C.G. and Grimshaw, T.W. 2012, *Fact-based Regulation for Environmental Protection in Shale Gas Development*. Energy Institute, University of Texas: Austin.

GWPC. 2009. *Modern Shale Gas Development in the United States: A Primer*. US Department of Energy.

Hancock, P.J. and Boulton, A.J. 2008. Stygofauna biodiversity and endemism in four alluvial aquifers in eastern Australia. *Invertebrate Systematics.* 22:117-126.

Hansen, M.J. and Clevenger, A.P. 2005. The influence of disturbance and habitat on the presence of non-native plant species along transport corridors. *Biological Conservation*. 125: 249-259.

Hanski, I. and Gilpin M. (1991). Meta-population dynamics: brief history and conceptual domain. *Biological Journal of the Linnaean Society* **42**: 3–16.

Harrison, S. (1991). Local extinction in a meta-population context: an empirical evaluation. *Biological Journal of the Linnean Society.* **42**:73-88.

Hatton, T. and Evans, R. (1998). *Dependence of ecosystems on groundwater and its significance to Australia*. Occasional Paper No. 12/98, LWRRDC, Canberra.

Hein, C. D. 2012. *Potential Impacts of Shale Gas Development on Bat Populations in the Northeastern United States*. An unpublished report submitted to the Delaware Riverkeeper Network, Bristol, Pennsylvania by Bat Conservation International, Austin, Texas.

Hobday, A.J. and Minstrell, M.L. 2008. Distribution and abundance of roadkill on Tasmanian highways: human management options. *Wildlife Research*. 35: 712-726.

Hubbard, M. W., Danielson, B.J. and Schmitz, R.A. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. *Journal of Wildlife Management*. 64: 707–712.

Hulme, P.E. 2009. Trade, transportation and trouble: managing invasive species pathways in an era of globalisation. *Journal of Applied Ecology*. 46: 10-18.

Hunter, T. 2011. *Regulation of Shale, Coal Seam and Tight Gas Activities in Western Australia*. Bond University, July 2011.

Jaeger, J.A.G. and Fahrig, L. 2004. Effects of Road Fencing on Population Persistence. *Conservation Biology*. 18: 1651-1657.

Johnson, C., Cogger, H., Dickman, C. and Ford, H. 2007. *Impacts of Land Clearing; The Impacts of Approved Clearing of Native Vegetation on Australian Wildlife in New South Wales*. WWF-Australia Report, WWF-Australia, Sydney.

Jones, F.V., Zimmerman, M.D. and Heinz, W. 2011. *Managing Environmental Risks for Shale Gas Exploration – Applying Lessons Learned in the US to New Ventures in Poland*. Society of Petroleum Engineers. SPE 140864.

Jones, M.E. 2000. Road upgrade, road mortality and remedial measures: impacts on a population of eastern quolls and Tasmanian devils. *Wildlife Research*. 27:289-296.

KPMG. 2011. *Shale Gas – A Global Perspective*. KPMG Global Energy Institute.

Kuuskraa, V., Stevens, S., Van Leeuwen, T. and Moodhe, K. 2011 *World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States*. US Energy Information Administration. U.S. Department of Energy.

Lach, L. and Thomas, M.L. 2008. Invasive ants in Australia: documented and potential ecological consequences. *Australian Journal of Entomology*. 47: 275-288.

Lambeck, R.J. (1997). Focal species: a multi-species umbrella for nature conservation. *Conservation Biology*. **11**: 849-856.

Ludwig, J., Tongway, D., Freudenberger, D., Noble, J. and Hodgkinson, K. (eds.) 1997. *Landscape Ecology Function and Management: Principles from Australia's Rangelands*. CSIRO, Melbourne.

Magnus, Z. 2006. *Wildlife Roadkill Mitigation Information Kit: A guide for local government and land managers*. (Ed. B. Chamberlain.) Tasmanian Environment Centre Inc.

Magnus, Z., Kriwoken, L.K., Mooney, N.J. and Jones, M.E. 2004. *Reducing the Incidence of Wildlife Roadkill: Improving the Visitor Experience in Tasmania*. CRC for Sustainable Tourism.

Mahan, P.S., Bates, P.B. and Dickman, C.R. (1998). Population indices for wild carnivores: a critical study in sand-dune habitat, south-western Queensland. *Wildlife Research*. 25: 217-227.

McIntyre, S. and Hobbs, R. (1999). A framework for conceptualizing human effects on landscapes and its relevance to management and research models. *Conservation Biology*. 13: 1282-1292.

McKay, S.F. and King, A.J. 2006. Potential ecological effects of water extraction in small, unregulated streams. *River Research and Applications*, 22: 1023-1037.

Michaels, C., Simpson, J.L. and Wegner, W. 2010. *Fractured Communities: Case Studies of Environmental Impacts of Industrial Gas Drilling*. Riverkeeper Inc. September 2010.

Miller J.T., Andrew R.A. and Maslin B.R. 2002. Towards and understanding of the variation in the Mulga complex (Acacia aneura and relatives). *Conservation Science WA*. 4: 19-35.

Moilanen, A. and Nieminen, M. (2002). Simple connectivity measures in spatial ecology. *Ecology*. **83**: 1131-1145.

Nevil, J., Hancock, P.J., Murray, B., Ponder, W., Humphreys, W.F., Phillips, M, and Groom, P.K. 2010 Groundwater dependent ecosystems and the dangers of groundwater overdraft : a review and an Australian perspective. *Pacific Conservation Biology*: 16, 187-208.

New York City Department of Environmental Protection (NYC-DEP) 2009. *Final Impact Assessment Report – Impact Assessment of Natural Gas Production in New York City Water Supply Watershed*. Report Prepared by Hazen and Sawyer.

NRMMC. 2009. *Australia's Strategy for the National Reserve System 2009-2030*. Natural Resource Management Ministeral Council. May 2009.

PMSEIC (2010). *Challenges at Energy-Water-Carbon Intersections*. Report of the PMSEIC Expert Working Group. Commonwealth of Australia. October 2010.

Ponder, W.F. 2004. Endemic aquatic macro-invertebrates of artesian springs of the Great Artesian Basin - progress and future directions. *Records of the South Australian Museum*. 7: 101–110.

Ramp, D. and Croft, D. 2002. *Saving Wildlife: Saving People on our Roads*. Annual Report 2002. University of New South Wales.

Ramirez, P. 2009. *Reserve Pit Management: Risk to Migratory Birds*. US Fish and Wildlife Service, Cheyenne, Wyoming.

Rana, S. 2008. *Facts and Data on Environmental Risks – Oil and Gas Drilling Operations*. Society of Petroleum Engineers. SPE 114993.

Read, M.A. and Brooks, J.J. 2000. Detecting effects of environmental water allocations in wetlands of the Murray–Darling Basin, Australia. *River Research and Applications*. 16: 479-496.

Royal Society and Royal Academy of Engineering. 2012. Extraction in the UK: A Review of Hydraulic Fracturing. June 2012.

Sadar M. H. (1994). *Environmental impact assessment.* Carleton University Press, Ottawa.

Saunders, D.A., Hobbs, R.J. and Margules, C.R. 1991. Biological consequences of ecosystem fragmentation: a review. *Conservation Biology*. 5: 18-32.

Sherriff, G., Wilson, B. and Steed, J. (2010). *ESG and the Energy Sector - Water Concerns: QLD Coal Seam Gas Developments*. J.P. Morgan, Asia Pacific Equity Research Article, November 2011.

Shoemaker D.J. 1994. *Cumulative Environmental Assessment*. Department of Geography. University of Waterloo, Canada.

SKM. 2010. *Mapping Groundwater Dependent Ecosystems in the Namoi Catchment*. Final Report to Namoi CMA. May 2010.

Smith, T. (2012). Environmental considerations of shale gas development. *Chemical Engineering Progress*. 108: 53-59.

Smith-Patten, B.D. and Patten, M.A. 2008. Diversity, seasonality and context of mammalian roadkills in the southern Great Plains. *Environmental Management*. 41: 844–852.

Spaling H. and Smit B. 1993. Cumulative environmental change: Conceptual frameworks, evaluation approaches, and institutional perspectives. *Environmental Management.* 17: 587-600.

Spellerberg, I. 1998. *Ecological effects of roads and traffic: a literature review*. Global Ecology and Biogeography. 7: 317-333.

Standards Australia/Standards New Zealand. 2004. *Australian/New Zealand Standard, Risk Management – Principles and Guidelines* AS/NZS ISO 31000:2009.

Standish, R.J., Cramer, V.A., Hobbs, R.J. and & Kobryn, H.T. 2006. Legacy of land-use evident in soils of Western Australia's wheatbelt. *Plant and Soil*. 280: 189-207.

Taylor, B.D. and Goldingay, R.L. 2004. Wildlife road-kills on three major roads in north-eastern New South Wales. *Wildlife Research*. 31: 83-91.

Thackway, R. and Cresswell. I, (Eds). 1995. *An Interim Biogeographic Regionalisation for Australia: A Framework for Establishing the National System of Reserves*, Version 4.0, Australian Nature Conservation Agency, Canberra.

Trombulak, S.C and Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*. 14: 18–30.

USEIA. 2011. *World Shale Gas Resources: An initial Assessment of 14 Regions Outside the United States*. US Energy Information Administration.

USEPA 2008. *An Assessment of the Environmental Implications of Oil and Gas Production: A Regional Case Study*. United States Environmental Protection Agency. Working Draft, September 2008.

USEPA 2011. *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. Office of Research and Development, U.S. Environmental Protection Agency, Washington D.C. February 2011.

Warner, D. (2011). Shale gas in Australia: a great opportunity comes with significant challenges. *Preview*. Dec 2011. pp. 18-21.

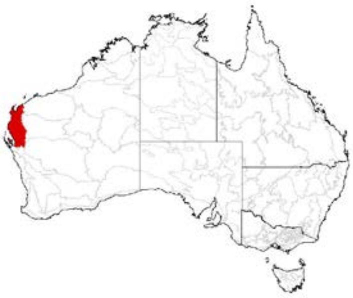
Williams, J., Stubbs, T. and Milligan, A. (2012). *An analysis of coal seam gas production and natural resource management in Australia*. Report prepared for the Australian Council of Environmental Deans and Directors. John Williams Scientific Services Pty Ltd, Canberra, Australia.

Yiasoumi, B., Gillett, J. and Bourke, C. 2009. *Managing blue-green algae in farm dams*. Primefact 414. Department of Primary Industries.

Appendix A

Brief description of Australian bioregions that could be affected by shale gas extraction

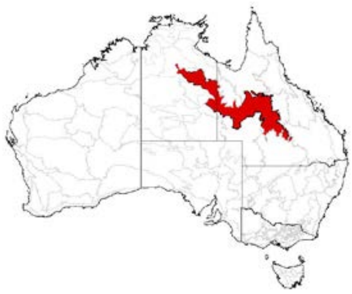
Bioregion	Description
 Arnhem Coast	The Arnhem Coast bioregion comprises a coastal strip extending from east of the Cobourg Peninsula to just north of the mouth of the Rose River in south-eastern Arnhem Land, and includes many offshore islands, most notably Groote Eylandt (and its satellites), the English Company and Wessel group, and the Crocodile Islands. Coastal vegetation includes well developed heathlands, mangroves and saline flats, with some floodplain and wetland areas, most notably the extensive paperbark forest and sedgelands of the Arafura Swamp (EA 2000). Inland from the coast, the dominant vegetation type is eucalypt tall open forest, typically dominated by Darwin woollybutt (*Eucalyptus miniata*) and Darwin stringybark (*E. tetrodonta*), with smaller areas of monsoon rainforest and eucalypt woodlands. The bioregion is entirely Aboriginal land that includes bauxite and manganese mining, and tourism. The region is biodiversity-rich and supports at least 15 threatened flora and fauna species. Major disturbance factors are excessive use of fire, and high density of feral pigs and cattle.
 Brigalow Belt North	The Brigalow Belt North bioregion in Queensland contains Permian volcanics and Permian-Triassic sediments of the Bowen and Galilee Basins that comprise undulating to rugged ranges and alluvial plains, support sub-humid to semi-arid woodlands of ironbarks (*Eucalyptus melanophloia, E. crebra*), Poplar Box (*E. populnea*), Brown's Box (*E. brownii*), Blackwood (*A. argyrodendron*) Brigalow (*Acacia harpophylla*) and Gidgee (*A. cambagei*) (EA 2000). The main rural land use is beef cattle grazing on pastoral leases, with about 90% of the bioregion grazed. A thriving horticulture industry is centred within an irrigation area around Bowen and coal mining is a major economic driver. Over 20% of the bioregion has been cleared of native vegetation to date, with woody vegetation loss in excess of 50% in Upper Belyando and Belyando Downs sub-regions. The Brigalow Belt North is an under-represented bioregion, having less than 10% of its extent formally reserved, despite over 60 threatened flora and fauna species have been recorded in the bioregion. This region is a stronghold of the *Brigalow (Acacia harpophylla dominant and co-dominant)*, the *Natural Grasslands of the Queensland Central Highlands and the northern Fitzroy Basin*, the *Weeping Myall Woodlands* and the *Semi-evergreen vine thickets of the Brigalow Belt (North and South) and Nandewar Bioregions* ecological communities, each listed as Endangered under the EPBC Act.

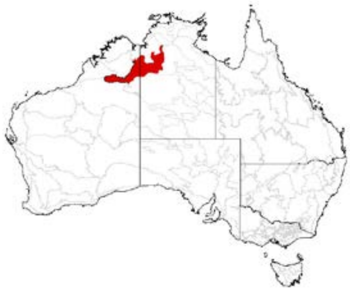
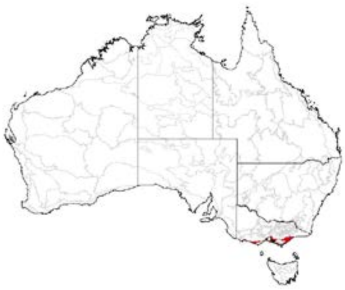
Bioregion	Description
 Carnarvon	Carnarvon is an arid bioregion in Western Australia that traverses part of the Southern Carnarvon Basin. It comprises Quaternary alluvial, aeolian and marine sediments that overly Cretaceous strata. It supports a mosaic of saline alluvial plains with samphire and saltbush low shrublands, Bowgada (*A. ramulosa var. linophylla*) low woodland on sandy ridges and plains, Snakewood (*A. xiphophylla*) scrubs on clay flats, and tree to shrub steppe over hummock grasslands on and between red sand dune fields. Limestone strata with *A. startii / bivenosa* shrublands outcrop in the north, where extensive tidal flats in sheltered embayments support mangrove communities (EA. 2000). The often sparse vegetation is largely contiguous. The bioregion supports extensive cattle and sheep grazing. About 85% of the bioregion is grazed, with unmanaged goats contributing to total grazing pressure.
 Central Arnhem	Central Arnhem is a bioregion that coincides with the McArthur Basin in the Northern Territory. It supports gently sloping terrain and low hills on Cretaceous sandstones and siltstones and lateritised Tertiary material. It supports Darwin Woollybutt (*E. miniata*) and Darwin Stringybark (*E. tetrodonta*) open forest and woodland with grassy understorey (EA 2000). Almost all the land is Aboriginal freehold with Hunbulwar the largest community. There are currently no major industries, only about 1% of the bioregion is grazed by domestic stock, and the landscape is relatively intact although it is burnt frequently. Only 6 threatened flora and fauna species have been recorded in this bioregion, although survey effort to date has been low. The bioregion is a stronghold for the *Arnhem Plateau Sandstone Shrubland Complex* ecological community which is listed as Endangered under the EPBC Act. Central Arnhem is under-represented, with less than 10% of its extent secured within the formal reserve system.
 Channel Country	The Channel Country bioregion coincides with the Cooper Basin in Queensland and South Australia. It is characterized by vast braided flood and alluvial plains surrounded by gravel or gibber plains, dunefields and low ranges on Cretaceous sediments. The bioregion supports forbfields and Mitchell grass (*Astrebla sp.*) downs, with intervening braided river systems (channels) of Coolabah (*E. coolibah*) woodlands and lignum/ saltbush (*Muehlenbeckia sp./ Chenopodium sp.*) shrublands (EA 2000). Vegetation is generally sparse and intact, although minor clearing has occurred on the Goneaway Tablelands in Queensland. Over 90% of the Channel Country is grazed by domestic stock, with macropods and invasive animals (pig, goat, rabbit, donkey, horse) contributing to total grazing pressure. A loss of native perennial grass and forb species has occurred in non-spinifex areas as a result of over-grazing. The bioregion supports about 20 threatened flora and fauna species. Despite a large area of the bioregion reserved in NSW (i.e. Sturt National park), less than 10% of the area of the Channel Country is formally reserved, thus it is an under-represented bioregion.

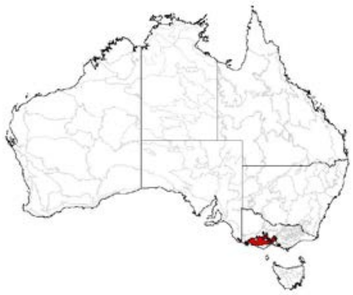
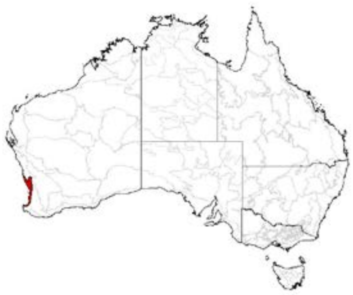
Bioregion	Description
 Dampierland	Dampierland is a semi-arid tropical bioregion in Western Australia that intersects part of the Canning Basin. It comprises four (4) distinctive systems (EA 2000): (1) Quaternary sandplains overlying Jurassic/Mesozoic sandstones with red soil hummock grasslands on hills; (2) Quaternary marine deposits on coastal plains, with mangroves, samphire - *Sporobolus* grasslands, *Melaleuca acacioides* low forests, and *Spinifex* - *Crotalaria* strand communities; (3) Quaternary alluvial plains associated with the Permian and Mesozoic sediments of Fitzroy Trough that support tree savannas of *Crysopogon* - *Dichanthium* grasses, with scattered *Eucalyptus microtheca* - *Lysiphyllum cunninghamii*, interwoven with riparian forests of River Gum (*E. camaldulensis*) and Cadjeput *Melaleuca* fringe drainages; and (4) Devonian reef limestones in the north and east, often manifest as spectacular gorges, that support sparse tree steppe over *Triodia intermedia* and *T. wiseana* hummock grasses and vine thicket elements. The main agricultural industries are beef cattle (about 75% of the bioregion is grazed) and horticulture. The region contains Ramsar-listed wetlands and 10 threatened flora and fauna species have been recorded. Dampierland is an under- represented bioregion, with only 1% of its extent formally reserved.
 Davenport Murchinson Ranges	This arid bioregion is within the Georgina Basin in the Northern Territory. It supports a chain of low rocky ranges formed from folded volcanics and sandstone, siltstone and conglomerates that contrast with the flat sandplain surrounds of the Tanami bioregion. Vegetation is contiguous and includes hummock grasslands and low open woodlands dominated by eucalypt and *Acacia* species. About 60% of the bioregion is grazed by domestic stock and burning is common. Feral donkeys and horses occur in large populations, most notably in the eastern part of the bioregion, and the invasive weed Parkinsonia (*Parkinsonia aculeata*) is problematic within rivers and creeks that flow north from the Davenport Range. The bioregion supports 10 threatened flora and fauna species but is under-represented, with less than 10% of its extent formally reserved.
 Desert Uplands	Desert Uplands is an semi-arid bioregion coinciding with the Galilee Basin in central Queensland. It comprises sandstone ranges and sand plains that support woodlands of White's Ironbark (*E. whitei*), Inland Yellow Jacket (*E. similis)* and White Bloodwood (*Corymbia trachyphloia*) (EA 2000). About 95% of the bioregion is grazed by domestic stock, and a modest level of inappropriate land clearing has occurred in the past, particularly in the Jericho sub-region. About 25 threatened flora and fauna species have been recorded in the Desert Uplands, and loss of biodiversity is recognised as a key management issue. The bioregion is likely to support *The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin,* listed as Endangered under the EPBC Act.

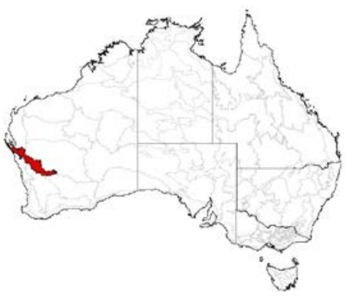
<table>
<tr><th>Bioregion</th><th>Description</th></tr>
<tr><td>
Finke</td><td>The Finke bioregion overlaps the South Australian and Northern Territory and includes part of the Amadeus Basin. It comprises arid sandplains, and dissected uplands and valleys formed from Pre-Cambrian volcanics. It supports spinifex hummock grasslands and acacia shrublands on red earths and shallow sands, and includes three major inland rivers – the Finke, Hugh and Palmer – each of which feeds into Lake Eyre during major flooding. Major land uses are cattle grazing (about 90% of the bioregion is pastoral leasehold) and Aboriginal land management. The bioregion contains 29 threatened flora and fauna species, and a rich diversity of desert fauna. Athel Pine (Tamarix aphylla) and Buffel Grass (Pennisetum ciliare) are significant invasive weeds in the Finke bioregion.</td></tr>
<tr><td>
Geraldton Sandplains</td><td>Located over part of the Southern Carnarvon Basin in Western Australia, the semi-arid Geraldton Sandplains bioregion supports mainly proteaceous scrub-heaths on the sandy earths of an extensive, undulating, lateritic sandplain mantling Permian to Cretaceous strata (EA 2000). It supports extensive York Gum (E. loxophleba) and Jam (A. acuminata) woodlands that occur on outwash plains associated drainage. It is a centre of high endemism, particularly for flora and reptiles, and various vegetation communities are identified as being ‘at risk’ in the absence of reservation. The bioregion also comprises nationally important wetlands, Grazing is practiced across at least 80% of the bioregion, and dryland cultivation and cropping and associated vegetation clearing is also prevalent.</td></tr>
<tr><td>
Gibson Desert</td><td>The Gibson Desert is an intact arid bioregion in Western Australia that comprises lateritic gibber plains, dunefields and sand plains on flat-lying Jurassic and Cretaceous sandstones of the Canning Basin. It supports Mulga (A. aneura) woodland over Lobed Spinifex (Triodia basedowii) on lateritic "buckshot" plains and mixed shrub steppe of acacia, hakea and grevillea over Soft Spinifex (T. pungens) on red sand plains and dune fields. Lateritic uplands support shrub steppe in the north and mulga scrub in the south. Quaternary alluvia associated with palaeo-drainage features support Coolabah (E. coolibah) woodlands over bunch grasses (EA 2000). Conservation and Aboriginal Lands are the main land uses, with no known grazing of domestic stock. There are no invasive flora in the Gibson Desert, however invasive fauna include feral pig, fox, rabbit, wild dog, cat and feral camel (which is increasing in numbers). A total of four mammal species and 1 reptile species are listed as threatened.</td></tr>
</table>

Bioregion	Description
 Great Sandy Desert	The Great Sandy Desert is a vast arid bioregion that covers a large part of the Canning Basin in Western Australia, extending into the Northern Territory. It is characterised by red sand plains, dunefields and remnant rock outcrops. It is intact in terms of contiguous cover, comprising mainly tree steppe grading to shrub steppe in the south (open hummock grassland of *T. pungens* and *Plectrachne schinzii,* scattered Desert Walnut (*Owenia reticulata)* and bloodwoods, *Acacia* spp, *Grevillea wickhamii* and *G. refracta*). Desert Oak (*Casuarina decaisneana*) occurs in the far east of the region. Calcrete and evaporite surfaces traverse the desert, and include extensive salt lake chains with samphire low shrublands, and *Melaleuca glomerata* - *M. lasiandra* shrublands (EA 2000). Tourism, mining and mineral exploration are the main land uses in the Great Sandy Desert. Pastoral leases cover the far western and eastern edges - about 7% of the bioregion is grazed. The region contains 30 threatened fauna species, including 10 considered to be extinct.
 Gulf Coastal	The Gulf Coastal bioregion coincides with the McArthur Basin in the Northern Territory. It comprises gently undulating plains, meandering rivers and coastal swamps, with some scattered rugged areas. The bioregion s dominated with Darwin Stringybark woodlands and samphire shrublands. Pastoral leasehold and Aboriginal Land are the most common tenures, with the main industries being grazing and mining. About70% of the bioregion is grazed, although grazing potential outside the eastern margin is considered to be low. A total of 16 threatened flora and fauna species have been recorded in the bioregion, and the bioregion is considered to be in a reasonably stable condition with no major land condition issues.
 Gulf Fall and Uplands	The Gulf Fall and Uplands bioregion coincides with the McArthur Basin in the Northern Territory and Queensland. It comprises spectacular gorges, undulating terrain with scattered low, steep hills on Proterozoic and Palaeozoic sedimentary rocks. Skeletal soils and shallow sands support Darwin Boxwood and Variable-barked Bloodwood (*Corymbia erythrophloia*) woodland to low open woodland with spinifex understorey (EA 2000). Cattle grazing and mining are the major industries, however the historic extent of clearing appears to have been low and the landscape exhibits a contiguous mosaic of vegetation types. About 70% of the Gulf Fall and Uplands bioregion is grazed and the landscape is burnt frequently. A total of 15 threatened flora and fauna species have been recorded in the bioregion.

Bioregion	Description
 MacDonnell Ranges	The MacDonnell Ranges of Central Australia partly coincide with the Amadeus Basin in the Northern Territory. The bioregion comprises visually spectacular high relief ranges and foothills covered with spinifex hummock grassland, sparse acacia shrublands, and woodlands along ephemeral watercourses. The main industries are cattle and tourism, with Alice Springs the major centre. The arid vegetation mosaic of the MacDonnell Ranges is contiguous, and about 60% is grazed by domestic cattle, with kangaroo, and feral pig, rabbit, camel, donkey and horse adding to overall grazing pressure. The MacDonnell Ranges is a diverse arid region, containing 38 threatened flora and fauna species.
 Mitchell Grass Downs	Mitchell Grass Downs spans across central Queensland into the Northern Territory and coincides with the Galilee and Georgina Basins. It comprises undulating downs on shales and limestones with grey and brown cracking clays, and supports Mitchell Grass (*Astrebla spp.)* grasslands and *Acacia* low woodlands (EA 2000). It is an under-represented bioregion, with less than 10% of its extent formally reserved. Over 30 threatened flora and fauna species have been recorded in the bioregion, and is likely to support *The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin,* listed as Endangered under the EPBC Act. The Mitchell Grass Downs support cattle and sheep grazing (the latter confined to eastern parts of the bioregion in Queensland), with over 95% of the bioregion grazed. The rate of vegetation clearing in the bioregion has been mixed, with concerted clearing of gidgee scrubs in the Southern Woody Downs sub-region in Queensland having commenced in the 1950s, and ongoing loss of Myall (*A. pendula*) for drought fodder. The bioregion supports increasing numbers of woody weeds of national significance, such as Prickly Acacia (*Acacia nilotica subsp. indica*).
 Naracoorte Coastal Plain	The Naracoote Coastal Plain in South Australia and Victoria is a broad coastal plain of Tertiary and Quaternary sediments with a regular series of calcareous sand ridges separated by inter-dune swales, closed limestone depressions and young volcanoes at Mount Gambier. It is part of the Otway Basin, Vegetation is dominated by heathy woodlands and mallee shrubland with wet heaths in the inter-dune swales. This bioregion has been extensively cleared for agriculture with grazing the major land use. Due to its variety of habitats, the Naracoorte Coastal Plain supports a highly diversity of biota. A number of species are on the western margins of their distribution from the wetter southeast of Australia, the southern extreme for drier mallee vegetation, or are unique to the bioregion. The bioregion supports EPBC-listed *Seasonal Herbaceous Wetlands (Freshwater) of the Temperate Lowland Plains* and is an important over-wintering area for the nationally endangered Orange-bellied Parrot (*Neophema chrysogaster*), The bioregion supports 35 listed flora and fauna species.

Bioregion	Description
 Ord Victoria Plain	The Ord Victoria Plain is a semi-arid bioregion coinciding with the Canning Basin in Western Australia, and includes ridges, plateaus and undulating plains on Cambrian volcanics and Proterozoic sedimentary rocks. The lithological mosaic has three main components: (1) Abrupt ranges and scattered hills mantled by shallow sand and loam soils supporting *Triodia* hummock grasslands with sparse low trees including Snappy Gum (*E. racemosa*); (2) Cambrian volcanics and limestones forming extensive plains with short grass (*Enneapogon* spp.) on dry calcareous soils and medium-height grassland communities (*Astrebla* and *Dichanthium*) on cracking clays. Riparian forests of River Gum fringe drainage lines; and (3) in the south-west, lateritised upland sandplains (EA 2000). Extensive grazing is the main industry with at least 80% of the bioregion is grazed. Despite this, the native vegetation mosaic is reasonably intact across the extent of the bioregion. A total of 8 threatened species have been recorded in the bioregion. The level of formal reservation is less than 10%.
 Sturt Plateau	The Sturt Plateau coincides with the Beetaloo and McArthur Basins in the Northern Territory. It comprises gently undulating plains on lateritised Cretaceous sandstones; neutral sandy red and yellow earths, and supports Variable-barked Bloodwood woodland with spinifex understorey (EA 2000). The major land use is extensive cattle grazing, with almost 80% of the bioregion grazed. Land clearing has been negligible, however use of fire is extensive and frequent. A total of 10 threatened fauna species have been recorded in the bioregion, but no threatened plants. Weeds spreading along and away from the new Alice Springs to Darwin railway corridor have introduced a new threat to the bioregion.
 South East Coastal Plain	The South East Coastal Plain occurs in southern Victoria and coincides with the Otway Basin. It incorporated undulating Tertiary and Quaternary plains that have been extensively cleared for agriculture. The vegetation includes lowland forests, open forests with shrubby or heathy understoreys, grasslands and grassy woodlands, heathlands, shrublands, freshwater and coastal wetlands, mangrove scrubs, saltmarshes, dune scrubs and coastal tussock grasslands (EA 2000). The bioregion has a number of values including EPBC listed *Seasonal Herbaceous Wetlands (Freshwater) of the Temperate Lowland Plains* (with Ramsar listings) and various endemic flora. Over 100 threatened flora and fauna species have been recorded in the bioregion.

Bioregion	Description
 South Eastern Queensland	The Maryborough Basin occurs entirely within South Eastern Queensland bioregion, which comprises sediments of the Moreton, Nambour and Maryborough Basins, including extensive alluvial valleys and Quaternary coastal deposits. The bioregion is very biologically diverse, containing various rainforests, tall moist forests, dry open forests, woodlands, wetlands, heaths and mangrove/ saltmarsh communities (EA 2000). It has over 150 federally listed threatened species, and many endemic species. A total of 13 wetlands in the bioregion are recognised as nationally significant. The bioregion is heavily populated and subject to considerable development pressure. Extensive areas of native vegetation have been cleared (and continue to be cleared) for urbanisation and agricultural expansion. This region is a stronghold of the *Littoral Rainforest and Coastal Vine Thickets of Eastern Australia* ecological community, listed as Critically Endangered under the EPBC Act.
 Southern (Victorian) Volcanic Plain	A flat to undulating plain in south-western Victoria, extending into South Australia, the Southern Volcanic Plain Bioregion coincides with part of the Otway Basin. The region is distinguished by volcanic deposits that formed an extensive basaltic plain with stony rises, old lava flows, numerous volcanic cones and old eruption points. It is dotted with shallow lakes and wetlands. Vegetation formerly consisted of damp sclerophyll forests, woodlands and grasslands which have been mostly cleared for agriculture. The extensive depletion and fragmentation of ecosystems in the region means that remnants are nearly all highly significant for conservation, including occurrences of the EPBC-listed *Natural Temperate Grassland of the Victorian Volcanic Plain*, EPBC-listed *Seasonal Herbaceous Wetlands (Freshwater) of the Temperate Lowland Plains*, and 28 wetland of national importance. Over 100 threatened flora and fauna species have been recorded in the bioregion.
 Swan Coastal Plain	The Swan Coastal Plain coincides with the Perth Basin in Western Australia. It exhibits a Warm Mediterranean climate and contains low lying coastal plains that is mainly covered with Banksia or Tuart woodlands on sandy soils, Swamp Sheoak (*Allocasuarina obesa*) on outwash plains, and paperbark in swampy areas. In the east, the plain rises to Mesozoic sediments dominated by Jarrah (*E. marginata*) woodland. The outwash plains, once dominated by Swamp Sheoak - Marri woodlands and *Melaleuca* shrublands, are extensive only in the south (EA 2000). A variety of plants are endemic to the region, and there are 26 wetlands of national significance. The bioregion also supports a number of threatened ecological communities, including two communities dominated by Marri (*Corymbia calophylla*).

Bioregion	Description
 Sydney Basin	The only bioregion in New South Wales with shale gas potential, the Sydney Basin comprises Mesozoic sandstones and shales, producing skeletal soils, sands and podzolics that support a variety of forests, woodlands and heaths within a distinctive landscape of sandstone plateaus and valleys. The Sydney Basin contains a number of important freshwater catchments that supply drinking water to Sydney and other major centres. It is a highly diverse region, containing coastal swamps and heaths, rainforests, tall eucalypt forest, dry eucalypt woodlands, and a number of important wetlands. It supports the *Blue Gum High Forest*, the *Cumberland Plain Shale Woodlands and Shale-Gravel Transition Forest*, the *Littoral Rainforest and Coastal Vine Thickets of Eastern Australia* and the *Turpentine-Ironbark Forest in the Sydney Basin Bioregion* ecological communities which are each listed as Critically Endangered under the EPBC Act, and also the *Shale/Sandstone Transition Forest* and *Upland Basalt Eucalypt Forests* communities, listed as Endangered under the EPBC Act. The Sydney Basin is a highly populated bioregion and is subjected to a number of development pressures.
 Tanami	The Tanami is a tropical arid bioregion that traverses parts of the Canning and Georgina Basins in Western Australia and the Northern Territory. It comprises mainly red Quaternary sandplains overlying Permian and Proterozoic strata which are exposed locally as hills and ranges. The sandplains support mixed shrub steppes of Corkbark Hakea (*Hakea suberea*), desert bloodwoods, acacias and grevilleas over *Triodia pungens* hummock grasslands. Wattle scrub over *T. pungens* hummock grass communities occur on the ranges. Alluvial and lacustrine calcareous deposits occur throughout. In the north they are associated with Sturt Creek drainage, and support *Crysopogon* and *Iseilema* short-grasslands often as savannas with River Red Gum (EA 2000). Over 1500 taxon have been recorded in the Tanami, including 26 threatened flora and fauna, About 25% of the Tanami is suitable for domestic grazing. Feral camels, horses and donkeys are a major management issue, and Parkinsonia is establishing around watering points of pastoral leases.
 Yalgoo	Yalgoo Bioregion in Western Australia is an arid to semi-arid bioregion in the Perth Basin. It is characterised by low woodlands to open woodlands of *Eucalyptus*, *Acacia* and *Callitris* on red sandy plains of the Western Yilgarn Craton and southern Carnarvon Basin. It includes the Toolonga Plateau of the southern Carnarvon Basin. It is rich in ephemeral species (EA 2000). Tenure is predominantly pastoral leasehold and sheep grazing is the main enterprise type. The region supports a rich diversity of flora and fauna, including 23 listed taxa.

Appendix B

IUCN Criteria for Assessing Status of Ecological Communities (from Benson 2006)

Note: The relevant consideration for a particular ecological community is whether any **one** criterion is met, not whether more than one or all criteria are met. The definitions of terms in this table are provided in Benson (2006).

		THREAT CATEGORY AND DEFINITIONS (DATA DEFICIENT CATEGORY NOT LISTED)					
No.	**Criterion**	**Presumed Extinct**	**Critically Endangered**	**Endangered**	**Vulnerable**	**Near Threatened**	**Least Concern**
1	Its decline in *geographical distribution* is:	**Total :** 100% decline in geographical distribution	**Very severe:** >90% decline in geographical distribution	**Severe:** 70-90% decline in geographical distribution	**Substantial:** 50-70% decline in geographical distribution	**Moderate:** 30-50% decline in geographical distribution	**Minor:** less than 30% decline in geographical distribution
2	Its area of occupancy is:	**Eliminated:** totally destroyed from original area of occupancy.	**Very restricted:** total area of occupancy of < 1000 ha and significant degradation or destruction is continuing.	**Restricted:** total area of occupancy of 1000-10,000 ha and significant degradation or destruction is continuing.	**Limited:** total area of occupancy of 10 000 - 50,000 ha and significant degradation or destruction is continuing.	**Common:** total area of occupancy of 50 000-500 000 ha and only minor degradation or destruction is occurring.	**Widespread:** total area o[f] occupancy of >500 000 h[a] and no significant degradation or destructio[n] is occurring.
	And the combination of depletion, degradation and continued threatening processes makes it likely that it could be lost in the:	NA (already lost)	immediate term	near term	medium term	long term	very long term

		Threat Category and Definitions (Data Deficient Category not listed)					
No.	**Criterion**	**Presumed Extinct**	**Critically Endangered**	**Endangered**	**Vulnerable**	**Near Threatened**	**Least Concern**
3	For a population of a native species that is likely to play a major role in the community, there is on a regional basis a:	**Total decline:** demonstrated or estimated a total loss of the key species, with no regeneration occurring, and that the natural recovery of the species is unlikely to occur. Artificial revegetation is the only means of re-establishing the species.	**Very severe decline:** demonstrated or estimated a decline of >90% in the pre-European abundance of key species and no or very little recruitment is occurring, and recovery is unlikely over the *very long term* unless the threatening processes are eliminated.	**Severe decline:** demonstrated or estimated a decline of 70-90% of the pre-European abundance of key species, and little recruitment is occurring and that natural recovery is unlikely over the *long term* unless the threatening processes are substantially reduced or eliminated.	**Substantial decline:** demonstrated or estimated a decline of 50-70% of the pre-European abundance of key species, and little recruitment is occurring and that natural recovery is likely over the *medium term* unless the threatening processes are reduced.	**Minor decline:** demonstrated or estimated a decline of 30-50% of the pre-European abundance of key species, and moderate recruitment is occurring and natural recovery is likely over the *near term* if the threatening processes are reduced.	**Insignificant decline:** demonstrated or estimated a decline of <30% of the pre-European abundance of key species, and vigorous recruitment is occurring and there is no apparent threat of major decline in the key species or the community.
4	The reduction in its integrity (condition and recoverability) across most of its *geographic distribution*, as indicated by loss of species and/or habitat structure, degradation of soils, changes in nutrient levels, or disruption of important community processes is:	**Destroyed:** integrity totally lost, community structure destroyed, a few species may survive as isolated individuals.	**Very severe:** many species extinct at most occurrences; major structural change including loss of some strata; edaphic processes severely degraded, exotic species abundant. *Regeneration* of substantial areas unlikely within the *long term* without the control of threatening processes.	**Severe:** many species extinct at some occurrences; structural change including loss or near loss of some strata; edaphic processes degraded, exotic species common. *Regeneration* of substantial areas is unlikely within the *medium term* without the control of threatening processes.	**Serious:** some species extinct from some occurrences; moderate structural change but most strata remain; edaphic processes often degradation, exotic species common. *Regeneration* is unlikely within the *near term* without the control of threatening processes.	**Minor:** few species extinct over its distribution; minor structural change with most of the strata remaining; edaphic processes near normal, exotic species uncommon and if present are not threatening the community. *Regeneration* of disturbed areas is likely within the *near term* with the control of threatening processes.	**Insignificant:** very few species extinct over its distribution; no or minor structural changes to strata and all of the original strata remain; edaphic processes functioning well, exotic species mostly absent or if present not a threat to the community. *Regeneration* not necessary as most of the community is relatively intact.

No.	Criterion	THREAT CATEGORY AND DEFINITIONS (DATA DEFICIENT CATEGORY NOT LISTED) Presumed Extinct	Critically Endangered	Endangered	Vulnerable	Near Threatened	Least Concern
5	Its rate of continuing detrimental change is: As indicated by: (a) a rate of continuing decline in its *geographic distribution*, or populations of a native species that are believed to play a major role in the community, or (b) intensification, across most of its *geographic distribution*, of degradation, leading to disruption of important ecological processes.	**Destroyed:** rate of decline not applicable as the community is totally destroyed and not able to naturally regenerate.	**Very rapid:** an observed, estimated, inferred or suspected detrimental change of at least 30% projected in the *immediate term*.	**Rapid:** an observed, estimated, inferred or suspected detrimental change of at least 30% projected in the *near term*.	**Moderate:** an observed, estimated, inferred or suspected detrimental change of at least 30% projected in the *medium term*.	**Slow:** an observed, estimated, inferred or suspected detrimental change of at least 30% projected in the *long term*.	**No change or improvement:** an observed, estimated, inferred or suspected detrimental change of less than 10% projected for the *very long term* or improvement in condition
6	A quantitative analysis shows that its probability of extinction, or extreme degradation over all of its *geographic distribution*, is:	100% already extinct	at least 50% in the *immediate term*	at least 50% in the *near term*	at least 50% in the *medium term*	at least 30% in the *long term*	less than 10% in the *very long term*

eco logical AUSTRALIA

HEAD OFFICE
Suite 4, Level 1
2-4 Merton Street
Sutherland NSW 2232
T 02 8536 8600
F 02 9542 5622

SYDNEY
Level 6
299 Sussex Street
Sydney NSW 2000
T 02 8536 8650
F 02 9264 0717

ST GEORGES BASIN
8/128 Island Point Road
St Georges Basin NSW 2540
T 02 4443 5555
F 02 4443 6655

CANBERRA
Level 2
11 London Circuit
Canberra ACT 2601
T 02 6103 0145
F 02 6103 0148

NEWCASTLE
Suites 28 & 29, Level 7
19 Bolton Street
Newcastle NSW 2300
T 02 4910 0125
F 02 4910 0126

NAROOMA
5/20 Canty Street
Narooma NSW 2546
T 02 4476 1151
F 02 4476 1161

COFFS HARBOUR
35 Orlando Street
Coffs Harbour Jetty NSW 2450
T 02 6651 5484
F 02 6651 6890

ARMIDALE
92 Taylor Street
Armidale NSW 2350
T 02 8081 2681
F 02 6772 1279

MUDGEE
Unit 1, Level 1
79 Market Street
Mudgee NSW 2850
T 02 4302 1230
F 02 6372 9230

PERTH
Suite 1 & 2
49 Ord Street
West Perth WA 6005
T 08 9227 1070
F 08 9322 1358

WOLLONGONG
Suite 204, Level 2
62 Moore Street
Austinmer NSW 2515
T 02 4201 2200
F 02 4268 4361

GOSFORD
Suite 5, Baker One
1-5 Baker Street
Gosford NSW 2250
T 02 4302 1220
F 02 4322 2897

DARWIN
16/56 Marina Boulevard
Cullen Bay NT 0820
T 08 8989 5601

BRISBANE
PO Box 1422
Fortitude Valley QLD 4006
T 0400 494 366