Priority threat identification, management and appraisal: Literature review

Biodiversity Research

Rocio Ponce-Reyes, Tara Martin , Stuart Whitten, Martine Maron and Josie Carwardine
GISERA Project Number 1215
May 2014

ISBN (print): 978-1-4863-0335-9

ISBN (online): 978-1-4863-0336-6

The Gas Industry Social and Environmental Research Alliance (GISERA) undertakes publicly-reported research that addresses the socio-economic and environmental impacts of Australia's natural gas industries. GISERA was co-founded by CSIRO and Australia Pacific LNG in July 2011. For further information visit www.gisera.org.au.

Citation

Ponce-Reyes R, Martin T, Whitten S, Maron M and Carwardine J (2014) Priority threat identification, management and appraisal: Literature review. May 2014. CSIRO, Australia.

Copyright and disclaimer

Important disclaimer

Contents

Figures

Tables

Acknowledgments

We thank for all the feedback during the GISERA workshop held in October 2013- especially Graeme Bartrim (Origin).

Executive summary

Biodiversity is threatened globally by a range of anthropogenic impacts on the extent, connectedness and intactness of habitats required for species persistence. The emergence and expansion of energy industries, such as Coal Seam Gas, into many farming regions, will compound existing threats to biodiversity in a region, and also bring new ones. This is particularly so in multiple-use regions where new threats can have synergistic and cumulative effects on the biodiversity. Multiple-use regions are often heavily cleared and fragmented making it impractical to create new, large and connected protected areas. Therefore alternative approaches are required for improving the long-term persistence of biodiversity through managing threats across tenure boundaries. Most important biodiversity regions in Australia and throughout the world lack a prioritised set of threat management actions to assist decision makers in allocating scarce resources to conserving biodiversity. The few examples that do exist are focused on relatively ecologically intact regions, such as the Kimberley in Western Australia. The purpose of this review is: 1) to identify the major threats to biodiversity in the region arising from multiple past, present and future land uses, including Coal Seam Gas and 2) to identify and prioritise a cost-effective set of management actions to address these threats.

The Brigalow Belt region in Queensland is one of the most ecologically transformed areas in Australia. It holds great importance in terms of its biodiversity, with 147 threatened species and 100 communities listed as threatened. The Brigalow Belt region has been subjected to historical broad scale clearing of native vegetation since mid 1800s for different uses: pastoral, agricultural, urbanisation, and more recently mining activities, which are expected to expand in the coming decades. While current conservation efforts in the region are important, they are expected to be insufficient to maintain biodiversity values in the face of these increasing threats. Some useful datasets exist to assist with decision analysis, however a complete set of empirical data for making informed decisions for this region are unavailable. This currently challenges decision-making in the region.

New systematic and more efficient and effective approaches to conservation priority setting have been developed in recent years. Decision science has become the basis of novel strategies and frameworks used to prioritise species, locations and more recently, actions in which to invest to improve long term persistence of biodiversity in a region. The approach requires the following basic principles of decision science: (i) a clear objective; (ii) a well-defined set of actions from which a subset will be chosen as priorities; (iii) a model of system behaviour to relate actions to their contributions toward meeting the objectives; (iv) the consideration of resource constraints. Structured Decision-Making – the application of decision science – uses tools such as expert elicitation and cost-effectiveness analyses to collect and evaluate information to advise on the most efficient use of resources.

Cost-effectiveness analyses enable comparisons of a range of management actions that will improve the persistence of biodiversity. This requires first knowing the status of biodiversity and its specific threats in an area. Second, identifying the major threats and potential management actions is needed. Third, prioritising those actions based on their cost-effectiveness in mitigating the threats. These can be done using a species or an ecosystem approach or a combination of both, depending on the conservation objective, threats and available resources.

This project will provide an analysis of threat management priorities for improving the persistence of biodiversity in the Brigalow Belt region of Queensland. It will involve the collation of the best available scientific information with expert knowledge to identify the most important threats to biodiversity in the region and the actions to abate them. Actions will be parameterised with costs, likely benefits and feasibility estimates, allowing their ecological cost-effectiveness to be ranked. The project will provide, for the first time, a region-wide analysis of alternative actions for managing threats to the Brigalow region biodiversity, which is a critical input for rational and defensible decision-making.

1 Background information

1.1 The decline in biodiversity

The world's ecological systems are in peril. Human activity during that past 50 years has led to unprecedented rates of decline in biodiversity (Butchart et al., 2010; Millennium Ecosystem Assessment, 2005) exceeding background rates of extinction by 100 to 10,000 times (He and Hubbell, 2011; Hoffmann et al., 2010; Pimm, 2000; Pimm et al., 1995). Human development has transformed between 20 and 70 percent of the area of the world's major biomes (Millennium Ecosystem Assessment, 2005; Rodríguez et al., 2011). Declines are occurring both within and outside of protected areas (Woinarski et al., 2011). Leading threats to biodiversity include the loss and fragmentation of native habitat as a result of agricultural expansion and urban and industrial development, invasion by exotic species, over-harvesting, over-grazing, altered fire regimes, water pollution, disease and industrial development (Burgman and Lindenmayer, 1998; Ehrlich and Ehrlich, 1981; McDonald et al., 2009; Northrup and Wittemyer, 2013; Tilman et al., 1994). Climate change presents an additional threat, which has the potential to exacerbate further the impacts of current threats (Miles et al., 2004; Parmesan, 2006; Williams et al., 2003).

1.2 Conserving biodiversity in multiple-use regions

The high rates of biodiversity loss experienced in the last few decades (Gaston et al., 2003; Groombridge, 1992; Thomas et al., 2004b) are expected to continue under current management trajectories (Brooks et al., 1997; Sala et al., 2000; Thomas et al., 2004a), and expected agricultural and industrial development (Güneralp, 2013; McKinney, 2002; Pauchard et al., 2006). Increasing numbers of regions are now multiple-use with highly fragmented native ecosystems. Habitat loss, species invasions and climate change are contributing to the emergence of ecosystems that exist without historical precedents (Hobbs et al., 2009; Hobbs et al., 2013). However, the biodiversity values of many modified and novel landscapes are still high (Hobbs et al., 2013; Jongman and Pungetti, 2004). The standard conservation policy response - protection of intact landscapes (McIntyre and Hobbs, 1999) as large individual conservation reserves - will be difficult if not impossible to achieve in these modified landscapes. For many species, particularly migratory and wide-ranging fauna, strict protection via reserves will be insufficient to ensure their conservation in the long-term (Stokes et al., 2010; Waltert et al., 2011). With less than 10% of terrestrial land and currently less than 1% of marine ecosystems under protection, and with increasing demands on land and sea for other uses, conservation will require changed land management across multiple tenures.

Conservation management outside protected areas includes managing the matrix, with appropriate management of areas including the appropriate management of areas where populations are most likely to persist in the long term (Cabeza and Moilanen, 2001; Margules and Pressey, 2000); the restoration of places that have already been substantially modified by anthropogenic activity (Moilanen et al., 2005); managing novel ecosystems and critical habitats such as breeding grounds and feeding grounds (Hall et al., 1997; Murphy and Noon, 1991); as well as areas where given species habitats are common, of high quality and close together (Hanski, 1998; Hanski and Ovaskainen, 2000). Regardless of land tenure, management of threats should be prioritised in locations that are likely to result in the greatest improvements for biodiversity persistence per unit cost (Carwardine et al., 2012; Carwardine et al., 2011; Firn et al., 2013).

A number of strategies are used to implement management of the matrix outside protected areas, including stewardship programs, private land agreements, incentive schemes, offset schemes and the regulation of development activities (Mackey et al., 2007; Woinarski et al., 2007; Young and Gunningham, 1996; Young et al., 1996). For example, 'the conservation landscape' concept (Sanderson et al., 2002) assumes that the existence of effective protected areas needs to be complemented by buffer zones in which land uses are actively managed to be "friendly to biodiversity", protecting critical habitat for different species (Gardner et al., 2007) and also contributing to the long term conservation value of the core protected areas (DeFries et al., 2007; Margules and Pressey, 2000). Land sharing strategies (Phalan et al., 2011) aim to maximise the benefits for biodiversity and agriculture. These include integrating biodiversity conservation and agricultural production through wildlife-friendly farming (Fischer et al., 2008; Green et al., 2005) or land sparing. Land for conservation, segregated from crops in order to minimise the encroachment by increasing yield production in already converted land is another strategy (Balmford et al., 2005; Green et al., 2005; Perfecto and Vandermeer, 2008).

One of the most transformed areas in Australia is the Brigalow Belt bioregion. It has been affected by cumulative impacts of extensive historical broad scale clearing of native vegetation for agricultural development (McAlpine et al., 2002b; Seabrook et al., 2006), urbanisation (Catterall et al., 1988); logging of native hardwood forests (Maron et al., 2011) and most recently, large-scale coal, oil and gas development (Dwyer et al., 2009) and coal seam gas (CSG) in particular. Development associated with CSG results in further habitat loss and fragmentation of the landscape (Walker et al., 2007; Walston et al., 2009). With ever-increasing demands for energy, oil and gas, companies are continually searching for new resources (Pedroni et al., 2013). While this search and subsequent production of new energy are expected to have an impact on the biodiversity of the region (Walker et al., 2007; Walston et al., 2009), it also provides motivation, opportunity and potential resources to address long-standing threats.

The challenge will be reconciling the potential conflicts of oil and gas development with the management of current threats. Increases in atmospheric greenhouse gas concentrations as a result of development and consumption increase the threat of rapid climate change. Further habitat loss and fragmentation and resulting weed incursions as a direct result of CSG development, compound current landscape degradation stemming from a long history of agricultural development. Resolving these conflicts is likely to be morally, philosophically and scientifically challenging. Only through an understanding of the threats and management actions to abate these threats will we be able to improve the persistence of biodiversity in a region under ever increasing levels of agricultural and industrial development (Northrup and Wittemyer, 2013).

1.3 Why do we need a project about priority threat identification, management and appraisal?

Limited conservation resources coupled with high species decline and extinction rates over the past 50 years (James et al., 1999; Vane-Wright et al., 1991) mean that it is typically not possible to manage all threats to biodiversity in all locations. This situation has stimulated the development and implementation of systematic and efficient approaches to conservation prioritisation (Moilanen et al., 2009; Pressey and Botrill, 2008). The most efficient use of resources often involves protecting biodiversity from specific threats. Usually there are differences in the costs, benefits and feasibility of actions that improve the persistence of the assets that we wish to protect, where some actions will represent better investments than others. These assets might be biodiversity values (for example, species and ecosystems) or sites of national and/or cultural significance. Conservation or threat management actions can be evaluated by predicting their importance, or their cost-effectiveness, for achieving pre-specified objectives, providing useful information for decision makers (Hajkowicz et al., 2008; Margules and Pressey, 2000; Possingham et al., 2006; Vane-Wright et al., 1991). The cost-effectiveness of each action in each location is determined by dividing the location specific expected benefits of each action by the expected costs in each location (Cullen et al., 2005; Levin and McEwan, 2001), providing a systematic and transparent approach for helping decision makers to choose between them (Carwardine et al., 2011; Firn et al., 2013). There are several ways to measure the benefits of actions, for example as the improvement in protected species habitat (Carwardine et al., 2008) or improvement in species persistence (Bottrill et al., 2008; Joseph et al., 2009) and the costs are usually financial management costs (Naidoo and Ricketts, 2006).

Conservation decisions are often hampered in many important regions due to the lack of formal data on species distribution, ecological processes and likely responses to threats and management actions. New approaches on methods for undertaking conservation management appraisal and prioritization using the expert knowledge to complement scientific data have been used effectively to gather missing information (Burgman et al., 2011; Kuhnert et al., 2010; Martin et al., 2012a; Martin et al., 2005). In many cases it may be better to make decisions based on expert knowledge rather than delay decisions due to a lack of data, especially when conservation decisions are urgently needed to avoid declines (Joseph et al., 2009; Martin et al., 2012c; Possingham et al., 2002). An important characteristic of undertaking conservation management appraisal and prioritization using experts knowledge is that the approach is flexible and adaptable to situations with different amounts of data, because empirical data and expert knowledge can be combined (Martin et al., 2012a). Also these approaches can be updated when more information is obtained.

Most important biodiversity regions in Australia and throughout the world lack a prioritised set of threat management actions to assist decision makers in allocating scarce resources to conserving biodiversity (Game et al., 2013). This is true of the Brigalow Belt in Australia, a multiple-use region with important biodiversity values that are facing increasing anthropogenic threats (Seabrook et al., 2006). While current conservation efforts in the region are important, they are expected to be insufficient to maintain biodiversity values in the face of these increasing threats. A project on threat identification, management and appraisal will combine the best available scientific information with expert knowledge to identify the most important threats to biodiversity in the region and the actions to abate them. The actions will then be parameterised with costs, likely benefits and feasibility estimates, allowing their ecological cost-effectiveness to be ranked (Carwardine et al., 2012). This will provide one layer of information to assist with decision-making on natural resource management, including for managing and off-setting threats in the region. A range of other information will also be required for decision making, including the cultural, social and economic values and preferences of people in the region and their interaction with biodiversity values, however the collection and processing of this information is outside the scope of this project.

1.3.1 PERSISTENCE OF SPECIES AND ECOSYSTEMS

In order to preserve biodiversity it is necessary to protect the natural processes that generate and maintain it. To ensure the persistence of the species, it is necessary to consider processes that generate and maintain the species, but also to address current and anticipate potential threats to those processes (Balmford, 1998). Extinction risk assessments can be useful in prioritization and management strategies for conservation by providing information on the likely losses of biodiversity under a given scenario (McCarthy et al., 2008). The process of estimating extinction risk, or conversely persistence likelihood, of biodiversity has typically focused on single species. For example, the globally accepted IUCN Red List for Threatened Species (IUCN, 2001), framework that identifies the species at most risk of extinction (Baillie et al., 2004; Butchart et al., 2004). The Red List uses quantitative criteria for transparent, repeatable and objective risk assessment while providing an impressive database on species from all groups including threatened and non-threatened species; and it can be applied at very different scales (across countries, regions and taxonomic groups). Several scientific studies on threat management have used species persistence estimates made by experts in order to compare the relative benefits of alternative management scenarios (Carwardine et al., 2011; Joseph et al., 2009). An exclusive focus on species-based approaches as a representation of the current status of biodiversity is unlikely to represent the status of all components of biodiversity (Franklin, 1993) unless all the species in the area are known and there are sufficient resources to assess them all. Protecting species via a single-species approach can also be costly, time consuming and it can fail to capture interactions between species (Chadès et al., 2012). Therefore, biodiversity assessments that consider higher levels of biological organization are required (Noss, 1996).

Ecosystems might represent biological diversity more effectively as a whole, rather than individual species (Cowling et al., 2004; Noss, 1996) because they include fundamental biotic and abiotic processes that are only indirectly considered in species assessments (Beechie et al., 2010). The provision of ecosystem services are also more likely to be driven and maintained by ecosystems than by individual species (Rodríguez et al., 2011). Using ecosystems as the conservation unit for extinction risk assessments may address higher levels of biological organization and their underlying processes (Cowling et al., 2004; Noss, 1996; Rodríguez et al., 2011). Those interactions or 'ecological processes' originate and maintain biodiversity. Ecosystem deterioration may also result in reductions in ecosystem services such as the loss of clean water, food, timber and fuel (Millennium Ecosystem Assessment, 2005). Ecosystem-level assessments may also be less time consuming than species-by-species assessments. Finally, this approach allows for the fact that ecosystems and vegetation communities themselves are often a valued conservation feature, as well as the species they contain. For example, the Australian National Reserve System (NRS) aims to include sufficient levels of each ecosystem within the protected area network to provide ecological viability and to maintain the integrity of populations, species and communities and including areas at a finer scale, to encompass the variability of habitat within ecosystems (CAPAD 2012).

2 Study region

2.1 Geographic localization- Bowen and Surat Basins and Brigalow Belt bioregion

The Brigalow Belt bioregion coincides with the Bowen and Surat geological basins, containing the hub of CSG development in Queensland (Figure 1). The largest coal reserve in Australia is the Bowen Basin. It is located in eastern Queensland and occupies about 160,000km^2. The Bowen Basin was formed in the Early Permian to Middle Triassic. This Basin has large accumulations of hydrocarbon and large volumes of methane gas at shallow depths. The methane accumulation has the potential for coal seam gas (CSG) developments. The Bowen Basin overlaps the northern section of the Surat Basin, which is one of the major CSG reserves in Queensland, containing over 64% of the proven and probable ('2P') CSG reserves in Australia (Geoscience Australia, 2010). In 2010–2011 the Surat Basin contributed approximately 113PJ to Queensland's energy supply (Queensland Mines and Energy, 2012). The extent of the Surat Basin covers approximately 300 million hectares of central southern Queensland and central New South Wales (NSW): it is situated less than 200 km from the Pacific Coast and extends inland for 500 km to Mitchell. Its northern limit approaches Taroom, while the southern limit is near Coonamble Embayment, near Dubbo, NSW. Exploration of this region for coal started in the early 1900s (Elliott, 1989).

Using geological basins for delimiting natural resource-industry projects is useful because there is a correlation between the age of the rock formation and the extracted resources. For example, the Surat Basin rocks were predominantly formed during the Jurassic period, when lakes, streams and coal swamp deposition formed hydrocarbon accumulations (John Williams Scientific Services Pty Ltd, 2012). Geology influences the distributional patterns of the biodiversity in an area; however it explains only part of the ecological processes affecting species persistence. These are better explained by bioregions. A bioregion is a relatively large land area that captures large-scale geophysical patterns. Bioregions are characterised by broad, landscape-scale features and environmental processes that influence the functions of entire landscapes and ecosystems, which can be linked to fauna and flora assemblages and their processes at the ecosystem scale. Therefore, when planning actions for conservation of the biodiversity using a bioregional approach is very useful. The Brigalow Belt bioregion coincides closely with the Bowen and Surat Basins in Queensland. This combined region extends from North Queensland, near Townsville, to the south of Dubbo in central –western New South Wales (Figure 1). The bioregion is split into the Brigalow Belt North (BBN) and Brigalow Belt South (BBS) based primarily on the climate. . The Brigalow Belt North bioregion has a semiarid to tropical climate with predominantly summer rainfall while the Brigalow Belt South bioregion has a hot to warm subtropical climate with summer-dominant rainfall. The Queensland part of the BBS has experienced one of the most rapid landscape transformation ever documented (Fensham and Fairfax, 2003; McAlpine et al., 2002c; Queensland Department of Natural Resources, 2005).

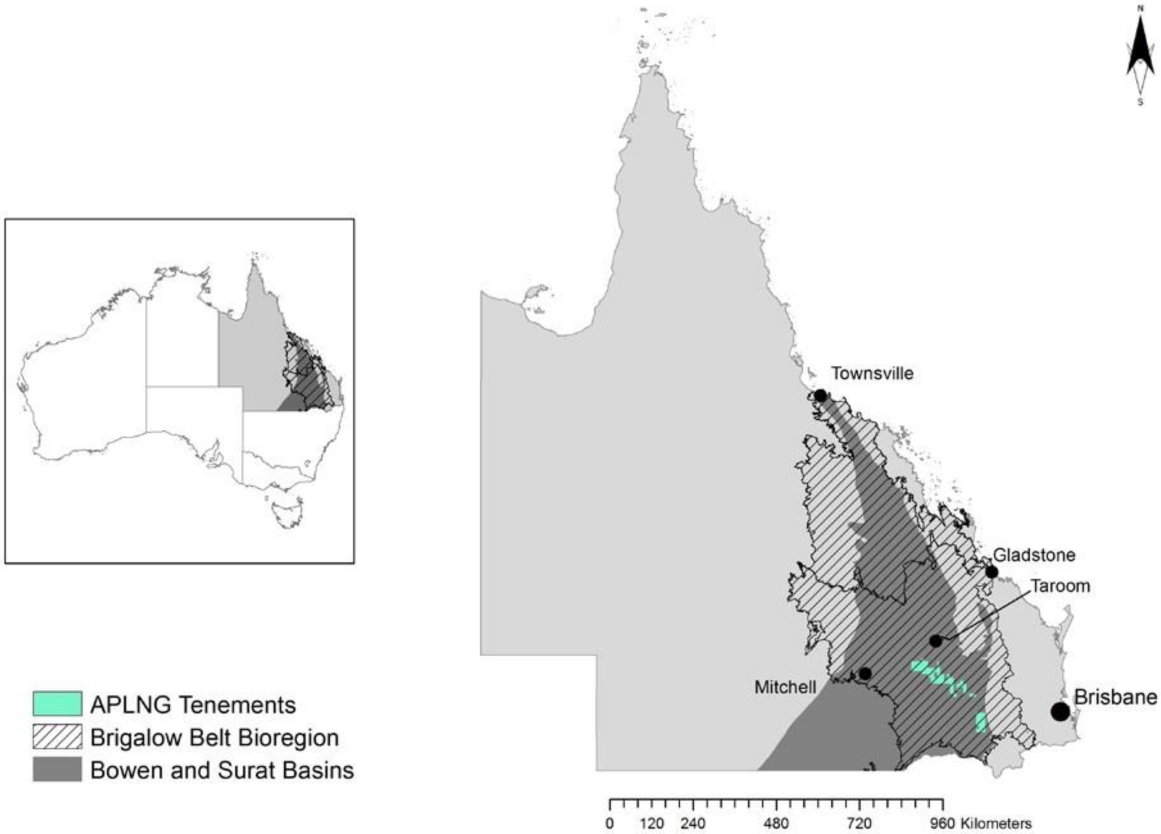

Figure 1 Study region

2.2 Biodiversity of the region

The Brigalow Belt bioregion is named after the dominant tree species in this region, the brigalow tree (*Acacia harpophylla*). In the south and west part of this bioregion Brigalow forests were the dominant vegetation type. Other important vegetation types in this region are alluvial open eucalypt woodlands (with poplar box (*Eucalyptus populnea*); coolabah (*E. microtheca*) and some Queensland bluegrass grassland (*Dicanthium sericeum*) (Queensland Herbarium, 2004). In the sandy ridges and plains the predominant species are cypress pine (*Callitris* spp.), bulloak (*Allocasuarina luehmannii*) and silver-leaved ironbark (*E. melanophloia*). In the north and east of the region, vegetation is mainly dry eucalypt woodland comprising ironbarks (*E. crebra* and allied species) and spotted gum (*Corymbia citriodora*) occurring on skeletal soils (Seabrook et al., 2006).

The extent of mature brigalow ecosystems in Queensland alone has been reduced from 7.5 M ha to around 600,000 ha since European settlement (Accad, 2001) and the remaining areas are mainly isolated, small, linear fragments (Dwyer et al., 2009). The clay soils supporting brigalow communities are relatively fertile, which has contributed to extensive clearing for agricultural and pastoral activities (Johnson, 1976, 1997; Scanlan, 1991). As a result, mature brigalow ecosystems are among the most threatened in Queensland (Johnson, 1997; Johnson and McDonald, 2005). The remnant brigalow forests are now protected as endangered ecological communities (Ngugi et al., 2011) under Australia's Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act, 1999), and as endangered regional ecosystems under the

Queensland Vegetation Management Act 1999 (QLD VM Act, 1999). Early in 2009, the Queensland government imposed a moratorium on the clearing of endangered secondary vegetation, including brigalow. This moratorium was lifted in October 2009 and replaced by the Vegetation Management (Regrowth Clearing Moratorium) Act, which has modest restrictions on the clearing of endangered ecosystems (Valbuena et al., 2010).

To control vegetation clearance, remnant vegetation communities in Queensland were classified into bioregional ecosystems (Sattler and Williams, 1999) and each of them was allocated a biodiversity status based on the relative amount of area covered by remnant native vegetation. There are 172 regional ecosystems described for the Brigalow Belt bioregion (please refer to http://www.ehp.qld.gov.au/ecosystems/biodiversity/regional-ecosystems/index.php). From those, 40 are classified as “endangered” by the Vegetation Management Regulation 2000. The Vegetation Management Regulations considers an endangered ecosystem as one in which the area of remnant vegetation for the regional ecosystem is less than 10% of the pre-clearing extent of the regional ecosystem. Regional ecosystems classified as “of concern” are those with the area of remnant vegetation between 10% to 30% of the pre-clearing extent of the regional ecosystem and less than 10 000 hectares. Finally regional ecosystems of “least concern” are those where the total area of remaining remnant vegetation is greater than 10 000 ha and greater than 30% of its pre-clearing extent. Sixty-two ecosystems in the BBS are “of concern”. The 72 remaining regional ecosystems are considered “least concern”.

The region is recognised by the Australian Government as a biodiversity hotspot and it contains some of the most threatened wildlife in the world, including populations of the endangered bridled nail-tail wallaby and the only remaining wild population of the endangered northern hairy-nosed wombat. The area also contains important habitat for rare and threatened species including the glossy black-cockatoo and the brigalow scaly-foot gecko and the golden tailed gecko. There are 1885 known vertebrate and 5762 known plant species in the region. Of these, some 151 are threatened in different categories, and ten species are already extinct (Table 1).

Table 1 Endangered species, including sub-species, in the Brigalow Belt bioregion in Queensland

	TOTAL SPECIES	EXTINCT	CRITICALLY ENDANGERED	ENDANGERED	VULNERABLE
Amphibians	72	1	0	4	1
Birds	773	1	0	11	5
Fish	608	0	0	0	2
Mammals	152	7	2	10	12
Reptiles	280	0	0	11	8
Plants	5762	1	1	25	69

[http://www.environment.gov.au/system/files/resources/a8015c25-4aa2-4833-ad9c-e98d09e2ab52/files/bioregion-brigalow-belt-north.pdf
http://www.environment.gov.au/system/files/resources/a8015c25-4aa2-4833-ad9c-e98d09e2ab52/files/bioregion-brigalow-belt-south.pdf
www.ala.org.au]

2.3 Main threats in the region

Being one of the most extensively cleared regions in Australia (McAlpine et al., 2002a), the Brigalow Belt bioregion’s remnant native vegetation is highly fragmented and disturbed with only less than 10% of the brigalow remnant vegetation remaining (Seabrook et al., 2006; Wilson et al., 2002). Europeans settled in the BBS bioregion in the 1840s (Seabrook et al., 2006); and with settlement commenced the landscape transformation. The first settlers were pastoralists focusing mainly on wool production, which by 1960 claimed most land (Nix, 1994). With increasing human settlements in the region, agriculture became more important. During the 1950s and early 1960s, much of the brigalow was cleared in order to establish improved pasture for grazing (Seabrook et al., 2006). Since then, the fertile areas of the region have been cleared and developed for crops and pasture, while less suitable areas are used for extensive grazing, forestry and environmental protection (Environment Australia, 2000). With the largest coal reserve in Australia (Bowen Basin) being located within the Brigalow Belt (BB) bioregion, significant areas have already been affected by coal mine developments, usually in the form of open-cut pits (Arnold et al., 2013). Clearing for mining and its associated activities and infrastructure is not regulated under the *Vegetation Management Act 1999* which regulates clearing for most other purposes (Butler, 2008). As a result of all of the above activities (clearing for grazing, agriculture, and new energy developments and its associated infrastructure), most native vegetation and the associated soils (in case of mining activities) has been disturbed and/or degraded with very few historical vegetation communities currently remaining (Butler, 2009). Additional threats, like invasive species, altered fire regimes and the emerging threat of climate change are also impacting on the extent and condition of the BB bioregion. Many of these threats are not only cumulative but are likely to have synergistic effects (Mantyka-Pringle et al., 2011).

2.3.1 GRAZING

Livestock grazing was the first significant threat imposed by European settlers in the Brigalow Belt. Despite the relatively high fertility of brigalow soils, mature brigalow ecosystems are characterized by a very sparse ground cover layer with limited grazing potential. Thus, over the last century, there was a concerted effort to clear the forests and woodlands and sow the fertile soils with exotic pasture (buffel grass – *Pennisetum ciliare*) and dryland cropping (Seabrook et al., 2006). Currently, about 80% and 90% of the Brigalow Belt South and the Brigalow Belt North bioregion, respectively, is grazed (Bastin and ACRIS Management Committee, 2008). The data from the Australian Bureau of Statistics shows that between 1992- 2011 stock density has fluctuated from 66 up to 105 Dry Sheep Equivalents / $km^{2,}$ depending on the seasonal quality.

Grazing by livestock (largely cattle and sheep) impacts biodiversity through a range of habitat changes, such as the direct removal of trees to promote grass growth; changes in structure and species composition of the understory grasslands themselves; loss of perennial tussock grasses in favour of annuals. These structural and compositional changes in the vegetation lead to altered habitat for fauna that use the vegetation for foraging, breeding and shelter (Martin and McIntyre, 2007). Soil compaction and erosion and degradation of riparian habitats are common impacts from grazing. Altered populations of native herbivores (kangaroos and wallabies) and naturalised introduced herbivores such as goats, donkeys and horses may also contribute to grazing pressure.

2.3.2 CLEARING FOR AGRICULTURE

The main agricultural products in the Brigalow Belt region are wheat, cotton and sorghum. Clearing for agriculture in the Brigalow Belt began during the 1870s, due to a decline in sheep numbers, probably because of overgrazing of palatable grass (Seabrook et al., 2006). Cropping was limited to the eastern part of the Darling Downs (Toowoomba). Agricultural growth was initially limited because produce was difficult to transport and the domestic market was small. The main agricultural products were cotton and crops used for animal fodder (Seabrook et al., 2006). Between 1880 and 1940 agricultural development increased, involving the clearing of brigalow, which was associated with fertile soil. Between 1950s and 1990s, the federal and state governments actively promoted human settlement in and clearing of the natural brigalow landscape to enable agricultural expansion (Lindenmayer and Burgman, 2005).

In Australia, agriculture has been one of the major drivers of landscape change with extensive conversion to native vegetation to crops and pastures. Since the 1990s concerns over the clearing extent has grown. This extends not only to the remaining patches of remnant vegetation, but also to the clearing of regrowth brigalow. *Acacia harpophylla* has an excellent capacity to resprout from via root suckers once the above-ground parts of trees have been removed via clearing (Johnson, 1964). Such sucker regrowth is common throughout the bioregion (Butler, 2009; Clewley, 2012) and in some areas regrowth has regrown to form dense forests with variable habitat value for native fauna (Bowen, 2009). Clearing of regrowth patches larger than two hectares was prohibited to protect "high value regrowth" under Queensland's Vegetation Management Act 1999 (amended later by the Vegetation Management and Other Legislation Amendment Act 2009). In this context, high value regrowth refers to native vegetation that isn't remnant, but hasn't been cleared since 31 December 1989. Such regrowth was mapped by the Department of Environment and Resource Management. The high-value regrowth map for the Vegetation Management Act used foliage protective cover (FPC) and SLATS clearing records back to 1991 to identify land that had woody FPC >11% in the year 2006 and had not had clearing detected on it since 1991. However no pre-screening based on regional ecosystems was done. This initial concept was 'simplified' into polygons using focal majority and also had a minimum polygon size imposed. Towns and orchards were manually removed (Don Butler, 2014, pers. comm.). Landholders required permits to clear mapped regrowth on their property. Brigalow trees are very hardy and grow back quickly if chopped off at the base and cattle dislike its taste. Brigalow grows in clay soils (Gunn, 1984) and they fix nitrogen and provide calcium to the soil. Therefore once Brigalow communities are removed, soil fertility declines and this is more pronounced for cropping systems than for pasture (Dwyer, 2007). Reductions in concentrations of organic carbon (Dalal R.C. et al., 2003; Graham et al., 1981), plant available nitrogen (Graham et al., 1981), total nitrogen, phosphorus and potassium (Dowling et al., 1986), and microbial biomass carbon and nitrogen (Grace et al., 1992) were detected. Also as these trees can withstand high levels of salinity in the soil they aid in managing water tables (Gates, 1972) and thus dryland salinity impacts on crop and pasture production. For cattle (and other animals) these trees provide important shade and shelter.

2.3.3 CSG INDUSTRY DEVELOPMENT AND ASSOCIATED INFRASTRUCTURE

The first large-scale CSG production commenced in Spring Gully in 2003 (Graeme Batrim, pers. comm.). This gas is used for industrial and domestic purposes, including power generation. In 2010, coal seam gas production represented 10% of Australian gas production. This figure is growing rapidly because of domestic and export demand. The geological setting for CSG resources relates directly to the sedimentary basins in which there are hydrocarbon and coal-rich strata (Erskine and Fletcher, 2013).

The research into the effect of CSG activities and infrastructure on wildlife has mostly been done in the USA and Canada. It has been demonstrated that CSG infrastructure's cumulative direct and indirect impacts has altered the habitat of some species including: the Greater sage-grouse, a ground dwelling bird now listed as endangered in Canada (Walker et al., 2007; Walston et al., 2009); the pronghorn - an antelope-like mammal (Beckmann et al., 2012); the Mule deer (Sawyer et al., 2006) and the Bald eagle (Carlson et al., 2012).

It is expected that the main environmental impacts of the CSG development in Queensland will be related to the extent of vegetation cleared to build infrastructure and the volume and quality of water used in the extraction process, its treatment, and the extent of built infrastructure associated with CSG operations (Coal seam gas developments - predicting impacts- April 2012- CSIRO). Increased edge effects are likely to be an important impact as Brigalow Belt vegetation is very fragmented already (Porensky and Young, 2013). Edge effect results from the interaction between two adjacent ecosystems separated by an abrupt transition, most often in this context between an area of remnant vegetation and a transformed land use such as a cleared paddock, road or other infrastructure, or an urban area, and this might affect the organisms living there due the changes in the biotic and abiotic conditions (Murcia, 1995). New roads, besides increasing the fragmentation of the landscape, can have a negative impact on mammals particularly due to road strikes (Taylor and Goldingay, 2010). Roads and traffic have also shown to have negative impact on species with lower reproductive rates, greater mobility, and larger body sizes (Rytwinski and Fahrig, 2012). Also, the density and distribution of amphibians, reptiles, birds and medium to large mammals tends to decline (see reviews in Fahrig and Rytwinski (2009)) as an effect of roads and other linear infrastructure. Not only that, even 3.6 m narrow roads and dirt tracks can inhibit the movement of some fauna species by creating habitat with increased predation risk (Richardson et al., 1997). Edges also offer ideal habitat for edge specialists such as Noisy Miners (*Manorina melanocephala*), a hyper-aggressive native honeyeater found throughout the eastern Australia. Once established, Noisy Miners aggressively exclude other woodland and forest birds from their territory (Maron and Kennedy, 2007). Introduction of edges, reduction of vegetation complexity and increased fire frequency or severity all contribute to increased Noisy Miner density, with potentially substantial impacts on the avifauna (Maron et al., 2013).

2.3.4 INVASIVE SPECIES

The term 'invasive species' is used to refer to any naturalised species that has a demonstrated capacity to spread in an area to which it has been introduced (Richardson et al., 2000). Throughout Australia some invasive plant species have drastically altered the plant species composition and the structure of native vegetation (Grice, 2006). This in turn can affect habitat quality for animals that rely on these vegetation communities. Invasive animals have also had a dramatic and devastating impact on Australian fauna. The Australia-wide decline in small to medium size mammals is attributed largely to predation by feral cats and foxes (Legge et al., 2011). Extensive grazing of the Australian landscape, made possible due to the provision of permanent water sources like dams and bores, during the last few decades has contributed to the expansion of populations of exotic weed and pest species such as camels, goats, horses and donkeys.

Currently Weeds Australia (http://www.weeds.org.au/ accessed on Dec 4th) has recorded 163 and 227 invasive species in the BBN and BBS bioregion respectively, including invasive species that occur in both regions. Those considered of significant importance are listed in table 2 (Martin et al., 2006). One of the first recorded invasive species in the BBS is the prickly pear (*Opuntia* spp.). It was first introduced into domestic gardens in the 1860s. By 1890s, the prickly pear was found throughout many of the brigalow forests in the south of the bioregion (Dodd, 1940). Prickly pear was not only a survivor of the big drought in 1901-02, it was also spread due to the practice of feeding it to livestock (Seabrook et al., 2006). By 1926 prickly pear had invaded 55% (12 million hectares) of the Southern Brigalow Belt. However by 1934, the prickly pear invasion ceased to be a problem due to the introduction of the moth, *Cactoblastis cactorum*, as a biological control (Dodd, 1940).

Pasture grasses, such as buffel grass, are the most threatening invasive plant species in the region because of their association with increased fire risk (Butler, 2008) as well as the reduced forage availability for native herbivores. Unlike native tussock forming grasses, buffel grass forms continuous swards of high biomass grass creating ideal conditions for fire. The increase in fire frequency as a result further enhances conditions for buffel grass establishment and spread creating ideal conditions for this commercially valuable but invasive species (Martin et al., 2012b).

Invasive animals in the region include feral pigs, rabbits, feral dogs / dingoes, foxes, feral cats, goats, deer and cane toads (Butler, 2008). The invasion of feral predators, has added to the reduction and population decline of many native animals- particularly small and medium size mammals. A single feral cat can kill between five and 30 animals in one night (see Legge et al 2011). The native predators which depend on small mammals, reptiles, amphibians and birds for their food source are also negatively impacted. Feral herbivores, such as rabbits and goats compete with native wildlife, damage vegetation and degrade the land.

Table 2 Weeds of significant importance in the Brigalow Belt bioregion in Queensland.

COMMON NAME	SCIENTIFIC NAME	COMMON NAME	SCIENTIFIC NAME
prickly acacia	*Acacia nilotica* subsp. *indica*	Lantana	*Lantana camara*
century plant	*Agave spp*	creeping lantana	*Lantana montevidensis*
alligator weed	*Alternanthera philoxeroides*	Leucaena Tree	*Leucaena leucocephala*
Gamba grass	*Andropogon gayanus*	African boxthorn	*Lycium ferocissimum*
Onion weed	*Asphodelus stulosus*	Devil's claw	*Martynia annua*
mother of millions	*Bryophyllum tubiflorum* and hybrids	mimosa	*Mimosa pigra*
Giant rubber	*Calotropis gigantea*	Chilean needlegrass	*Nassella neesiana*
Buffel grass	*Cenchrus ciliaris and* (*Pennisetum ciliare* (L.)	Nees olive	*Hymenachne amplexicaulis*
Green poisonberry	*Cestrum parqui*	parkinsonia	*Parkinsonia aculeate*
Siam weed	*Chromolaena odorata*	parthenium weed	*Parthenium hysterophorus*
Spear thistle	*Cirsium vulgare*	Bahia grass	*Paspalum notatum*
Afghan melon	*Citrullus lanatus*	African fountain grass	*Pennisetum setaceum*
Lesser swinecress	*Coronopus didymus*	Lippia	*Phyla spp.*
rubber vine	*Cryptostegia grandiflora*	mesquite	*Prosopis* spp.
Fierce thorn-apple	*Datura ferox*	Peruvian peppertree	*Schinus molle*
Aleman grass	*Echinochloa polystachya*	Coffee senna	*Senna occidentalis*
African lovegrass	*Eragrostis curvula*	Flannel weed	*Sida cordifolia*
Harrisia cactus	*Harrisia martinii*	Paddy's Lucerne	*Sida rhombifolia*
Yorkshire fog	*Holcus lanatus*	giant tail grass	*Sporobolus natalensis, S. jacquemontii* and *S. pyramidalis*
Coolatai grass, tambookie	*Hyparrhenia hirta*	Giant Parramatta grass	*Sporobolus fertilis*
Thatch grass	*Hyparrhenia rufa*	Stylo	*Stylosanthes scabra*
Hyptis	*Hyptis suaveolens*	athel pine	*Tamarix aphylla*
Yellow-flowered devil's claw	*Ibicella lutea*	Grader grass	*Themeda quadrivalvis*
Purple morning glory	*Ipomoea indica*	Noogoora burr	*Xanthium occidentale*
bellyache bush	*Jatropha gossypifolia*	Chinese apple	*Ziziyphus mauritiana*

Source: Martin et al., 2006

2.3.5 FIRE

Altered fire regimes may become a threat in the Brigalow Belt. According to Nix (1994) in pre-European times, fire was presumably rare in mature brigalow forests due to very sparse grass cover. However due to the widespread pastoral development in recent years, more open brigalow ecosystems (both mature and regrowth), have become prone to exotic grass species invasions, particularly buffel grass (Dwyer, 2010; Dwyer et al., 2010). Exotic grass invasion promotes more frequent, hotter fires, as it increases fuel loads; this can kill native woody stems and facilitate further grass invasion (Butler and Fairfax, 2003).

Fire has not been an important threat in most years in the BBS with a maximum of 3.5% of the bioregion burnt in 2004 (Bastin and ACRIS Management Committee, 2008). For the BBN 5.4% of the bioregion area was burnt in 1997, while 3.1% was burnt in 2001 (Bastin and ACRIS Management Committee, 2008). Fire was insignificant in other years between 1998 and 2005. Increased fire extent in 1997 and 2001 may have been initiated by preceding higher rainfall and suitable conditions for burning. Also the frequency of fire between 1997 and 2005 was low (Bastin and ACRIS Management Committee, 2008). However if the climate changes as predicted, with increased temperatures and lower and altered rainfall patterns, the probability of high-intensity fires is likely to increase throughout the region.

2.3.6 CLIMATE CHANGE

The climate is changing globally at an unprecedented rate due to industrialisation and the resultant increase in atmospheric greenhouse gases concentrations (IPCC, 2007b). Substantial changes can be expected in natural and human-altered systems driven by rising atmospheric CO_2, ocean acidification, increasing temperatures, declining rainfall, altered rainfall patterns, altered oceanic currents and changed disturbance regimes (IPCC, 2007a). These will result in shifts in species distributions, changes in interactions between species and species extinctions (Williams et al., 2012). However the synergistic effects of climate change and habitat loss on species extinctions haven't been fully explored (Mantyka-Pringle et al., 2011). Climate change is additional to existing pressures acting on already stressed ecosystems, and it will interact with disturbance regimes (such as altered fire regimes), land use change, water abstraction, pollution, over harvesting, habitat degradation, disease and pathogens, eutrophication, invasive alien species and other agents of change; which will create rapid ecosystem transformations and reduce the supply of familiar ecosystem goods and services (Williams et al., 2012).

To understand the potential risks of climate change on a species and plan for actions to protect them, it is important that the dynamics of the populations are understood in connection with the spatial features of landscapes (Opdam and Wascher, 2004). Also land managers would benefit from additional support to identify sources of native or alien invasive species or diseases that are most likely to disrupt their ecosystems (Williams et al., 2012).

2.4 Existing threat management and priorities

Biodiversity conservation in the Brigalow Belt bioregion has received increasing attention due to the rapid and extensive loss of habitat that has occurred (e.g. Gordon (1978); Sattler and Webster (1984)).Brigalow communities are classified as endangered and are poorly represented in conservation reserves (Butler, 2008; Young et al., 1999). Approximately 2.3% of the Brigalow North bioregion and 4.5% of the Queensland part of the Brigalow South bioregion are reserved in protected areas. Currently there are 29 National Parks, four Conservation Parks and one Resource Reserve that protect brigalow ecosystems (http://www.ehp.qld.gov.au/). In addition, some state forests are managed primarily for nature conservation by the Department of Natural Resources and Mines (http://www.nrm.qld.gov.au/).

There are eight Natural Resource Management regions covering parts of the Brigalow Belt bioregion (NRM; Table 2). The NRMs were identified by the Australian Government in association with state and territory governments between 2002-04 and they are based on catchments or bioregions. The NRM groups are funded by the Government through the Caring for our Land program, to achieve national targets - projects that improve biodiversity and sustainable farm practices. Caring for our Country aims to achieve an environment that is healthy, better protected, well-managed, and resilient and provides essential ecosystem services in a changing climate.

Table 3 Natural Resource Management regions in the Brigalow Belt bioregion in Queensland.

NRM REGION	NRM BODY	CONTACT
Border Rivers Maranoa-Balonne	Queensland Murray-Darling Committee	http://www.qmdc.org.au/
Burdekin	North Queensland Dry Tropics NRM	http://www.nqdrytropics.com.au/
Burnett Mary	Burnett Mary Regional Group for NRM	http://www.bmrg.org.au
Condamine	Condamine Alliance	http://www.condaminealliance.com.au/
Desert Channels	Desert Channels Queensland	http://www.dcq.org.au/
Fitzroy	Fitzroy Basin Association	http://www.fba.org.au/
South East Queensland	South East Queensland Catchments	http://www.seqcatchments.com.au/
South West Queensland	South West NRM	http://www.southwestnrm.org.au/about/

Also in this area, local Indigenous groups, industry bodies, land managers, farmers, Landcare groups, communities and governmental agencies are working to protect the biodiversity of the region (McAlpine et al., 2011)). A preliminary list of organisations working in the area is shown in Table 4.

Table 4 groups working in the Brigalow Belt area

GROUP	CONTACT
AgForce Queensland	http://www.agforceqld.org.au/
Australian Bush Heritage Fund	http://www.bushheritage.org.au/
Australian Conservation Foundation	http://www.acfonline.org.au/
Australia Wildlife Conservancy	http://www.australianwildlife.org/
Queensland Farmers Federation	http://www.qff.org.au/
Queensland Resources Council	https://www.qrc.org.au/
Queensland Conservation Council	http://qldconservation.org.au/
The Wilderness Society	http://www.wilderness.org.au
WWF Australia	http://www.wwf.org.au/
Condamine Alliance	http://www.condaminealliance.com.au/
Department of Environment and Resource Management Brigalow Catchment Study	http://www.derm.qld.gov.au/science/projects/ brigalow/ index. html
Department of Environment, Water, Heritage and the Arts listing of brigalow communities as threatened ecosystems	http://www.environment.gov.au/biodiversity/threatened/communities/brigalow.html
Department of Environment, Water, Heritage and the Arts Brigalow Belt Forests in Queensland	http://www.environment.gov.au/biodiversity/threatened/publications/brigalow.html

Myall Park Botanic Garden	www.myallparkbotanicgarden.org.au
Queensland Environmental Protection Agency database of regional ecosystems	http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems
Queensland Murray Darling Committee (QMDC) Inc.	http://www.qmdc.org.au

Our desktop study so far has revealed a number of threats, for which we can generate a set of preliminary management actions (Table 5). For example, the threat of land clearing may be addressed with legislation. Avoiding the incursion of invasive species and in particular the spread of exotic grasses is an important management action that protects against altered fired regimes. Protection and facilitated recovery of brigalow regrowth will be an important component of broader ecosystem recovery (Butler, 2008)(Dwyer et al. 2010b).

Table 5 Current and potential management actions for threats in the Brigalow Belt region

THREAT	MANAGEMENT ACTIONS
Habitat loss and fragmentation	Halting clearing of native vegetation Expanding the area formally protected (such as classifications within the National Reserve System) Protection and restoration of native vegetation on private land Restoration via native revegetation, and inoculation of soil with beneficial microorganisms Passive restoration of natural regrowth, including fire and grazing management Captive breeding and translocation
Invasion by non-native species	Preventing introductions via regulation and quarantine Surveillance, detection and eradication of new arrivals Containment of slow-spreading species Controlling existing invaders by pesticides or herbicides, baiting, and culling Protection of ecosystems and species by removal (plants) or fences (feral predators and herbivores), or moving at-risk species to islands Biological control
Livestock grazing	Management of grazing (stocking rate and access to water) Protecting vulnerable species or ecosystems from grazing pressure Spelling areas from grazing to allow recovery
Altered fire regimes	Controlled burning where fires are too infrequent Suppression of non-native invasive grasses with high fuel load (e.g. gamba grass and buffel grass) or fire-assisted shrubs (e.g. broom) Maintaining buffers with low fuel loads around brigalow forest patches
Over-harvesting of native species	Regulation and anti-poaching enforcement Compensation to offset loss of harvests Captive breeding and reintroduction programs
Water pollution, both marine and freshwater	Regulation of chemical and fertiliser use and dumping of waste Minimising water use in irrigated agriculture
Disease	Lower risk of spread through strategies based on epidemiology Disease-free locations of suitable habitat Quarantine through isolation or destruction of infected individuals to minimise spread Captive breeding and release of disease-free populations

Source: Martin et al., (In press)

2.5 Relevant available data

One of the first steps of our method is to define the ecological, tenure, political and administrative boundaries of the study region. As these factors often relate to current and potential management efforts and also they constrict the information, expert knowledge, funding and feasibility of a project (Carwardine et al., 2012). To do so relevant data that is currently available is listed in table 3.

Table 6 Relevant available data

RELEVANT AVAILABLE DATA
Natural resources/ environment Map of vegetation cover Map of soils Map of waterholes Map of watercourse lines Map of land uses Map of land tenure Threatened species distributions or point localities
Social/political Delineation of Surat and Bowen Basins and Statistical Local Areas Map of localities Map of places names Map of populated places/settlements
Infrastructure – current and proposed future expansions of the following Map of roads Map of rail lines Map of electricity poles Map of pipelines Map of wells Map of any other known or potential future development

3 Existing research and advancements in methodologies

Once the biodiversity and its specific threats in an area are known (Section 2), it is necessary to evaluate the use of limited financial resources for conservation in the most efficient way to improve the persistence of biodiversity. Improvements in biodiversity persistence can be estimated using a species or an ecosystem approach or a combination of both, depending on the conservation objective, threats and available resources. A combined species and ecosystem approach is likely to be the most robust. Defining a set of possible actions to improve persistence, and the differences in the costs, benefits and feasibility of these actions, enables the cost-effectiveness of the actions to be compared. This provides essential information for assisting with decision making.

3.1 Estimating persistence requirements of species and ecosystems

Little research exists directly on estimating the persistence requirements of ecosystems. However there are approaches that can be drawn upon to address this question, particularly some of those used for estimating species persistence requirements. Here we summarise the most relevant of these: the species-area relationship, metapopulation analyses, IUCN red list criteria, and target-setting approaches for conservation planning.

The 'species-area relationship' (SAR) is a cornerstone tool in modern ecological science (Rosenzweig, 1995) and conservation biology. It has been used many times to successfully predict the extinction of species based on habitat reduction (e.g. Brooks et al. (1997) Pimm (1998); Pimm and Askins (1995) and Pimm et al., (1995)). The SAR describes the number of species that can occur in an area depending on the size of that area. The species area relationship has the form of:

$$\boldsymbol{S = cA^z} \tag{1}$$

where *S* is the number of species in an area, *A* is habitat area and *c* (the y-intercept) and *z* (the slope) are constants. For example, if a reduction in area occurs, the total number of species is expected to decrease as a consequence.

Using the SAR in conservation decisions has some limitations. One key limitation is due to the time-lag between habitat loss and species loss (Brooks et al., 1999). Thus, the time scale is too long to be useful for short-term decisions and the extinction estimates assume that species have uniformly distributed range requirements (Ney- Nifle and Mangel, 2000). SAR also do not account for species persistence. SAR take the first encounter of a species, this means, that by finding only one individual the species is considered present in an area without considering if it is the last individual, or if abundance is still high (He and Hubbell, 2011). SAR has often been used to determine the size of land that needs to be set aside for protected areas. However the matrix embedding a protected area is often ignored. Recent research

(Franklin and Lindenmayer, 2009; Prugh et al., 2008) has shown that improving the matrix quality may lead to higher returns than only manipulating size and configuration of remnant patches (Prugh et al., 2008). However, it has also been shown, that in highly fragmented landscapes, SAR can be biased, resulting in artefactual thresholds (Maron et al., 2011).

Metapopulation analyses incorporate more explicit measures of population viability, such as extinction risk (Nicholson and Ovaskainen, 2009; Ponce-Reyes et al., 2013). The extinction risk, in a population model, is a function of the ecology of the species, for example their dispersal ability, area requirements and landscape configuration (Hanski, 1998). Using simple patch-occupancy approximation models that estimate the mean time to extinction (e.g. the metapopulations model proposed by Frank and Wissel (2002)),the metapopulations model proposed by Frank and Wissel (2002)), one can calculate the extinction risk of populations (Day & Possingham, 1995). For example, Ponce-Reyes et al. (2013) estimated which vertebrates (with different life histories) endemic to Mexican cloud forests were more threatened to extinction due to habitat loss caused by climate and/or land use change.

As part of the IUCN Red Listing process, Rodríguez et al. (2011) proposed four criteria for estimating the extinction risk of ecosystems (Red List Criteria V1.0) and developed as a systematic, transparent and repeatable framework with global standards for assessing the status of ecosystems (Keith et al., 2013; Nicholson et al., 2009; Rodríguez et al., 2012). These have since been further refined (Red List Criteria V2.0, (Keith et al., 2013)) to include five criteria (A-E) representing symptoms of ecosystem collapse, relating to: (A) change in distribution; (B) distribution size; the extent and degree of degradation to the (C) abiotic environment and (D) the biotic processes and interactions; and (E) a quantitative assessment of the risk of ecosystem collapse. Ecosystem collapse has been defined as a theoretical threshold beyond which an ecosystem no longer sustains most of its characteristic native biota or the abundance of its biota that have a key role in ecosystem organization (e.g. unique functional groups) (Keith et al., 2013).

Setting targets is an essential part of systematic conservation planning, implementation, and monitoring. Targets are quantitative interpretations of broad conservation goals established in policy by experts, implementing agencies, or other stakeholders (Margules and Pressey, 2000; Pressey et al., 2003). They provide a clear purpose for conservation decisions, lending them accountability and defensibility (Pressey et al., 2003)- basic characteristics of systematic conservation planning. To formulate explicit targets for conservation, it is necessary to evaluate the available data on biodiversity in a region and its threats.

3.2 Cost-effective threat management prioritisation

There is an extensive literature of conservation priority setting approaches, tools and applications. Here we restrict our discussion to the literature on systematic tools that are used to prioritise the management of threats to biodiversity using a return on investment framework and approaches that could be used to this end with some modifications. A return on investment framework prioritises actions using a Cost-effectiveness analysis approach (CEA). CEA has emerged as a useful tool in conservation for enabling more informed and justifiable investments for prioritizing threat management for biodiversity (Carwardine et al., 2012). In table 7 we show a summary of the different structured decision making tools depending on their values and approaches. The approach requires the following basic principles of decision science: (i) a clear objective; (ii) a well-defined set of actions from which a subset will be chosen as priorities; (iii) a model of system behaviour to relate actions to their contributions toward meeting the objectives; (iv) the consideration of resource constraints. Structured Decision-Making – the application of decision science – uses tools such as expert elicitation and cost-effectiveness analyses to collect and evaluate information to advice on the most efficient use of resources.

Table 7 Summarizes the representation of the different Structure Decision -Making tools

	MULTIPLE-FEATURES	BIODIVERSITY BENEFIT	FEASIBILITY (SOCIAL & TECHNICAL)	COST	SPATIAL (FINE RESOLUTION)	IMPLEMENTATION
PPP	x (sequentially)	x	x	x		
Back on Track		x	x			x
Systematic Conservation Planning with zones	x	x	x	x	x	
Cost-effective threat/appraisal	x	x	x	x		
INFFER	x	x	x	x		x
Conservation Action Planning – open standards (TNC)	x	x	x			x

Single species approaches

Project prioritization protocol (PPP) is an optimal resource allocation framework where costs, benefits (including species values), and the likelihood of management success are considered simultaneously. PPP was originally designed for allocating resources to New Zealand's threatened-species projects (Joseph et al., 2009) but now it has since been applied in many other places. PPP provides a framework to rank species-specific conservation projects based on species uniqueness, probabilities of extinction and costs. Mace et al. (2006) developed a similar framework that estimates the probability of recovery of species as a function of the funding while maximising the number of species recovered. The approach by McCarthy et al. (2008) calculates the probability of change of threat category when receiving any funding versus none.

Back on Track is the first species prioritisation framework to be implemented in Australia. It was established with funds from the Queensland Government (former Department of Environment and Resource Management) and the Australian Government (Department of the Environment). This initiative prioritises Queensland's native species for conservation management and recovery, while enabling strategic allocation of limited resources and increasing the capacity of government by making information widely accessible so NRM bodies and communities can make informed decisions. Back on Track has six stages and it is based on the research of Marsh et al., (2007). Stage 1 identifies the priority threatened species for each NRM region in Queensland. Stage 2 collates regional specific information. In stage 3 local expertise and knowledge of threats and actions to achieve species recovery are gathered through workshops. The fourth stage involves the post workshop research and the development of action documents and consultation. Stage five produces the Regional Actions for Biodiversity document and the sixth and final stage implements and reviews it. Back on track is not a cost-effectiveness prioritisation approach, as it does not integrate information on the costs of conservation actions or the expected benefits of taking the actions on species persistence, in order to prioritise them.

Landscape-scale or ecosystem approaches

Systematic conservation planning with zones can be used to prioritise threat management spatially using conservation planning programs that assign areas to 'zones' representing different management actions. Effective conservation zoning plans must integrate the management of multiple uses and therefore account for different types of interactions between and among activities. For example, Marxan with Zones (Watts et al., 2009) is a systematic planning software that evaluates the consequences and trade-offs of alternative zoning configurations, which is critical for informed decision making. It allows the user to define multiple objectives, multiple zones and accept multiple costs making the software versatile and suitable for a wide range of resource management problems. The objectives and constraints can be based on economic, social, cultural or biological spatial features. Systematic conservation planning with zones can be used to estimate the contribution of a diverse range of land uses to achieving conservation goals. It can prioritise investments in alternative conservation strategies by accounting for the relative contribution of different land uses ranging from production forest to well-managed protected areas (Wilson et al., 2010). Prioritising threat management with a conservation planning with zones approach is most useful when a small number of actions are under consideration, and when the resolution of the analysis is fine, i.e. highly spatially explicit. As with traditional systematic conservation planning approaches, the zonal approach has not typically harnessed expert derived information on species persistence estimates, relying instead of mapped data of species distributions.

Investment Framework for Environmental Resources (INFFER) is an 'asset-based approach' that assesses and prioritises environmental and natural resource projects developed by (Pannell et al., 2012). INFFER requires an extensive participation of decision makers and stakeholders; it integrates a comprehensive set of information about projects while explicitly assessing uncertainties and information gaps. It also analyses the most appropriate policy mechanism for each project. INFFER has four stages: identify important environmental assets in the region; remove the assets that are less likely to provide opportunities for cost effective public investment; develop detailed assessments of projects for a subset of assets, and finally negotiate the funding for the projects. INFFER is typically used to prioritise the protection of natural resource 'assets' rather than biodiversity per se, but applies a cost-effectiveness approach similar to the above threat management prioritisation approach. However, this approach is not within the scope of this project because it includes social values and benefits in the analysis.

Cost-effective threat management appraisal is a landscape scale approach based on cost-effectiveness and can be applied across broad regions. It estimates the benefits of alternative management actions by improvements in species persistence (1–probability of extinction) across a number of conservation features. It can use empirical data and/or expert scientific information including traditional ecological knowledge (Martin et al., 2012a) of the targeted biodiversity features and of their likely responses to threats as well as feasible management actions for the region. The targeted biodiversity features may be any number of species, ecosystems, and ecosystem processes or services provided the relevant knowledge exists (Carwardine et al., 2012).

This approach has been applied to provide a cost-effectiveness prioritisation of threat management in the Kimberly region (Carwardine et al., 2011). To do so, information on the ecological features of the region, their threats, key threat management actions and the costs required to restore the wildlife were gathered in two expert workshops with many follow-up consultations. Similarly, for the Lake Eyre Basin (LEB), scientists together with a group of experts provided a prioritisation of invasive plant management strategies. They identified the key invasive plant species that needed to be targeted in order to protect the ecosystem intactness across the bioregions of the LEB, the level of investment required and the likely reduction in invasive species dominance gained per dollar spent on each strategy (Firn et al., 2013).

The approach involves identifying the relative cost-effectiveness of taking different management actions for improving the probability of persistence of species and threatened ecosystems The useful outputs of these approaches include providing the likely biodiversity outcomes under different management scenarios including a 'do nothing' scenario, the suite of actions and funds required to achieve persistence, and the best use of a limited budget to maximise expected ecological benefit. The cost-effectiveness of actions is evaluated by combining the information on benefits, feasibility and costs. Following Carwardine et al. (2011), the benefit B_{ij} of action *i* (or a set of management activities) in bioregion *j*, is defined by the difference in persistence probability of all wildlife species in the bioregion with and without implementation of that action,

$$B_{ij} = \sum_{x=n} N_x \cdot (P_i - P_0) \qquad (2)$$

Where:

x = the number of ecological groups

N_x = the number of species in group x

P_i = the probability of persistence under action ij

P_0 = the probability of persistence under a no management scenario.

The total cost now (C_{ij}) of an action that requires ongoing implementation over a number of years (t) at a discount rate per year (r) was determined using the present value equation, which measures the present value of a series of equal payments over a number of time series:

$$C_{ij} = \frac{C_{annual} \cdot t}{(1+r)^t} \qquad (3)$$

The cost-effectiveness, in ecological terms, of an action-bioregion *ij* is then defined by:

$$CE_{ij} = \frac{B_{ij} \cdot Pr_{ij}}{C_{ij}} \qquad (4)$$

Where:

Pr_{ij} = the feasibility, probability of success of the action (averaged over all actions in a package)

C_{ij} = the total cost of the action (summed over all activities in a package).

The lack of empirical data on species distributions and likely responses to threats and management actions impedes the application of conservation strategies in many regions. When formal survey data in a region is incomplete, regional experts and land owners can potentially provide a lot of knowledge of the ecology of the system and their expertise in natural resource management (Carwardine et al., 2012; Carwardine et al., 2011; Firn et al., 2013; Martin et al., 2012a; Martin et al., 2005).

Governments and other investors must be able to discern between alternative threat management actions, using transparent information on the likely costs, risks, and benefits of taking action compared to inaction when developing or managing threat management development and plans in a region (Possingham et al., 2001). For these analyses it is necessary to estimate the costs relevant to the suite of conservation management actions. Sometimes, this is done based on previous experiences of undertaking something similar. Costs of actions may vary depending on the land tenure or management cost, so a range of likely costs needs to be implemented. Benefits are a measure of how much better off biodiversity will be if the action is implemented compared with if it is not. The benefit can be measured as an improvement in the persistence of a species, species group or other ecological feature. The expected benefits are estimated by multiplying the potential benefits by the feasibility, or the likelihood that the benefit will be achieved. The feasibility is a probability of success to 1, of an action being achieved (1) or not (0); taking into account of social, economic, knowledge and logistical constraints. Feasibility may vary depending of the land tenure, land use time and funds. However it needs to be summarized or averaged to provide one feasibility estimate per action per evaluation unit (Carwardine et al., 2012).

3.3 Advancements and gaps in the field

Recent research has shown the utility of threat identification and appraisal approaches (Carwardine et al., 2011; Firn et al., 2013). Due to the novelty of these tools and their application, there are many areas for possible improvement. For example, the approach may be improved by considering a finer resolution of costs and biodiversity persistence parameters and improving expert estimates by combining them with empirical information using Bayesian Belief Networks. The adaptability of the approaches to uncertainties and future challenges and changes after implementation is also an area of rich research potential.

Adaptive management is a systematic approach for improving resource management by learning from management outcomes (Williams et al., 2009). It can be implemented using a range of different methods depending on the study system (Westgate et al., 2013). There is a general agreement that the process typically involves the following steps (modified form Duncan and Wintle (2008), (Keith et al. (2011); Williams et al. (2009)):

1. Identification of management goals in collaboration with stakeholders.
2. Specification of multiple management options, one of which can be 'do nothing'.
3. Creation of a rigorous statistical process for interpreting how the system responds to management interventions. This stage typically involves creation of quantitative conceptual models and/or a rigorous experimental design.
4. Implementation of management action(s).
5. Monitoring of system response to management interventions (preferably on a regular basis).
6. Adjust management practice in response to results from monitoring.

The Nature Conservancy developed a methodology **Conservation action planning (CAP),** based on an adaptive management framework of setting goals and priorities, developing strategies, implementing the strategies and measuring the results. CAP has many strengths, for example, it integrates the context and outcomes with planning and actions through a clear framework for the analyses of the threats. It focuses on key values, and it could be adapted to assess social and cultural values, even though it was originally created to investigate biodiversity values. However CAP does not cover all elements of management effectiveness (www.conserveonline.org/workspaces/cbdgateway/cap/practices).

According to Westgate et al. (2013), adaptive management may not be well suited to testing management options associated with some large-scale ecological phenomena or factors that are important at multiple spatial scales or across multiple land tenures. Results of an extensive literature search found only three projects that involved truly large scale problems: Waterfowl management (Williams et al., 1996), the Northwest Forest Plan (Stankey et al., 2003), and wolf management in the Yukon (Hayes et al., 2003). Applying adaptive management to large-scale projects may be difficult due to the need for co-ordination required for land managed under different tenures, by different organizations and/or private individuals with different management priorities, goals, values and reward systems.

4 Conclusion

Conserving biodiversity requires more than representing the current distributional patterns of species by creating protected areas. This is especially true in multiple use regions with high biodiversity importance and increasing threats associated with new development, such as the Brigalow Belt region of Queensland. Current conservation efforts in the Brigalow Belt, while important, are expected to be insufficient to ensure the persistence of this unique ecosystem and its biodiversity. Conflicts between further agricultural intensification and industrial development for oil and gas and brigalow conservation are acute. It is necessary that decision makers consider processes that maintain species, to ensure the persistence of the species under current conditions but also under anticipated future scenarios (Balmford et al., 1998). A cost-effectiveness approach to prioritise threat management is a rational approach for prioritising actions that best improve the wildlife persistence per dollar spent under situations of limited resources, data and time. The lack of formal data on species distribution, ecological processes and likely responses to threats and management actions is an issue for the Brigalow Belt and many other important regions. However undertaking conservation management appraisal and prioritization using the expert knowledge to complement scientific data is an effective way to gather missing information (Burgman et al., 2011; Kuhnert et al., 2010; Martin et al., 2012a; Martin et al., 2005). These relatively new methods of undertaking conservation management appraisal and prioritization using the expert knowledge are flexible and adaptable to situations with different amounts of data availability (Martin et al., 2012a). The alternative of taking no actions and waiting until empirical data exist, is likely to result in further loss of species (Martin et al., 2012c).

This project will produce a prioritised set of threat management actions to assist decision makers in allocating scarce resources to conserve biodiversity in a multiple-use region with important biodiversity values that are facing increasing anthropogenic threats (Seabrook et al., 2006), in particular CSG and coal. While conflicts are high, development brings opportunities and potentially, resources for action. The information provided by appraisal approaches, combining the best available scientific information with expert knowledge, can be useful to guide investment for the conservation of biodiversity, including for managing and off-setting threats in the region. This approach allows urgent and accountable decision making even where formal systematic data is lacking, which is particularly important in a region where timely conservation decision making is required to stem the decline of biodiversity and ensure ecosystem persistence .

CSIRO

References

Accad, A., (2001) Remnant Vegetation in Queensland: Analysis of Pre-clearing, Remnant 1997–1999 Regional Ecosystem Information. Queensland Herbarium, Toowong, Qld.

Arnold, S., Audet, P., Doley, D., Baumgartl, T. (2013) Hydropedology and ecohydrology of the Brigalow Belt, Australia: Opportunities for ecosystem rehabilitation in semiarid environments. Vadose Zone J.

Baillie, J.E.M., Hilton-Taylor, C., Stuart, S.N. (2004) 2004 IUCN Red List of threatened species. A global species assessment.

Balmford, A. (1998) On hotspots and the use of indicators for reserve selection. Trends Ecol. Evol. 13, 409.

Balmford, A., Green, R.E., Scharlemann, J.P.W. (2005) Sparing land for nature: exploring the potential impact of changes in agricultural yield on the area needed for crop production. Global Change Biology 11, 1594-1605.

Balmford, A., Mace, G.M., Ginsberg, J.R., (1998) The challenges to conservation in a changing world: putting processes on the map, in: Mace, G.M., Balmford, A., Ginsberg, J.R. (Eds.), Conservation in a changing world. Cambridge University Press, pp. 1-28.

Bastin, G., ACRIS Management Committee, (2008) Rangelands 2008 — Taking the Pulse, in: Committee, A.M. (Ed.). National Land & Water Resources Audit, Canberra.

Beckmann, J.P., Murray, K., Seidler, R.G., Berger, J. (2012) Human-mediated shifts in animal habitat use: Sequential changes in pronghorn use of a natural gas field in Greater Yellowstone. Biological Conservation 147, 222-233.

Beechie, T.J., Sear, D.A., Olden, J.D., Pess, G.R., Buffington, J.M., Moir, H., Roni, P., Pollock, M.M. (2010) Process-based Principles for Restoring River Ecosystems. BioScience 60, 209-222.

Bottrill, M.C., Joseph, L.N., Carwardine, J., Bode, M., Cook, C., Game, E.T., Grantham, H.S., Kark, S., Linke, S., McDonald-Madden, E., Pressey, R.L., Walker, S., Wilson, K.A., Possingham, H.P. (2008) Is conservation triage just smart decision making? Trends in Ecology & Evolution 23, 649-654.

Bowen, M.E., C. A. McAlpine, L. M. Seabrook, A. P. N. House, and G. C. Smith (2009) The age and amount of regrowth forest in fragmented brigalow landscapes are both important for woodland dependent birds. Biological Conservation 142, 3051-3059.

Brooks, T., Pimm, L., J., O. (1999) Time lag between deforestation and bird extinction in tropical forest fragments. Conservation Biology 13, 1140-1150.

Brooks, T.M., Pimm, S.L., Collar, N.J. (1997) Deforestation predicts the number of threatened birds in insular southeast Asia. Conservation Biology 11, 382-394.

Burgman, M.A., Carr, A., Godden, L., Gregory, R., McBride, M., Flander, L., Maguire, L. (2011) Redifining expertise and improving ecological judegement. Conservation Letters 4, 81-87.

Burgman, M.A., Lindenmayer, D.B. (1998) Conservation Biology for the Australian Environment. Surrey Beatty and Sons, Chipping Norton, Sydney, Australia.

Butchart, S.H.M., Stattersfield, A.J., Bennun, L.A., Shutes, S.M., Akçakaya, H.R., Baillie, J.E.M., Stuart, S.N., Hilton-Taylor, C., Mace, G.M. (2004) Measuring Global Trends in the Status of Biodiversity: Red List Indices for Birds. PLoS Biol 2, e383.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vié, J.-C., Watson, R. (2010) Global Biodiversity: Indicators of Recent Declines. Science 328, 1164-1168.

Butler, D.W., (2008) Recovery plan for the "Brigalow (Acacia harpophylla dominant and co-dominant" endangered ecological community (draft of July 2008), in: Report to the Department of the Environment and Water Resources, C. (Ed.). Queensland National Parks and Wildlife Service, Brisbane.

Butler, D.W. (2009) Planning iterative investment for landscape restoration: Choice of biodiversity indicator makes a difference. Biological Conservation 142, 2202-2216.

Butler, D.W., Fairfax, R.J. (2003) Buffel grass and fire in a gidgee and Brigalow woodland: a case study from central Queensland. Ecological Management and Restoration 4, 120-125.

Cabeza, M., Moilanen, A. (2001) Design of reserve networks and the persistence of biodiversity. Trends in Ecology & Evolution 16, 242-248.

Carlson, J.T., Harmata, A.R., Restani, M. (2012) Environmental contaminants in nestling bald eagles produced in Montana and Wyoming. Journal of Raptor Research 46, 274-282.

Carwardine, J., O'Connor, T., Legge, S., Mackey, B., Possingham, H.P., Martin, T.G. (2012) Prioritizing threat management for biodiversity conservation. Conservation Letters 5, 196-204.

Carwardine, J., O’Connor, T., Legge , S., Mackey, B., Possingham, H.P., Martin, T.G., (2011) Priority threat management to protect Kimberley wildlife, in: Sciences, C.E. (Ed.).

Carwardine, J., Wilson, K.A., Ceballos, G., Ehrlich, P.R., Naidoo, R., Iwamura, T., Hajkowicz, S.A., Possingham, H.P. (2008) Cost-effective priorities for global mammal conservation. Proceedings of the National Academy of Sciences 105, 11446-11450.

Catterall, C.P., Kingston, M.B., Park, K., Sewell, S. (1988) Deforestation, urbanisation and seasonality: Interacting effects on a regional bird assemblage. Biological Conservation 84, 65-81.

Chadès, I., Curtis, J.M.R., Martin, T.G. (2012) Setting realistic recovery targets for interacting endangered species. Conservation Biology 26, 1016-1025.

Clewley, D., R. Lucas, A. Accad, J. Armston, M. Bowen, J. Dwyer, S. Pollock, P. Bunting, C. McAlpine, T. Eyre, A. Kelly, J. Carreiras, and M. Moghaddam (2012) An Approach to Mapping Forest Growth Stages in Queensland, Australia through Integration of ALOS PALSAR and Landsat Sensor Data. Remote Sensing 4, 2236-2255.

Cowling, R.M., Knight, A.T., Faith, D.P., Ferrier, S., Lombard, A.T., Driver, A., Rouget, M., Maze, K., Desmet, P.G. (2004) Nature Conservation Requires More than a Passion for Species. Conservation Biology 18, 1674-1676.

Cullen, R., Hughey, K.F.D., Fairburn, G., Moran, E. (2005) Economic analyses to aid nature conservation decision making. Oryx 39, 327-334.

Dalal R.C., Eberhard R., Grantham T., D.G., M. (2003) Application of sustainability indicators, soil organic matter and electrical conductivity, to resource management in the northern grains region. Australian Journal of Experimental Agriculture, Ecosystems & Environment 43, 253-259.

DeFries, R., Hansen, A., Turner, B.L., Reid, R., Liu, J. (2007) Lnd use change around protected areas: management to balance human needs and ecological function. Ecological Applications 17, 1031-1038.

Dodd, A.P., (1940) The Biological Campaign Against Prickly-Pear. The Commonwealth Prickly Pear Board, Brisbane.

Dowling, A.J., Webb, A.A., Scanlan, J.C. (1986) Surface soil chemical and physical patterns in a brigalow - dawson gum forest central Queensland, Australia. Australian Journal of Ecology 11, 155-162.

Duncan, D.H., Wintle, B.A., (2008) Towards adaptive management of native vegetation in regional landscapes, in: Pettit, C., Cartwright, W., Bishop, I., Lowell, K., Pullar, D., Duncan, D. (Eds.), Landscape Analysis and Visualisation: Spatial Models for Natural Resource Management and Planning. Springer-Verlag, Berlin.

Dwyer, J.M., (2007) Restoration of Remnant Population and Community Structure in Brigalow Regrowth. University of Queensland.

Dwyer, J.M., Fensham, R.J., Buckley, Y.M. (2010) Agricultural legacy, climate, and soil influence the restoration and carbon potential of woody regrowth in Australia. Ecological Applications 20, 1838-1850.

Dwyer, J.M., Fensham, R.J., Butler, D.W., Buckley, Y.M. (2009) Carbon for conservation: Assessing the potential for win–win investment in an extensive Australian regrowth ecosystem. Agriculture, Ecosystems & Environment 134, 1-7.

Dwyer, J.M., R. Fensham, and Y. M. Buckley (2010) Restoration thinning accelerates structural development and carbon sequestration in an endangered Australian ecosystem. Journal of Applied Ecology 47, 681-691.

Ehrlich, P., Ehrlich, A. (1981) Extinction. Ballantine Books, New York.

Elliott, L. (1989) The Surat and Bowen Basins. APEA Journal 29, 398-416.

Environment Australia, (2000) Revision of the Interim Biogeographic Regionalisation of Australia (IBRA) and Development of Version 5.0 – Summary Report. Department of Environment and Heritage, Canberra.

EPBC Act, (1999) Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), in: Government, A. (Ed.), Office of Legislative Drafting and Publishing (OLDP), Canberra.

Erskine, P.D., Fletcher, A.T. (2013) Novel ecosystems created by coal mines in central Queensland's Bowen Basin. Ecological Processes 2, 1-12.

Fahrig, L., Rytwinski, T. (2009) Effects of roads on animal abundance: An empirical review and synthesis. Ecology and Society, 14:21.

Fensham, R.J., Fairfax, R.J. (2003) A land management history for central Queensland, Australia as determined from land-holder questionnaire and aerial photography. Journal of Environmental Management 68, 409-420.

Firn, J., Martin, T.G., Walters, B., Hayes, J., Nicol, S., Chades, I., Carwardine, J., (2013) Priority threat management of invasive plant species in the Lake Eyre Basin, CSIRO Climate Adaptation Flagship Working paper No. 17 (CSIRO and Queensland University of Technology).

Fischer, J., Brosi, B., Daily, G.C., Ehrlich, P.R., Goldman, R., Goldstein, J., Lindenmayer, D.B., Manning, A.D., Mooney, H.A., Pejchar, L., Ranganathan, J., Tallis, H. (2008) Should Agricultural Policies Encourage Land Sparing or Wildlife-Friendly Farming? Frontiers in Ecology and the Environment 6, 380-385.

Frank, K., Wissel, C. (2002) A formula for the mean lifetime of metapopulations in heterogeneous landscapes. The American Naturalist 159, 530-552.

Franklin, J.F. (1993) Preserving biodiversity: species, ecosystems or landscapes? Ecological Applications 3, 202-205.

Franklin, J.F., Lindenmayer, D.B. (2009) Importance of matrix habitats in maintaining biological diversity. Proceedings of the National Academy of Sciences 106, 349-350.

Game, E.T., Kareiva, P., Possingham, H.P. (2013) Six Common Mistakes in Conservation Priority Setting. Conservation Biology 27, 480-485.

Gardner, T.A., Caro, T., Fitzherbert, E.B., Banda, T., Lalbhai, P. (2007) Conservation value of multiple-use areas in East Africa. Conservation Biology 21, 1516-1525.

Gaston, K.J., Blackburn, T.M., Goldewijk, K.K. (2003) Habitat conversion and global avian biodiversity loss. Proceedings of the Royal Society of London. Series B: Biological Sciences 270, 1293-1300.

Gates, C.T. (1972) Ecological response of Australian native species *Acacia harpophylla* and *Atriplex nummularia* to soil salinity - Effects on water content, leaf area, and transpiration rate. Australian Journal of Botany 20, 261-272.

Geoscience Australia, (2010) Australia's Identified Mineral Resources.

Gordon, G., (1978) The bush -here, there and everywhere, in: Lavery, H.J. (Ed.), Exploration North, A Natural History of Queensland. Richmond Hill Press and Queensland Government.

Grace, P.R., Macrae, I.C., Myers, R.J.K. (1992) Factors influencing the availability of mineral nitrogen in clay soils of the brigalow (*Acacia harpophylla*) region of central Queensland. Australian Journal of Agricultural Research 43, 1197-1215.

Graham, T.W.G., Webb, A.A., Waring, S.A. (1981) Soil nitrogen status and pasture productivity after clearing of brigalow (*Acacia harpophylla*). Australian Journal of Experimental Agriculture and Animal Husbandry 21, 109-118.

Green, R.E., Cornell, S.J., Scharlemann, J.P.W., Balmford, A. (2005) Farming and the fate of wild nature. Science 307, 550-555.

Grice, A.C. (2006) The impacts of invasive plant species on the biodiversity of Australian rangelands. The Rangeland Journal 28, 27-35.

Groombridge, B. (1992) Global Biodiversity. Chapman & Hall, London.

Güneralp, B. (2013) Futures of global urban expansion: uncertainties and implications for biodiversity conservation. Environmental research letters 8, 014025.

Gunn, R.H., (1984) Soil landscapes of the Brigalow Belt in Queensland, in: A, B. (Ed.), The Brigalow Belt of Australia Queensland Department of Primary Industries, Brisbane, pp. 7-21.

Hajkowicz, S., Higgins, A., Miller, C., Marinoni, O. (2008) Targeting conservation payments to achieve multiple outcomes. Biol. Conserv . 141, 2368–2375.

Hall, L.S., Krausman, P.R., Morrison, M.L. (1997) The Habitat Concept and a Plea for Standard Terminology. Wildlife Society Bulletin 25, 173-182.

Hanski, I. (1998) Metapopulation dynamics. Nature 396, 41-49.

Hanski, I., Ovaskainen, O. (2000) The metapopulation capacity of a fragmented landscape. Nature 404, 755-758.

Hayes, R.D., Farnell, R., Ward, R.M.P., Carey, J., Dehn, M., Kuzyk, G.W., Baer, A.M., Gardner, C.L., O'Donoghue, M. (2003) Experimental reduction of wolves in the Yukon: ungulate responses and management implications. Wildl. Monogr., 1-35.

He, F., Hubbell, S.P. (2011) Species-area relationships always overestimate extinction rates from habitat loss. Nature 473, 368-371.

Hobbs, R.J., Higgs, E., Harris, J.A. (2009) Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution 24, 599-605.

Hobbs, R.J., Higgs, E.S., Hall, C. (2013) Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons, USA.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T.M., Butchart, S.H.M., Carpenter, K.E., Chanson, J., Collen, B., Cox, N.A. (2010) The Impact of Conservation on the Status of the World's Vertebrates. Science 330, 1503.

IPCC, (2007a) Climate change 2007: impacts, adaptation and vulnerability, in: Press, C.U. (Ed.), New York.

IPCC, (2007b) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland.

IUCN, (2001) Red List categories and criteria. IUCN, Gland, Switzerland.

James, A.N., Gaston, K.J., Balmford, A., . (1999) Balancing the Earth's accounts. Nature 401, 323–324.

John Williams Scientific Services Pty Ltd, (2012) An analysis of coal seam gas production and natural resource management in Australia.

Johnson, R.W., (1964) Ecology and Control of Brigalow in Queensland. Queensland Department of Primary Industries, Brisbane.

Johnson, R.W. (1976) Competition between brigalow (Acacia harpophylla) suckers and establishing pastures following pulling and burning. Qld. J. Agric. Anim. Sci. 33, 43–65.

Johnson, R.W., (1997) The Impacts of clearing on brigalow communities and consequences for conservation, in: Hale, P., Lamb, D. (Eds.), Conservation Outside Nature Reserves. Centre for Conservation Biology, University of Queensland, Brisbane pp. 359–363.

Johnson, R.W., McDonald, W.J.F., (2005) Understanding biological and ecological processes as a means of managing remnant brigalow communities, in: Exelby, A., Melzer, A. (Eds.), Remnant Vegetation in the Brigalow Belt Management and Conservation. Central Queensland University, Gladstone, Qld pp. 14–21.

Jongman, R.H., Pungetti, G. (2004) Ecological Networks and Greenways: Concept, Design, Implementation. Cambridge University Press.

Joseph, L.N., Maloney, R.F., Possingham, H.P. (2009) Optimal Allocation of Resources among Threatened Species: a Project Prioritization Protocol. Conservation Biology 23, 328-338.

Keith, D.A., Martin, T.G., McDonald-Madden, E., Walters, C. (2011) Uncertainty and adaptive management for biodiversity conservation. Biol. Conserv. 144, 1175–1178.

Keith, D.A., Rodriguez, J.P., Rodriguez-Clark, K.M., Nicholson, E., Aapala, K., Alonso, A., Asmussen, M., Bachman, S., Basset, A., Barrow, E.G., Benson, J.S., Bishop, M.J., Bonifacio, R., Brooks, T.M., Burgman, M.A., Comer, P., Comin, F.A., Essl, F., Faber-Langendoen, D., Fairweather, P.G., Holdaway, R.J., Jennings, M., Kingsford, R.T., Lester, R.E., Mac Nally, R., McCarthy, M.A., Moat, J., Oliveira-Miranda, M.A., Pisanu, P., Poulin, B., Regan, T.J., Riecken, U., Spalding, M.D., Zambrano-Martinez, S. (2013) Scientific Foundations for an IUCN Red List of Ecosystems. Plos One 8, 1-25.

Kuhnert, P.M., Martin, T.G., Griffiths, S.P. (2010) A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecol Lett 13, 900-914.

Legge, S., Kennedy, M.S., Lloyd, R.A.Y., Murphy, S.A., Fisher, A. (2011) Rapid recovery of mammal fauna in the central Kimberley, northern Australia, following the removal of introduced herbivores. Austral Ecology 36, 791-799.

Levin, H.M., McEwan, P.J. (2001) Cost-Effectiveness Analysis: Methods and Applications. Sage Publications, Thousand Oaks, California.

Lindenmayer, D.B., Burgman, M.A. (2005) Prractical conservation biology. CSIRO, Collinwood,Australia.

Mace, G.M., Possingham, H., Leader-Williams, N., (2006) Prioritizing choices in conservation, in: Macdonald D., Service, K. (Eds.), Key topics in conservation biology. Blackwell Publishing, Oxford, pp. 17–34.

Mackey, B.G., Soulé, M.E., Nix, H.A., Recher, H.F., Lesslie, R.G., Williams, J.E., Woinarski, J.C.Z., Hobbs, J., Possingham, H.P., (2007) Towards a scientific framework for the WildCountry project, in: Wu, J., Hobbs, R.J. (Eds.), Key Topics and Perspectives in Landscape Ecology. Cambridge University Press, pp. 92–208.

Mantyka-Pringle, C.S., Martin, T.G., Rhodes, J.R. (2011) Interactions between climate and habitat loss effects on biodiversity: a systematic review and meta-analysis. Global Change Biology 18, 1239-1252.

Margules, C.R., Pressey, R.L. (2000) Systematic conservation planning. Nature 405, 243-253.

Maron, M., Bowen, M., Fuller, R., Smith, J.C., Eyre, T.J., Mathieson, M., Watson, J.E.M., McAlpine, C.A. (2011) Spurious thresholds in the relationship between species richness and vegetation cover. Global Ecology and Biogeography.

Maron, M., Grey, M.J., Catterall, C.P., Major, R.E., Oliver, D.L., Clarke, M.F., Loyn, R.H., Mac Nally, R., Davidson, I., Thomson, J.R. (2013) Avifaunal disarray due to a single despotic species. Diversity and Distributions 19, 1468-1479.

Maron, M., Kennedy, S. (2007) Roads, fire and aggressive competitors: Determinants of bird distribution in subtropical production forests. Forest Ecology and Management 24-, 24-31.

Marsh, H., Dennis, A., Hines, H., Kutt, A., McDonald, K., Weber, E., Williams, S., Winter, J. (2007) Optimizing Allocation of Management Resources for Wildlife. Conservation Biology 21, 387-399.

Martin, T.G., Burgman, M.A., Fidler, F., Kuhnert, P.M., Low-Choy, S., McBride, M., Mengersen, K. (2012a) Eliciting expert knowledge in conservation science. Conservation Biology 26, 29-38.

Martin, T.G., Campbell, S., Grounds, S. (2006) Weeds of Australian rangelands. The Rangeland Journal 28, 3-26.

Martin, T.G., Carwardine, J., Broadhurst, L.M., Ferrier, S., James, C., Sheppard, A., Whitten, S., Chades, I., (In press) Tools for managing and restoring biodiversity, in: Morton, S. (Ed.), Conserving Biodiversity. CSIRO publishing.

Martin, T.G., Kuhnert, P.M., Mengersen, K., Possingham, H.P. (2005) The Power of Expert Opinion in Ecological Models Using Bayesian Methods: Impact of Grazing on Birds Ecological Applications 15, 266-280.

Martin, T.G., McIntyre, S. (2007) Impacts of livestock grazing and tree clearing on birds of woodland and riparian habitats. Conservation Biology 21, 504-514.

Martin, T.G., Murphy, H., Liedloff, A., (2012b) Invasive species and climate change: a framework for predicting species distribution when data are scarce, CSIRO Climate Adaptation Flagship Working Paper No. 13G.

Martin, T.G., Nally, S., Burbidge, A.A., Arnall, S., Garnett, S.T., Hayward, M.W., Lumsden, L.F., Menkhorst, P., McDonald-Madden, E., Possingham, H.P. (2012c) Acting fast helps avoid extinction. Conservation Letters 5, 274-280.

McAlpine, C.A., Fensham, R.J., Temple-Smith, D.E. (2002a) Biodiversity conservation and vegetation clearing in Queensland: principles and thresholds. The Rangeland Journal 24, 36-55.

McAlpine, C.A., Lindenmayer, D.B., Eyre, T.J., Phinn, S.R. (2002b) Landscape surrogates of forest fragmentation: Synthesis of Australian Montreal Process case studies. Pacific Conservation Biology 8, 108-120.

McAlpine, C.A., Maron, M., Smith, G., Bowen, M., Seabrook, L., Dwyer, J.M., Butler, S., Graham, C., Goulding, W., (2011) Conseerving biodiversity in brigalow landscapes, http://www.gpem.uq.edu.au/docs/Brigalow/ConservingBrigalowLandscapesl.pdf.

McAlpine, C.A., Sutcliffe, T., Taylor, K., (2002c) One hundred and fifty years of landscape change for two sub regions of the Southern Brigalow: Patterns and management implications, in: Franks, A.J., Playford, J., Shapcott, A. (Eds.), Landscape Health of Queensland. Brisbane: Royal Society of Queensland, pp. 27-41.

McCarthy, M.A., Thompson, C.J., Garnett, S.T. (2008) Optimal investment in conservation of species. Journal of Applied Ecology 45, 1428-1435.

McDonald, R.I., Fargione, J., Kiesecker, J., Miller, W.M., Powell, J. (2009) Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for the United States of America. Plos One 4, e6802.

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

McKinney, M.L. (2002) Urbanization, biodiversity, and conservation. BioScience 52, 883-890.

Miles, L., Grainger, A., Phillips, O. (2004) The impact of global climate change on tropical forest biodiversity in Amazonia. Global Ecology and Biogeography 13, 553-565.

Millennium Ecosystem Assessment, (2005) Ecosystems and human well-being: Biodiversity synthesis. World Resources Institute.

Moilanen, A., Franco, A.M.A., Early, R.I., Fox, R., Wintle, B., Thomas, C.D. (2005) Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. Proceedings of the Royal Society B: Biological Sciences 272, 1885-1891.

Moilanen, A., Wilson, K.A., Possingham , H., (2009) Spatial Conservation Prioritization: Quantitative Methods and Computational Tools Oxford University Press, p. 320.

Murcia, C. (1995) Edge effects in fragmented forests: implications for conservation. Trends Ecol Evol 10, 58-62.

Murphy, D.D., Noon, B.D. (1991) Coping with Uncertainty in Wildlife Biology. The Journal of Wildlife Management 55, 773-782.

Naidoo, R., Ricketts, T.H. (2006) Mapping the Economic Costs and Benefits of Conservation. PLoS Biol 4, e360.

Ney- Nifle, M., Mangel, M. (2000) Habitat Loss and Changes in the Species-Area Relationship. Conserv. Biol. 14, 893-898.

Ngugi, M.R., Johnson, R.W., McDonald, W.J.F. (2011) Restoration of ecosystems for biodiversity and carbon sequestration: Simulating growth dynamics of brigalow vegetation communities in Australia. Ecological Modelling 222, 785-794.

Nicholson, E., Keith, D.A., Wilcove, D.S. (2009) Assessing the Threat Status of Ecological Communities. Conservation Biology 32, 259-274.

Nicholson, E., Ovaskainen, O., (2009) Conservation prioritisation using metapopulation models, in: moilanen, A., Wilson, K., Possingham , H. (Eds.), Spatial Conservation Prioritization. Quantittive Methods and Computational Tools. Oxford University Press, Oxford.

Nix, H.A., (1994) The Brigalow, in: Dovers, S. (Ed.), Australian environmental history: essays and cases. Oxford University Press, Melbourne, Victoria, Australia.

Northrup, J.M., Wittemyer, G. (2013) Characterising the impacts of emerging energy development on wildlife, with an eye towards mitigation. Ecology Letters 16, 112-125.

Noss, R.F. (1996) Ecosystems as conservation targets. TREE 11, 351.

Opdam, P., Wascher, D. (2004) Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117, 285-297.

Pannell, D.J., Roberts, A.M., Park, G., Alexander, J., Curatolo, A., Marsh, S.P. (2012) Integrated assessment of public investment in land-use change to protect environmental assets in Australia. Land Use Policy 29, 377-387.

Parmesan, C. (2006) Ecological and Evolutionary Responses to Recent Climate Change. Annual Review of Ecology, Evolution, and Systematics 37, 637-669.

Pauchard, A., Aguayo, M., Peña, E., Urrutia, R. (2006) Multiple effects of urbanization on the biodiversity of developing countries: The case of a fast-growing metropolitan area (Concepción, Chile). Biological Conservation 127, 272-281.

Pedroni, P.M., Jaramillo, H., Torres, C.M.d.L., Navarrete, H., Bernal-Ramirez, J., Reed, T. (2013) A partnership approach to addressing applied ecological research needs of an oil and gas business. Journal of Applied Ecology 50, 539-543.

Perfecto, I., Vandermeer, J. (2008) Biodiversity Conservation in Tropical Agroecosystems. Annals of the New York Academy of Sciences 1134, 173-200.

Phalan, B., Onial, M., Balmford, A., Green, R.E. (2011) Reconciling food production and biodiversity conservation: Land sharing and land sparing compared. Science 333, 1289-1291.

Pimm, S.L., (1998) Extinction, in: Sutherland, W.J. (Ed.), Conservation science and action. Blackwell Science, Oxford, United Kingdom, pp. 20–38.

Pimm, S.L. (2000) Conservation connections. Trends Ecol. Evol. 15, 262.

Pimm, S.L., Askins, R.A. (1995) Forest losses predict bird extinctions in eastern North America. Proc. Natl. Acad. Sci. USA 92, 9343.

Pimm, S.L., Russell, G., Gittleman, J., T., B. (1995) The future of biodiversity. Science 268, 347–354.

Ponce-Reyes, R., Nicholson, E., Baxter, P.W.J., Fuller, R.A., Possingham, H. (2013) Extinction risk in cloud forest fragments under climate change and habitat loss. Diversity and Distributions 19, 518-529.

Porensky, L.M., Young, T.P. (2013) Edge-effect interactions in fragmented and patchy landscapes. Conservation Biology, 509-551.

Possingham, H., Ryan, S., Baxter, J., Morton, S., (2002) Setting Biodiverstity priorities; A paper prepred as part of the activities of the working group producing the report Sustaining our Natural Systems and Biodiversity. Prime Minister's Science, Engineering and Innovation Council, Australia.

Possingham, H.P., Andelman, S.J., Noon, B.R., Trombulak, S., Pulliam, H.R. (2001) Making smart conservation decisions. Island Press, Washington DC.

Possingham, H.P., Wilson, K.A., Andelman, S.J., Vynne, C.H., (2006) Protected areas: goals, limitations, and design, in: Groom, M.J., Meffe, G.K., Carroll, C.R. (Eds.), Principles of Conservation Biology. Sinauer Associates Inc., Sunderland, MA, pp. 509-533.

Pressey, R., Botrill, M.C. (2008) Opportunism, threats, and the evolution of systematic conservation planning. Conservation Biology in press.

Pressey, R.L., Cowling, R.M., Rouget, M. (2003) Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. Biological Conservation 112, 99-127.

Prugh, L.R., Hodges, K.E., Sinclair, R.E., Brashares, J.S. (2008) Effect of habitat area and isolation on fragmented animal populations. PNAS 105, 20770–20775.

QLD VM Act, (1999) Vegetation Management Act 1999. Queensland Government, Office of the Queensland Parliamentary Council, Brisbane.

Queensland Department of Natural Resources, (2005) The Statewide Landecover and Tree Study.

Queensland Mines and Energy, (2012) Queensland's coal seam gas overview — industry update.

Richardson, D.M., Pyek, P., Rejmanek, M., Barbour, M.G., Panetta, F.D., West, C.J. (2000) Naturalization and invasion of alien plants: concepts and definitions. Diversity and Distributions 6, 93–107.

Richardson, J.H., Shore, R.F., Treweek, J.R., Larkin, S.B.C. (1997) Are major roads a barrier to small mammals? Journal of Zoology 243, 840-846.

Rodríguez, J.P., Rodríguez-Clark, K.M., Baillie, J.E.M., Ash, N., Benson, J., Boucher, T., Brown, C., Burgess, N.D., Collen, B.E.N., Jennings, M., Keith, D.A., Nicholson, E., Revenga, C., Reyers, B., Rouget, M., Smith, T., Spalding, M., Taber, A., Walpole, M., Zager, I., Zamin, T. (2011) Establishing IUCN Red List Criteria for Threatened Ecosystems. Conservation Biology 25, 21-29.

Rodríguez, J.P., Rodríguez-Clark, K.M., Keith, D.A., Barrow, E.G., Benson, J., Nicholson, E., Wit, P., (2012) IUCN Red List of Ecosystems, SAPIENS. Institut Veolia Environnement.

Rosenzweig, M.L. (1995) Species diversity in space and time. Cambridge University Press, Cambridge.

Rytwinski, T., Fahrig, L. (2012) Do species life history traits explain population responses to roads? A meta-analysis. Biological Conservation 147, 87-98.

Sala, O.E., Stuart Chapin , F., III, Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M.n., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., Wall, D.H. (2000) Global Biodiversity Scenarios for the Year 2100. Science 287, 1770-1774.

Sanderson, E.W., Redford, K.H., Vedder, A., Coppolillo, P.B., Ward, S.E. (2002) A conceptual model for conservation planning based on landscape species requirements. Landscape and Urban Planning 58, 41-56.

Sattler, P., Williams, R., (1999) The conservation status of Queensland's bioregional ecosystems. Queensland Environmental Protection Agency, Brisbane.

Sattler, P.S., Webster, R.J., (1984) The conservation status of brigalow (*Acacia harpophylla*) communities in Queensland, in: Bailey, A. (Ed.), The Brigalow Belt of Australia. Royal Society of Queensland, Brisbane.

Sawyer, H., Nielson, R.M., Lindzey, F., McDonald, L.L. (2006) Winter habitat selection of mule deer before and during development of a natural gas field. Journal of Wildlife Management 70, 396-403.

Scanlan, J.C. (1991) Woody overstorey and herbaceous understorey biomass in Acacia harpophylla (brigalow) woodlands. Aust. J. Ecol., 16, 512–529.

Seabrook, L., McAlpine, C., Fensham, R. (2006) Cattle, crops and clearing: Regional drivers of landscape change in the Brigalow Belt, Queensland, Australia, 1840–2004. Landscape and Urban Planning 78, 373-385.

Stankey, G.H., Bormann, B.T., Ryan, C., Shindler, B., Sturtevant, V., Clark, R.N., Philpot, C. (2003) Adaptive management and the Northwest Forest Plan – rhetoric and reality. J. Forest. 101, 40–46.

Stokes, E.J., Strindberg, S., Bakabana, P.C., Elkan, P.W., Iyenguet, F.C., Madzoké, B., Malanda, G.A.F., Mowawa, B.S., Moukoumbou, C., Ouakabadio, F.K., Rainey, H.J. (2010) Monitoring great ape and elephant abundance at large spatial scales: Measuring effectiveness of a conservation landscape. Plos One 5, e10294.

Taylor, B.D., Goldingay, R.L. (2010) Roads and wildlife: Impacts, mitigation and implications for wildlife management in Australia. Wildlife Research 37, 320-331.

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., de Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Townsend Peterson, A., Phillips, O.L., Williams, S.E. (2004a) Extinction risk from climate change. Nature 427, 145-148.

Thomas, J.A., Telfer, M.G., Roy, D.B., Preston, C.D., Greenwood, J.J.D., Asher, J., Fox, R., Clarke, R.T., Lawton, J.H. (2004b) Comparative Losses of British Butterflies, Birds, and Plants and the Global Extinction Crisis. Science 303, 1879-1881.

Tilman, D., May, R.M., Lehman, C.L., Nowak, M.A. (1994) Habitat destruction and the extinction debt. Nature 371, 65 - 66

Valbuena, D., Bregt, A.K., McAlpine, C., Verburg, P.H., Seabrook, L. (2010) An agent-based approach to explore the effect of voluntary mechanisms on land use change: A case in rural Queensland, Australia. Journal of Environmental Management 91, 2615-2625.

Vane-Wright, R.I., Humphries, C.J., Williams, P.H. (1991) What to protect?--Systematics and the agony of choice. Biological Conservation 55, 235-254.

Walker, B.L., Naugle, D.E., Doherty, K.E. (2007) Greater Sage-Grouse Population Response to Energy Development and Habitat Loss. Journal of Wildlife Management 71, 2644-2654.

Walston, L.J., Cantwell, B.L., Krummel, J.R. (2009) Quantifying spatiotemporal changes in a sagebrush ecosystem in relation to energy development. Ecography 32, 943-952.

Waltert, M., Bobo, K.S., Kaupa, S., Montoya, M.L., Nsanyi, M.S., Fermon, H. (2011) Assessing Conservation Values: Biodiversity and Endemicity in Tropical Land Use Systems. Plos One 6, e16238.

Watts, M.E., Ball, I.R., Stewart, R.S., Klein, C.J., Wilson, K., Steinback, C., Lourival, R., Kircher, L., Possingham, H.P. (2009) Marxan with Zones: Software for optimal conservation based land- and sea-use zoning. Environmental Modelling & Software 24, 1513-1521.

Westgate, M., J.,, Likens, G., E.,, Lindenmayer, D.B. (2013) Adaptive management of biological systems: A review. Biological Conservation 158, 128-139.

Williams, B.K., Johnson, F.A., Wilkins, K. (1996) Uncertainty and the adaptive management of waterfowl harvests. J. Wildl. Manage. 60.

Williams, B.K., Szaro, R.C., Shapiro, C.D., (2009) Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington DC.

Williams, K.J., Dunlop, M., Bustamante, R.H., Murphy, H.T., Ferrier, S., Wise, R.M., Liedloff, A., Skewes, T., Harwood, T.D., Kroon, F., Williams, R.J., Joehnk, K., Crimp, S., Stafford Smith, M., James, C., Booth, T., (2012) Queensland's biodiversity under climate change: impacts and adaptation – synthesis report, in: Report Prepared for the Queensland Government, B. (Ed.). CSIRO Climate Adaptation Flagship, Canberra.

Williams, S.E., Bolitho, E.E., Fox, S. (2003) Climate change in Australian tropical rainforests: an impending environmental catastrophe. Proceedings of the Royal Society of London. Series B: Biological Sciences 270, 1887–1892.

Wilson, B.A., Neldner, V.J., Accad, A. (2002) The extent and status of remnant vegetation in Queensland and its implications for statewide vegetation management and legislation. Rangeland Journal 24, 6-35.

Wilson, K.A., Meijaard, E., Drummond, S., Grantham, H.S., Boitani, L., Catullo, G., Christie, L., Dennis, R., Dutton, I., Falcucci, A., Maiorano, L., Possingham, H.P., Rondinini, C., Turner, W.R., Venter, O., Watts, M. (2010) Conserving biodiversity in production landscapes. Ecological Applications 20, 1721-1732.

Woinarski, J., Mackey, B., Nix, H., Traill, B.J. (2007) The Nature of Northern Australia. Natural values, ecological processes and future prospects. The Australian National Press E Press.

Woinarski, J.C.Z., Legge, S., Fitzsimons, J.A., Traill, B.J., Burbidge, A.A., Fisher, A., Firth, R.S.C., Gordon, I.J., Griffiths, A.D., Johnson, C.N., McKenzie, N.L., Palmer, C., Radford, I., Rankmore, B., Ritchie, E.G., Ward, S., Ziembicki, M. (2011) The disappearing mammal fauna of northern Australia: context, cause, and response. Conservation Letters 4, 192-201.

Young, M., Gunningham, N., (1996) Mixing instruments and institutional arrangements for optimal biodiversity conservation, OECD International Conference an Biodiversity Incentive Measures, Cairns, Australia.

Young, M.D., Gunningham, N., Elix, J., Lambert, J., Howard, B., Grabosky, P., McCrone, E., (1996) Reimbursing the Future: An evaluation of motivational, voluntary, price-based, property-right, and regulatory incentives for the conservation of biodiversity. Department of the Environment, Sport and Territories Biodiversity Unit.

Young, P.A.R., Wilson, B.A., McCosker, J.C., Fensham, R.J., Morgan, G., Taylor, P.M., (1999) Brigalow Belt, in: Sattler, P., Williams, R. (Eds.), The Conservation Status of Queensland's Bioregional Ecosystems. Environmental Protection Agency, Brisbane, Australia, pp. 1-81.

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION

Biodiversity Resilient Australian Biodiversity Assets Theme (BRABA)
Rocio Ponce-Reyes
t +61 7 3833 5709
e Rocio.PonceReyes@csiro.au

Ecosystem-Sciences
Josie Carwardine
t +61 7 3833 5682
e Josie.Carwardine@csiro.au
w http://www.csiro.au/people/Josie.Carwardine.aspx

Ecosystem-Sciences
Stuart Whitten
t +61 2 6246 4359
e Stuart.Whitten@csiro.au
w www.csiro.au/people/stuart.whitten.html