SCOPING STUDY: FINAL REPORT

The Potential Impacts of Coal Seam Gas on Biodiversity

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A study prepared for the University of Queensland
Centre for Coal Seam Gas

The Sustainable Minerals Institute

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EXECUTIVE SUMMARY

Background

Terrestrial biodiversity in eastern Australia has been extensively affected by agricultural development and the expansion of coal seam gas (CSG) developments will potentially have additional impacts. Currently, there is little scientific research on the current or potential impacts of CSG activities and infrastructure on biodiversity in Australia. Internationally, the limited research (mainly in the USA), has found that CSG-related activities are having a range of measurable ecological impacts on the wildlife and habitats studied. It has also been found that these impacts are multi-scale (local and regional) and potentially cumulative (different projects in a region having compounded effects).

Aims and Scope

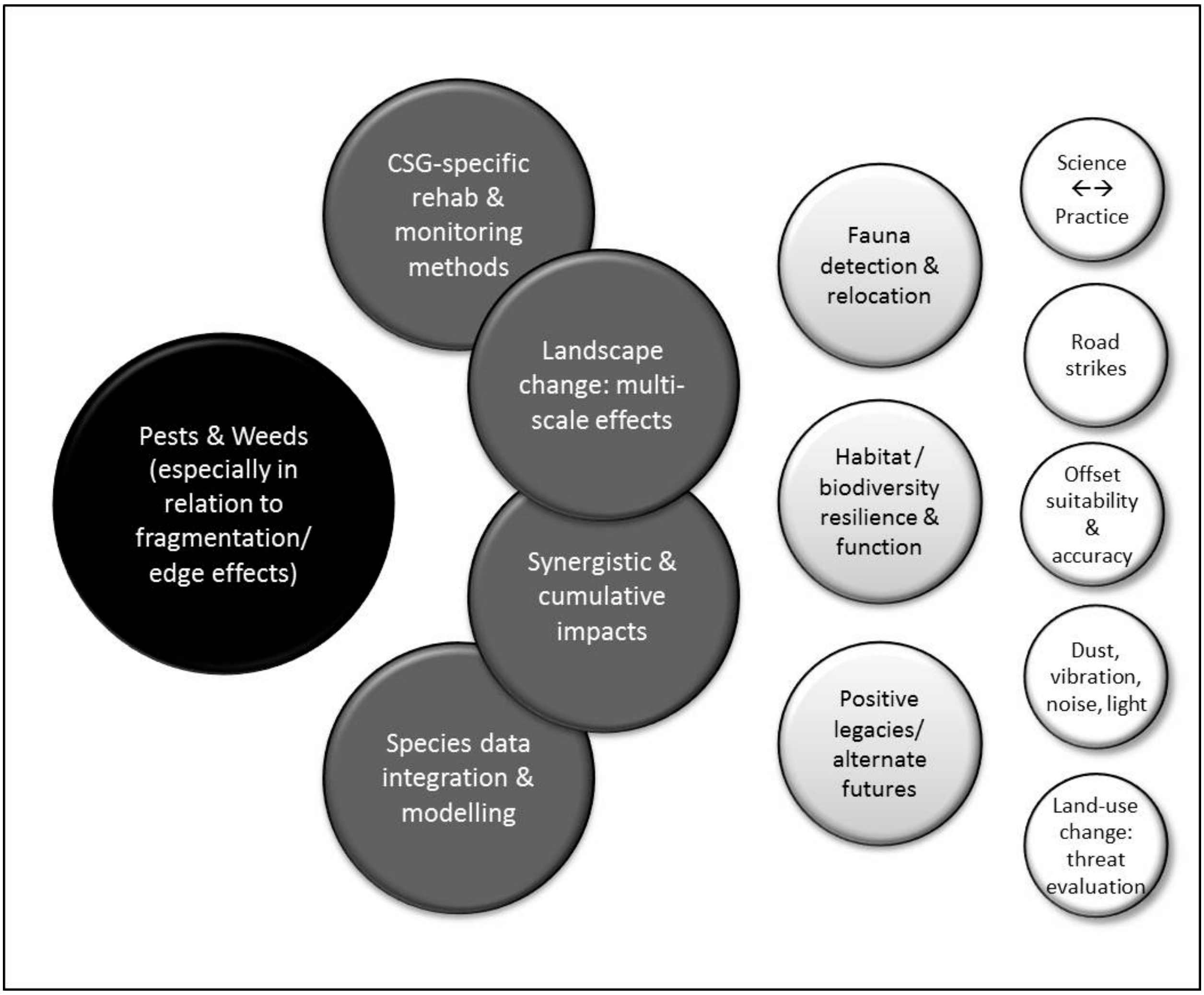
This scoping study investigated the potential impacts of CSG infrastructure and operations on terrestrial biodiversity through: 1) a review of scientific and industry literature, 2) eliciting expert opinion, and 3) by analysis of remote sensing data through a case study. Our assessment of these sources revealed knowledge gaps and suggested priorities for research.

Key research gaps

- **Mandated studies address threatened species, not biodiversity/ecosystems -** No independent research has been completed in Australia on the effects of CSG activities and infrastructure on terrestrial biodiversity, despite acknowledgement by industry and scientists of potential impacts. Environmental impact assessments have generally been limited to focus on threatened species and meeting regulatory requirements, rather than taking a holistic approach to effects on biodiversity. Furthermore, the majority of current research in CSG impacts in the environment relates to human health or groundwater rather than effects on native animal and plant communities.
- **No knowledge about effects of mitigation measures -** There is a range of probable impacts from CSG activities, including habitat loss and fragmentation, increased effects of noise, dust, invasive species, barriers to species movement and interactions with existing threats (i.e., CSG activities compounding the impacts imposed by agriculture). Mitigation of several of these potential impacts is attempted in CSG industry management plans; however, the effectiveness of these actions is not known, particularly in relation to landscape-scale and cumulative effects.
- **Insufficient information on effective rehabilitation practices specific to the CSG industry -** There is a lack of information on the most appropriate rehabilitation, management and monitoring procedures following land disturbance by CSG. Such knowledge is imperative for successful restoration of functional ecosystems.
- **No research agenda on biodiversity enhancement as a positive legacy -** There is a need to evaluate alternative restoration and landscape management approaches to those that are currently planned and/or conducted in CSG-resource development regions. These could be used by the CSG industry to leave a lasting positive legacy for biodiversity.

Research Priorities

Research priorities were determined by considering the number of times and depth that specific knowledge gaps were discussed in the scientific and legislative literature review and expert elicitation. Priorities are ordered according to highest (largest and darkest circle) to lowest in the figure below.



Three example projects are provided in the table overleaf, which encompass or provide the foundation of the five highest priority research areas for the potential impacts of CSG development on terrestrial biodiversity.

Project	Outline
1. Pests and CSG infrastructure Examine potential changes to pest and weed distribution and density, particularly in relation to future management costs and agricultural and environmental damage	Stage 1: Assess edge effects and fragmentation associated with CSG roads, pipelines and well pads on potential increase/introduction of pest species. Stage 2: Research impacts of feral predators and weeds on native fauna and flora species, including endangered, rare and vulnerable species currently listed as common.
2. Industry data repository Develop a geographically-referenced terrestrial flora and fauna data repository by sourcing data acquired during CSG Environmental Impact Studies (EIS) and monitoring programs, which can be used to determine cumulative impacts.	Stage 1a & 2: Develop and integrate/link current data from EISs and monitoring/management programs into a central repository, aligning with WA's SEAK database of EIS data. Stage 1b: Develop standard methods for surveys, monitoring, and assessment to ensure consistent future data collection. Stage 3: Use database for species mapping and habitat modelling for threatened and indicator species. Stage 4: Develop methods to evaluate cumulative impacts from the database.
3. *Best practice rehabilitation -* Determine 'best practice' rehabilitation procedures in relation to CSG-specific disturbances to leave a legacy of ongoing native biodiversity.	Stage 1: Assess the role of native plant and animal recolonisation/regeneration in the restoration of habitats and conduct an empirical analysis of indicators of successful rehabilitation. Stage 2: Characterise techniques and benchmarks suitable for the CSG industry (by reviewing other land uses and conducting field trials) to enable successful rehabilitation.

Additional significant research topics that were identified through the scoping project are listed below, which complement and extend the focused research topics above.

1. Extend the existing industry work on habitat mapping and ecological requirements for threatened species to a range of other vulnerable species (as identified from the workshop and industry priorities);
2. Quantify the edge and fragmentation effects of CSG development and operations on selected fauna and flora identified from scientific literature, environmental assessments, workshop and industry priorities (complementing project 2 above on pest species);
3. Investigate and develop remote sensing methods to assess habitat characteristics and quality, including monitoring the progress of rehabilitation over fine and regional scales (e.g. transmission pipelines).

These topics would further develop landscape-scale ecological knowledge and management tools to aid in managing and/or mitigating the effects of CSG developments and operations on the region's terrestrial biodiversity and site rehabilitation.

CONTENTS

Glossary of key ecological terms used in this study.

Term	**Explanation**
Barrier effect	When roads serve as barriers to movement of individual animals in a species. This can impair ‘gene flow’ (Balkenhol and Waits 2009) (e.g. animals can become inbred and more vulnerable to disease, deformities, etc.).
Biodiversity	There are three levels of interrelated and interdependent diversity: 1) genetic: the variety of genetic information contained in the individual plants, animals and microorganisms; 2) species: the variety of species in a region and on earth, generally; and 3) ecosystem: the variety of habitats, biological communities and ecological processes (DSEWPC 2001).
Core habitat	Habitat away from edges (e.g., roads) that supports species who are sensitive to disturbance (Pearson 2002).
Dissection	The subdivision or carving up of an area using equal-width lines (Forman 1995).
Edge effect	The effect of both non-living (e.g., soil erosion) and living (e.g., weed invasion) processes on species at the boundary of two different habitats (e.g. forest and cleared land) that result in a detectable difference in composition, structure, or function near the edge, as compared with the ecosystem on either side of, away from the edge (Harper *et al.* 2005)
Fragmentation	Fragmentation is the process by which habitat is broken apart into smaller parcels, and different to pure habitat loss (Fahrig 2013).
Habitat	Sites having appropriate levels of resources required for a given species (Pearson 2002). That is, a place where a species lives and thrives.
Habitat loss	Reduction in the total area of habitat in the landscape (Fahrig 2013).
Habitat corridor	An area of habitat connecting wildlife populations that differs from adjacent land uses (Diamond 1975); for example, a long strip of trees in a wheat field leading from one forest to another.
Habitat diversity	The numbers of different habitat types present in the landscape (Kallimanis *et al.* 2008).
Landscape change	Transformation of the landscape by several spatial, overlapping processes such as perforation (e.g., roads to well pads), fragmentation (e.g., roads through an area) and attrition (Forman 1995). This can be natural or anthropogenic.
Landscape metrics	Spatial statistics that quantifies the structure of elements in the landscape within a designated landscape boundary (McGarigal *et al.* 2002); for example, size of a habitat patch, or total length of an edge.
Patch	A contiguous region of similar habitat that differs from its surroundings (Pearson 2002).
Perforation	The process of making holes in an object, such as a habitat or land type (Forman 1995); for example, clearing roads in remnant vegetation to a two-hectare plot for a well pad.
Scale • Site • Patch • Landscape	The spatial and temporal scale on which a particular effect principally operates and thus can be most appropriately studied (Wu and Hobbs 2007). • < 1 ha. • 1-100s ha. • entire landscape of multiple patches covering 1000s ha.

AIM AND SCOPE

This scoping study investigated the potential effects of coal seam gas (CSG) infrastructure and operations on terrestrial biodiversity. We reviewed scientific and industry literature, collected expert opinion and conducted a preliminary investigation on the effectiveness of remote sensing to detect changes in vegetation condition. From these sources, we identified current knowledge gaps and priorities for research that usefully extend and complement research undertaken by the CSG industry as part of EIS and other regulatory requirements. Further research into the potential impacts of CSG infrastructure and operations on terrestrial biodiversity will identify cumulative impacts as well as providing guidance on how the CSG industry can leave a positive legacy for future generations.

Although the focus was primarily on biodiversity of land-based animals (terrestrial fauna) in Queensland, it is acknowledged that CSG developments may also affect other biota and systems, including aquatic ecosystems and groundwater-dependent ecosystems (e.g. wetlands and springs). However, these latter ecosystems are already the subject of considerable research and assessments, driven by concerns about potential risks to water resources, particularly due to the potential cumulative effects of multiple projects. Conversely, the potential effects of CSG operations on terrestrial biodiversity have received little attention.

BACKGROUND

The global production of CSG (and other unconventional gas) has increased significantly in the past two decades. In Australia, there has been significant investment in using CSG resources to produce liquefied natural gas (LNG) for export. As a consequence, Queensland's CSG industry has grown rapidly over the past 15 years (DEEDI 2012), with predictions suggesting that up to 40,000 wells may be sunk with the current operational plans (CSIRO 2012a).

Coal seam gas resources in eastern Australia occur primarily within the Brigalow Belt Bioregion, which extends from northern inland New South Wales to central Queensland. Although characterised by brigalow vegetation (*Acacia harpophylla*), the bioregion has a diversity of ecosystems, including eucalypt open forest and woodland, grassland, cypress pine forest, native grassland and river (riparian) eucalypt communities (McAlpine *et al.* 2002).

CSG Regulation

In Australia, CSG exploration and extraction activities are primarily licensed under state or territory legislation and typically assessed through an Environmental Impact Statement (EIS) process, often resulting in regulation by a bilateral agreement with the Australian Government. This bilateral agreement comes into effect when a CSG project has the potential to have an impact on matters protected under national environment law, such as nationally-designated threatened and migratory species, wetlands designated as having international importance, or places receiving a national or world heritage designation.

In Queensland, CSG is regulated by the *Environmental Protection Act 1994* or the *State Development and Public Works Organisation Act 1971*, the *Water Act 2000*, the *Water Supply (Safety and Reliability) Act 2008*, *Vegetation Management Act 1999*, the *Nature Conservation Act 1992* and the *Forestry Act 1959* (DEHP 2013a), while the Queensland government also has a CSG/LNG

Compliance Plan 2012-13 (DEHP 2012). In November 2012, the federal government of Australia announced the establishment (and members) of an Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, with the committee's terms of reference including improving the collective scientific understanding of the water-related impacts of CSG and large coal mining developments (Australian Government 2012).

CSG and Biodiversity

Expansion of the CSG industry in eastern Australia represents, potentially, a set of significant impacts on terrestrial biodiversity in an area that has already been extensively affected by other human activities such as agriculture, mining and infrastructure development. Although there is ongoing research on the environmental impacts of CSG production on water (e.g., risks posed to surface streams and landscapes by the use and disposal of saline coal seam gas water; DERM 2010), there is currently little research on terrestrial biodiversity. The potential effect from CSG operations on local, terrestrial ecosystems, such as loss and fragmentation, is yet to be dealt with adequately in the policy and regulatory environments of either State or Commonwealth legislation (e.g., CSIRO 2012a). Furthermore, it has been recommended that natural gas production should be managed in a similar way to to the other industries competing for land, water and biodiversity resources in the affected landscapes (Williams *et al.* 2012). For example, using a whole-of-system analysis to understand how much degradation the landscape can incur before it starts to lose function, and new methods and thinking such as cumulative risk assessment (Williams *et al.* 2012), can help avoid piecemeal and potentially ill-conceived policy initiatives and changes in industry regulation in the future.

Coal seam gas exploration, extraction, processing, storage and transport require the construction, maintenance and operation of various above-ground infrastructures. The grid of production wells and associated access tracks, as well as transmission pipelines to sea ports, can contribute to the perforation and fragmentation of remnant native vegetation (average metrics of clearing in Appendix 1). Although much of the area required to be cleared for construction of pipelines and wells is rehabilitated post-CSG operations, access and maintenance tracks may remain for the life of the structure; additionally, the length of time before rehabilitated land offers comparative habitat quality as remnant vegetation is typically protracted (e.g. decades).

Human activities, including the use of natural resources and modification of land cover, have had a significant effect on wildlife around the world (DeFries *et al.* 2010; Bennett *et al.* 2011; Granados *et al.* 2012; Gubbi *et al.* 2012; Lesmerises *et al.* 2012). For example, approximately one-quarter of mammals world-wide are in danger of extinction, while more than half of all mammal populations are in decline (Davidson *et al.* 2009). Policy to mitigate biodiversity loss is designed to recognise the need to manage multiple threatening processes simultaneously over longer terms (Brook *et al.* 2008). Like other developing industry that changes land cover and use, the infrastructure and activities associated with CSG extraction are expected to have an effect on native fauna and flora. In addition, as CSG predominantly occurs within (disturbed) agricultural landscapes, the expectations and demands placed on the CSG industry may be more extensive than on historical users of the same land surfaces. To respond to such demands, and to ensure that they are reasonable in the context, it is essential to understand current and historical land uses, as well as monitoring and adaptively managing CSG activities to minimise or mitigate negative effects, or enhance positive effects, on native biodiversity.

APPROACH

1. A project team was assembled, comprising:
   - Dr Peter Erskine, Dr Elizabeth Williams and Dr Birte Schoettker (The University of Queensland, Sustainable Minerals Institute, Centre for Mined Land Rehabilitation); and
   - Associate Professor Clive McAlpine, Dr Christine Adams-Hosking and Dr Leonie Seabrook (The University of Queensland, School of Geography, Planning and Environmental Management, Landscape Ecology and Conservation Group).

2. Team members undertook:

   A. A review of scientific literature to ascertain current research and identify gaps in knowledge related to potential impacts of CSG operations on biodiversity.

   B. A literature review of recent and current environmental conditions imposed on CSG by regulatory bodies, as well as CSG Company Environmental Management Plans and other controls to mitigate negative environmental impacts.

   C. A stakeholder workshop to scope knowledge related to the effects of CSG and its related infrastructure on terrestrial biodiversity. The workshop involved a range of university and government scientists, environmental consultants, regional Natural Resource Management body representatives and environmental specialists from the CSG industry.

   D. Further discussion with CSG industry environmental representatives, stimulated at the workshop, resulted in the identification of industry research priorities.

   E. A preliminary investigation using remote sensing data and analysis at a sample site in the CSG region of Queensland enabled assessment of vegetation condition and extent indicators to demonstrate the potential technologies and methodologies that could support the identification of potential impacts of CSG on terrestrial biodiversity.

   F. Synthesis of findings from the above tasks into research priorities and suggested topics.

CONCEPTUAL FRAMEWORK

The patterns and potential impacts of CSG infrastructure and operations on native fauna and flora can be observed at multiple spatial and temporal scales. CSG extraction will result in some effects that are similar to those of existing human activities, such as road infrastructure and vehicle traffic, clearing of remnant vegetation, and the associated noise, dust and erosion. However, the effect of some CSG activities, including gas processing facilities, well flares and storage dams, is not yet known.

Fine-spatial scale (1-10 ha): At fine-spatial scales (e.g., at the well, processing plant, or pipeline easement level; see average clearing metrics in Appendix 1), CSG modifies the local habitat conditions for plants and animals (Figure 1). The most prominent of these effects is the dissection of remnant native forests and woodlands by CSG infrastructure, creating edge effects associated with biological invasions, noise, dust, light and vehicular traffic. These changes in environmental conditions may also affect species using pasture areas. Nonetheless, fine-spatial scale effects typically vary among plants and animals, and they are ecosystem and species-specific.

Landscape-scale (1000s ha): At larger spatial scales, the structure and function of whole landscapes may change through the fragmentation, subdivision, shrinkage and perforation of native vegetation (Figure 2); consequently, the cumulative landscape impacts of multiple small-scale disturbances become important. These impacts could include changes in wildlife movement patterns, elevated predation risk, and associated impacts on species' distributions and population viability, as well as the flow of nutrients, sediments and chemicals into aquatic ecosystems, such as wetlands and streams.

Regional Scale (1000s km^2): Multiple-CSG resource developments modify the structure and function of regional landscape mosaics by the construction of sets of multiple well pads connected by infrastructure corridors containing roads and pipelines. In addition, administrative centres and workforce accommodation to support CSG developments are established; for example, the urban footprint of regional service centres (such as Chinchilla and Dalby) have been expanded to service gas projects and associated infrastructure. The resulting increase in traffic volume on local and arterial roads, combined with changes to the timing of peak traffic loads to suit a mobile workforce, escalates, for example, the likelihood of wildlife deaths from vehicular strike.

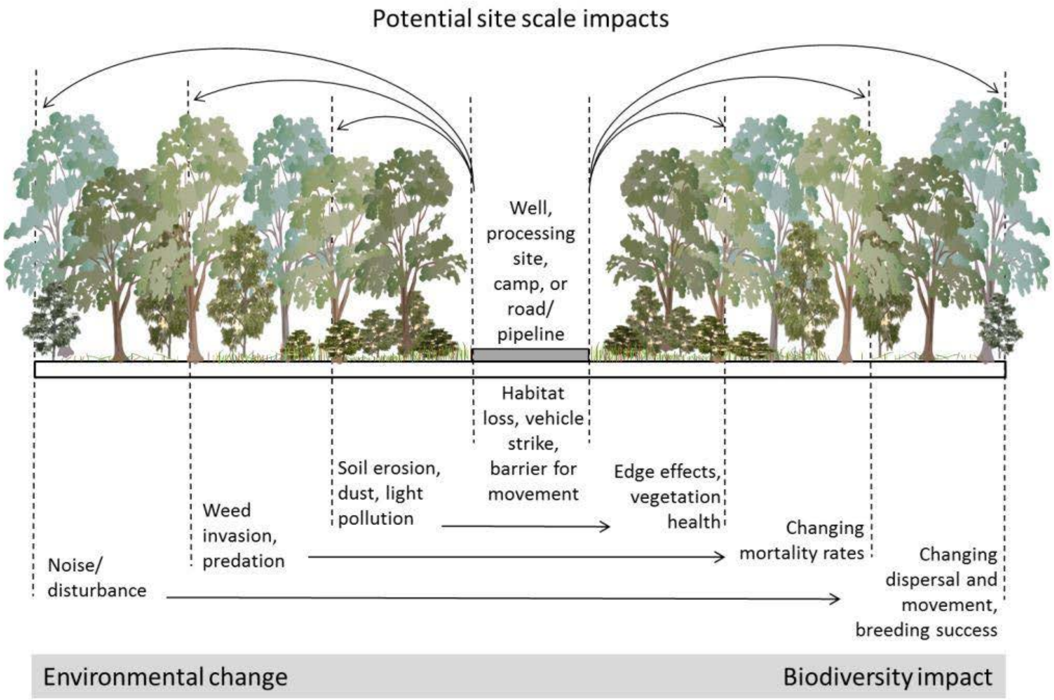


Figure 1: Conceptual diagram of potential site-scale effects of CSG infrastructure and operations on the surrounding ecosystems.

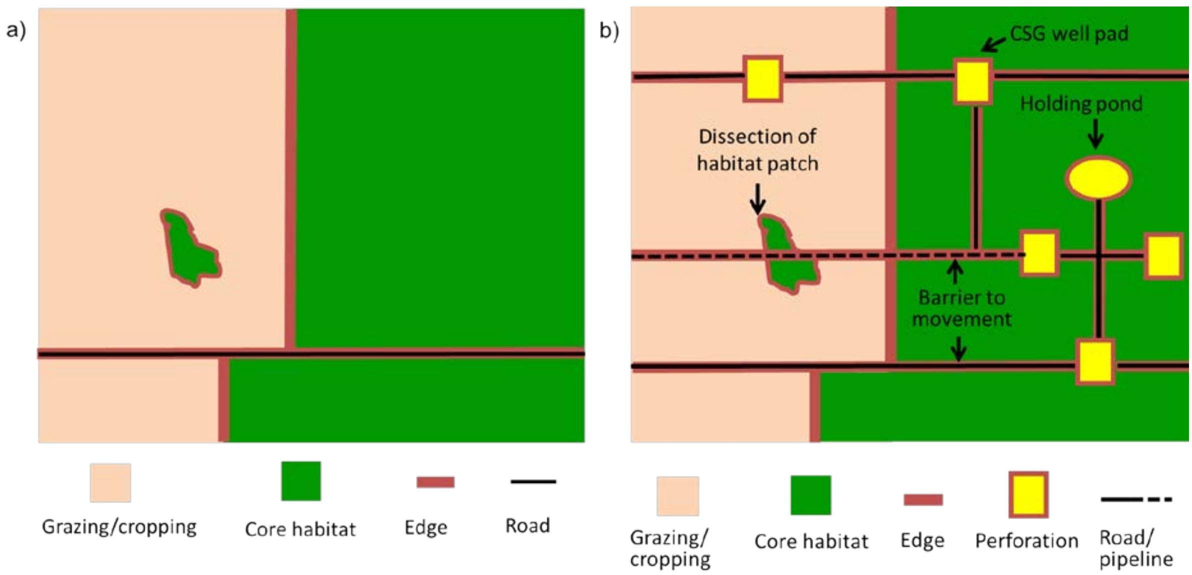


Figure 2: Examples of changes to landscape-scale patterns before (a) and after (b) CSG development that affects core or fragments of remnant vegetation.

A: SCIENTIFIC LITERATURE REVIEW

Methods

The literature reviewed consisted of academic and government publications sourced from the Web of Science (v. 5.9) database and the Google search engine, with a combination of the following search strings used: coal bed methane and coal seam gas and (landscape), and (wildlife) and (fragmentation), and (habitat), mining and (fragmentation) and (habitat) and (landscape), infrastructure and (wildlife), roads and (wildlife) and (edge effect).

Key Findings

Historical land-use impacts

In Queensland, native biodiversity is in decline due to the cumulative impacts of extensive historical broad scale clearing of native vegetation for agricultural development (McAlpine *et al.* 2002; Seabrook *et al.* 2006), urbanisation (Catterall *et al.* 1998) and logging of native hardwood forests (Maron *et al.* 2012). Historically, in the southern Brigalow Belt from 1840-2000, the percentage of remnant vegetation declined to approximately 40%, with *Acacia* declining to less than 20% (Seabrook *et al.* 2006). Long-term, such clearing in brigalow is predicted to require at least 90 years of recovery before regrowth regains 90% of its species richness and structural characteristics (Bradley *et al.* 2010). As remnant and regrowth forests and woodlands on private and public land are important refuges for threatened species and other wildlife (e.g., koala; Adams-Hosking *et al.* 2012), it is important for effective regulation and long-term planning in industry to determine whether newly emerging land use changes will contribute to the declining biodiversity in Queensland.

Landscape change: habitat loss and fragmentation

The loss and fragmentation of habitat is one of the potential effects of CSG developments. In the USA, it is estimated that an individual CSG well typically disturbs 1.6 hectares, with up to five wellheads, multiple access roads, gas collection pipelines, a water disposal mechanism and power lines or generators (Bergquist *et al.* 2007). The 50,000 wells in the Powder River Basin are estimated to require the construction of 27,000 kilometres of new roads and 32,000 kilometres of pipelines. Potential environmental impacts include drilling, the development of infrastructure such as pads, pipelines, dams and access roads (Bergquist *et al.* 2007), and withdrawal and disposal of the co-produced water into nearby streams (Flores *et al.* 2001). Kiviat (2013) pointed out that there has been little study of the impacts of high-volume horizontal hydraulic fracturing (HVHHF) on habitats and biota for (shale) mining natural gas in Pennsylvania. This author asserted that impacts on freshwater organisms (e.g., Brook trout, freshwater mussels), fragmentation-sensitive animals (e.g., forest-interior breeding birds, forest orchids), and species with restricted geographic ranges (e.g., Wehrle's salamander, Tongue-tied minnow) are potentially serious due to the rapid development of HVHHF over a large region.

Fragmentation has considerable consequences for animal biodiversity, predominantly due to resource availability being significantly reduced. For example, in China, forest harvesting, mining, seismic oil and gas exploration and production have fragmented the habitat of the Giant panda (Mang *et al.* 2007). Fragmentation and perforation (e.g., by roads) can lead to increased exotic species invasion into remnant vegetation, including dominant grasses (Fairfax and Fensham 2000) and pest vertebrates, such as European red foxes (Graham *et al.* 2012). In particular, highly fragmented agricultural landscapes are more likely to have elevated levels of invasive-predator activity from foxes and Feral cats than in remnant vegetation (Graham *et al.* 2012).

Native fauna composition and dominance can also be influenced, with high road densities and disturbance in forests linked to the proliferation of native "pest species", such as Noisy miners, an aggressive honeyeater that excludes other small passerine birds such as wrens, thrushes and finches (Maron 2009; Eyre *et al.* 2009). Additionally, small perforations (~7 ha) within forests can influence the ecological processes in most of the surrounding forest due to the pervasiveness of edge effects (Riitters *et al.* 2002). This factor may have consequences in the Queensland gasfields where there is clearing of small areas of forest for CSG gas well pads and pipelines.

<u>Edge effects</u>

Edges are widely acknowledged as having an important role in the distribution, abundance and persistence of species (Harper *et al.* 2005) and their effect is complex and specific to different species and habitats. The variability in species response is associated with resource distribution and use (Ries *et al.* 2004) and other biological requirements (Schlaepfer and Gavin 2001). Local factors such as climate, edge characteristics, stand attributes, and biotic (living) factors affect edge contrast (Harper *et al.*, 2005) and the shape of, and distance from, the edge of vegetation patches influence the intensity of edge effects (Lindenmayer and Fischer 2006).

Despite these complexities, if it is possible to predict the intensity and response of animal populations to edge effects, these predictions could be used in management plans to attenuate the detrimental effects of fragmentation exposure to edges (Murcia 1995). Management approaches that acknowledge the potential for edge interactions are particularly important in fragmented landscapes (Porensky and Young 2013), such as the Brigalow Belt region.

Increasing scientific knowledge about edge effects, and the predominance of edge effects in dispersed resource extraction (i.e., CSG and shale gas wells), could lead to regulation on these specific issues. It is important that such regulation is based on well-founded science and systematic research rather than an alarmist focus on specific species or habitats.

<u>Roads and wildlife</u>

The study of roads and wildlife is a burgeoning research area due to the human costs associated with collisions with large mammals and the impacts on wildlife from landscape fragmentation due to roads and subsequent road strikes (Taylor and Goldingay 2010). Some species benefit or show no response to roads and related infrastructure, including insects in leaf litter (Delgado *et al.* 2013), lizards (Schlaepfer and Gavin 2001), carrion feeders, and small mammals and birds (Fahrig and Rytwinski 2009). However, various negative effects of roads have been observed for other species. For example, the density and distribution of amphibians, reptiles, birds and medium to large mammals tends to decline (see reviews in Fahrig and Rytwinski 2009; Benítez-López *et al.* 2010). Species with lower reproductive rates, greater mobility, and larger body sizes have been shown to be more susceptible to negative effects of roads and traffic (Rytwinski and Fahrig 2012).

Animal mortality by road strikes is a direct negative effect, with an estimated one million vertebrates killed on USA roads each year (Lalo 1987). In Australia, road fatalities have increased pressures on local populations of the Swamp wallaby (Ramp and Ben-Ami 2006) and native Swamp rats (Stephens *et al.* 2013). Indirectly, roads can create barriers to wildlife movement, subdividing wildlife populations with demographic and probably genetic consequences (Forman and Alexander 1998). Roads and dirt tracks as narrow as 3.6 metres can inhibit the movement of fauna (Richardson *et al.* 1997), due to the creation of 'hostile' or open habitats (increasing predation risk) and the abrupt habitat change of roads and tracks in forest or woodland habitats (Burnett 1992). Additionally, road avoidance due to traffic noise can significantly decrease bird densities (Forman and Alexander 1998).

Gas infrastructure and wildlife

Most quantitative research into the effect of CSG activities and infrastructure on wildlife has been in the USA. For example, the Greater sage-grouse (a ground-dwelling bird) has been particularly studied due to the decline it is range and its requirement for specialised sagebrush (*Artemisia* spp.) habitat, which occurs in many areas of gasfield development. For example, in Wyoming, the direct impacts of natural gas development account for a relatively small area; however, the cumulative direct (e.g., loss of habitat) and indirect impacts (e.g., degradation of habitat) has altered a substantial amount of big sagebrush habitat (Walston *et al.* 2009). Furthermore, due to the rapid, widespread changes to their habitat due to natural gasfield development in Wyoming and Montana, the number of male Greater sage-grouse observed on leks (communal areas for courtship displays) has reduced (Walker *et al.* 2007). In light of such research, there are recommendations to avoid CSG activities in sage-grouse breeding habitats (Connelly *et al.* 2000), with integration of the protection of these birds and other important wildlife habitat into management guidelines recently introduced (e.g., Wyoming Game and Fish Department 2010). This demonstrates that systematic research on a single species and its habitat can lead to habitat guidelines, which can affect the nature and extent of gasfield development.

Negative effects of gas infrastructure and subsequent landscape change on other species have been predicted or observed. Populations of Pronghorn (an antelope-like mammal) and Mule deer abandoned habitat close to well pads and infrastructure in Wyoming gasfields (Beckmann *et al.* 2012; Sawyer *et al.* 2006). Additionally, coal-bed methane wells contributed to environmental contaminant exposure of Bald eagles in Montana and Wyoming due to contamination in the fish they consume (Carlson *et al.* 2012). As Bald eagles are a protected species, such research may lead to additional controls on CSG regulation and operations.

Dust, noise, vibration and light

The construction and operation of roads, facilities and infrastructure for CSG developments can result in the production of dust, noise, vibration and light. Increased dust deposition can affect vegetation health (Doley and Rossato 2010) and habitat quality. Noise, vibration and light emissions can provide either beneficial or detrimental influences on the breeding and foraging behaviour of wildlife.

The impacts to fauna of dust accumulation on roadside vegetation may be dependent on how such areas are used. For example, the foraging distribution of grazing ungulates (e.g., zebra and buffalo) in Tanzania was influenced by vehicle dust on roads, with animals avoiding the dustier side of the road (Ndibalema *et al.* 2008). Conversely, for animals that use road verges as habitat, dust may have a minor effect; small ground-dwelling mammals in a Brisbane forest patch were as abundant close to dusty roads (5-10 m) as at a distance (60-100 m) (Jones *et al.* 2012).

Noise is generally detrimental to wildlife, disturbing behaviour and health. Behavioural modifications due to noise have been observed in laboratory studies for open-cut mining in Queensland (Clive Phillips, personal communications). Conversely, a study by McGregor *et al.* (2008) suggested that small mammals avoid the road surface itself rather than the noise from traffic. Elevated stress levels were found in Greater sage-grouse due to natural gas drilling and road noise, which may lead to avoidance of otherwise suitable habitat (Blickley *et al.* 2012). Such avoidance behaviour due to road noise has been observed in bat species (Bennett and Zurcher 2012) and Caribou (Dyer *et al.* 2001), with changes in behaviour extending up to 250 m on either side of roads (Dyer *et al.* 2001). Consequently, these influences can result in barrier effects (e.g., reducing local movement for resources and breeding) as described in the section above on *Roads and wildlife*.

The influence of vibration on wildlife is relatively unknown. However, vibration has been found to cause early hatching of reptiles in Australia which can pose problems for animal health and population survival (Doody and Paull 2013). Research on the impacts of artificial lighting is increasing, with somewhat contradictory findings. For example, artificial light can either provide a concentrated food source such as insects, increasing foraging efficiency, or completely deter foraging in microbats (Rydell 2006).

Summary of key findings from the scientific literature review

1. There has been little scientific research on the potential impacts of CSG activities and infrastructure on biodiversity in Australia (Appendix 2). For example, a search on the Web of Science, a database that provides access to current multidisciplinary information from high impact research journals using the keywords ‘coal seam gas’ and ‘biodiversity’, revealed only one scientific paper. This single paper examined the microbiology of coal (Midgley *et al.* 2008), which is not relevant to biodiversity in the context of this report. The majority of CSG and biodiversity research has been conducted in the USA, yet it is still not abundant (Appendix 3). The key findings from the USA literature suggest that for the species that have been studied, CSG or CBM/shale-related activities are having ecological impacts on these animals. Although there is a larger body of literature globally on the impacts on wildlife from various types of mining, this is not specific to CSG or CBM. As indicated above, species react differently to human disturbance, with some benefitting from changes in conditions and others declining. The lack of knowledge about the response of Australian species may mean that current CSG industry management plans will not effectively address impacts of operations on threatened species, and additional remedial actions or regulation may be required.

2. Australian ecosystems are different to ecosystems in other parts of the world, such as the USA. Most CSG-related environmental literature in Australia is currently focussed on aquatic ecology and ground and surface water quality, and there is a clear gap in research and knowledge regarding the potential impacts on terrestrial biodiversity from CSG activities in Australia.

3. The potential impacts on biodiversity from CSG activities identified from the scientific literature review extend across different spatial scales and are highly varied according to the species being studied (Table 1).

Table 1: Key research topics identified from the scientific literature review

CSG and biodiversity		
Site-scale effects	**Landscape-scale effects**	**Regional-scale effects**
↓	↓	↓
Edge effects:	**Landscape change:**	**Synergies:**
• Habitat loss and degradation for animals and plants with small ranges • Gap crossing • Noise, dust, light • Invasive species (plant and animal)	• Landscape-level effects associated with habitat loss, fragmentation, subdivision and perforation • Scaling up site-scale effects • Impacts of linear infrastructure such as pipelines, roads and increased traffic volumes	• Effects on species' distributions, resilience and persistence • Interactions with existing threats (e.g. climate change, clearing for agriculture)

B: LEGISLATIVE AND INDUSTRY LITERATURE REVIEW

Methods

The Environmental Authorities (EAs) of 18 Petroleum Leases (PLs) and 20 Petroleum Pipeline Licences (PPLs) were broadly reviewed to collate the range of environmental conditions imposed on CSG operations. The list of selected EAs (Appendix 4) was determined by searching the Public Register of Environmental Authorities (DEHP 2013b) for PLs or PPLs that were operating in local government authorities within or bordering the Brigalow Belt and that predominantly involve CSG activities. This list was correct as at April 2013, and Authority to Prospect tenures were not reviewed. Where referred to in EAs, other government documents and guidelines were considered (e.g., Australian Standards, Petroleum Industry [including CSG] Minimising Pest Spread Guidelines). The Environmental Management Plans and supporting documentation from the four major CSG proponents operating in Queensland were reviewed to determine the typical controls undertaken by CSG companies to mitigate or minimise potential environmental impacts.

Key Findings

Habitat loss, fragmentation and edge effects

As described above, habitat loss, fragmentation and associated processes are recognised as a significant potential effect of CSG activities, due to the inherent spatial design of wells, Right of Ways (ROWs) and access tracks.

Clearing is restricted in environmentally sensitive areas in the environmental conditions for CSG operations, with industry practices further protecting other remnant vegetation where possible. Specifically, approximately 23% of the current 5,961 wells are within remnant vegetation according to data analysed from DEHP (2013c) and DNRM (2013a). Minimising the fragmentation of remaining vegetation is also an objective in environmental management plans; however, this is difficult in areas where CSG wells and ROWs coincide with large blocks of remnant vegetation. Clearing in such instances is typically restricted to a width of 6-10 metres for roads and is rehabilitated as soon as practicable.

Whether such fragmentation and perforation still provides a barrier for local fauna movement and genetic exchange in the Brigalow Belt is unknown. Additionally, as mentioned in the scientific literature review above, edge effects from roads may resonate further into the adjacent vegetation than the road width alone and remain for a considerable time after rehabilitation.

Noise/vibration, dust and light

Regulatory conditions state that noise, vibration, dust and light must not cause an environmental nuisance at sensitive places. For terrestrial biodiversity, this incorporates protected areas (as per the Nature Conservation Act 1992), which for the Brigalow Belt bioregion, comprises mainly of national parks.

Monitoring of these emissions must be undertaken if a complaint has been received to determine if the described regulatory limits have been exceeded. Additionally, operations must develop and implement a Noise Monitoring Plan, which details the monitoring procedures and the complaint process. Also required is modelling and assessment of operational activities for potential nuisance sources.

Similarly, selected EAs require the proponent to notify and consult with any potentially affected persons prior to commencing dust-generating activities. CSG companies also use various controls, including prioritising the use of electricity or gas over fuel generators (noise), minimising clearing, and watering roads (dust), utilising hoods or shields to deflect light from non-essential areas and positioning CSG facilities (e.g., processing plants) in areas away from dwellings and remnant vegetation.

However, both the regulatory conditions and industry practices target humans or protected areas when minimising emissions. In particular, the reliance on a complaint being lodged for the investigation of a nuisance in protected areas reaffirms the priority to humans and their occupancy/visitation of an area. As only 6% of remnant vegetation within the Brigalow Belt has protected area status (data from DNRM 2013a, 2013b), regulatory conditions that are only applicable to declared protected areas may be inadequate to conserve sustainable levels of biodiversity at the landscape scale. Although industry practices attempt to limit impacts on remnant vegetation and the subsequent inhabiting fauna, whether these current controls and practices are effective for conserving biodiversity in the wider region – for addressing cumulative impacts - is not yet known.

<u>Animal pests</u>

Several introduced animals are widespread on the reviewed petroleum leases, including foxes and feral cats. As these are declared Class 2 pests, landholders are required to control manage these animals as per the *Land Protection (Pest and Stock Route Management) Act 2002*. In particular, in Australia foxes and feral cats are credited with causing the extinction of at least 18 native mammals and the decline in overall biodiversity (Johnson *et al.* 2007).

Current environmental conditions typically require the development and implementation of a Pest Management Plan, which includes the identification, distribution and control of pests that increase due to CSG activities. Industry procedures often follow these conditions, with some operations continually monitoring and actively managing pests. Other CSG operations propose that pest management is not feasible due to the transient nature of many pest species. In addition, key performance indicators of pest and weed management plans are often weed-oriented, with little quantitative measures on pest species.

The potential impacts of pest animal proliferation due to CSG-related activities are likely to be minimised where continual active monitoring and subsequent control measures are conducted. Where such measures are not incorporated, there is an increased risk to terrestrial biodiversity. In particular, foxes and feral cats are known to increase in number in fragmented and perforated landscapes, which provide additional movement corridors with easy access to adjacent cover (Graham *et al.* 2012). As various CSG infrastructure incorporates linear clearing for construction and/or continued access and maintenance (ROW, well access tracks, etc.), fox and cat numbers may proliferate within and surrounding project areas. Such pests have particular bearing for threatened species in the CSG gasfields, with several species known to be predated upon by foxes and/or cats (DEWHA 2008a, 2008b).

Given the preference of pest animals to use linear landscape disturbances (such as those caused by CSG activities), the impact of pests on threatened wildlife and overall biodiversity is currently a significant unknown. Such information is important due to feral animals being recognised as serious threats to native animals and plants (Australian Government 2011). In particular, as various threatened species are known to be negatively influenced by pest animals, this has further implications for the CSG industry Significant Species Management Plans if current pest management practices are inadequate.

Direct fauna harm or mortality

Various CSG activities could cause injury or death to native fauna, which may in turn influence overall biodiversity.

Relocations and pipeline trenching

Legislative conditions require fauna management procedures to be developed and implemented by suitably qualified persons. As a result, CSG company environmental plans adopt various measures to mitigate harm, including: 1) qualified spotter-catchers conducting searches prior to clearing; 2) translocation of hollow limbs/trees or other nesting material to adjacent undisturbed habitat; 3) pipeline trenches open for minimum time possible, with various ramps/escape avenues and regularly checked for entrapped animals; 4) pipes capped prior to full installation to prevent use by fauna; and 5) temporary exclusion fences around trench lines. Records of relocations are typically submitted to regulatory or government/research institutions.

Although not isolated to CSG operations, it is unknown whether fauna relocations to adjacent undisturbed habitat will ensure long-term survival of the individuals. For example, if food or nesting sources are scarce, relocations may create an increased strain on resources leading to starvation or increased predation risk. Additionally, some species are highly territorial, which may produce conflict when combining individuals or populations, particularly for animals with small home ranges.

Research on whether relocated individuals persist in their new habitat would provide confidence that this practice, which attempts to mitigate impacts on fauna as required in EAs, is an appropriate procedure or whether alternatives need to be sought.

Wildlife drowning in lined dams

There is a potential risk of fauna drowning in the increased number of lined dams or ponds associated with CSG activities (e.g. construction of 31 dams for one project, with ponds covering138, 000 hectares). Current environmental conditions state that all dams must be fenced to prevent or minimise access and entrapment of livestock and wildlife. Typically, CSG fencing aims to restrict livestock access, but few plans detail fencing to prevent access by wildlife (particularly small-bodied species).

Although acknowledged as a potential impact in industry EISs, there is minimal literature available on the risk of wildlife drowning in lined water bodies. Alternatively, these water bodies may contribute positively to biodiversity, by providing an otherwise uncommon habitat in semi-arid areas (particularly for waterbirds), as seen at other mineral extraction projects in Queensland (E. Williams, A. Fletcher and P. Erskine, pers. observations). Further research is warranted to determine if CSG water bodies are beneficial or detrimental to biodiversity, and, if the latter, whether further mitigation measures are required.

Road strikes

Although fauna mortalities due to vehicle strikes are acknowledged in EIAs and EMPs, there are no direct regulatory conditions relating to this potential effect. Industry practices to mitigate vehicle strikes include limiting speed on project-controlled roads in high fauna areas, training staff in regard

to driving safety, and assessment of collisions. It is often stated that CSG traffic will primarily be outside the peak fauna activity times of dawn, dusk and night.
Whether the current industry practices alleviate vehicle strikes is unknown. Considering the body of evidence of road effects on animals (see scientific literature review above) and the increased traffic in CSG project areas (GasFields Commission Queensland 2013), this knowledge gap is of concern.

Potential cumulative impacts

Cumulative impacts arising from the above potential CSG effects are particularly important due to their difficult detection and often subtle or protracted onset within one area or time period. Therefore, biodiversity values may be compromised before an impact is detected. Before April 2013, EAs often stated that reports on cumulative impacts (including regional impacts on terrestrial flora and fauna, biodiversity values and listed species and ecosystems) were to be submitted to the Queensland Government CSG Industry Monitoring Group. However, this group was not formed, with the required information on cumulative impacts expected to be met within other CSG project reporting requirements (Helen Schultz, pers. comm.). In terms of industry controls and practices, cumulative impacts are predominantly or solely mitigated by the prevention or minimisation of clearing.

Considering cumulative impacts may be formed at various temporal and spatial scales, and hence across several CSG companies or reporting timeframes, it would be difficult for individual companies to quantify and monitor at company level due to the lack of available data from other CSG companies. As such, it is unknown whether the procedures implemented to replace the role of the CSG Industry Monitoring Group on tracking cumulative impacts are adequate.

Summary of key findings and knowledge gaps identified from the legislative and industry literature review

The main findings and mitigation of impacts on biodiversity from the legislative and industry literature review are outlined in Table 2. In particular:

1. It is not known whether current practices mitigate the effects of habitat fragmentation and the associated ecological processes (such as edge effects).
2. There is inconsistent monitoring and management of pests between the various CSG operations. Additionally, monitoring the effects of noise, vibration, dust and light is currently oriented only toward humans.
3. The extent to which CSG operations contribute to wildlife mortality is unknown. Furthermore, wildlife survival after relocation is not followed, monitoring for wildlife road strikes is opportunistic, and whether lined dams are a hazard or a haven is yet to be determined.
4. It is unknown whether the current government methods for collating and assessing data will detect cumulative impacts, nor is it known if current practices to mitigate any potential cumulative impacts (if found) are adequate.

Such knowledge gaps have the potential to lead to future biodiversity and environmental degradation, as current management and mitigation attempts may not address the impacts of CSG infrastructure and operations on native biodiversity. This may lead to increased financial expenditures for the CSG industry in the future, such as amplified management costs to remedy impacts caused by the current practices and/or social licence difficulties.

Table 2: Summary of the potential effects on biodiversity of CSG operations, including an evaluation of detection and mitigation.

	Scale of impact on biodiversity	Under current regulatory conditions and industry practices, likelihood of: Detection	Mitigation	Reason for '?' scores
Habitat fragmentation and associated effects	Patch – Landscape	✗	?	Not known whether current practices mitigate fragmentation
Noise/vibration, dust and light	Site - Patch	?	✓	Monitoring targeted to humans and their occupancy/visitation or in protected areas
Animal pests	Patch – Landscape	✓ / ?	✓	Inconsistent monitoring of pests between CSG operations
Direct fauna harm or mortality: • Relocations • Wildlife drowning • Road strikes	Site - Patch	? ✗ ?	✗ ✗ ? / ✓	Survival after relocation is not known Monitoring for road strikes is opportunistic and whether subsequent controls will suitably mitigate the impact is unknown
Potential cumulative impacts	Landscape	?	?	It is unknown whether the current government methods for collating and assessing data will detect cumulative impacts, nor if current practices mitigate any potential cumulative impacts (if found)

C: WORKSHOP - RESEARCH QUESTIONS AND RESEARCH TOPICS

The aim of the stakeholder workshop was to identify key questions that would help to develop future research priorities on the potential impacts of CSG on terrestrial biodiversity, by stimulating discussions between CSG industry environmental representatives and government, research scientists and environmental consultants. The outcomes of these discussions were then compared with the topics identified in the review of scientific and industry documentation.

Key Findings

Two science and two management questions within the relevant key research topics were identified in the workshop (see Appendix 5 for further details within each question):

<u>Science Questions</u>

1. What are the multi-scale, multi-functional response of plants, animals (mammals, birds, reptiles, amphibians, invertebrates) and wetlands/riparian ecosystems, to CSG infrastructure and operations, and how does this impact vary across multiple land-uses such as farming and bushland.

2. What are the alternative futures for biodiversity from different restoration and landscape management approaches in CSG-resource development regions, and what strategies can enable the CSG industry to leave a positive legacy for biodiversity in CSG-resource regions?

<u>Management Questions</u>

3. How do we effectively embed ecological science into on-ground practice to minimise negative impacts of CSG infrastructure and operation on terrestrial biodiversity?

4. How do we better integrate existing data collected by CSG industry and consultants during the EIS process? Such integration efforts would include how to develop measuring and monitoring standards to ensure that future data is consistent between collectors.

D: RECOMMENDATIONS FOR BIODIVERSITY RESEARCH FROM CSG INDUSTRY REPRESENTATIVES

The stakeholder workshop facilitated further discussion with CSG industry representatives on research topics that the industry considered to be a priority. The four main themes recommended are shown below, with further detail in Appendix 6.

1. A strategic evaluation of threats (encompassing all land uses and histories) and identification of research priorities for biodiversity in the Brigalow Belt.
2. Research on habitat and species distribution, including mapping and modeling, with implications for management and mitigating impacts, particularly of threatened species and relating to cumulative impacts.
3. The impacts of edge effects and fragmentation on pest species (flora and fauna) and the subsequent risk to native species and habitats.
4. Development of CSG industry specific restoration and rehabilitation criteria and monitoring methods.

E: PRELIMINARY INVESTIGATION USING REMOTE SENSING DATA

The ability to rapidly and quantitatively identify baselines and assess variability and changes in vegetation over time would be an extremely useful management tool. Remote sensing imagery offers an opportunity to do this, where satellite or airborne images of vegetation condition can act as a surrogate for biodiversity.

Although there is no academic literature that explicitly employs remote sensing applications to assess potential impacts of CSG on biodiversity, remote sensing technologies are currently being investigated for its applicability to monitor CSG infrastructure in Queensland.

Background

The Australian Government recognises that measuring the extent (abundance and distribution of vegetation types) and condition (quality of vegetation; Bleby *et al.* 2008) of native vegetation are important surrogates for indigenous biodiversity. Extent and condition are used as two of the indicators of regional biodiversity in order to evaluate Commonwealth investments in regional biodiversity conservation (Higgins 2006). There is some question over the usefulness of some current landscape surrogate measures, such as vegetation mapping as sole indicators, as they may not be biologically and statistically significant for all elements of the biota (Lindenmayer *et al.* 2002); that is, they may not provide a trustworthy measure.

However, there is a growing trend of using vegetation condition in a broader regional context to monitor and report on progress and achievement of aims of regional, state and national administration of the landscape and biodiversity (Nelder 2006; Bleby *et al.* 2008). Remote sensing data and analyses can provide a relatively inexpensive means of deriving environmental information, including vegetation condition, in a consistent and regular manner to complement field-based research (Sheffield 2006; Bleby *et al.* 2008; Feilhauer *et al.* 2013).

Such data is important in the identification and protection of areas of high conservation value because many areas are large, not easily accessible, subject to change, or sensitive to the surrounding landscape (Muchoney 2008). Remote sensing (satellite and airborne) data can be critical in identifying conservation priorities, establishing and managing protected areas, monitoring conservation targets and evaluating strategies (see review in Wiens *et al.* 2009). Specifically, hyperspectral (with narrow bandwidths and many bands in the electromagnetic spectrum) and high spatial resolution imagery has increasingly gained relevance in biodiversity applications. It has been used to determine: 1) the potential to detect community composition providing direct insights into spatial ecological patterns (Schmidtlein *et al.* 2012); and 2) tracking plant invasions and assessing habitat and species diversity (Rocchini *et al.* 2010; He *et al.* 2011). Time series information (e.g., photographs captured daily, weekly, or monthly) is also important for identifying and forecasting natural variability in vegetation, disturbances, and biodiversity change (Verbesselt *et al.* 2012).

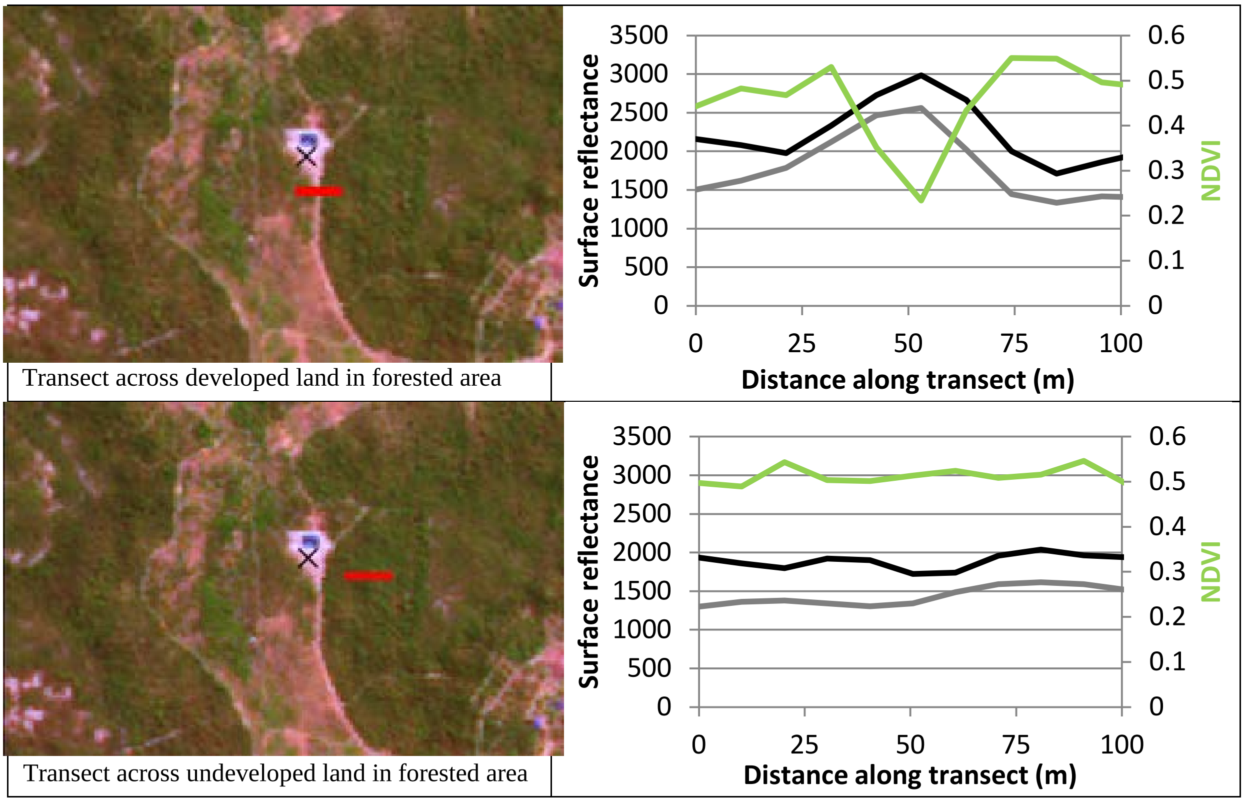
Data

A sample site was chosen from the CSG gasfields southwest of Chinchilla that contains multiple land uses. Imagery from the SPOT 5 satellite from 6th May 2004 and 4th April 2005 at 10 metre spatial resolution were provided by the Remote Sensing Centre of DSITIA. In addition, a satellite-acquired foliage projective cover (FPC) index that represents a measure of overstorey foliage cover (Danaher *et* *al.* 2010), computed from a multiple linear regression model derived from the surface reflectances of the SPOT imagery was acquired from DSITIA. Further information on the methodology and analyses undertaken are provided in Appendix 5.

Key findings

Using topographically corrected surface reflectances, a ‘greenness’ index (Normalised Difference Vegetation Index [NDVI]) was calculated as a proxy for identifying spatial changes in vegetation condition in the sample study area. There was distinct variation between developed and non-developed areas in both 2004 and 2005 (Figure 3) across a forest area.

Annual differences in the amplitude of surface reflectances are visible between 2004 and 2005. That emphasises the need for time series information to identify variability from natural changes in vegetation. The sensitivity of the NDVI for the developed- versus the forested- transect is distinct given the spatial and spectral resolution of the available imagery from the SPOT sensor. It may be possible to differentiate and assess vegetation condition or other vegetation properties and landscape characteristics that have been influenced by other land uses (such as agriculture) in comparison to CSG activities. However, the viability this approach requires further analysis than could be achieved for this document.



Transect across developed land in forested area

Transect across undeveloped land in forested area

Figure 3: An example of the use of remote sensing technologies to detect differences in surface reflectance (black line: 2004, grey: 2005) and vegetation condition (green: calculated NDVI from 2005 reflectance imagery) across a developed forest area and an undeveloped forest area. Satellite images on left are from SPOT 2005 RGB with transects depicted by red lines.

Summary of key findings of the remote sensing sample investigation

1. For several decades, remote sensing data, science and related applications have been used to guide and complement field-based assessments of a wide array of issues related to ecosystem science; they have been employed across various spatial scales (site, patch, landscape, regional, global) including the capability to function as proxies for biodiversity value.

2. There has been little, if any, scientific research specifically on how remote sensing can assist in assessing the potential impacts of CSG and its related infrastructure on biodiversity in Australia.

3. Rapid developments in remote sensing sensor technologies, data acquisition, data processing and analysis capabilities promise to deliver many opportunities for targeted and multi-disciplinary synergies to assess and quantify the impacts of land-use (including CSG) on biodiversity.

Specifically, the analysis of higher spatial resolution and hyperspectral imagery could effectively provide a baseline (such as vegetation condition and/or invasive species distributions) for future monitoring and management. The analysis of a combination of remotely sensed structural and biophysical vegetation information could substantially advance the identification of habitat diversity and quality, the quantification of significant changes in land cover (such as disturbances), and the improvement or validation of existing classifications of the landscape. However, analysis of time-series is imperative to ensure that human impacts are differentiated from natural variation.

Implications from acquiring, storing, analysing and integrating data from different remotely sensed sensors for industry and government are manifold. They range from an improved understanding of the ecosystem under investigation (such as the decomposition of time series of data into natural and human induced signals) and an improved data pool, with increased options to operate and report transparently. The timely, appropriate and accurate monitoring and oversight of different CSG activities require reliable data critical to understanding developments, ensuring compliance and responding to incidents relating to CSG (which is a recommendation of the NSW Chief Scientist and Engineer; NSW CSE 2013). By using time series information, industry and government could access and use more reliable, repeatable, and up-to-date data that has the potential to be more cost-effective than the current methods of field work and remote sensing data. The additional time series information would ensure a commitment to high levels of monitoring, with data quality, monitoring effectiveness and financial benefits likely to improve through time. For example, the identification of a pre-, during-, and post-CSG status (condition, structure and composition of the land cover) at landscape/regional scale and at different temporal scales could be possible, as well as providing tools for quantifying and analysing cumulative impacts of multiple activities sharing the same space.

FUTURE RESEARCH AREAS AND PRIORITIES

This scoping study identifies a number of common areas where scientific research can address the major knowledge gaps identified from reviews of scientific literature, environmental assessments and expert opinion, as summarised in earlier sections. Although it is recognised by the scientific and CSG industry communities that CSG activities will potentially impact terrestrial biodiversity (e.g. QGC 2009; APLNG 2012; CSIRO 2012a, 2012b; Santos 2012; Williams *et al.* 2012; Arrow Energy 2013), no independent research has been completed to date in Australia to address these knowledge gaps. Failure to understand the effect on Australian species may mean that current CSG industry management plans will not effectively address impacts of operations on threatened species, and additional remedial actions or regulation may be required that will increase the cost of compliance.

The Gas Industry Social and Environmental Research Alliance (GISERA) is currently in the early stages of conducting a priority threat identification project on biodiversity across the CSG development region (15% complete as at August 2013, GISERA 2013), which would somewhat resolve the first recommendation provided by CSG industry representatives (see Section D). GISERA are also conducting field research on the impacts of fire management in the grasslands near the CSG gasfields, with an estimated completion date of late 2015. However, the topics identified in this report remain largely unstudied and are of particular importance to industry with regard to successfully meeting their environmental management obligations under state and federal regulation, and minimising the potential cost of more restrictive regulation in the future.

Research priorities from this study were determined by considering the number of times and the depth that specific knowledge gaps or potential impacts were discussed in the scientific and legislative literature review, as well as at the stakeholder workshop and within research interests of the CSG industry. Priorities are ordered according to highest (largest and darkest circle) to lowest (Figure 4); for example, research on pests and weeds in relation to increased fragmentation and edge effects was raised within the literature, at the workshop and by the CSG industry.

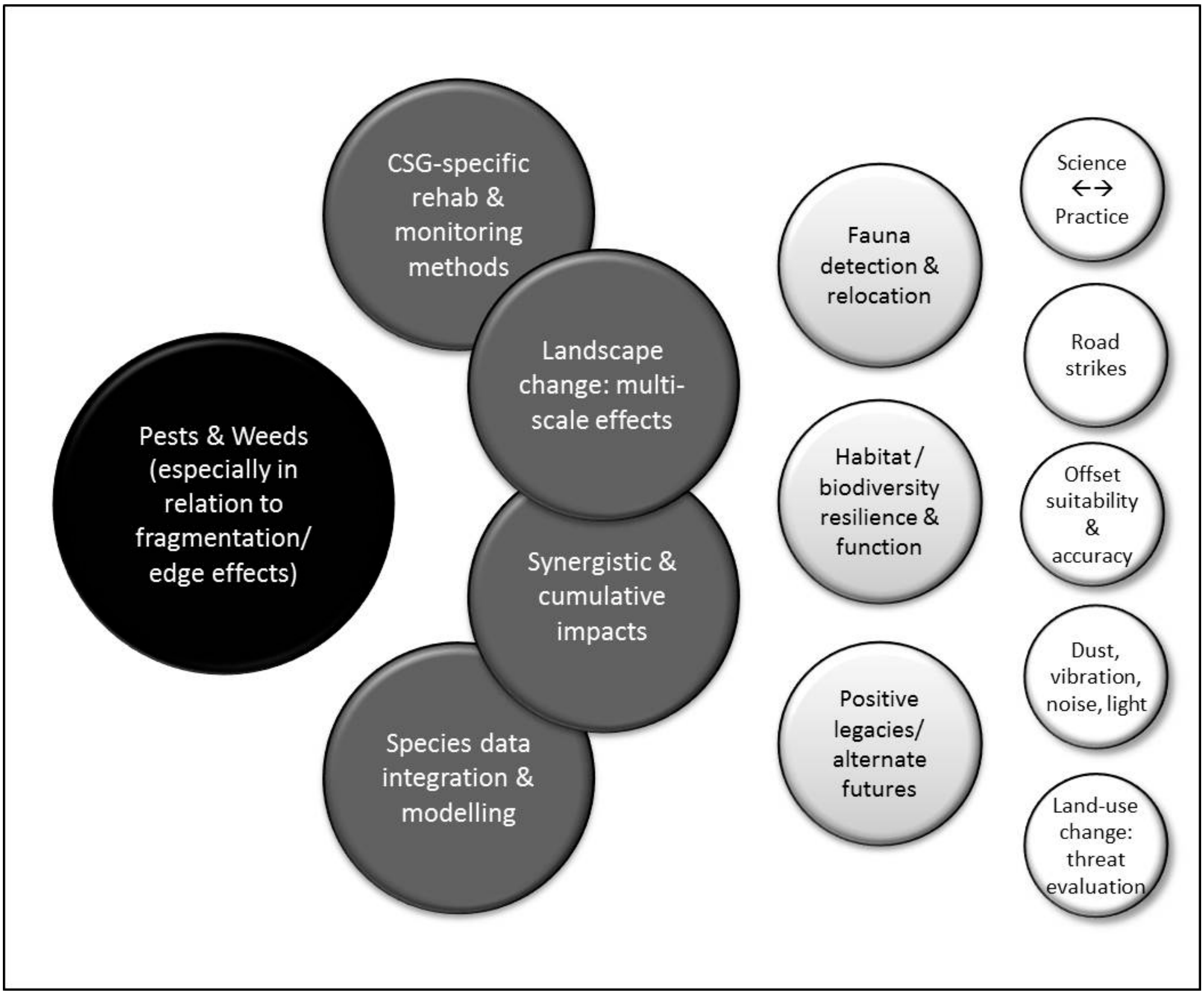


Figure 4: Knowledge gaps established during the scoping study according to priority (left: highest priority).

Three projects are considered a priority for research into the potential impacts of CSG development on terrestrial biodiversity (Table 3). These were developed in close consultation with scientists, ecologists and CSG representatives who attended the stakeholder workshop.

Table 3. Details for recommended research priority projects.

<table>
<tr><th>Project</th><th>Outline</th><th>Suggested timeframe</th></tr>
<tr><td rowspan="2">1. Pests and CSG infrastructure
Examine potential changes to pest and weed distribution and density, particularly in relation to future management costs and agricultural and environmental damage</td><td><u>Stage 1:</u> Assess edge effects and fragmentation associated with CSG roads, pipelines and well pads and impacts on native vegetation and potential increase/ introduction of pest species.</td><td>3 years</td></tr>
<tr><td><u>Stage 2:</u> Research impacts of feral predators on native species, e.g. Squatter pigeon.</td><td>2 years</td></tr>
<tr><td rowspan="5">2. Industry data repository
Develop a geographically-referenced terrestrial flora and fauna data repository by sourcing CSG Environmental Impact Studies (EIS) and monitoring programs, which can be used to determine cumulative impacts.</td><td><u>Stage 1a:</u> Develop/design (after consultation with CSG companies and environmental consultants) a central repository for future integration of current data from EISs and monitoring/management programs. This could be aligned with Western Australia’s EIS database (SEAK: Sharing Environmental Assessment Knowledge), which is currently in development, to ensure national consistency.</td><td>6 months</td></tr>
<tr><td><u>Stage 1b</u>: Develop standard methods for surveys, monitoring, and assessment to ensure consistent future data collection.</td><td>12 months (concurrent to Stage 1a)</td></tr>
<tr><td><u>Stage 2:</u> Collate and input EIS data from CSG companies for future data-mining.</td><td>6 months</td></tr>
<tr><td><u>Stage 3</u>: Use database for species mapping and modelling for threatened and indicator species.</td><td>1 year</td></tr>
<tr><td><u>Stage 4:</u> Develop methods to evaluate cumulative impacts from the database.</td><td>2 years</td></tr>
<tr><td rowspan="2">3. Best practice rehabilitation
Determine ‘best practice’ rehabilitation procedures in relation to CSG-specific disturbances to leave a legacy for the future.</td><td><u>Stage 1</u>: Assess the role of native plant and animal recolonisation/regeneration in the restoration of habitats and conduct an empirical analysis of indicators of successful rehabilitation.</td><td>2 years</td></tr>
<tr><td><u>Stage 2</u>: Characterise techniques, suitable to the CSG industry by reviewing other land uses and conducting field trials, to enable successful rehabilitation, establishing benchmarks.</td><td>3 years</td></tr>
</table>

Additional important research topics that were identified through the scoping project are listed overleaf, which complement and extend the focused research above.

- Optimise management of the effects of CSG developments and operations on the region's terrestrial biodiversity and site rehabilitation by further developing landscape-scale ecological knowledge and management tools. Studies of specific impacts would be embedded in this larger project, including:
    1. extending existing industry work on habitat mapping and ecological requirements for threatened species to a range of other vulnerable species (from the workshop and industry priorities);
    2. quantifying the edge and fragmentation effects of CSG development and operations on selected fauna and flora identified from scientific literature, environmental assessments, workshop and industry priorities (complementing project 2 above on pest species); and
    3. investigating and developing remote sensing methods to assess habitat characteristics and quality, including monitoring the progress of rehabilitation.

These examples of individual research projects could be integrated into a larger project that would assess the cumulative impacts of CSG infrastructure developments and operations on terrestrial biodiversity. It would provide the maximum benefit to the CSG industry and result in world class research. This opportunity was recognised at the Scoping Study workshop attended by representatives of the science community, local government, environmental consultants and the CSG industry.

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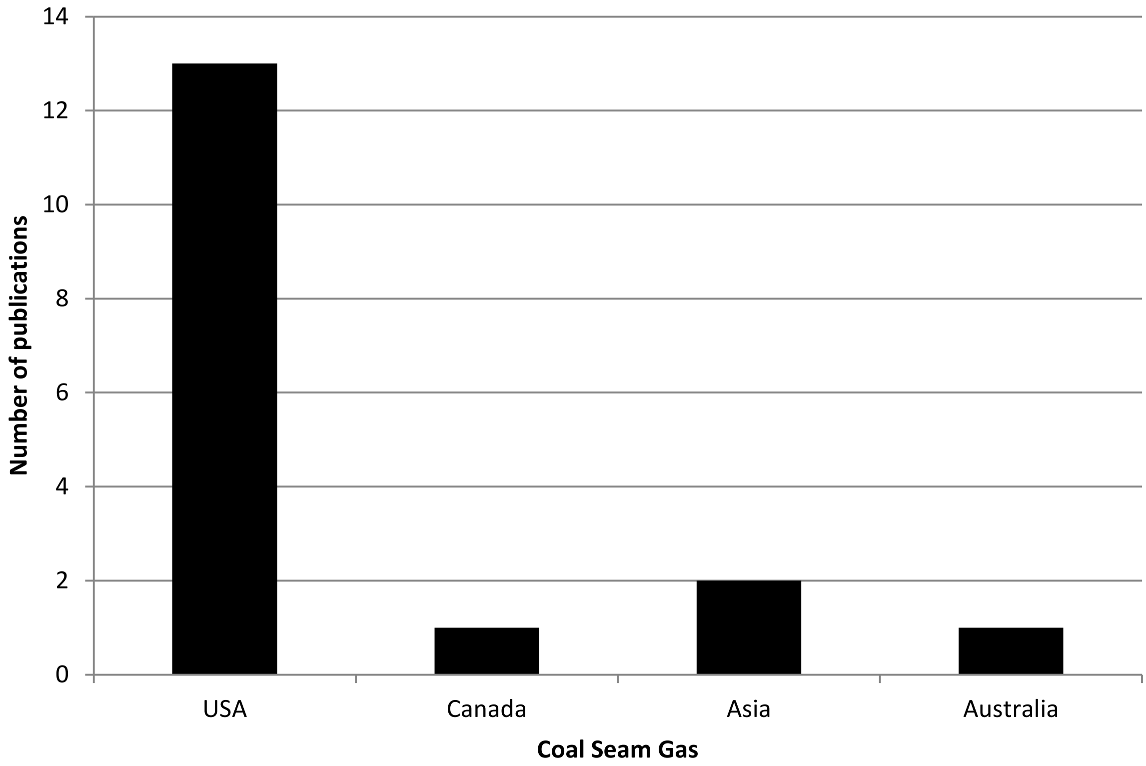
APPENDIX 1 – AVERAGE CLEARING REQUIRED FOR CSG INFRASTRUCTURE

Approximate width (for pipelines) or area (for other facilities) of clearing required for various infrastructure, as per major CSG companies Environmental Management Plans.

Infrastructure	Construction	Operation	Lifespan
Production wells	0.5-1 ha	0.01-0.5 ha	15-20 years
Gathering pipelines (width)	10-25 m	6 m	15-20 years
High pressure gas pipeline (width)	30 m	6 m	30-40 years
Transmission pipeline (width)	30-40 m	6-30 m	40 years
Field compressing facility	5 ha		
Processing facility	7-20 ha		
Well grid	750-1000 m		

APPENDIX 2 – GEOGRAPHIC SCOPE OF CSG SCIENTIFIC PUBLICATIONS

Number of research publications reviewed that specifically addressed CSG/CBM and biodiversity. The majority of current CSG literature, both in Australia and internationally, addresses aquatic ecology and ground and surface water quality.



APPENDIX 3 - SUMMARY OF SCIENTIFIC LITERATURE

This summary outlines the scientific literature that specifically addressed coal seam gas or coal bed methane mining-related impacts on wildlife.

Reference	Locality	Study topic	Impact	Major findings
Beckmann *et al.* (2012)	USA	Effects on female pronghorn from inside gas field developments.	Habitat alterations	Fivefold sequential decrease in habitat patches.
Bergquist *et al.* (2007)	USA	To evaluate the potential effects of CBM development on native plant species distribution and patterns of non-native plant invasion.	Ecosystem disturbances	The combined disturbance subplots had significantly greater soil salinity than the control sites. CBM development and associated disturbances may facilitate the establishment of non-native plants.
Blickley *et al.* (2012)	USA	Experimental playback study to isolate the impacts of noise from industrial activity (natural gas drilling and road noise) on stress levels in greater sage-grouse.	Physiological stress	Results suggest that chronic noise pollution can cause greater sage-grouse to avoid otherwise suitable habitat, and can cause elevated stress levels in the birds who remain in noisy areas.
Braun *et al.* (2005)	USA	Seasonal habitat requirements for sage grouse.	Impacts of oil and gas wells with surface pipelines, noise, etc.	All proposed habitat manipulations should carefully consider the current condition of habitat and status of the sage-grouse population, to provide habitat for sage-grouse nesting and early brood rearing.
Carlson *et al.* (2012)	USA	Environmental contaminants in nestling bald eagles.	Contamination	Bald eagle nestlings may experience adverse effects from mercury contamination. Additional monitoring must occur as coal-fired plants and the CBM industry expands.
Connelly *et al.* (2000)	USA	Guidelines to manage sage grouse populations and their habitats.	Habitat loss	Oil and gas activities should be discouraged in sage-grouse breeding habitats.
Flores *et al.* (2001)	USA	Impacts of coalbed methane development in the powder river basin, Wyoming.	Riparian biodiversity.	Discharge of water on the surface by CBM wells; the volume of water produced and the effect on flow rates in nearby streams.
Kiviat (2013)	USA	Risks to biodiversity from hydraulic fracturing for natural gas.	Chemical, habitat fragmentation	Impacts are potentially serious due to the rapid development of High-volume horizontal hydraulic fracturing over a large region.

Reference	Locality	Study topic	Impact	Major findings
Linke *et al.* (2005)	Canada	Habitat use of grizzly bears in Alberta with radio tracking in areas host to mining, seismic oil and gas exploration and production.	Changing landscape metrics and landscape use.	The landscape structure of the grizzly bear population will continue to change as a function of increased levels of resource extraction activities in the near future.
Mang *et al.* (2007)	Asia: China	Evaluation of habitat of giant panda considering mining, seismic oil and gas exploration and forest harvesting activities.	Habitat fragmentation	The areas that are suitable for panda had decreased 20.66 km (2) from 2000 in total due to human activities.
Montana Fish, Wildlife and Parks	USA	Impacts on endangered or threatened species from CBM development.	Noise and other disturbance, road building and traffic, networks of pipeline.	Montana's prime CBM territory contains numerous federally protected endangered, threatened or special concern species, which are further threatened by CBM development.
Sawyer *et al.* (2006)	USA	Winter habitat selection of Mule deer before and during dev. of natural gas field.	Habitat loss.	Mule deer less likely to occupy areas in close proximity to well pads than those farther away.
Walker *et al.* (2007)	USA	Greater Sage-Grouse population response to energy development.	Habitat loss.	From 2001 to 2005, the number of males observed on leks in CBNG fields declined more rapidly than leks outside of CBNG.
Walston *et al.* (2009)	USA	Quantifying spatiotemporal changes in a sagebrush ecosystem in relation to energy development from 1985-2006.	Habitat decline.	By 2006, natural gas development directly impacted 2.7% (1750 ha) of original Wyoming big sagebrush habitat. Indirect impacts affected as much as 58.5% of the original big sagebrush habitat.
Williams *et al.* (2012)	Australia	An analysis of coal seam gas production and natural resource management in Australia.	Effects on biodiversity	More knowledge is needed on natural resource limits and resilience under increasing usage, including the development of tools for management and assessment of cumulative impact.
Wyoming Game and Fish Department (2010)	USA	Recommendations for Development of Oil and Gas Resources Within Important Wildlife Habitats	Habitat fragmentation	Habitat treatments may not be an effective option to offset additional impacts of oil and gas developments within these areas.

APPENDIX 4 – ENVIRONMENTAL AUTHORITIES REVIEWED

Gasfields	Pipelines
EPPG00652513	EPPG00305013
EPPG00662213	EPPG00547813
EPPG00672313	EPPG00570213
EPPG00700113	EPPG00674013
EPPG00797813	EPPG00674213
EPPG00853013	EPPG00690413
EPPG00853213	EPPG00720913
EPPG00878413	EPPG00721013
EPPG00885313	EPPG00827613
EPPG00889613	EPPG00836213
EPPG00898213	EPPG00881613
EPPG00903513	EPPG00896313
EPPG00928713	EPPG00903813
EPPG00932613	EPPG00905613
EPPG00935413	EPPG00928713
EPPG00972513	EPPG00935413
EPPG00984113	EPPG00959513
EPPG00986213	EPPG00967813
	EPPG00967913
	EPPG00986413

APPENDIX 5 – SUGGESTED FOCAL TOPICS FOR EACH SCIENCE AND MANAGEMENT QUESTION IDENTIFIED IN THE EXPERT WORKSHOP

Science Questions

1. What are the multi-scale, multi-functional response of plants, animals (mammals, birds, reptiles, amphibians, invertebrates) and wetlands/riparian ecosystems, to CSG infrastructure and operations and how does this vary across multiple land-uses?

   - Species: Identifying biodiversity benefits or losses in the 'local' story
     - Habitat and responses to disturbance is species-specific
     - Iconic/threatened vs. more common species, and identifying keystone species
     - Differences in 'functional response': plants, mammals, reptiles, birds, invertebrates
     - Changes in species composition

   - Ecosystems: Identifying ecosystems at risk
     - Fragmentation of intact forest areas
     - Native grasslands
     - Wetlands and riparian ecosystems

   - Function: Identifying and quantifying landscape processes
     - Multi-scale, multi-functional responses (temporal and spatial) of biodiversity to CSG (different stages and activities) across different land uses
     - Time-lags and different stages of development- cycle of change
     - Metapopulation processes, interspecific interactions, genetic diversity
     - Recruitment, recovery, resilience, thresholds
     - Does different intensity/density of CSG developments change the effects

2. What are the alternative futures for biodiversity from different restoration and landscape management approaches in CSG-resource development regions? How can the CSG industry leave a lasting positive legacy for biodiversity in CSG-resource regions?

   - Scenario modelling across multiple-scales, policy settings, alternative restoration strategies, management approaches, and uncertainties

   - Ecosystem services:
     - Which species contribute and how?
     - Changes in vegetation condition and health

   - Offsetting:
     - Baseline of how to value offsets for flora and fauna
     - Cooperation regarding offsets
     - Strategic offset rehabilitation, habitat corridors etc.

   - Relocation:
     - Cost-effectiveness and feasibility
     - Survival after release
     - Better spotter-catcher detection (e.g. cryptic and subterranean)

- Rehabilitation:
  - How is it done and how valuable?
  - Regrowth versus plantings/provenances
  - Pests and weeds
  - Develop/design uniform monitoring and measurement methods
  - Post- CSG development monitoring

- On-ground strategy for leaving the legacy of biodiversity

<u>Management Questions</u>

3. How to effectively embed ecological science into on-ground practice to minimise negative impacts of CSG infrastructure and operation on terrestrial biodiversity?

    - Collaboration and communication
    - Integrated/cohesive land management practices
    - Collaboratively planning strategic areas for protection

4. How to better integrate existing data collected by CSG industry and consultants during the EIS process? This also includes how to develop measuring and monitoring standards to ensure future data is consistent between collectors?

    - Data collection and determining baselines
    - Access to background information, e.g. existing EIS data, knowledge gaps
    - Identify existing methods of data collection
    - Whole of system stocktake (groups and species)
    - Synthesise existing data
    - Comprehensive database
    - Observational fieldwork

APPENDIX 6 – DETAILED RECOMMENDATIONS FROM CSG INDUSTRY REPRESENTATIVES

1. A strategic evaluation of threats (encompassing all land uses and histories) and identification of research priorities for biodiversity in the Brigalow Belt
    - similar to the CSIRO project undertaken for the Kimberley region of Western Australia

2. Research on threatened habitat and species distribution, including mapping and modeling, with implications for management and mitigating impacts
    - habitat mapping and modeling of threatened species listed under the *Environmental Protection and Biodiversity Conservation Act 1999* or the *Nature Conservation Act 1992*
    - investigation of the potential benefit of CSG activities for the provision of habitat for the Squatter pigeon (southern; *Geophaps scripta scripta*) and species persistence
    - examination of whether ground litter quality is a predictor of occurrence for the Common death adder (*Acanthophis antarcticus*), Collared delma (*Delma torquata*) and Dunmall's snake (*Furina dunmalli*)
    - identifying non-intrusive ways to detect species breeding in hollow-bearing trees, such as (but not limited to) the Turquoise parrot (*Neophema pulchella*), Black-chinned honeyeater (*Melithreptus gularis*) and Glossy black-cockatoo (*Calyptorhynchus lathami*)
    - evaluation of different artificial structures (e.g. nest boxes) to mitigate roost loss for microbats, such as the Little pied bat (*Chalinolobus picatus*) and South-eastern long-eared bat (*Nyctophilus corbeni*)
    - determining if LiDAR and other remote sensing technologies (including drones) can be used to improve habitat assessment and distribution predictors for target species
    - research on the biology and management of *Bertya pedicellata*
    - investigation of the genetic variation of *Brachychiton bidwillii* within the CSG gasfields and/or whether a new species or subspecies is present
    - evaluation of methods to identify threatened plant species that is appropriate to the Brigalow Belt
    - state-and-transition models for threatened communities where CSG activities occur

3. The impacts of edge effects and fragmentation on pest species (flora and fauna) and the subsequent risk to native species and habitats
    - assessment of the edge effects associated with linear CSG infrastructure on native vegetation and the potential increase or introduction of pest species, including the identification of which species utilize such areas and their role in biodiversity
    - research on the potential impacts of feral predators and the role of linear infrastructure on the Squatter pigeon

4. CSG industry specific restoration and rehabilitation criteria and monitoring
    - determining suitable management and end goals for rehabilitation, including the creation of fauna habitat, restoring a diversity of native species and re-establishing agricultural soils, and whether these can be provided simultaneously
    - assessment of the role of native fauna in the natural restoration of habitats, including seed dispersal, selective grazing and distribution and spread of non-native plants
    - empirical analysis of practical and relevant indicators of successful rehabilitation to indicate when vegetation communities are self-sustaining and resilient

- establishment of successful rehabilitation benchmarks, instead of end state species composition
- investigating the use of Unmanned Aerial Vehicles or other technology for remote monitoring of rehabilitation in large-scale projects
- innovative equipment or techniques suitable to the CSG industry to enable successful rehabilitation; for example, improving trenching methods and restoration

APPENDIX 7 - REMOTE SENSING METHODOLOGY

Imagery from the SPOT 5 satellite from 6th May 2004 and 4th April 2005 at 10 m spatial resolution were provided by the Remote Sensing Centre of DSITIA. The topographically corrected surface reflectances represent the spectral bands in the electromagnetic spectrum as follows: band 1 in the green at 500-590 nm, band 2 in the red at 610-680 nm, band 3 in the near infrared at 780-890 nm, and band 4 in the shortwave infrared at 1580-1750 nm.

Additionally, a foliage projective cover (FPC) index computed from multiple linear regression model and derived from the surface reflectances above was acquired that represents overstorey FPC (developed by DSITIA; Danaher *et al.*, 2010). FPC is the metric of vegetation cover adopted in many Australian vegetation classification frameworks and is defined as the vertically projected percentage cover of photosynthetic foliage of all strata (Specht 1983). That is, equivalently, the fraction of the vertical view that is occluded by foliage. FPC of the woody and shrub life forms of more than 2 m height is considered a more suitable indicator of a plant community's radiation interception and transpiration than crown cover since Australian plant communities are dominated by trees and shrubs with sparse foliage and irregular crown shapes (Specht and Specht 1999).

Proxies for vegetation condition

The Normalised Difference Vegetation Index (NDVI) can be used as an indicator of the greenness of vegetation and thus a potential proxy of vegetation condition. This is mostly because live green vegetation absorbs visible light (solar radiation) as part of photosynthesis and scatters (reflects) solar energy in the near infrared. Thus, NDVI has been shown to be influenced by the fractional cover of the ground by vegetation, the vegetation density and the vegetation greenness. This difference in absorption is unique and provides a measure of the greenness of the vegetation. Such vegetation indices represent one of the most commonly used approaches in analysing remote sensing data in the optical domain.

It is calculated from the red and near-infrared (NIR) surface reflectances of the 2005 SPOT imagery as follows:

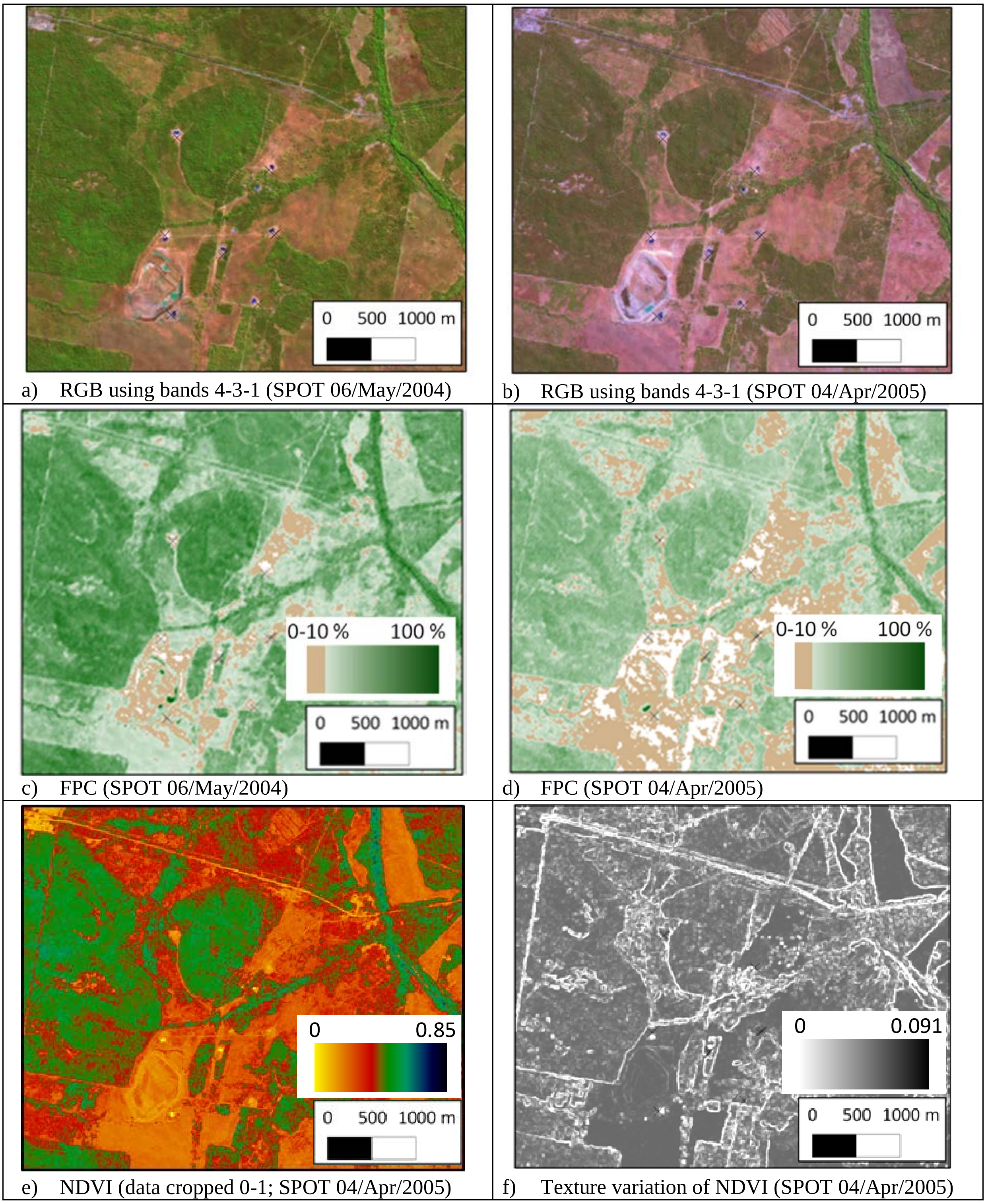
$$NDVI = (NIR - red) / (NIR + red).$$

NDVI typically ranges from 0 up 1. Specifically, NDVI decreases as leaves come under water stress, become diseased or die. However, classical vegetation indices are sensitive to the desired information (e.g. the amount of vegetation), as well as other factors such as soil colour changes, illumination condition and atmospheric effects (Verstraete and Pinty 1996). This needs to be considered when interpreting NDVI data; particularly in open plant canopies, such as Australian savannas, where much of the vegetation is non-green. As a measure of spatial heterogeneity the variation in NDVI texture was calculated. The texture is an occurrence measure that uses the number of occurrences of each grey level within the processing window (here three times three pixels) for the texture calculations, with remotely sensed spectral heterogeneity being linked to species diversity (Rocchini *et al.* 2012).

The similarity in key vegetation features of the Regional Ecosystem being assessed ('developed') with those of the same reference Regional Ecosystem is often used as a measure of the condition for biodiversity (Eyre *et al.* 2011). Thus, a transect at a forest site was manually selected and drawn on the SPOT imagery. The reference state here is represented by the transect in an undeveloped area assumed to represent the same ecosystem that the nearby developed transect formerly contained. The surface reflectance from band 4 (a short-wave infrared wavelength that shows reflectance of vegetation and varies depending on plant type and their water content), from the SPOT imagery for 2004 and 2005 and the NDVI from 2005 were extracted for those transects and plotted.

Proxy for vegetation extent

The SPOT derived FPC imagery of 2004 and 2005 representing 0-100 % FPC were mapped, with areas of ≤10 % FPC set to represent bare areas. The chosen methodology and measures resulted in the depiction of various grades of woody vegetation density, including areas of higher greenness, bare areas and linear features of homogeneous texture of the sample site (Figure A5.1 a) to f)).



a) RGB using bands 4-3-1 (SPOT 06/May/2004)

b) RGB using bands 4-3-1 (SPOT 04/Apr/2005)

c) FPC (SPOT 06/May/2004)

d) FPC (SPOT 04/Apr/2005)

e) NDVI (data cropped 0-1; SPOT 04/Apr/2005)

f) Texture variation of NDVI (SPOT 04/Apr/2005)

Figure A5.1 Remotely sensed imagery and derived products from two years of SPOT imagery for the sample study area that can be interpreted as proxies for assessing vegetation condition and extent. SPOT surface reflectance values for a) 2004 and b) 2005 are shown with RGB images using the bands 4-3-1 depicting the landscape in near-true-colour. FPC imagery for the same years is shown in c) and d). NDVI values e) and texture f) from 2005 imagery are also shown. Note, in d) all values of ≤10 % were set to a single colour (beige) representing bare ground, since the reliability of the product below this threshold is not given.