Scientific review
of the
impacts of land clearing
on
threatened species in Queensland

2017

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Citation

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Cover Photos

Clearing of *Livistona nitida,* a listed near threatened plant species near Taroom Photo H.A. Dillewaard; *Petauroides volans* Greater Glider, an EPBC vulnerable species from Barakula State Forest Photo M.T. Mathieson; *Cycas megacarpa* is an endangered species endemic to southeast Queensland Photo Paul Forster

Executive summary

- Internationally and nationally, habitat loss is the greatest threat to threatened species.
- More than 400 ecologists, including leading conservation scientists from Australia and around the world, have issued a declaration in 2016 warning of the devastating impacts of land clearing on Australia's biodiversity.
- Numerous scientific, peer reviewed studies have been published warning of the impacts of land clearing on biodiversity and threatened species.
- The woody vegetation clearing rate in Queensland increased in the period 2013-2015 to 296,000 hectares per year, and was 3.8 times the rate of woody vegetation clearing in 2009-10.
- The Brigalow Belt, Central Queensland Coast, New England Tableland, Southeast Queensland and Wet Tropics bioregions are fragmented landscapes resulting from historical and recent land clearing. The Mulga Lands and Desert Uplands bioregions have been increasingly fragmented in recent years.
- Land clearing causes species death and habitat loss, but also exacerbates other threatening processes, particularly in fragmented landscapes.
- Land clearing reduces the resilience of threatened species populations to survive future perturbations such as climate change.
- Apart from the immediate impacts of clearing, significant time lags occur before the full cumulative impact on biodiversity is realised.
- The impact of the previous century of land clearing has resulted in small, fragmented relictual populations of many native species. Any further land clearing will further elevate the extinction pressure arising from loss of habitat and a range of other threatening processes which are exacerbated by fragmentation.
- Land clearing has significant negative impacts offsite e.g. (sediment runoff into streams, rivers, wetlands and the Great Barrier Reef marine lagoon), and is a major contributor to climate change through greenhouse gas outputs, and rainfall and temperature dynamics.
- Land clearing has been directly responsible for two plant species becoming extinct in the wild, and has been identified as a threatening process for many of the 739 threatened flora species and 210 threatened fauna species in Queensland.
- Eight species are discussed in a series of case studies indicating the major reduction in the area and quality of habitat that historic and recent land clearing has caused.
- The current State protected area estate and voluntary nature refuge estate combined only retain 11.4% of the pre-clearing potential habitat for terrestrial threatened species, and hence are unlikely to prevent further species from becoming extinct.

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Introduction

On a world scale, the biggest drivers of biodiversity decline are the overexploitation of species through logging, hunting, fishing, collecting from the wild, and agriculture (the production of food, fodder, fibre and fuel crops, livestock farming, aquaculture and timber plantations) (Maxwell *et al.* 2016) to feed and fuel human population growth and increasing per capita consumption (Pimm *et al.* 2014). For clear-fell logging, cropping, timber plantations and in many cases of pastoral and agricultural activity, the natural vegetation is first cleared and then generally replaced with monocultures of non-native plants or, at the least, a substantially reduced plant diversity. This clearing results in the immediate death and displacement of the native flora and fauna, and the modified landscapes that result are unable to support the previous biodiversity levels. Habitat loss is the most important threat to species persistence in the wild at the global scale (Baillie *et al.* 2004, Millennium Ecosystem Assessment 2005), in the United States of America (Wilcove *et al.* 1998) and Canada (Venter *et al.* 2006). Habitat loss is also the greatest threat affecting Australia's threatened species (Evans *et al.* 2011, Driscoll *et al.* 2017).

In Queensland, 91% of the clearing of woody vegetation in 2014-15 was to increase pasture for livestock grazing, while forestry (5.4%), cropping (1.7%), mining (1.1%), infrastructure (0.3%) and settlement (0.7%) accounted for a small proportion of the total 296,000 hectares cleared in that year (Queensland DSITI, 2016). The impact of tree clearing has been recognised as a key threatening process under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC) since April 2001. At the time of assessment by the Commonwealth Threatened Species Scientific Committee, it was recognised that land clearing directly threatens the survival, abundance or evolutionary development of at least five native species and at least four ecological communities (DEE 2016). Queensland legislated the Vegetation Management Act 1999 (VMA), an Act which by international standards provides strong regulatory protection. It lists among its purposes the regulation of the clearing of vegetation to conserve remnant vegetation, prevent land degradation, prevent the loss of biodiversity, maintain ecological processes and reduce greenhouse gas emissions (McGrath 2007). After the enactment of the VMA in September 2000, the area of tree clearing in Queensland progressively declined, especially after 2006, until major alterations to the VMA in 2013, including development approvals for clearing remnant vegetation for high value agriculture, led to increased levels in tree clearing since that time (see Figure 7). The VMA has never addressed clearing (cropping or improved pastures) in non-wooded grassland regional ecosystems, e.g. the *Dichanthium sericeum* tussock grasslands. Mangroves are similarly not addressed in the VMA, but are regulated under the Fisheries Act 1994. The VMA provides protection for the essential habitat of species listed under the Nature Conservation (Wildlife) regulation, provided at least three essential habitat factors for the listed species, and some life stage of the species are present.

"The large scale destruction and removal of native woodlands, forests, wetlands and grasslands remains the biggest single threat to biodiversity in Australia, rivalled only by the impact of introduced species" (The Brigalow Declaration: signed by 420 ecologists in 2003). This view was expressed in the State of the Environment Committee in 2011 (SEC 2011) and in July 2016 where over 400 scientists and four scientific societies signed a scientists' declaration warning of the deleterious impacts of accelerating forest, woodland and grassland destruction in Australia. "As land clearing once again escalates, so too will these losses of wildlife. The loss of habitat is among the greatest of threats to Australia's unique threatened species" (SCBO 2016).

Evidence for the large and irreversible negative impact of vegetation clearance on Australia's biodiversity is unquestionable (DEST 1995; SOE 2001; Possingham *et al.* 2002; NLWRA 2002; Cogger, *et al.*, 2003, Garnett *et al.* 2011). Greater levels of habitat protection are essential to

prevent more species from becoming threatened in the future, adding to our already burgeoning list of threatened species (Doherty *et al.* 2015; Niebuhr *et al.* 2015; Woinarski *et al.* 2015). Habitat removal eliminates the plant and animal species that lived in it; increases risks to wildlife from introduced predators; impacts surface and groundwater-dependent ecosystems, and fragments habitat so that individuals are unable to move through the landscape. Further, and perhaps more concerning, it seriously reduces the ability of species to adapt and move in response to the pervasive and increasing effects of climate change (Reside *et al.* 2012; Travis *et al.* 2013).

Key threatening processes to biodiversity

The key threats to biodiversity in Australia are: habitat loss and fragmentation of habitat; climate change; land-use change; invasive species and pathogens; grazing pressure; altered fire regimes; and changed hydrology (State of the Environment Committee 2011).

The most frequently cited threats in listings under the EPBC Act and resulting recovery plans are habitat fragmentation and the spread of invasive species (State of the Environment Committee 2011). The conceptual framework of the State of the Environment Committee (2011) (Figure 1) show how the primary drivers of economic and population growth act through intermediate drivers such as the agricultural, forestry, mining and fishing industries and urban and peri-urban expansion to exert the many threatening processes (pressures) on species populations and habitats. The nett effect of the combinations of these threatening processes is generally deleterious to the breeding and / or survival of species, communities and ecosystems, and the quality of habitat.
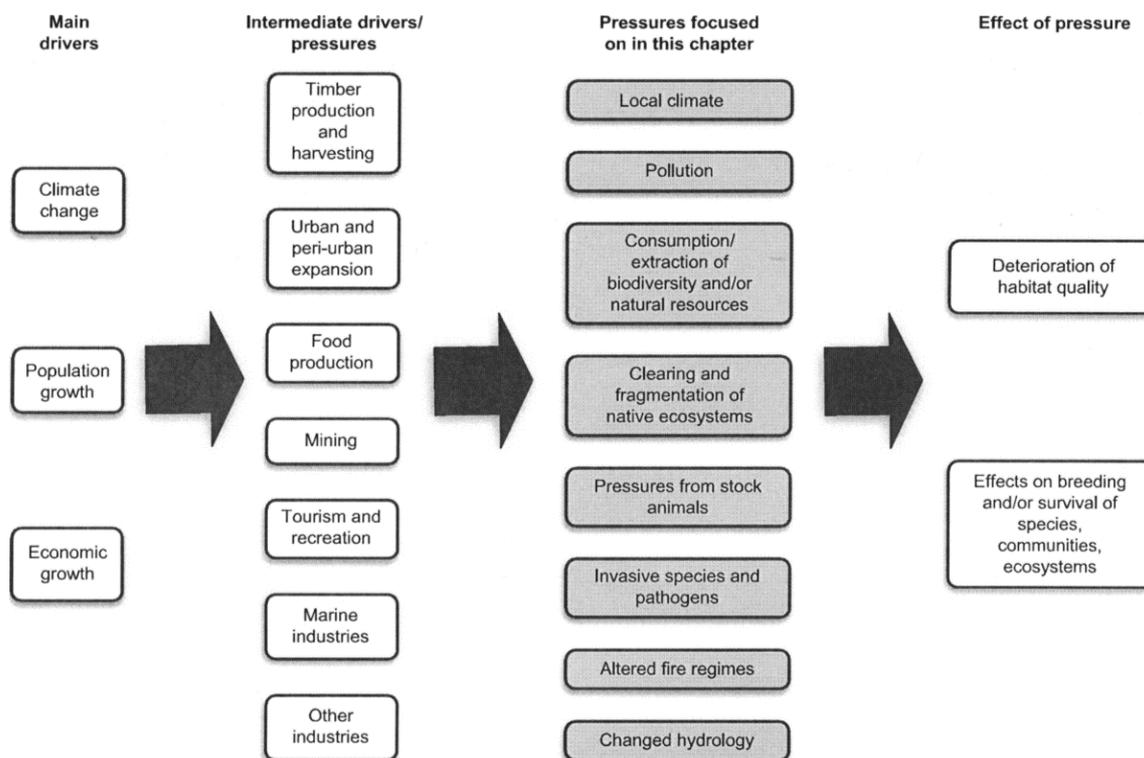
Figure 1 Conceptual framework of drivers and pressures on Australia's biodiversity. From State of the Environment Committee (2011).

Of the seven major threatening processes analysed for EPBC listed threatened species (extinct, critically endangered, endangered, vulnerable), Evans *et al.* (2011) found habitat loss had the greatest impact (80%) on species and occurred in more than 85% of subcatchments within Australia, including all the coastal and subcoastal bioregions of Queensland (see Figure 2).
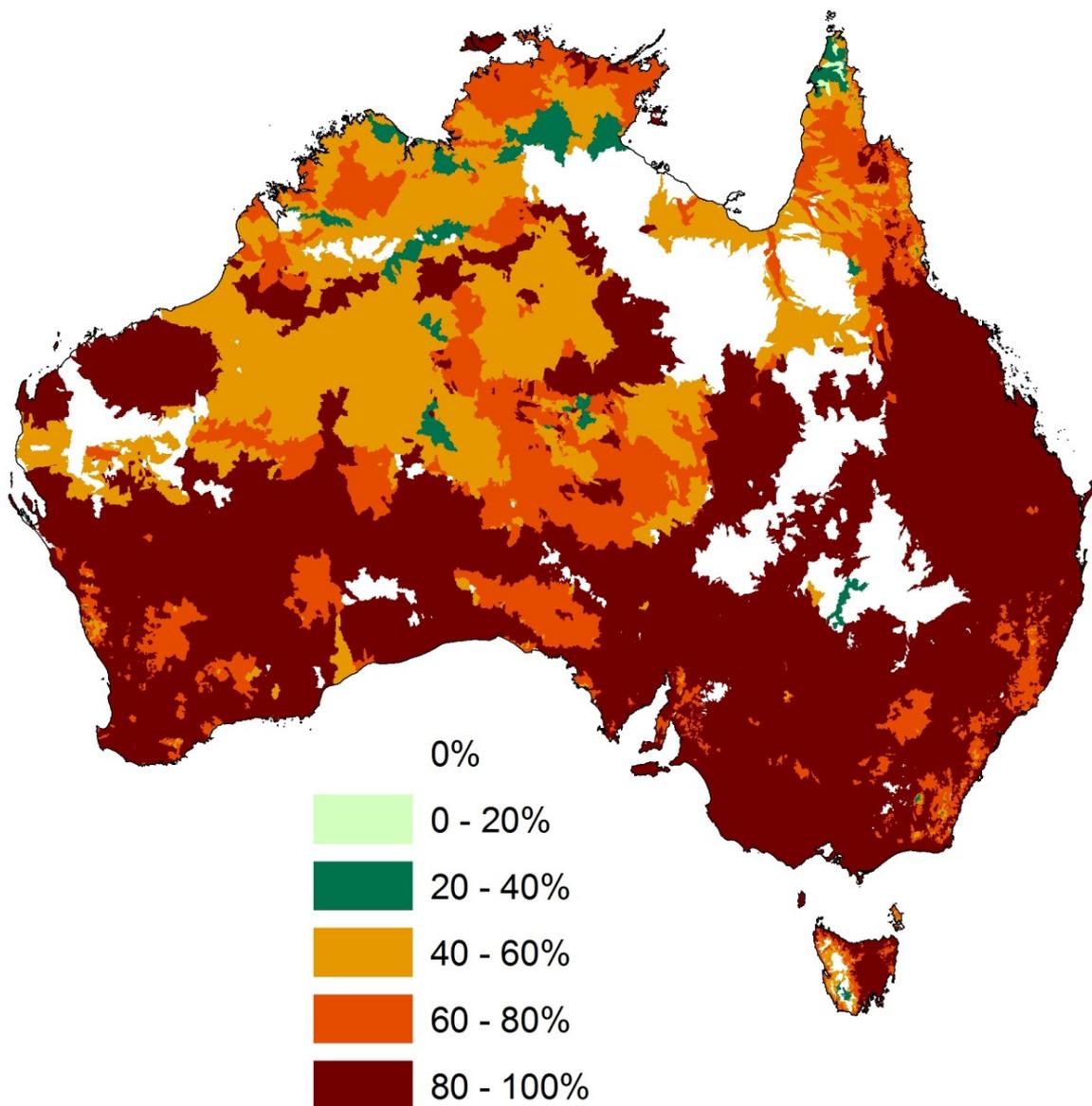
Figure 2 Percentage of threatened freshwater and terrestrial species in each subcatchment affected by habitat loss. From Evans *et al.* (2011).

To quantify the impact of historical clearing on species' populations, the amount of the species habitat that has been destroyed (through clearing or cropping) can be used as a surrogate. However, the loss and decline of populations of individual species is most likely even higher than that implicated by the loss of habitat, because other threatening processes begin to have a greater impact when a species is within in a fragmented landscape. This impact can affect species differently with sedentary species being more likely to be highly impacted.

Land clearing as a driver towards species extinction

Broad-scale land clearing may lead to drastic population declines that culminate in the elimination of local and regional populations, and this may eventually lead to the total extinction of a species. This extinction process follows (see Figure 3):

1) the direct death of individuals during clearing,

2) the subsequent local and regional extinction of populations, and

3) the potential total extinction of the species across its entire range (Cogger *et al.* 2003).
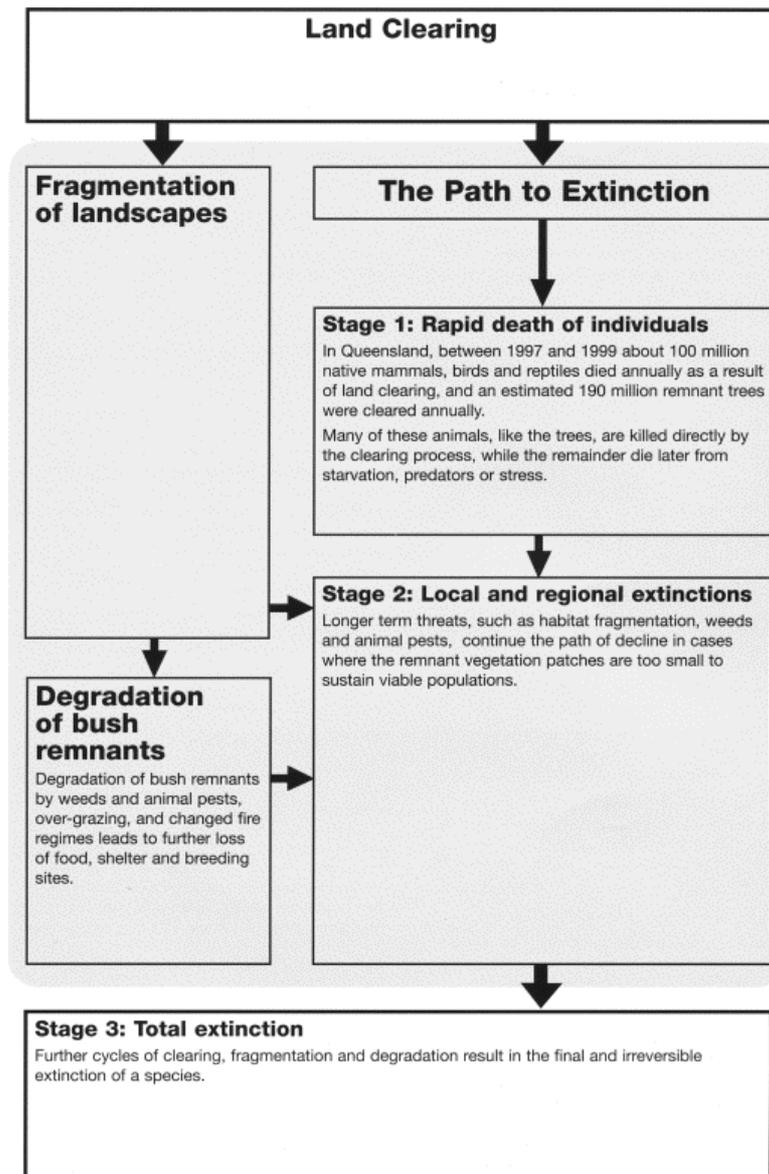
Figure 3 Land clearing, landscape fragmentation and the path to extinction. From Cogger *et al.* (2003)

The direct impact of land clearing on plants and animals.

In the process of tree clearing, numerous individual plants and animals are killed or die soon after. It has been estimated that between 1997 and 1999, when 446,000 hectares of remnant vegetation were cleared each year in Queensland, that 2.1 million mammals, 8.5 million birds, 89 million reptiles and 190 million trees died as a result (Cogger *et al.* 2003). Most plants and many animals

die at the time of clearing, but many animals that manage to escape during the clearing process soon die from stress, starvation or predation. Mobile species that manage to reach remaining areas of vegetation are frequently repelled by the resident fauna resulting in diminished breeding opportunities and/ or having to compete for limited food and resources, which again leads to increased levels of stress, starvation and predation. Many animals have a high level of attachment to a site, and will remain and eventually die in degraded habitats that can no longer support them.

Indirect impacts of land clearing

While widespread species are generally not threatened by single clearing events, the cumulative impacts of many smaller events resulting in habitat losses, fragmentation and degradation of remaining vegetation will result in a significant threat to the viability of even widespread species through the "death by a thousand cuts" scenario (Laurance 2010). It may take decades, even centuries for clearing impacts to be fully evident (DEST 1995).

Compounding negative impacts of fragmentation

Fragmentation (the breaking up of large areas of intact vegetation) is the main modifier of forest ecosystem function and resilience, with relative intactness deteriorating as patches of remnant forest become smaller and more isolated (Saunders *et al.* 1991; Wilcox and Murphy 1985). An analysis of global forests revealed that 70% of remaining forest is within one kilometre of the forest's edge and therefore subject to the degrading impacts of fragmentation (Haddad *et al.* 2015). Habitat fragmentation reduces biodiversity by up to 75% and by decreasing biomass and altering nutrient cycles, it impairs important ecosystem functions. These negative impacts are greatest in the most isolated and smallest fragments, and they increase in impact over time (Haddad *et al.* 2015). In general, higher levels of fragmentation and destruction of populations, subpopulations and individuals result in reduced genetic variation within a species, especially in the longer term through attrition of unique individuals and gene combinations (Frankham 1996). Lower genetic diversity reduces a species' potential adaptability and resilience in the face of a changing environment or extreme events. Weeks *et al.* (2016) found that random genetic drift effects are widespread in threatened Australian mammals, and will lead to the erosion of genetic diversity within a species. They argue that conservation strategies such as translocation of individuals may be required to maintain the genetic diversity and ecological resilience of isolated populations in fragmented landscapes.

There has been a substantial volume of research in Australia assessing the effect of fragmentation on tropical forests (e.g. Goosem and Marsh 1997; Hannah *et al.* 2007; Laurance 1991; 1997) and temperate forests (e.g. Antos and White 2004; Davies *et al.* 2001; Debuse *et al.* 2007; Ford *et al.* 2009; Hester and Hobbs 1992; Hobbs 1993; Holland and Bennett 2010; Margules *et al.* 1994; Ross *et al.* 2002; Saunders *et al.* 1987; Yates *et al.* 1994). All of these studies found fragmentation to be of considerable detriment to biodiversity. Indeed, the time since fragmentation is an important consideration given that extinction lags (the time taken for extinction to occur following disturbance) can be on the order of decades or more (Ross *et al.* 2002). Patch size and landscape connectivity have been shown to have a strong relationship with retained biodiversity (Bowen *et al.* 2007). Larger patches are less susceptible to ecological edge effects, e.g. weed invasion, and are more likely to sustain viable populations (McIntyre *et al.* 2000, Lindenmayer *et al.*1999). Landscape connectivity relates to the capacity for a species to disperse through the landscape between suitable patches of habitat, and has important implications for species persistence (With 2004). Landscapes with low connectivity mean populations become largely isolated and vulnerable to genetic suppression and local extinction (Bennet *et al.* 2000). The dispersal ability of the species is an important factor determining the impact of connectivity for a species (Tischendorf and Fahrig

2000). BioCondition (Eyre *et al.* 2015) is a widely-used condition assessment framework that provides a measure of how well a terrestrial ecosystem is functioning for biodiversity values. As well as scoring the structural and floristic attributes of the site, the patch size, connectivity and site context are measured as they are important factors affecting the ability of a site to sustain biodiversity.

Extinction debt/ cumulative impacts

The consequences of the initial clearing and the subsequent processes of fragmentation, increased predation, and weed infestation, can mean that the full effects of broad scale clearing may take many decades to become evident. This time lag or "extinction debt" means that even if no more land clearing occurs, many populations may still decline over the decades and become extinct in the future (Cogger *et al.* 2003). Queensland is likely to be carrying a large extinct debt particularly in the heavily cleared and fragmented bioregions.

Indirect impacts of land clearing on offsite habitats.

The impacts of land clearing can affect areas and habitats far removed from the site of initial land clearing. There is widespread concern over the impacts of land clearing on freshwater and marine habitats through increased erosion and sedimentation (Ludwig and Tongway 2002), and the additional potential pollution of these habitats through the subsequent land uses, e.g. nutrient runoff from agricultural and grazing lands and alluvial mining, and its impact on the rivers, wetlands and the Great Barrier Reef lagoon (Ainsworth *et al.* 2016, Brodie and Pearson 2016, Commonwealth of Australia 2014a, 2015, Fabricius *et al.* 2014, 2016). Alluvial gullies eroding into terraces and elevated floodplains along river frontage are a major sediment source in northern Australia rivers (Shellberg and Brooks 2013).

Photo 1 Gully erosion which accelerated post clearing in north Queensland. Photo J.G. Shellberg.

A major impact of native vegetation clearance on ecological processes is the alteration of hydrological cycles and the resultant rise in water tables and increased salinity (Walker *et al.* 1993; DEST 1995, Lambers 2003). A study of dryland salinity in the Murray-Darling Basin by the Dryland

Salinity Management Working Group "established that changed land use, particularly broad scale clearing of native vegetation and its replacement with systems which use less water, is the principal cause of secondary dryland salinity" (DSMWG 1993,pp. 11-23, 24).
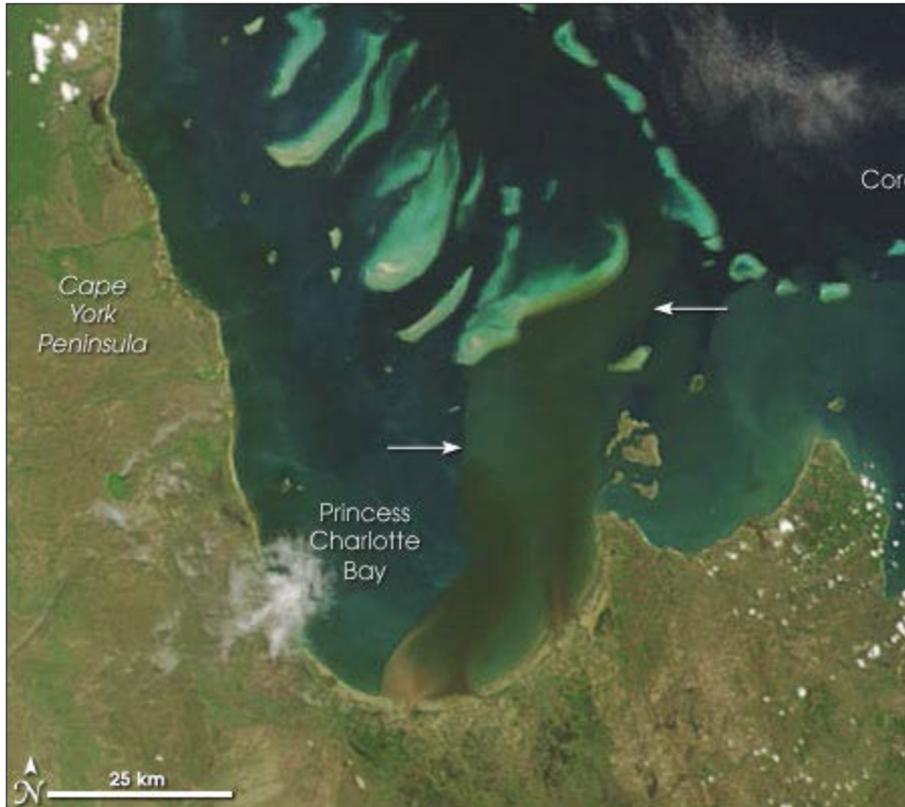
Photo 2 Flood plume emanating from the Normanby catchment in February 2007. From Shellberg and Brooks 2013.

Indirect impacts of land clearing on climate

Deforestation has two principal effects on climate. First, the physical act of vegetation clearance releases substantial quantities of greenhouse gases including carbon dioxide into the atmosphere, which increases overall carbon emissions and exacerbates anthropogenic climate change (IPCC 2007, Bradshaw 2012).

Queensland consistently contributes disproportionately to Australia's national greenhouse gas emissions from land use, land use change and forestry (LULUCF). In 1990, when clearing was over half a million hectares per year, Queensland contributed 65% of national LULUCF emissions (Commonwealth of Australia 2014b). By 2011-12 the clearing rate had slowed significantly in Queensland, but had also dropped in all other States. In essence, Queensland has greatly reduced its LULUCF emissions, but nonetheless maintains its long dominance of national LULUCF (Butler and Halford 2015).

Secondly, forest clearance over large areas also affects local climate conditions such as temperature variation and precipitation patterns (Deo 2011; Deo *et al.* 2009; Junkermann *et al.* 2009; Narisma and Pitman 2003, 2006; Pitman *et al.* 2004). As a result of modifying vegetation cover, the solar energy available for plant transpiration, evaporation and convection between the land and the atmosphere, soil moisture feedbacks and complex interactions are all changed, leading to more rapid local climate anomalies (Deo 2011; Bradshaw 2012). The clearing of deep-rooted native vegetation and replacing it with shallow-rooted crops or pastures reduces cloud

formation and rainfall, resulting in a warmer, drier climate (McAlpine *et al.* 2009; Syktus and McAlpine 2016).

Almost half of the 213 Australian threatened species assessed by Lee *et al.* (2015) were considered vulnerable to climate change impacts with more restricted species being more vulnerable than widespread species. There is a complex suite of climate change factors requiring mitigation actions to be tailored for individual species. Of the species assessed, amphibians were the most vulnerable group, followed by plants, reptiles, mammals and birds. Laidlaw and Forster (2012) demonstrate that increasing temperatures under climate change scenarios will cause the populations of five threatened allopatric species of *Macrozamia* cycads to become increasingly isolated from each other, further reducing genetic exchange and exacerbating existing threatening processes.

The history of land clearing in Queensland

The history of land clearing in Queensland initially followed the settlement of European colonists across the State. From 1824 onwards, as soon as settlements were established, vegetation was cleared to allow agricultural and pastoral activities to expand.
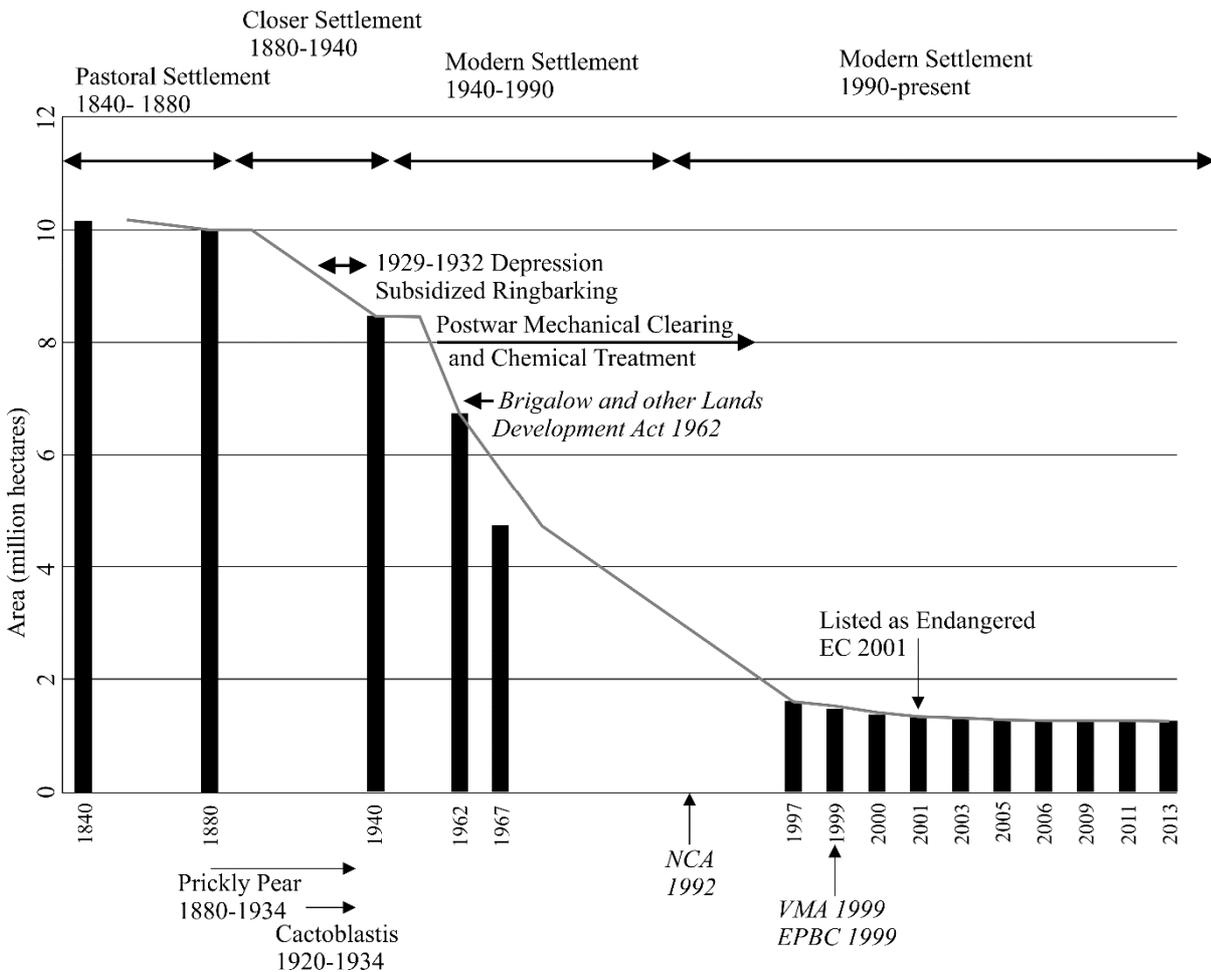
Figure 4 Diagram illustrating the decline in extent in the brigalow broad vegetation group (BVG25 in Neldner *et al.* 2015), annotated with social, economic and legislative drivers and extent figures derived from Seabrook *et al.* (2006). Preclearing and remnant brigalow extent 1997-2013 data are from Accad and Neldner (2015). From Neldner (in press).

Clearing was a difficult manual process, and with a low population, the initial area cleared was not extensive, although ringbarking was a widespread practice in the 1860s (Powell 1998). However, it was targeted at areas seen as productive from a cropping perspective and located close to settlements. The majority of vegetation clearing in Queensland has occurred in the last 60 years, which is later than in some southern states (Bradshaw 2012).

The development of mechanical and chemical clearing techniques greatly enhanced the capacity to clear land, and together with Government policies that promoted the settlement and development of land starting post-World War II extensive areas of Queensland were cleared primarily for agricultural and pastoral purposes. This is illustrated for the brigalow broad vegetation group (BVG) in the Brigalow Belt Bioregion in Figure 4.
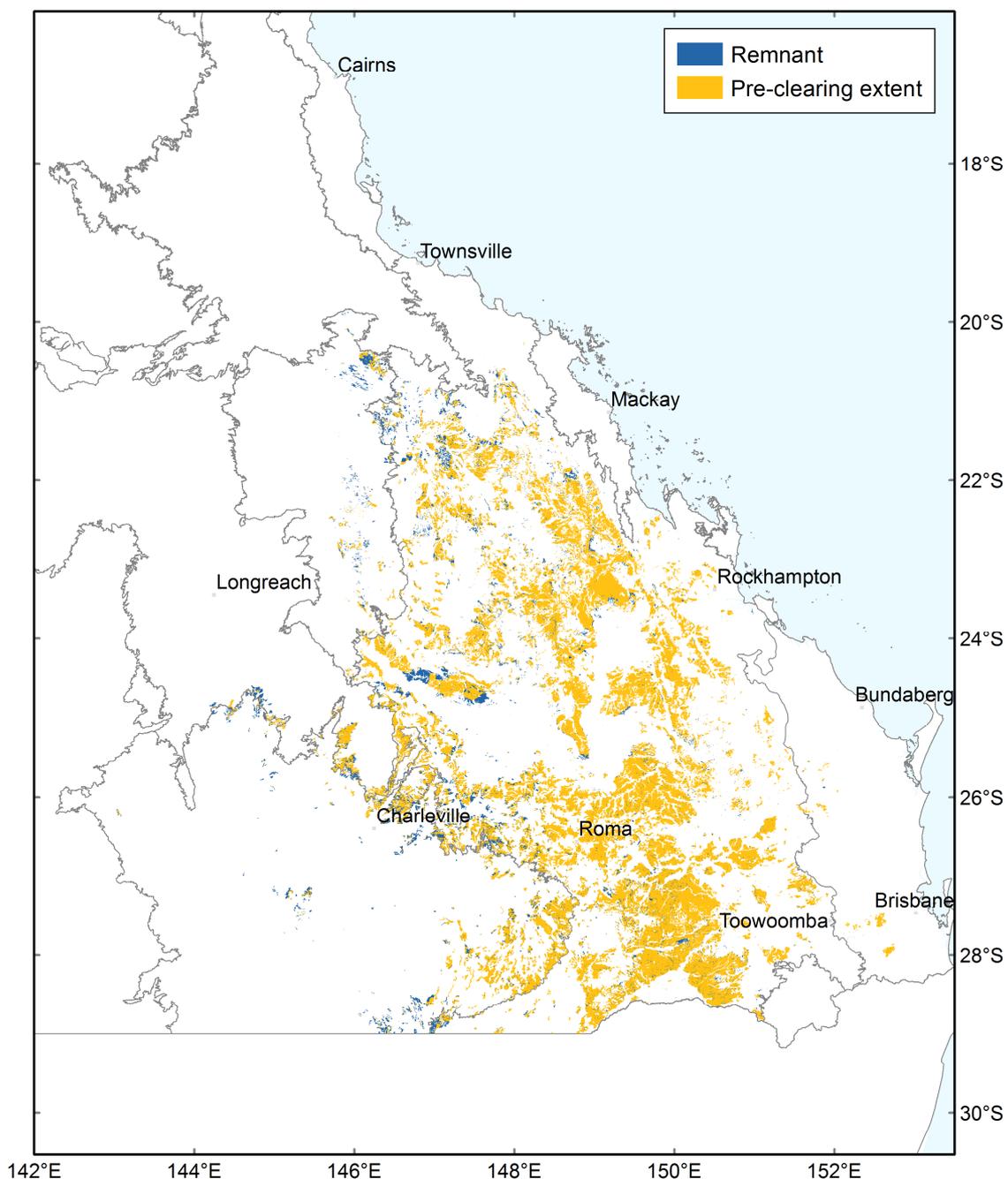
Figure 5 Map of pre-clearing and remnant 2013 extent of brigalow BVG25 (From Neldner *et al.* 2015)

The situation presented in Figure 5 for the brigalow broad vegetation group (BVG 25, Neldner *et al.* 2015) is similar for the habitat of many of our listed species in the Southeast Queensland and Brigalow Belt bioregions, where historic mechanised clearing during the twentieth century has reduced the habitat and hence the populations to only remnants of what they were previously.
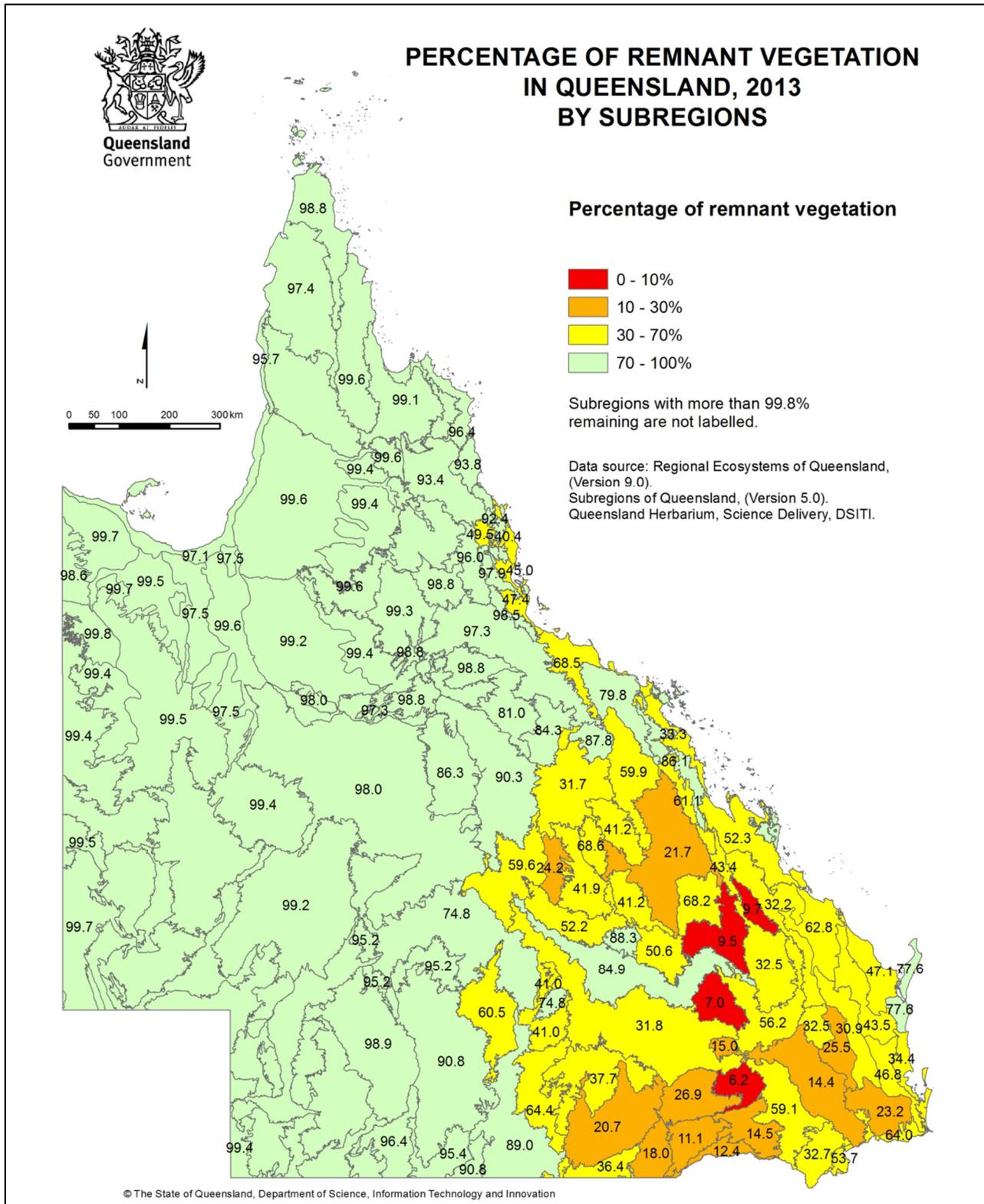
Figure 6 Remnant regional ecosystem vegetation in 2013 as a percentage of the pre-clearing extent by subregion (from Accad and Neldner 2015).

In the case of the brigalow BVG25 less than 20% of their pre-clearing distribution extent remains (Accad and Neldner 2015). Most brigalow regional ecosystems are listed as endangered (<10% of extent remains) or of concern (10-30% of extent remains) under the Vegetation Management Act 1999. The brigalow ecological community is also listed as endangered under the Commonwealth EPBC Act 1999. Consequently, species have smaller populations that are dispersed across more fragmented landscapes, and are more susceptible to a range of other threatening processes, e.g. competition from weeds, altered fire regimes, altered and more extreme climate and/or predation from feral animals. Any additional clearing will exacerbate the situation, intensifying the impacts of threatening processes and lead to local extinctions, which through a cumulative process can result in eventual extinction in the wild (Cogger *et al.* 2003).

Land clearing and agricultural expansion since the 1880s make the Brigalow Belt bioregion one of the most ecologically transformed areas in Queensland. Within the Brigalow Belt, eight species are extinct including local populations of the eastern quoll and northern bettong, and the global population of the Darling Downs hopping-mouse (Ponce Reyes *et al.* 2016).This pattern of land development is repeated for the other Queensland bioregions where clearing is substantial (>30% of the bioregion) e.g. the coastal bioregions of Southeast Queensland, Central Queensland Coast and the Wet Tropics, and the New England Tableland bioregions (see Figure 6). Cutting of fodder trees for stock feed during periods of drought has been a management practice in the Mulga Lands bioregion since settlement, but substantial mechanised and broad scale clearing of areas of mulga (*Acacia aneura*) only commenced in the latter half of the twentieth century. Considerable damage to the waterway frontage land soils was done in the Mulga Lands by overgrazing by the large flocks of sheep on the floodplains of the rivers and creeks during the Federation drought (1895-1903) (McAlpine 2016).

Areas with substantial timber resources were reserved under The Crown Lands Act of 1876 , with 161 Timber Reserves (636,484 Hectares) and 16 State Forests (81,980 hectares) reserved by 1885 (Powell 1998). Areas of special scenic beauty and flora and fauna values were designated as National Parks from 1908 under the State Forests and National Parks Act 1906. However legislation to preserve biodiversity (Nature Conservation Act 1992) and limit land clearing on leasehold land (Land Act leasehold clearing provisions in 1989) and freehold land (Vegetation Management Act 1999) (VMA) was not proclaimed until the last decade of the twentieth century.

The introduction of the Vegetation Management Act 1999 has resulted in a significant reduction in the amount of land clearing since its full implementation in 2000. The woody clearing rate was reduced from more than 700,000 hectares/year in 2000 to a low of 77,590 hectares/year in 2009-10. However policy changes to the VMA in 2013 reversed this trend and led to an increase in land clearing in subsequent years; 261,000, 295,000 and 296,000 hectares per year for 2012-13, 2013-14 and 2014-15 respectively (SLATS 2016) (see Figure 7). It should also be noted that the VMA does not apply to grassland ecosystems which cover 21% of Queensland (BVGs 30-33 In Neldner *et al.* 2015), so clearing or cropping of grassland is not regulated in Queensland. The endangered natural grasslands of the Queensland Central Highlands and the northern Fitzroy Basin (including regional ecosystems 11.3.21, 11.4.4, 11.4.11, 11.8.11, 11.9.3, 11.9.12, and 11.11.17), and Natural Grasslands on Basalt and Fine-textured Alluvial Plains of Northern New South Wales and Southern Queensland (including regional ecosystems 11.3.21 and 11.3.24) are listed under the EPBC, and are habitat for listed fauna species such as the *Geophaps scripta scripta* (squatter pigeon), *Neochima ruficauda ruficauda* (star finch), *Lerista allaniae* (Retro slider), and *Tympanocryptis condaminensis* (Condamine earless dragon), and listed flora species such as *Dichanthium queenslandicum* (king bluegrass), *Thesium australe* (Austral toadflax) and *Picris evae* (hawkweed) (DESEWPC 2012).
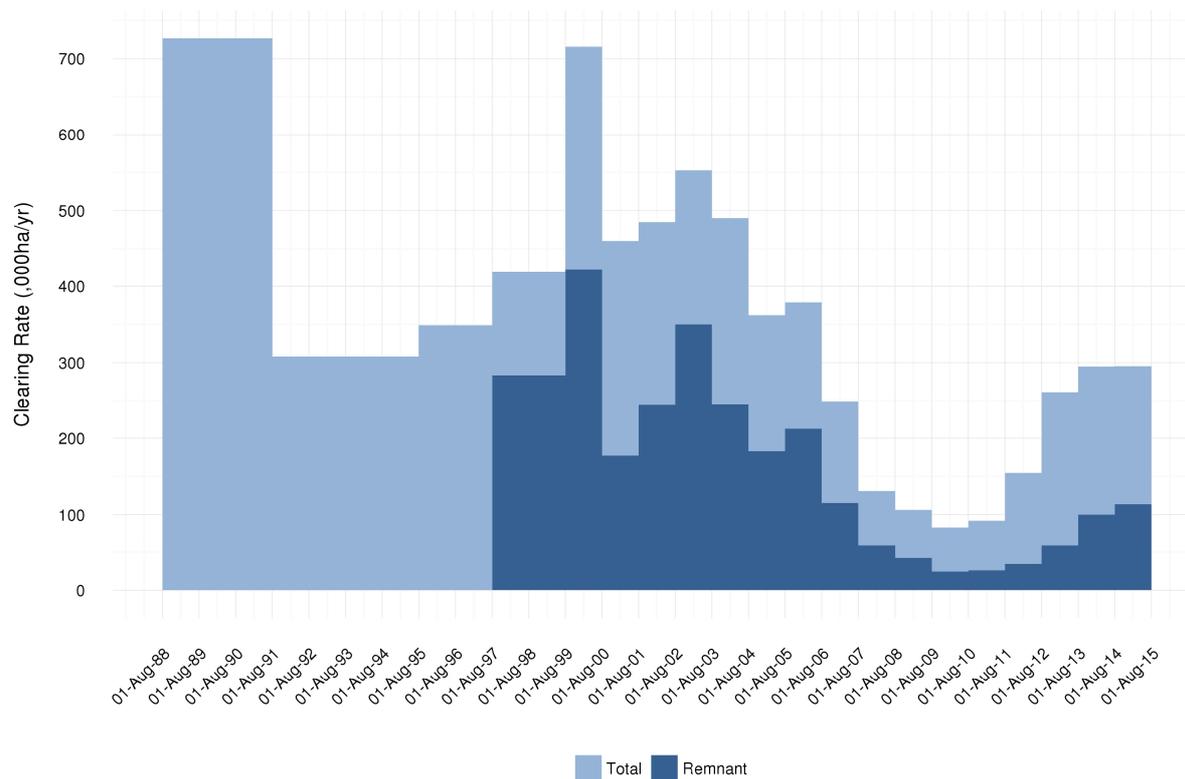
Figure 7 Annual woody vegetation clearing rate in Queensland (1988–2015) (DSITI 2016). Satellite imagery has been analysed since 1988. Remnant vegetation mapping and statistics are based on regional ecosystem mapping and are available from 1997 onwards (Accad and Neldner 2015).

The impacts of further clearing on fragmented relictual populations

Habitat fragmentation changes ecological patterns, processes and interactions in communities (Fahrig 2001, 2002, 2003, Hu *et al.* 2012) and community assembly processes (Hu *et al.* 2016). Habitat fragmentation appears to facilitate and encourage invasion of feral species (Gibson *et al.* 2013). As discussed in the previous sections, for many broad vegetation groups and the wildlife species that are dependent on them, any future clearing will further deplete and fragment an already fragmented landscape that is carrying significant extinction debts. Hence the impact of additional clearing is likely to be considerably more than would be suggested by a simple analysis of the species-area relationship (Pimm *et al.* 2014). Woinarski *et al.* (2006) documented this in the Emerald region for the period from 1973 to 2002 where 25-29% of woodland sites were cleared, woodland fauna declined not only regionally, but also declined in the woodland patches remaining.

Loss of wildlife species from landscapes tends to occur once clearing exceeds 20% of the landscape, and rapidly accelerates when less than 30% of the native vegetation remains (Andren 1994, Morgan 2001, Fahrig 2002, McAlpine *et al.* 2002). Sixteen subregions in Queensland already have less than 30% remnant vegetation (see Figure 6). The number of species of woodland-dependent birds collapsed when the tree cover in the northern Victorian landscape declined below 10% (Radford *et al.* 2005). Maron *et al.* (2012) have shown that actual thresholds for decline may be impacted by landscape productivity and the natural cover of the vegetation,

cautioning against a simple threshold for all landscapes.
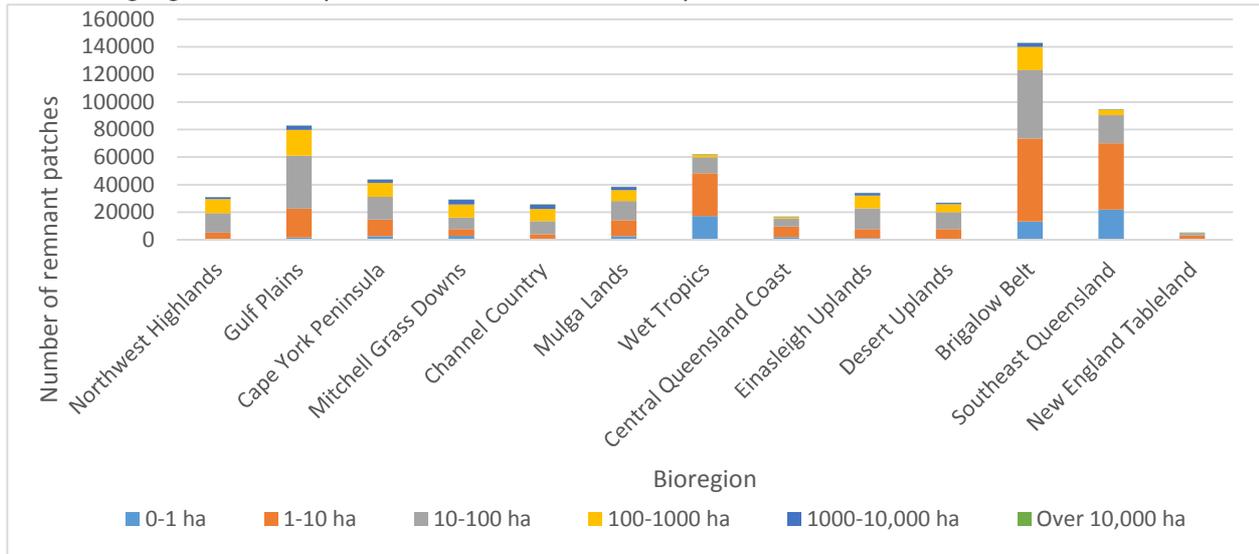
Figure 8 Number of various size remnant patches in Queensland bioregions. From Department of Environment and Heritage Protection (2016).
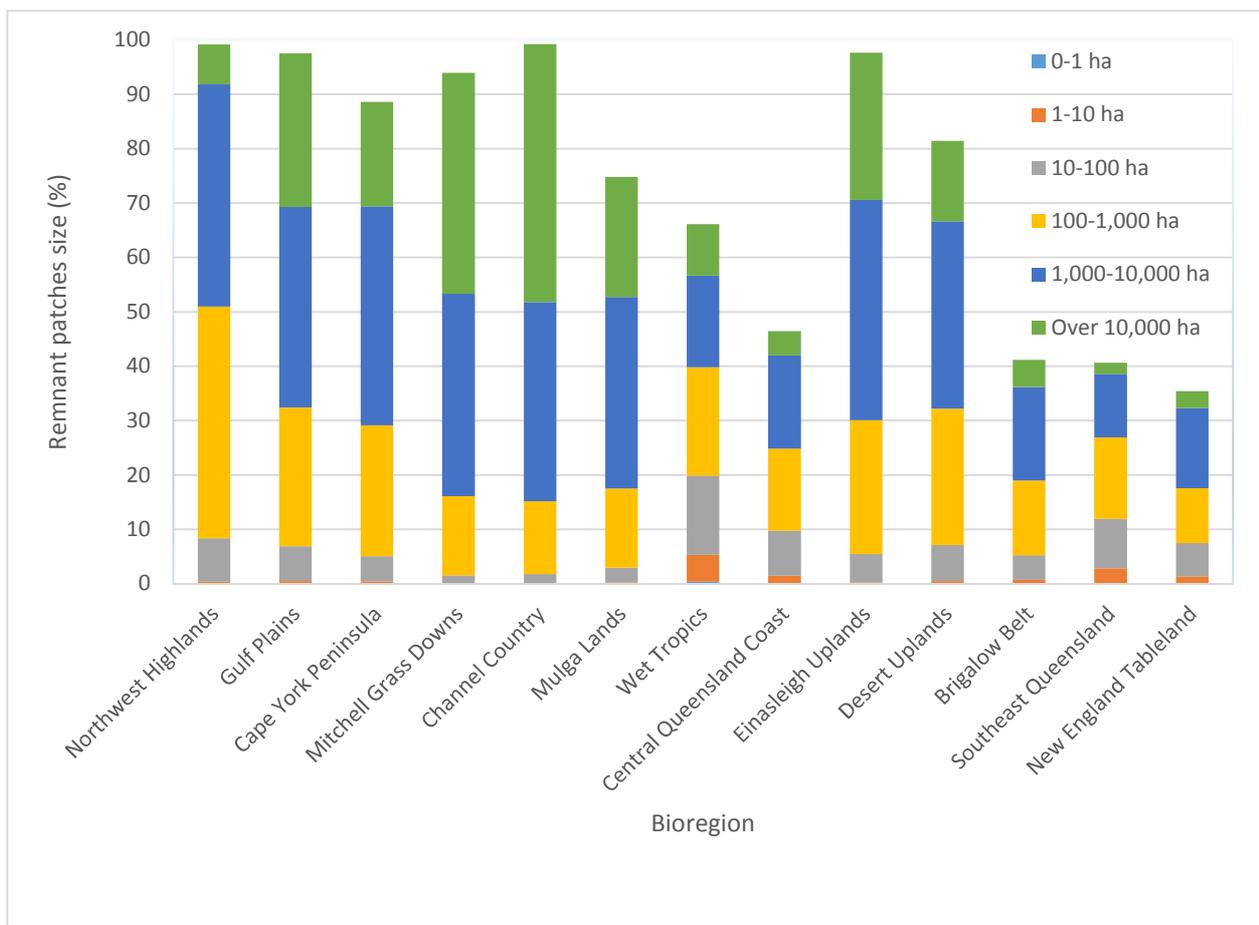
Figure 9 Proportion of Queensland bioregions composed of various size remnant patches. From Department of Environment and Heritage Protection (2016).

Woinarski *et al.* (2006) suggest that for at least some fauna species declines may become evident when the overall proportion of native vegetation falls below 40%. Models of extinction rates of small mammals in fragmented landscapes in Thailand estimated mean extinction half-life (50% of

the resident species disappearing) to be 13.9 years (Gibson *et al.* 2013). Similar extinction rates were observed by Ferraz *et al.* (2003) who found 100 hectare forest fragments in the central Amazon lost half of their understorey bird species in less than 15 years.

The Southeast Queensland, Brigalow Belt, New England Tableland and the Wet Tropics (particularly the coastal lowlands and Atherton Tableland) bioregions are highly fragmented with large numbers of remnant patches that are less than 10 hectares in size (see Figure 8).
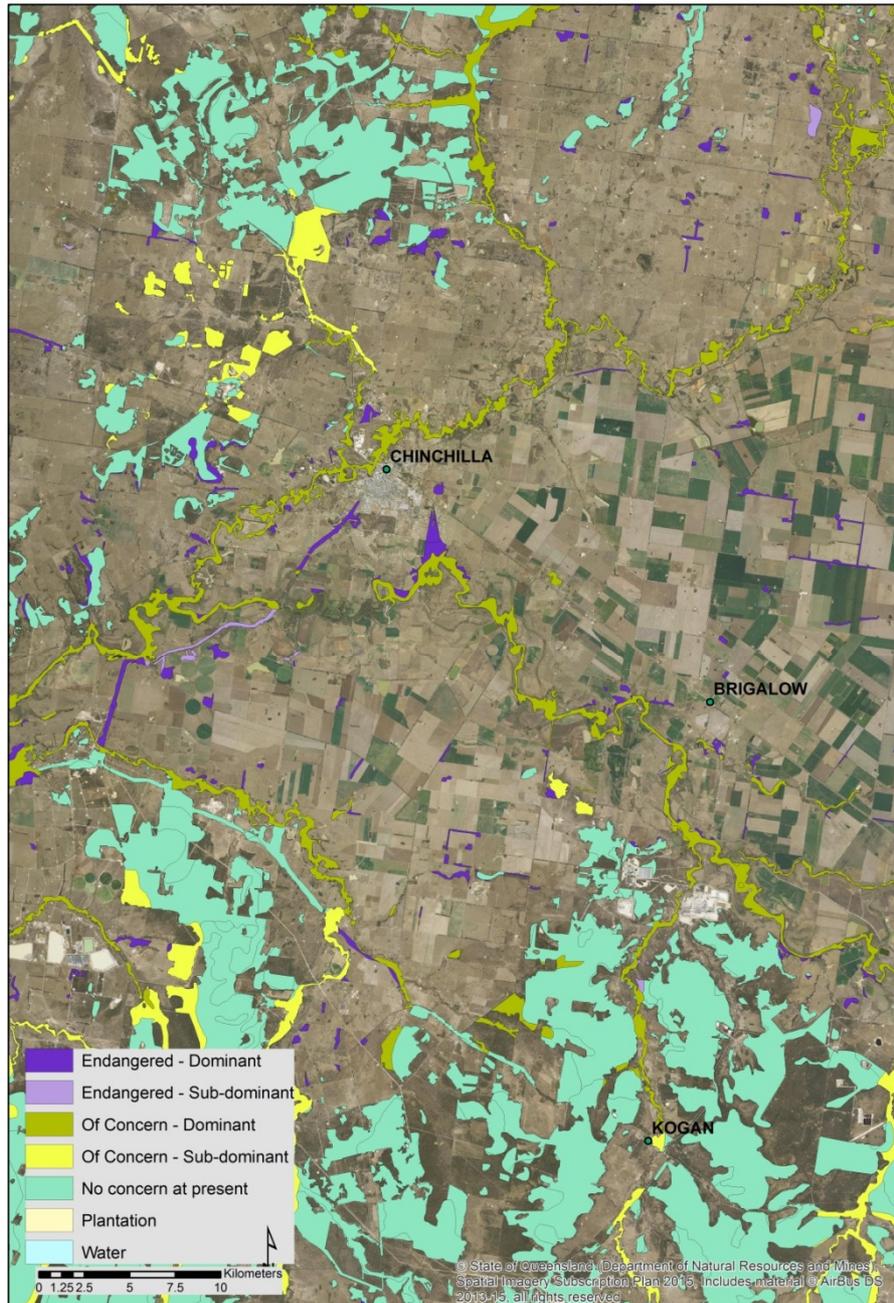
Figure 10 Fragmented remnant 2013 vegetation coloured by biodiversity status for the area near Chinchilla where cropping and grazing are the main land uses. Queensland Globe, State of Queensland 2016.

Examples of increasing fragmentation are common. In the Lockyer Valley catchment of Queensland, there was a 37% increase in the number of forest fragments between 1973 and 1997 and a 54% decrease in mean patch size (from 33.7 to 15.4 ha) (Apan *et al.* 2000). In the Herbert catchment (Queensland), mean eucalypt woodland patch size decreased from 818 ha in 1860, 546 ha in 1943, 465 ha in 1977 to 392 ha in 1996 (Johnson *et al.* 2000). This process of fragmentation increases the impact of environmental weeds and feral animals (Gibson *et al.* 2013) by creating much more extensive edges and linear corridors allowing for more effective hunting of predators and colonisation of fragmented areas by these exotic plant and animal species. Certain native species such as noisy miners *Manorina melanocephala* (Maron and Fitzsimmons 2007, Eyre *et al.* 2009) and yellow-throated miners *M. flavigula* (Kutt *et al.* 2016) may also benefit from fragmentation and interact to disrupt the ecological functioning that prevails in extensive woodland ecosystems by outcompeting and excluding insect- and nectar-feeding bird species (MacNally *et al.* 2012).In Queensland, the brigalow BVG which occurs on fertile and potentially arable soils has been most impacted by land clearing with only 12.5% of the pre-clearing distribution remaining in 2013. Ponce Reyes *et al.* (2016) conclude that without effective implementation of a range of conservation strategies they predict that 21 species are likely to be lost from the Brigalow Belt bioregion in the next 50 years. The implementation of their strategies is estimated to cost an average annualised cost of $57.5 million/ year, and would avert the loss of 12 species (including the koala and bridled nail-tail wallaby) from the region, with a further nine species (including the northern hairy-nosed wombat and Condamine earless dragon) having a greater than 50% chance of being functionally lost from the bioregion.

In addition to the brigalow BVG, a further five eucalypt woodland BVGs, five rainforest BVGs and a *Melaleuca quinquenervia* dominated BVG have less than 50%, and a further 31 BVGs, 50-58% of their pre-clearing distribution remaining in 2013 (Neldner *et al.* 2015). For these 43 BVGs, which are concentrated in the south-east and coastal regions of Queensland, the impact of the previous century of land clearing is being exacerbated by the extra pressures of continued clearing and habitat degradation, fragmentation, feral predators and weeds, grazing, altered fire regimes, diseases and pathogens, altered hydrology and climate change, to potentially cause local and regional extinctions of species. Any additional land clearing on these already relictual populations will further elevate the extinction pressure arising from loss of habitat and the aforementioned threatening processes.

Time scales for applying IUCN criteria for animal and plant population decline

The IUCN criteria relating to animal and plant population declines in the assessment of species conservation status use a time scale that is much shorter (measured for the longer of 10 years or three generations) than the span of tree clearing impacts. Thus, the substantial major impacts of historical clearing cannot be taken into consideration in the species assessment for short-lived species, e.g. annual or biennial plants, many insects and invertebrates. While for long-lived trees, three generations can include an assessment period of up to 100 years, for most other species the historic clearing will not be included in the assessment of the current IUCN and NCA status. Any clearing or further fragmenting of the remaining habitats may however trigger rapid decline in the populations of these species.

Table 1 Currently listed threatened fauna species in Queensland. Nature Conservation (Wildlife) regulation listed taxa (23 September 2016)

Taxon group	Extinct in Wild	Endangered	Vulnerable	Total
amphibians	3	13	19	35
birds	1	17	36	54
fishes		4	5	9
insects		3	5	8
malacostracans		1	1	2
mammals	6	15	29	50
reptiles		12	37	49
snails		2	1	3
TOTAL FAUNA	**10**	**67**	**133**	**210**

Table 2 Currently listed threatened flora species in Queensland. Nature Conservation (Wildlife) regulation listed taxa (23 September 2016)

Taxon group	Extinct in Wild	Endangered	Vulnerable	Total
club mosses	2	4	5	11
conifers				0
cycads		9	14	23
ferns	8	9	28	44
higher dicots	8	146	330	484
lower dicots		3	16	19
monocots	4	54	98	156
algae			1	1
TOTAL FLORA	**22**	**225**	**492**	**739**

In addition to the species listed under the NCA (see Table 1 and Table 2), there are an additional six fauna species listed as endangered or critically endangered, and nine fauna species listed as vulnerable that occur in Queensland under the Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act 1999. There are also 13 threatened ecological communities (four rainforest, two eucalypt, two melaleuca, two grasslands, brigalow, saltmarsh and artesian spring ecological communities) listed under the EPBC Act that occur in Queensland.

The listing of species is a time consuming process. A review of the United States Endangered Species after 30 years found that the US Fish and Wildlife Service failed to list thousands of at-risk species and has exhibited bias in the species that were listed. At least 42 species have become extinct during delays in the listing process. The backlog of listings was primarily because of insufficient resources given to the task and political intervention in the process (Greenwald *et al.* 2005). The slow and inadequate process of listing species as threatened was one of the contributing factors in the extinction of three Australian species from 2009 to 2014 (Woinarski *et al.* 2016). Although nearly all of the 843 formerly "rare" flora and fauna species in Queensland have been assessed by the Species Technical Committee in the last eight years. There has not been a systematic review of Queensland threatened species listings. More resources are required to enable all listings to be regularly reviewed (on a five yearly basis); to evaluate all newly described taxa; and assess species that are data deficient or particularly prone to a new threatening process such as climate change or disease such as myrtle rust. Broadhurst *et al.* (2016) recommend surveying all endangered plant species in National Parks that are not part of an existing monitoring program, or have not been surveyed in the last two years.

The threatened species lists world-wide have few or no species of invertebrates, non-vascular plants and fungi, and this is most likely reflecting the poor state of knowledge for these groups. The best known fauna are the vertebrates in Queensland – yet there is only a patchy and incomplete knowledge across the State even for these (Smith 2013). There is a wider distributional knowledge of the vascular plants in Queensland, and this has been improved by the systematic vegetation sampling for the regional ecosystem mapping program (Neldner 2014). Knowledge, however, is still incomplete with up to 50 new vascular plant species described for Queensland each year (Queensland Herbarium 2015) and 800 under-collected vascular plant species (<10 specimens in the Queensland Herbarium) yet to be assessed. Significant resources and field skills are required to address this lack of knowledge to ensure additional species are not lost through ignorance or poor understanding, and subsequent inadequate recovery processes (Woinarski *et al.* 2016).

Methods of assessing the impact of land clearing on threatened species

In this paper, three methods are used to examine this question.

Method 1. How often is land clearing recognised as threatening process for a listed species?

The Queensland Back on Track species prioritisation framework (BoT1) (DEHP 2016b) of priority species (mostly threatened species) was conducted between 2005 and 2009. Panels of technical experts identified 34 major threats for plants. The most frequently listed threats are compiled in Table 3.

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Table 3 Back on Track1 assessment of threats to priority (mostly listed) species

Major Threats	Number of flora species affected by threat
Weeds unspecified (58), lantana (9), mistflower (6),ponded pasture (4),buffel grass (2), exotic pasture (2), Gamba grass (1), rubber vine (1)	83
Inappropriate fire regimes	73
Clearing of vegetation (47), clearing and fragmentation (16)	63
Inappropriate grazing regimes	38
Road maintenance (24), Linear infrastructure development (9)	33
Plant collectors	32
Urban development	27
Small population size	26
Mining (18), extractive industry (3)	21
Feral animals - pigs (14), goats (2),	16
Potential decline in stronghold populations in the region	14
Flow regime (11), impoundments (3)	14
Drainage of habitat (6), water quality (4),groundwater extraction (1)	11
Lack of information in the region	10
Rural-residential development	7
Recreation / tourism (6), boating activities (1)	7
Site maintenance (4), change in land use (2)	6
Disease	1

Weeds (83), inappropriate fire regimes (73), and clearing of vegetation (47 species) were the most frequently assigned threats. Inappropriate grazing regimes (38) and illegal plant collection (32) also affect a significant number of plant species. The effects of most of these identified threats have been amplified because only relictual populations remain as a result of historical clearing.

A similar study of the identified threats to EPBC listed species conducted by Evans *et al.* (2011) concluded that habitat loss impacted on the highest number of extant threatened species (81%)

and spatially covered the most extensive terrestrial area of Australia (85%) (see Figure 2 and Figure 11).
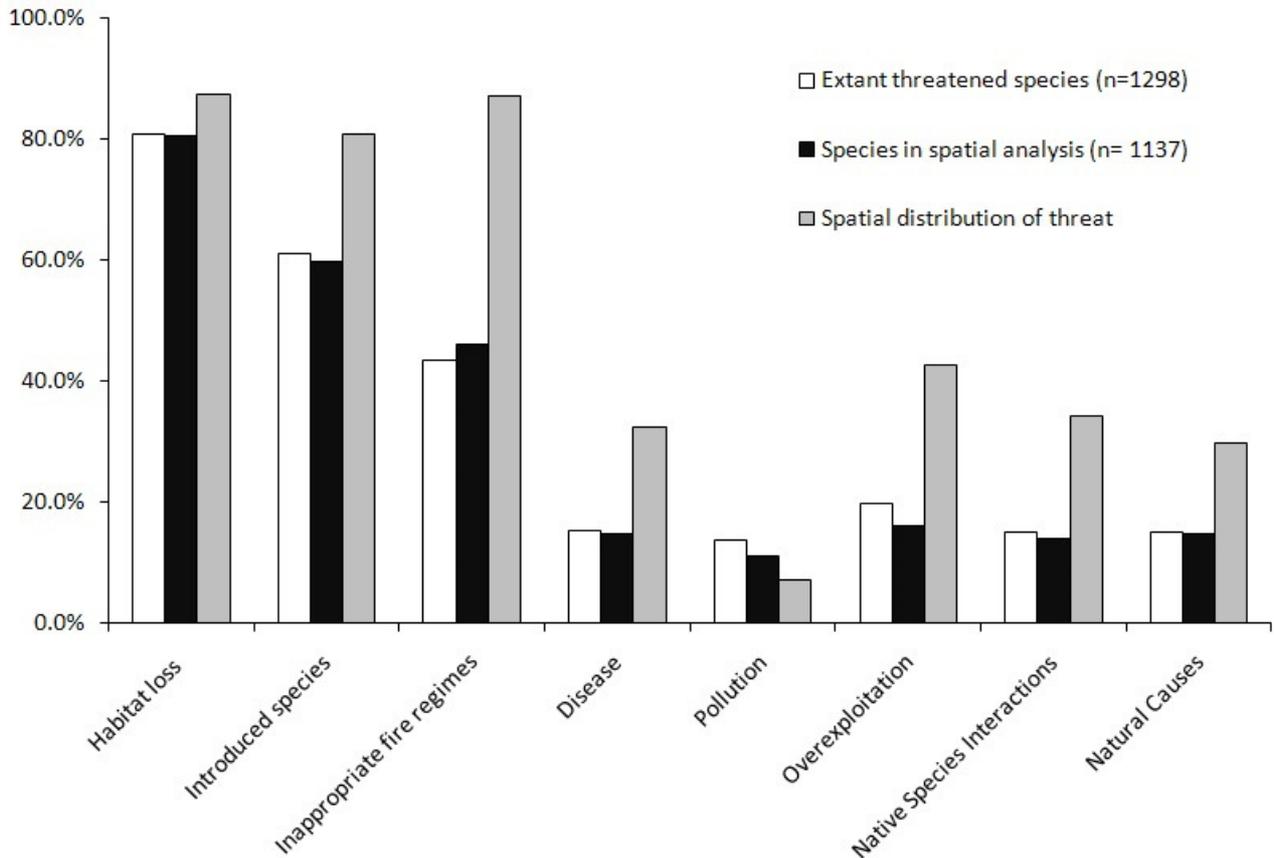
Figure 11 Analysis of threats for EPBC listed species (From Evans *et al.* 2011)

Most (>75%) Australian species assessed were affected by multiple threatening processes, with a mean number of 3.0 threats for plants and 2.5 for animals (Evans *et al.* 2011). A world-wide study of animal extinctions found that feral predators including cats, rats and foxes have contributed to 58% of all bird, reptile and mammal extinctions (Doherty *et al.* 2016). Invasive mammalian predators are often associated with fragmented landscapes and can compound the impacts of habitat loss and fragmentation (Graham *et al.* 2012).

Method 1. Conclusions

Habitat loss caused by land clearing and fragmentation is one of the most frequently identified threatening processes for plant and animal species listed under the NCA and wildlife listed under the EPBC. Land clearing also facilitates and heightens the impacts of multiple other threatening processes.

Method 2. Modelled species distributions

A comparison of the modelled pre-clearing potential habitat distribution of terrestrial threatened species with the remnant potential habitat in 2013 provides a method of quantifying the likely impact that habitat loss through clearing has had on the overall species population. Modelled potential habitat can be used as a surrogate for a species' distribution (e.g. Figure 12) and allows statistics to be calculated regarding habitat loss and temporal trends (see Table 4).The relative reduction in potential habitat can be used as a scientifically robust surrogate of habitat loss and population trends for a species. This species distribution modelling approach cannot, however, account for the additional threatening processes and stresses brought on by the fragmentation of the habitat into isolated relict patches of assorted areas.

The Maxent modelling method employed by the Queensland Herbarium (Laidlaw and Butler 2012; Laidlaw *et al*. in prep.) utilises records of species presence across Queensland, modelled climate attributes (annual mean temperature, temperature seasonality, annual precipitation and mean moisture index of the lowest quarter moisture index), topographic ruggedness, land zone (Wilson and Taylor 2012) and pre-clearing broad vegetation group (BVG)(Neldner *et al.* 2015) to produce models of potential pre-clearing habitat for Queensland's threatened species. This modelling approach of developing an environmental envelope distribution model with Maxent software (Phillips *et al.* 2006) and then using the remnant regional ecosystem mapping to achieve a realised species distribution has been used in studies such as Vanderduys *et al.* (2016) assessment of endangered black-throated finch habitat. For species lacking adequate presence records for modelling (less than 10 presence records), known records have been buffered by one kilometre to allow their incorporation into this analysis.

Modelled potential habitat (Maxent)
for Cossinia australiana (Endangered)

Cossinia australiana remnant habitat 2013
Cossinia australiana pre-clearing habitat

Presence records for
Cossinia australiana (Endangered)

Cossinia australiana records
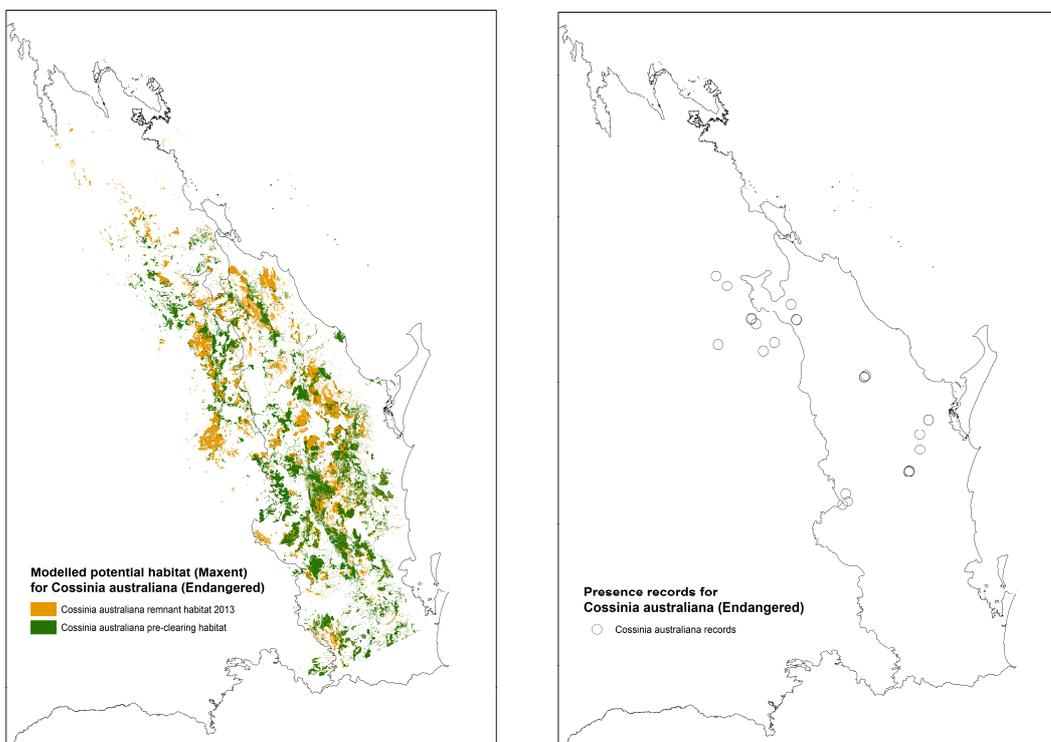
Figure 12 Example of modelled potential pre-clearing and remnant 2013 habitat for an endangered Queensland plant species *Cossinia australiana* based on 36 presence records

Table 4 Statistics derived from modelling of pre-clear potential habitat of _Cossinia australiana_, and proportion of potential habitat cleared up until 1997 and 1997-2013

Species	Pre-clear (ha)	% of Pre-clear in 1997	% of Pre-clear in 2013	Area cleared to 1997 (ha)	Area cleared 1997 to 2013 (ha)	% of 1997 remnant cleared
Cossinia australiana	2,022,346	43.6%	42.6%	1141045	18950	2.15%

Laidlaw _et al._ (in prep.) combined the modelled potential pre-clearing distributions of terrestrial threatened Queensland flora and fauna to produce pre-clearing threatened species habitat density maps (Figure 13 and Figure 15) and statistics of the area of potential habitat. This map coverage was then clipped to the 2013 remnant vegetation coverage to quantify the amount of potential habitat remaining in 2013 (Figure 14 and Figure 16). These density maps and associated statistics are included in the State of Environment 2015 report (DEHP 2016).

Table 5 Area of Queensland pre-clear threatened flora habitat and 2013 remnant habitat by species group. From DEHP (2016).

Flora habitat group	Pre-clear habitat (Ha)	Remnant 2013 habitat (ha)	% of Pre-clear habitat in 2013
Eucalypt forest and woodland	35,083,169	24,690,063	70.4
Rainforest and scrub	24,832,256	14,133,713	56.9
Acacia forest, woodland and shrubland	13,582,898	9,013,790	66.4
Wetland and Melaleuca open woodland	13,229,989	8,530,487	64.5
Grassland and forbland	8,045,082	2,733,918	34.0
Heath and other coastal community	4,343,665	2,737,299	63.0
TOTAL	99,117,059	61,839,270	62.4

The flora habitat groups are an amalgamation of 1:5M broad vegetation groups (Neldner _et al._ 2015) as in Queensland State of Environment Report 2015. Rainforests and scrubs (BVG1), eucalypt forests or woodlands (BVG2-7) , Acacia forests, woodlands and shrublands (BVG9-11), wetlands and Melaleuca open woodlands (BVG8,15), grassland and forblands(BVG13,14), and heath and other coastal communities (BVG12,16).
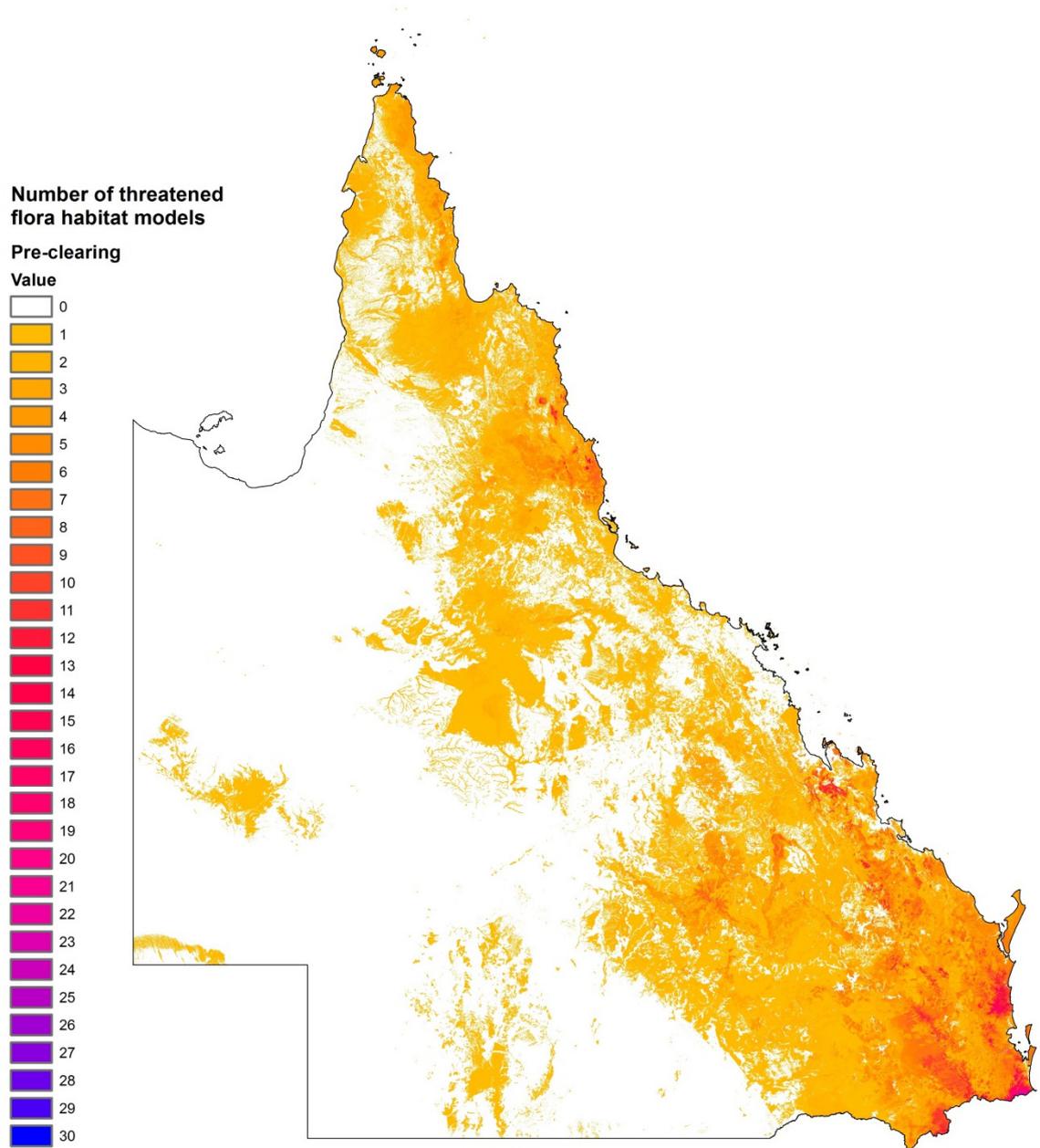
Figure 13 Density of terrestrial, pre-clearing, threatened flora habitat across Queensland, determined by the number of co-occurring flora habitat models. (Laidlaw *et al*. in prep).

**Number of threatened
flora habitat models**

Remnant vegetation 2013

Value

	0
	1
	2
	3
	4
	5
	6
	7
	8
	9
	10
	11
	12
	13
	14
	15
	16
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	29
	30
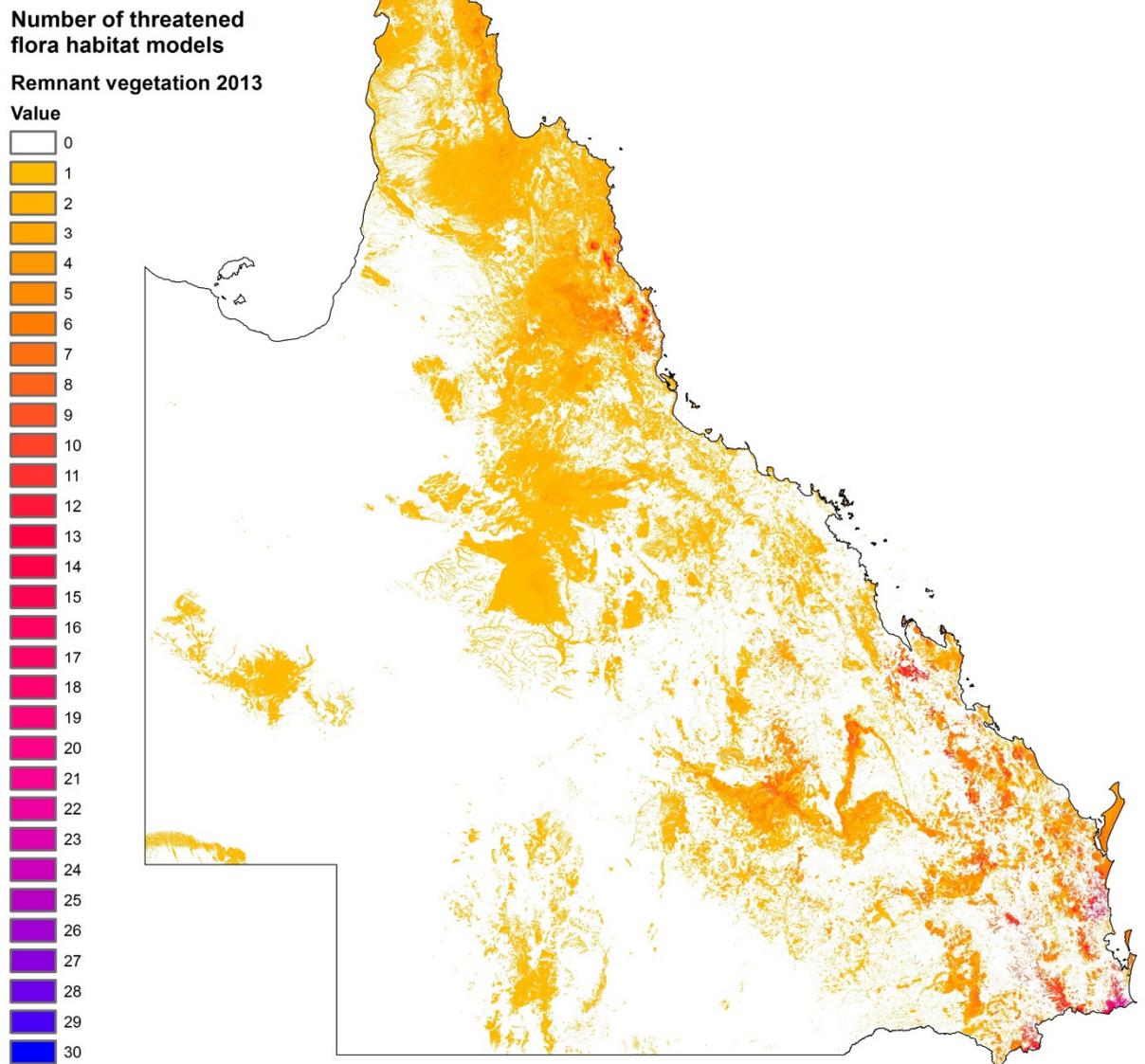
Figure 14 Density of terrestrial, remnant 2013, threatened flora habitat across Queensland, determined by the number of co-occurring flora habitat models. (Laidlaw *et al*. in prep).

While a large proportion of the pre-clearing threatened flora habitat in Queensland remains in 2013, the proportion varies greatly between bioregions and subregions and among flora groups (Modified BVGs)(Table 5). New England Tableland, Southeast Queensland, Brigalow Belt and Mulga Lands bioregions have the greatest losses of remnant habitat (Laidlaw *et al.* in prep.). Between 57% (rainforest and scrub species) and 70% of the pre-clearing habitat (eucalypt forest and woodland species) for most threatened flora habitat remained uncleared in 2013. The grassland and forbland habitats for threatened flora are the exception with only 34% of the pre-clearing habitat remaining in a natural state in 2013 (Laidlaw *et al.* in prep.).
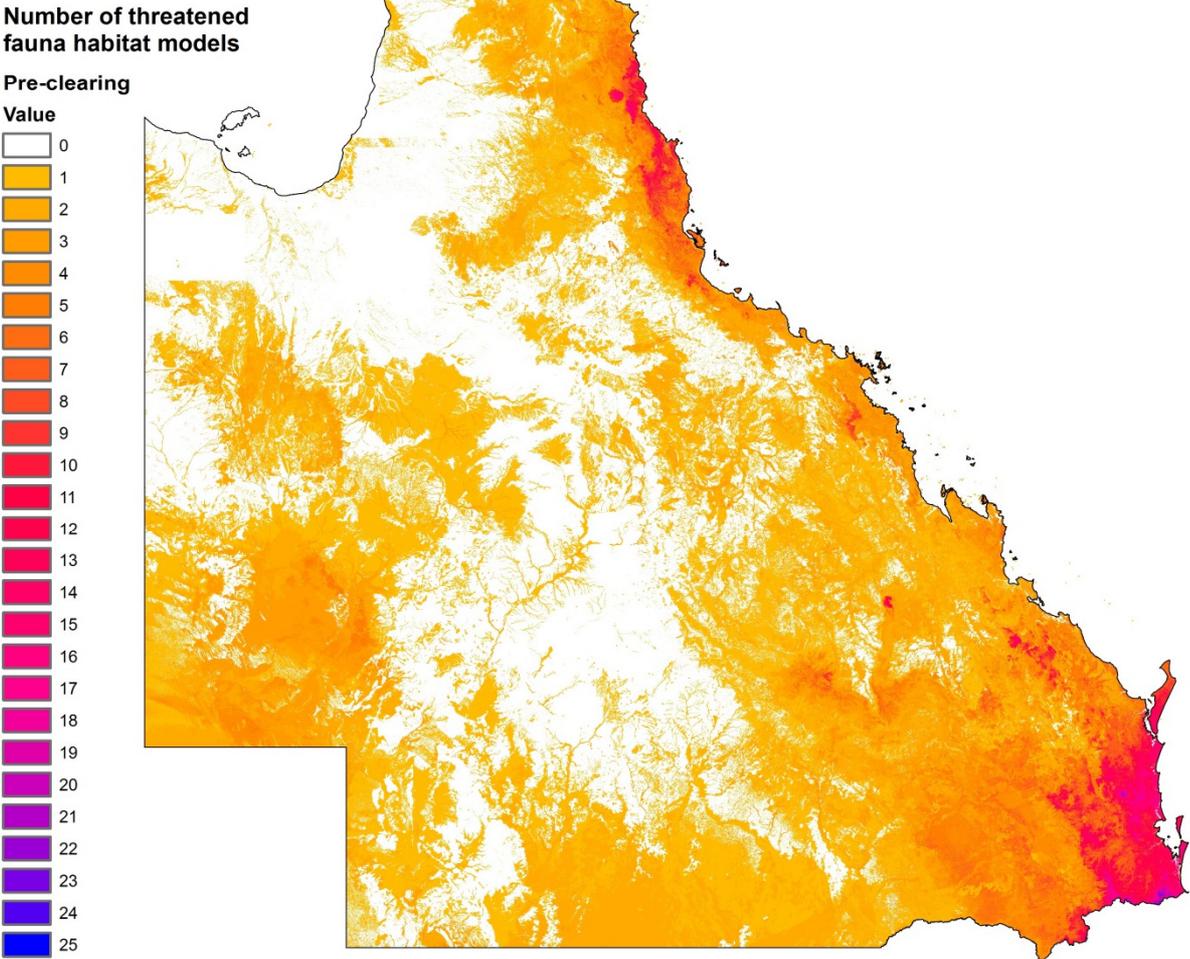
Figure 15 Density of terrestrial, pre-clearing, threatened fauna habitat across Queensland, determined by the number of co-occurring fauna habitat models. (Laidlaw *et al.* in prep).

**Number of threatened
fauna habitat models**

Remnant Vegetation 2013

Value

	0
	1
	2
	3
	4
	5
	6
	7
	8
	9
	10
	11
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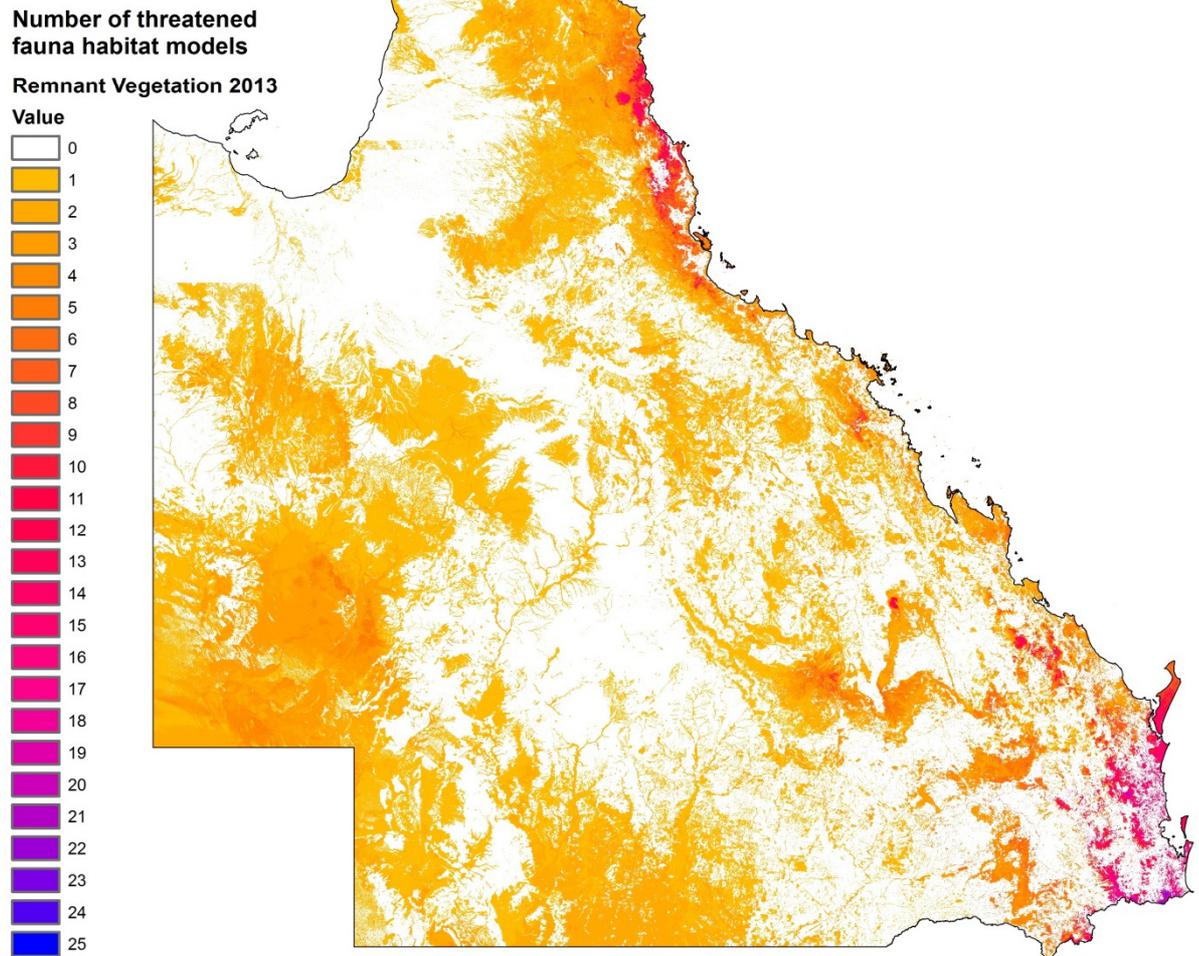
Figure 16 Density of terrestrial, remnant 2013, threatened fauna habitat across Queensland, determined by the number of co-occurring fauna habitat models. (Laidlaw *et al.* in prep).

Table 6 Area of Queensland pre-clear threatened fauna habitat and 2013 remnant habitat by species group. From DEHP (2016).

Group	Pre-clear habitat (ha)	Remnant 2013 habitat (ha)	% of pre-clear habitat in 2013
Birds	78,148,239	55,659,676	71.2
Mammals	39,941,885	33,544,685	84.0
Reptiles	32,254,203	16,840,736	52.2
Amphibians	3,462,358	2,421,497	69.9
Invertebrates	6,633,788	2,497,779	37.7
TOTAL	160,440,473	110,964,373	69.2

Across Queensland, 30% of the potential pre-clearing habitat for terrestrial fauna species has been cleared, and 110,964,373 hectares of pre-clearing modelled habitat was still remnant in 2013 (Table 6). Southeast Queensland, Wet Tropics, Brigalow Belt and New England Tableland bioregions had the highest densities of threatened fauna species habitat in 2013. The amount of habitat cleared varied between the fauna groups with the losses being highest for threatened reptiles (48%, 38 species) and 62% for the 10 threatened invertebrates (Laidlaw *et al.* in prep.).

Table 7 Historical and contemporary loss of potential habitat of threatened terrestrial flora.

Number of threatened flora species	Percentage of pre-clearing habitat remnant in 1997				Percentage of 1997 remnant habitat cleared by 2013			
	0-30%	>30-50%	>50-<100%	100%	0-5%	>5-10%	>10-<30%	≥30%
Endangered	24	37	113	45	196	15	7	1
Vulnerable	23	36	315	108	463	11	6	2
Total	**47**	**73**	**428**	**153**	**659**	**26**	**13**	**3**

Table 8 Historical and contemporary loss of potential habitat of threatened terrestrial fauna.

Number of threatened fauna species	Percentage of pre-clearing habitat remnant in 1997				Percentage of 1997 remnant habitat cleared by 2013			
	0-30%	>30-50%	>50-<100%	100%	0-5%	>5-10%	>10-<30%	≥30%
Endangered	6	6	40	3	48	5	1	1
Vulnerable	3	8	77	12	92	8	0	0
Total	**9**	**14**	**117**	**15**	**140**	**13**	**1**	**1**

Table 9 Threatened plant species where the loss of potential habitat is greater than 3% (3.16-4.8%) in the 1997-2013 period, based on Maxent habitat models (Laidlaw *et al.* in prep.).

Species	flora habitat group	% of pre-clear is remnant	% of pre-clear is remnant 2013	habitat loss rem1997-rem2013 % pre-clear	Bioregion	Driver
Corymbia clandestina	eucalypts	85.84	81.04	4.80	BB	grazing
Cadellia pentastylis	rainforest	37.14	32.87	4.27	BB	grazing
Acacia ammophila	acacias	97.77	93.68	4.10	MUL	fodder
Zieria furfuracea subsp. *gymnocarpa*	heaths	43.14	39.54	3.59	SEQ	urban
Eryngium fontanum	wetland	82.04	78.49	3.55	DEU	grazing
Livistona lanuginosa	eucalypts	72.99	69.51	3.48	DEU	grazing
Allocasuarina emuina	heaths	43.32	40.03	3.29	SEQ	urban
Micromyrtus carinata	heaths	72.24	69.04	3.19	BB	clearing
Lasiopetalum sp. Proston JABaker 17	eucalypts	59.36	56.21	3.16	BB, SEQ	clearing

Table 10 Threatened plant species where the loss of potential habitat is greater than 3% (3-30.6%) in the 1997-2013 period, based on 1km buffer spatial mapping (Laidlaw *et al.* in prep.).

Species	flora habitat group	% of pre-clear is remnant	% of pre-clear is remnant 2013	habitat loss rem1997-rem2013 % pre-clear	Bioregion
Ptilotus brachyanthus	eucalypts	100.00	69.35	30.65	MGD,BB
Rutidosis crispata	eucalypts	65.76	42.03	23.73	BB
Tylophora linearis	eucalypts	89.22	71.51	17.71	BB
Gunniopsis sp. Edgbaston	wetland	100.00	86.19	13.81	DEU
Westringia parvifolia	eucalypts	31.71	19.42	12.28	BB
Micromyrtus rotundifolia	acacias	83.30	73.40	9.90	BB, DEU
Sarcolobus vittatus	wetland	53.83	47.64	6.18	CYP
Allocasuarina thalassoscopica	heaths	36.66	31.17	5.49	SEQ
Spathoglottis plicata	wetland	82.16	77.29	4.86	CYP
Eucalyptus paedoglauca	eucalypts	100.00	95.36	4.64	EIU
Genoplesium tectum	wetland	64.85	60.46	4.38	WET
Eriocaulon carsonii subsp. orientale	wetland	81.10	77.01	4.08	BB, DEU
Eucalyptus nudicaulis	eucalypts	99.29	95.33	3.96	NWH
Plectranthus habrophyllus	eucalypts	61.71	58.06	3.65	SEQ
Hydrocotyle dipleura	wetland	98.03	94.62	3.41	DEU, MUL
Brachychiton sp. Ormeau	rainforest	47.19	43.95	3.24	SEQ
Leptospermum venustum	eucalypts	81.32	78.10	3.22	BB
Borya inopinata	heaths	100.00	96.78	3.22	EIU
Eriocaulon carsonii subsp. *carsonii*	wetland	74.19	71.14	3.04	MGD, MUL
Endiandra floydii	rainforest	48.99	45.99	3.00	SEQ

Table 11 Threatened fauna species where the loss of potential habitat is greater than 3% (3.16 -5) in the 1997-2013 period, based on Maxent habitat models (Laidlaw *et al.* in prep.).

Species	Common name	% of pre-clear is remnant	% of pre-clear is remnant 2013	habitat loss rem1997-rem2013 % pre-clear	Bioregion
Lophochroa leadbeateri	Major Mitchell cockatoo	80.52	75.52	5.00	BB,CHC,MGD, MUL
Nyctophilus corbeni	Corben's long-eared bat	53.59	49.90	3.69	BB, SEQ
Egernia rugosa	Yakka skink	54.40	50.74	3.66	BB
Geophaps scripta scripta	squatter pigeon	50.45	46.93	3.52	BB
Lasiorhinus krefftii	northern hairy nosed wombat	67.05	63.56	3.49	BB
Grantiella picta	painted honeyeater	60.86	57.48	3.39	All except CYP, WET, CQC
Denisonia maculata	ornamental snake	70.06	65.83	4.23	BB

Method 2. Conclusions

Species have been impacted to varying degrees depending on historical clearing in the habitats they occupy. An analysis of historical and contemporary extent of habitat loss for plants and animals are provided in Table 5 and Table 6. For Queensland between 57 and 70% of the pre-clearing habitat for most threatened flora species and 73.7% of the 155 currently listed remained uncleared in 2013. However in the fragmented bioregions much of this habitat is broken up into small patches which are vulnerable to a number of threatening processes.

Tables 7-10 demonstrate that although historic clearing (prior to 1997) is a major driver of the threatened status of these species, that even since the introduction of the VMA in 2000, the area of potential habitat was reduced in the period 1997-2013 by at least three percent for 29 species of threatened flora and nine species of threatened fauna. This will be reducing the populations of these species by directly killing a large number of individuals, but also further increasing the effects of threatening processes as a result of fragmentation. The current populations of threatened biodiversity are generally restricted to the small patches remaining after decades of clearing and habitat fragmentation, and hence are less resilient to threatening processes or change caused by climate variability.

Method 3. Status of known records of threatened plant species

Another method has been used to examine the fate of Herbarium specimen-backed records of threatened plant species. This is particularly applicable to the majority of plants and sedentary substrate dependent animals that do not move around the landscape, whereas mobile fauna are more problematic. The method is simply to intersect the point location of known high precision records of threatened plant species with the remnant regional ecosystem mapping. This assumes that if the record falls within mapped remnant vegetation then it is more likely to still be extant, whereas if it occurs in non-remnant vegetation (which can include completely cleared areas and areas of regrowth) it is far less likely to have persisted post-clearing. This assumption is more likely to be true for a tree than a grass which may persist in more disturbed situations. Other sources of potential error in this analysis are the precision of the data point for each record, and the scale and accuracy of the regional ecosystem mapping.

While there are limitations with this method (as there are with the other methods), the results can be interpreted as an indication of the impact of land clearing on the habitat and population of a species. While the most robust assessment would be to re-survey the known records to determine whether viable populations or individuals still persist, this would require substantial resources, and monitoring of sites or species is currently extremely limited in extent and occurs very infrequently.

Table 12 Analysis of presence records in 2013 remnant vegetation for threatened plant species (Laidlaw *et al.* in prep.).

	No. of species examined	Percentage of threatened flora species records in each clearing class (where 0% = no clearing, and 100 = all non-remnant)				
		0%	>0-30	>30-50	>50-<100	100
All species	701	52.9	22.4	13.7	8.7	2.3
By status						
Endangered	219	50.2	18.3	15.5	12.3	3.7
Vulnerable	482	54.1	24.3	12.9	7.1	1.7
By broad habitat						
rainforest	333	56.8	16.2	16.5	9.3	1.2
eucalypts	195	48.2	34.9	8.7	6.7	1.5
acacias	25	44.0	16.0	20.0	16.0	4.0
heaths	80	50.0	28.8	13.8	5.0	2.5
grass	16	37.5	0.0	18.8	37.5	6.3
wetlands	52	59.6	15.4	9.6	5.8	9.6

Method 3. Conclusions

As shown in Table 12, although nearly 53% threatened plant species have all their presence records in remnant vegetation in 2013, the other 47% are highly likely to have had a significant percent of the known records cleared. Eleven percent have more than 50% of their records likely to be cleared, and 2.3% (16 species) likely to have all previously known locations cleared by 2013. As would be expected the situation is worse for plant species listed as endangered than those listed as vulnerable with 16% and 8.8% respectively, having more than 50% of their records likely to have been cleared (Laidlaw *et al.* in prep.).

Across the broad habitats, rainforests have the highest number of records of threatened plant species, followed by the more extensive eucalypt woodlands and open forests. Both the wetlands (59.6%, 31 species) and rainforests (56.8%, 189 species) have the most species that have all their presence records in remnant vegetation, while the grasslands (37.5%; 6 species) have fewest. Grasslands also have the highest proportion of species (43.8%; 7 species) where more than 50% of the records are no longer in remnant vegetation (Laidlaw *et al.* in prep.). This may be a reflection of government policies over the last decades that have reserved large remnant areas of rainforest through National Parks and World Heritage Areas, e.g. the Wet Tropics, and Gondwana WHAs, and the cessation of rainforest logging, whereas clearing of grasslands is not regulated by the Vegetation Management Act.

The statistics presented in Table 12 are likely to underestimate the real situation. This is because the majority of specimen backed records on which they are based were collected in the last 50 years (see Figure 17), after the main period of substantial clearing for agricultural development. In other words, much habitat would already have been cleared prior to systematic botanical exploration of a region, and potentially undiscovered species may have already gone extinct during that time. The regional ecosystem survey and mapping program contributed 28% of the specimens to the Queensland Herbarium in the period from 1970 to 2011, demonstrating how valuable systematic survey programs are for the advancement of botanical knowledge (Neldner 2014).
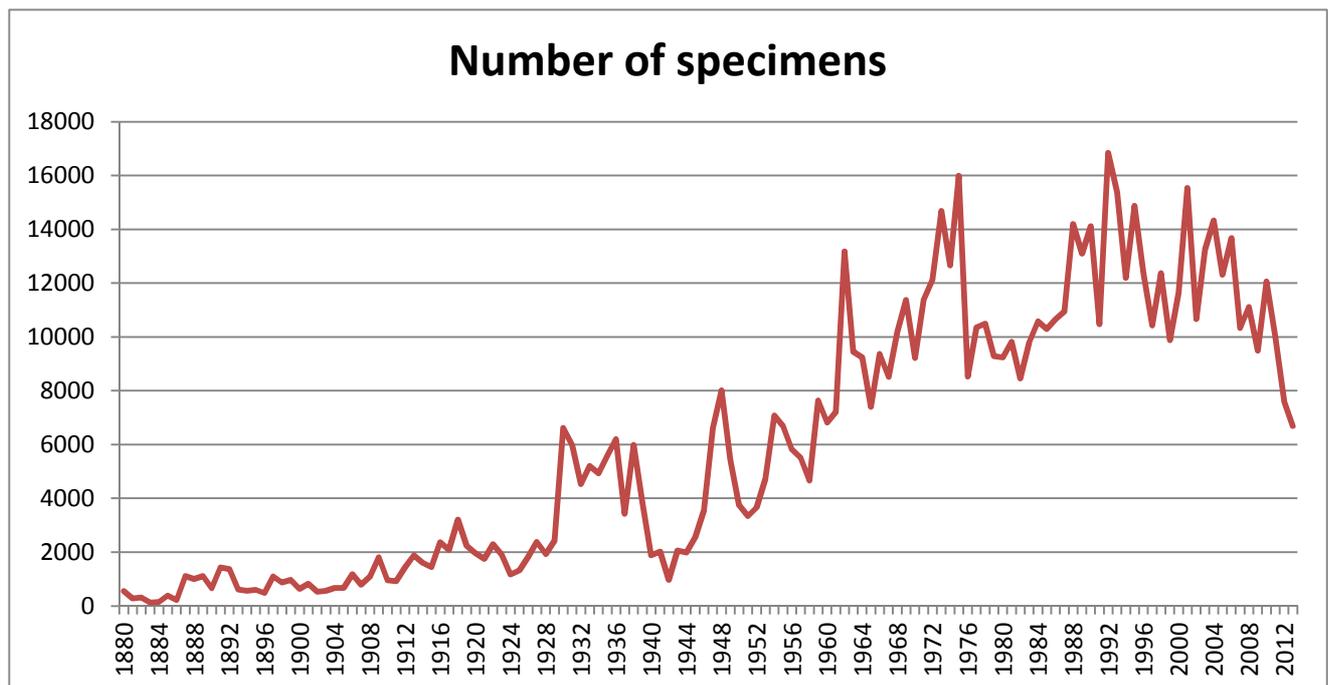
Figure 17 Number of specimens incorporated into the Queensland Herbarium (1880-2013).

The impact of further land clearing on near threatened flora and fauna

Queensland currently has 233 flora species and 33 fauna species listed as Near Threatened under the Nature Conservation Act. As discussed earlier, most of these species currently exist as fragmented relictual populations which make them more susceptible to a range of threats, and many are already carrying an extinction debt that will impact on populations in the future. Further land clearing will both directly affect these relict populations and exacerbate the additional threatening processes.

It is likely that if land clearing continues at current rates into the future (i.e. 296,000 hectares/ year), increasing numbers of near threatened species will meet the threatened criteria for the NCA and EPBC in the near future. However the number of near threatened species impacted has not been evaluated in this report. There is a need for a systematic review of all NCA and EPBC listings on a five yearly basis to update the listing on any new population or threat information.

Will Queensland's protected areas prevent further loss of threatened species?

Queensland currently has 9,663,596 hectares (5.59% of the State) in protected areas and a further 4,005,582 hectares (2.31% of Queensland) in nature refuges (DEHP 2016). Will this be sufficient to prevent further loss of species diversity? Studies of vascular plants in Western Australia (Gove *et al.* 2008) and in Japan (Akasaka *et al.* 2016), animals globally (Rodrigues *et al.* 2004), and plants and animals over the whole continent of Australia (Watson *et al.* 2011) have found that large-ranged species are well captured by reserves, while narrow-ranged species were disproportionally missed. As an example, Watson *et al.* (2011) found that Australian threatened species with a geographic range below 10 km^2 are 11 times more likely to be absent from the protected area estate than those with a range of more than 1000km^2.

Protected areas provide essential habitat for many species, e.g. of the 41 endangered or significant plant species found in Commonwealth National Parks, the majority were restricted to the National Parks with inadequate ex-situ collections (living or seed bank) to re-establish the species should extinction events occur (Broadhurst *et al.* 2016).The amount of potential habitat of threatened plant and animal species captured within Queensland's protected area network, nature refuges and state forests is presented in Table 13. It shows that even after combining the State protected area estate (8.8%) and voluntary nature refuge estate (2.6%), only 11.4% of the pre-clearing potential habitat for terrestrial threatened species is protected. It is highly unlikely that this low proportion of potential habitat will be able to maintain the current threatened species. Watson *et al.* (2011) found for Australia, the habitat for 166 (12.6%) of 1320 terrestrial threatened species occurred entirely outside protected areas. Only 259 (19.6%) species were reserved at the target levels of greater than 10% of the range if the geographic range was greater than 10,000 km^2, or at least 1000 km^2 or 100% of range for more restricted species. Gove *et al.* (2008) suggest that once 10% of land is reserved it will cover most of the large range species, and subsequent additional reserves or voluntary agreements should be specifically targeted to restricted threatened species. Therefore it is important to preserve habitat in the matrix between protected areas through other mechanisms such as nature refuges and strong vegetation management legislation. Even having sufficient habitat in protected areas will not ensure the survival of threatened species, unless these areas are well resource and managed for other threats such feral animals and weeds and diseases (Woinarski *et al.* 2016).

Table 13 Amount of potential habitat of threatened terrestrial species in protected areas.

Area of Potential Habitat	Threatened flora	Threatened fauna	Threatened flora and fauna
Potential pre-clearing habitat (km^2)	653290	1026110	1175266
Potential habitat in 2013 remnant vegetation (km^2)	429594 (65.8%)	755730 (73.7%)	876458 (74.6%)
Potential habitat within QLD protected area estate (km^2)	51011 (11.9%)	70743 (9.4%)	77284 (8.8%)
Potential habitat within Nature Refuges (km^2)	12027 (2.8%)	17789 (2.3%)	22785 (2.6%)
Potential habitat in Protected areas [#] (km^2)	63038 (14.7%)	88532 (11.7%)	99969 (11.4%)
Potential habitat in State forestry areas^ (km^2) that was remnant in 2103	25314 (5.9%)	28423 (3.8%)	28818 (5.9%)

[#]Protected areas includes the Queensland protected estate (National Parks, Regional Parks, Aboriginal Lands, Torres strait Island Lands, Cape York Peninsula Indigenous Lands and Coordinated Conservation Areas), and Nature Refuges (private lands protected by a legally binding conservation covenant between landholders and the Queensland government).

^State forestry areas includes State Forests, Forest Reserves and Timber Reserves

Has land clearing caused any species to become extinct in the wild in Queensland?

Queensland currently has 10 fauna species and 22 flora species listed as extinct in the wild. It is difficult to attribute causes to these extinctions, but in many cases habitat destruction has contributed to and exacerbated the factors that have led to the extinction of the species.

Psephotus pulcherrimus (paradise parrot)

This beautiful bird has not been sighted since 1927. It occurred in open grassy ironbark (*Eucalyptus crebra, E. melanophloia*) and bloodwood (*Corymbia* spp.) woodlands on river flats in an extensive area in the southern Brigalow Belt bioregion, and was relatively abundant up until the 1880s.

Photo 3 Painting of paradise parrot by W.T. Greene (1884-87).

The reasons for extinction of the paradise parrot are thought to be habitat modification through overgrazing, altered fire regimes, and prickly pear invasion, together with destruction of the termite mounds used for nesting (frequently used for ant-bed tennis court construction), predation from cats, foxes and goannas, and trapping by humans for sale as pets (Garnett et al. 2011).

Corchorus thozetii
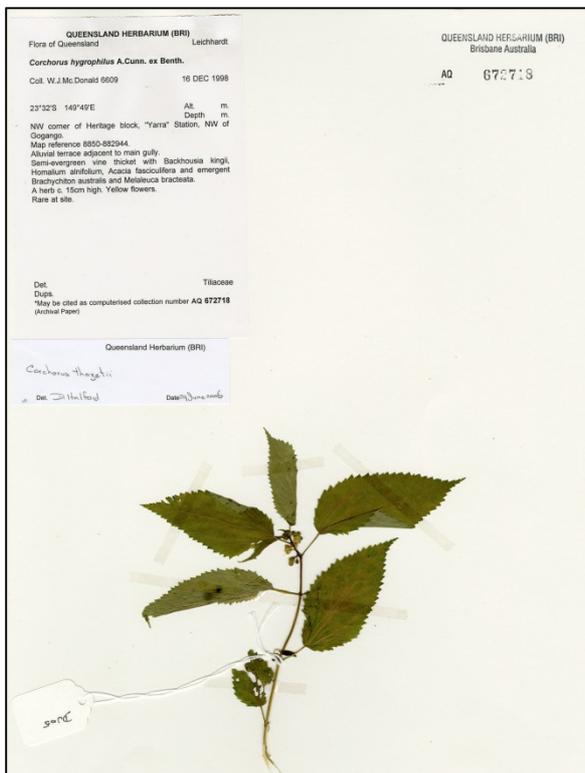
Corchorus thozetii is a small shrub that was described in 1995 based on a couple of specimens held in the National Herbarium of Victoria, Melbourne and collected by Thozet sometime in nineteenth century. It occurred close to Rockhampton. It was presumed extinct, as no specimens had been found for over 100 years (Halford 1995). In 2006, a specimen of *C. thozetii* collected near Duaringa in 1998 by Bill McDonald was located in the Queensland Herbarium collection misidentified as *C. hygrophilus*. However when the habitat for this new locality was investigated, it was found to have been cleared and cropped. Hence it appears land clearing was been the cause of the disappearance of the last known location of the species.

Photo 4 The only Queensland Herbarium specimen of *Corchorus thozetii,* which is now extinct in the wild. Collector W.J.F. McDonald 6609.

Calotis glabrescens

Calotis glabrescens is a small herb that has been described from a single specimen collected in 1944 by C.T. White west of Inglewood. It was noted as moderately common at the time and occurring in open forest land. The property where it was collected and most of the surrounding properties have been cleared for cropping. The species has been searched for in nearby State Forests but has not been found. It is likely that land clearing has caused the extinction of this species.

Photo 5 The only Queensland Herbarium specimen of *Calotis glabrescens*, which is now extinct in the wild. Collector C.T. White 12623.

Land clearing impacts on selected threatened species

Case study 1. *Cadellia pentastylis* (ooline)

Cadellia pentastylis is a tree growing to 10m tall, but occasionally reaching 25m tall. It occurs in the Brigalow Belt bioregion in southern Queensland and northern New South Wales, primarily in semi-evergreen vine thickets and brigalow communities that have been listed as endangered ecological communities under the EPBC. The species is listed as vulnerable both under the EPBC and NCA. The loss of habitat through land clearing for grazing or cropping is the primary threat to the species. Stock grazing and fire may also kill seedlings and adult plants. As is typical of many habitats in the Brigalow Belt, much of the clearing (63%) of its modelled habitat occurred prior to 1997, however another 4.3% of the preclearing habitat has been cleared between 1997 and 2013. The species has been listed as vulnerable under the EPBC since 2000, hence killing of the trees is prohibited. However 57% of the presence records appeared to be cleared by 2013. The loss of more habitat and individuals from a population that is already reduced to only a third of its original size is a serious threat to the species (DEWHA 2016a).

Photo 6 Ooline *Cadellia pentastylis*. Photo D.W. Butler

Modelled potential habitat (Maxent) for Cadellia pentastylis (Vulnerable)

Cadellia pentastylis remnant habitat 2013

Cadellia pentastylis pre-clearing habitat
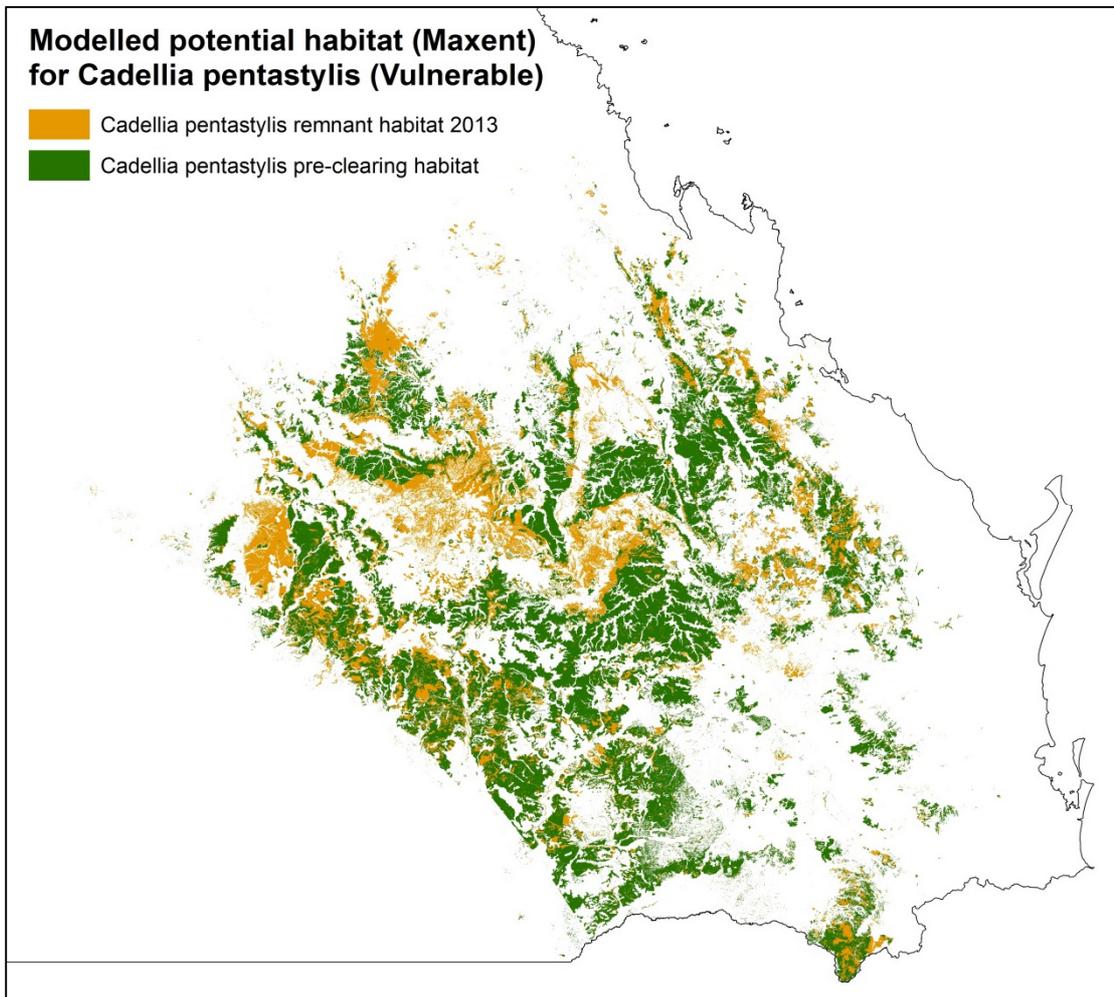
Figure 18 Modelled potential pre-clearing and remnant 2013 habitat for a vulnerable plant species ooline *Cadellia pentastylis* based on 49 presence records

Case study 2. *Brachychiton* sp. (Ormeau L.H.Bird AQ43581) (Ormeau bottle tree)

This tree with a distinct swollen, bottle-like trunk grows up to 25 metres tall and is restricted to the highly urbanised area of Ormeau in Southeast Queensland. It has been listed as Endangered under the NCA since 2009 and critically endangered under the EPBC since 2013. There are only 400 individuals remaining in the area (Leiper 2016), and its extent of occurrence is only 6.5 km^2 with an area of occupancy of less than 1 km^2. This species occurs in riparian rainforest and is associated with the EPBC listed 'Lowland Rainforest of Subtropical Australia ecological community'. Its small population with presumably low genetic diversity, is continuing to be threatened by clearing for urbanisation or extractive mining, and fire (which kills seedlings and will kill adult trees if intense enough) (DEWHA 2016b).

Photo 7 *Brachychiton* sp. (Ormeau L.H.Bird AQ43581) Upper Ormeau. Photo G.P. Guymer.

Case study 3. *Poephila cincta cincta* (black-throated finch)(southern)

This fairly sedentary and gregarious finch has declined throughout the southern part of its range. The southern subspecies is listed as endangered both under the NCA and EPBC. As it is fairly sedentary, local threatening processes can have a big impact on populations. The decline of this species in the southern part of its range began in the early Twentieth Century with the extensive clearing for sheep grazing (Franklin 1999; Garnett *et al.* 2011). There are a number of factors associated with agricultural and pastoral development that have combined to cause further decline. The subspecies requires intact woodlands, a water source and a year-round supply of grass seeds. Clearing removes the woodland and fragments the habitat, while overgrazing reduces grass seed availability particularly in the critical time of seed scarcity of the early wet season. The remaining small isolated populations are more vulnerable to predation, drought-induced food shortages and human trapping (Curtis *et al.* 2012). The bird is no longer known from southern Queensland and northern New South Wales, with further retreats in range occurring in the Gulf Plains and Einasleigh Uplands bioregions during the period of 1975-2000 (Vanderduys *et al.* 2016). Hence for many parts of its former range, this species is regionally extinct.

Photo 8 Black-throated finch *Poephila cincta cincta.* Photo E.P. Vanderduys.

The post 2000 records of the sub-species are confined to the Desert Uplands and northern Townsville Plains subregion of the Brigalow Belt bioregions. The modelled distribution of the sub-species in 1997 was only 82.6% of its pre-clearing distribution, but further reduced by 70,067 hectares (3.3% of the pre-clearing habitat) between 1997 and 2013. This species is showing significant recent range and population reductions.

**Modelled potential habitat (Maxent)
for Poephila cincta cincta (Endangered)**

■ Poephila cincta cincta remnant habitat 2013
■ Poephila cincta cincta pre-clearing habitat
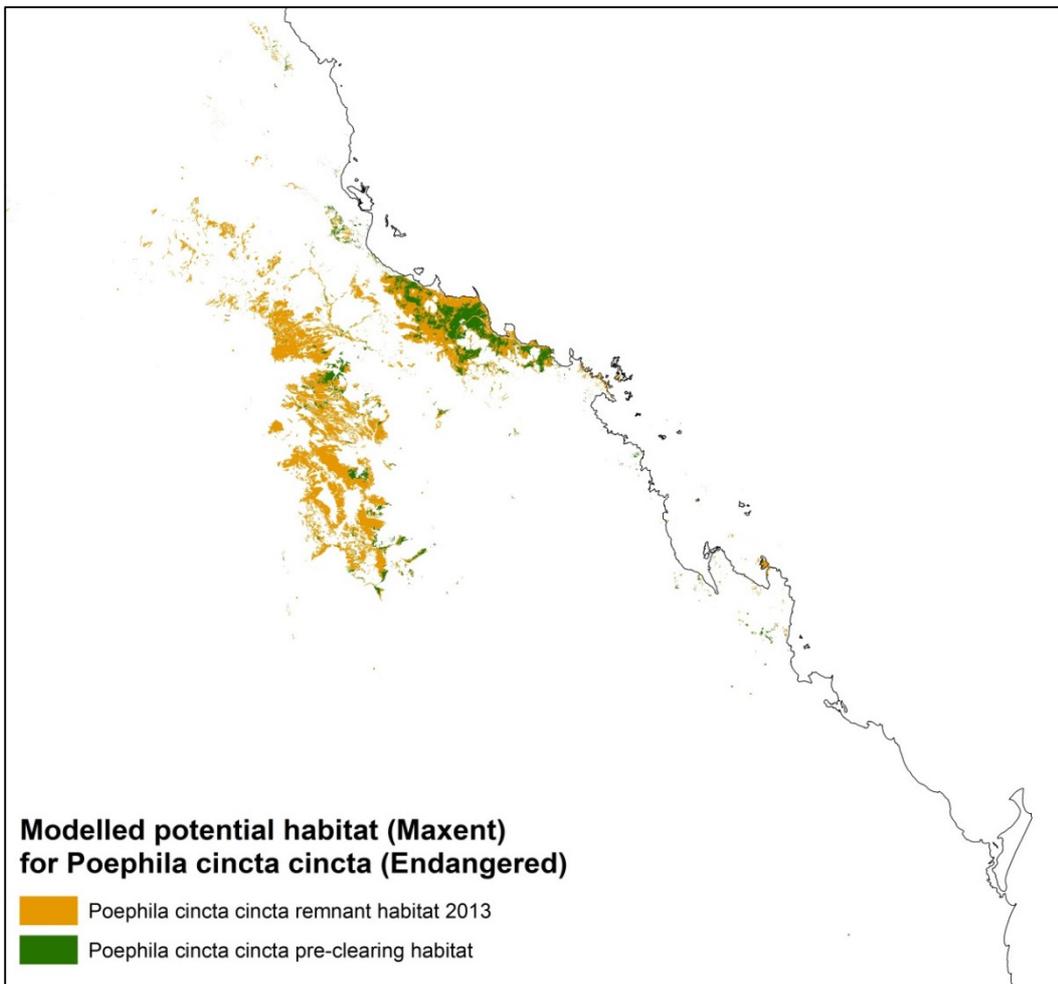
Figure 19 Modelled potential pre-clearing and remnant 2013 habitat for the endangered black-throated finch subspecies *Poephila cincta cincta* based on 469 presence records

Vanderduys *et al.* (2016) demonstrate that over half of the remaining distribution of this sub-species is under extractive or exploratory mining tenure, especially in the Galilee Basin, so that even if offsetting was attempted, "no nett loss" in habitat could not be achieved. Clearing for urban development near Townsville is threating the largest subpopulations, and the birds do not persist for long once pastoral land is subdivided into rural lifestyle blocks (Garnett *et al.* 2011; Curtis *et al.* 2012).

The Carmichael mine site is home to the largest population of the finch, and keeping the habitat intact is the key to maintaining the population. Offsetting the loss of habitat from mine development will not avoid serious detrimental impacts on the finch (Reside *et al.* 2016).

Case Study 4. *Phascolarctos cinereus* (koala)

The koala is one of Australia's most iconic animals, and formerly occupied a large part of the relatively continuous belt of woodlands and open-forests in eastern Australia, with a sparse occurrence in the semi-arid woodlands, primarily on riparian vegetation. Up until 1927, koalas were heavily hunted for their fur (one million skins were sold in the open season in Queensland in 1919). By the time hunting was legislated against in 1927 in Queensland (earlier in southern states), the koala populations had been devastated. But as in the case of other native species where hunting was the main threatening process and the basic habitat was in good condition, (e.g. estuarine crocodiles, humpback whales), koala populations substantially recovered post 1927 (Martin and Handasyde 1999). Queensland koala populations were considered relatively secure at the end of the 1990s (Melzer *et al.* 2000). In the last 50 years, habitats for koalas have been reduced by land clearing (57% of the potential pre-clearing distribution had been cleared in Queensland by 2013) and the remaining habitats are severely fragmented. Koalas need to come to the ground to move from one food or shelter tree to the next or in search of a mate, and at this time they are vulnerable to attacks by domestic or wild dogs, or to being struck by vehicles on busy roads. The disease *Chlamydia psittaci* is also a threatening process for stressed koalas living in a fragmented landscape. Periods of extreme heat and drought, and associated fires, are also known to cause significant mortality (DEE 2012). In the last 15 years, the interacting threats and the extinction debt from previous clearing have caused the populations of koalas in Queensland to rapidly decline (McAlpine *et al.* 2015). The rate of decline in the national population has been estimated to be close to 30% in the last three generations (DEE 2012, McAlpine *et al.* 2012), while it has been estimated that a decline of 80.3% in the Koala Coast and 54.3% in Pine Rivers has occurred between 1996 and 2014 (Rhodes *et al.* 2015, DEHP 2017). Recent surveys estimate 80% decline in koala numbers across the Mulga Lands bioregion from a mean estimate of 59,000 in 1995 (Sullivan *et al.* 2004) to 11,600 in 2009 (Seabrook *et al.* 2011). An overall decline of 53% was estimated for Queensland populations (20% for the Desert Uplands to 73% for the Mulga Lands bioregions) over the past three generations and the next three generations (15-21 years) (Adams-Hosking *et al.* 2016).

Photo 9 Koala *Phascolarctos cinereus* at Mt Warning, New South Wales. Photo V.J. Neldner.

Habitat loss is the most serious threat to koalas in Queensland and News South Wales (Martin and Handasyde 1999). Land clearing is the direct cause of many deaths, but has also created the fragmented relictual landscapes that expose the koala to the additional threatening processes described above. Climate change causing more extreme weather particularly in the western part of the koala's distribution, and the expansion of coal and coal seam gas developments and associated infrastructure are additional new threats (McAlpine *et al.* 2015). Any additional clearing of its habitat only further compounds the multiple threats to this vulnerable species.
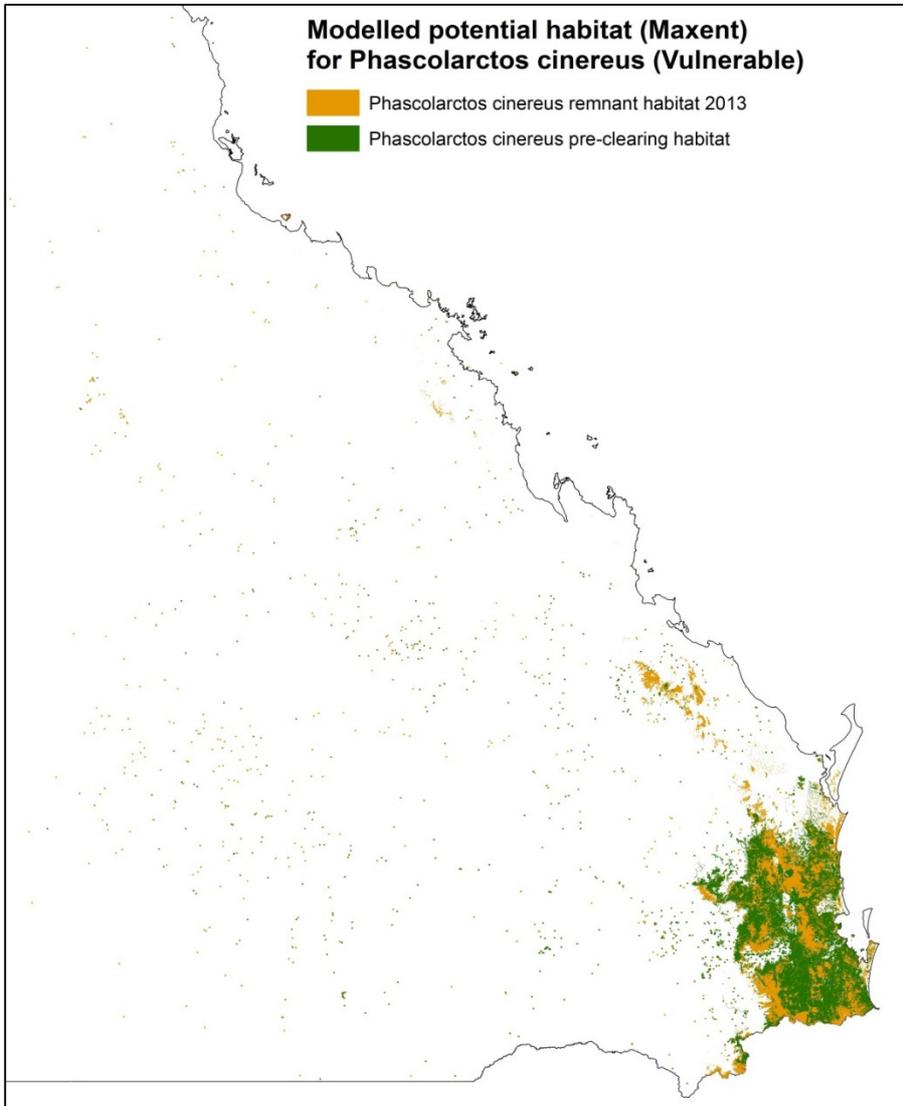
Figure 20 Modelled potential pre-clearing and remnant 2013 habitat for the vulnerable koala *Phascolarctos cinereus* based on 38947 presence records.

In **Figure 20** the dots throughout western and central Queensland represent previous confirmed locations. Modelled habitat was present in these areas but was at a lower probability of occurrence than the conservative threshold (equal training sensitivity and specificity) applied, and hence not displayed on this map.

Modelling of koala distribution and abundance for Central Queensland populations was conducted by Alistair Melzer of Central Queensland University, and based on (a) relative abundance of koala food tree species as described in regional ecosystem descriptions, and (b) expert knowledge of koala use of the central Queensland regional landscape. The habitat ranks are:

Rank 0 = no habitat values; Rank 4-5 = highest value. Combination of ranks 3 to 5 represent the best koala landscapes although koalas are found at varying densities from rank 1-2 (very low) to rank 4-5 (relatively high). For the Isaac Regional Council area, there was a 30% or higher decline in the area of all rankings of koala habitat from the pre-clearing conditions, apart from the no habitat values area which was 56% higher in the remnant 2013 mapping.
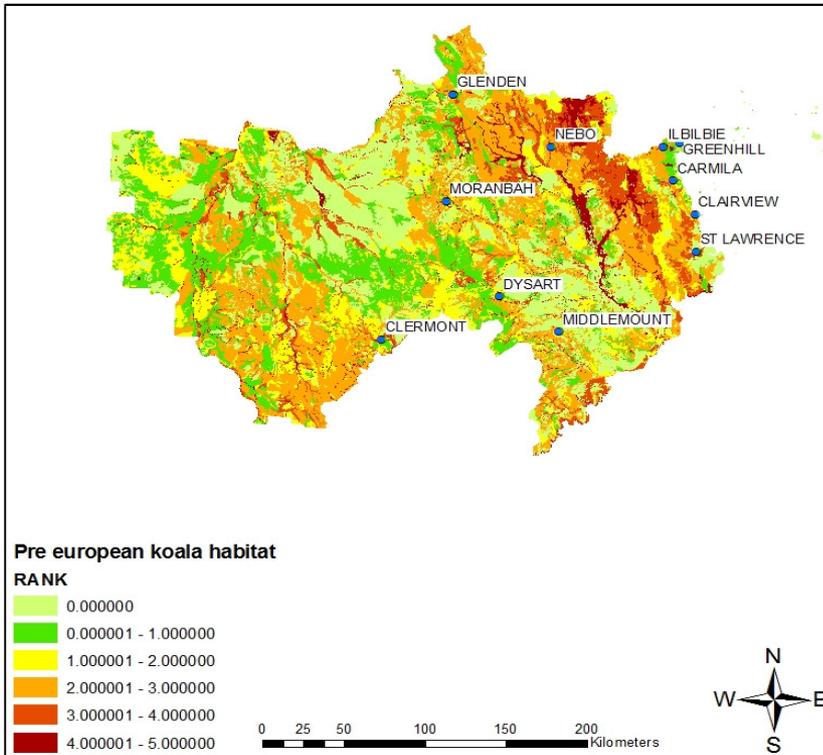
Figure 21 Pre-clear koala habitat for Isaac Regional Council in Central Queensland. A. Melzer, pers. comm.
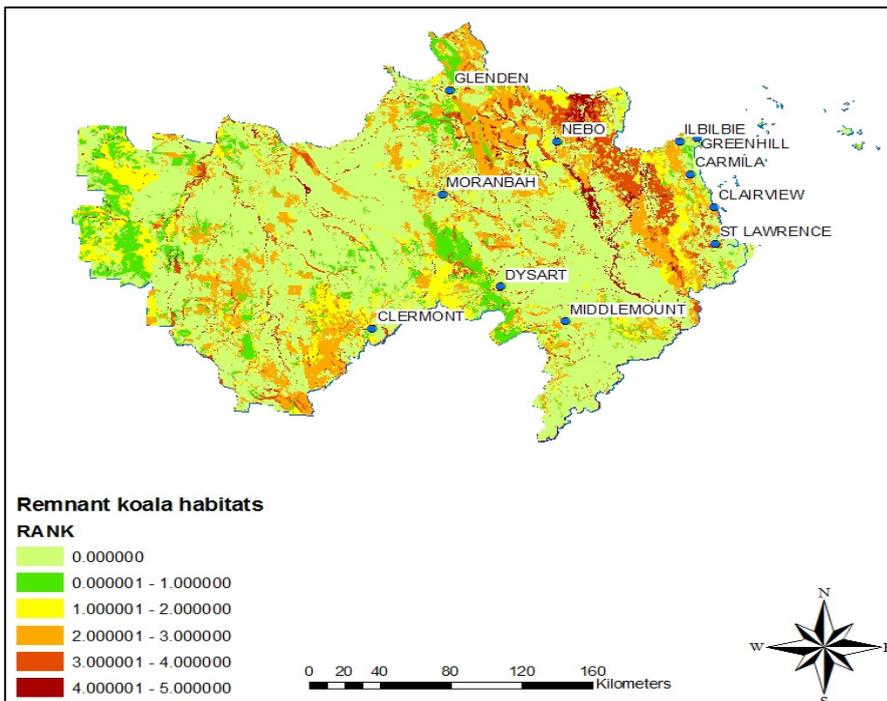
Figure 22 Remnant 2013 koala habitat for Isaac Regional Council in Central Queensland. A. Melzer, pers. comm.

Case Study 5. *Petaurus gracilis* (mahogany glider)

The mahogany glider was reinstated as a species in 1993 (Van Dyck 1993) after nearly a century of taxonomic oversight (Woinarski *et al.* 2015). It is restricted to the largely cleared and fragmented coastal lowlands in the southern Wet Tropics bioregion. It is estimated that 50% (Jackson *et al.* 2011) to 80% (Parsons 2012) of its habitat of eucalypt and melaleuca woodlands and open forests has been cleared. The remainder is heavily fragmented, with resident colonies facing local extinction. Land clearing is the primary reason that this species is endangered, with extensive habitat clearing extending at least until the 1990s (Jackson *et al.* 2011). The species faces a number of additional threats because of the fragmented landscape it now occurs in, the potential damage to fragments from cyclones and the continued decline in habitat quality (Parsons 2012, Woinarski *et al.* 2014).

Photo 10 Mahogany glider *Petaurus gracilis* near Ingham. Photo L.D. Hogan
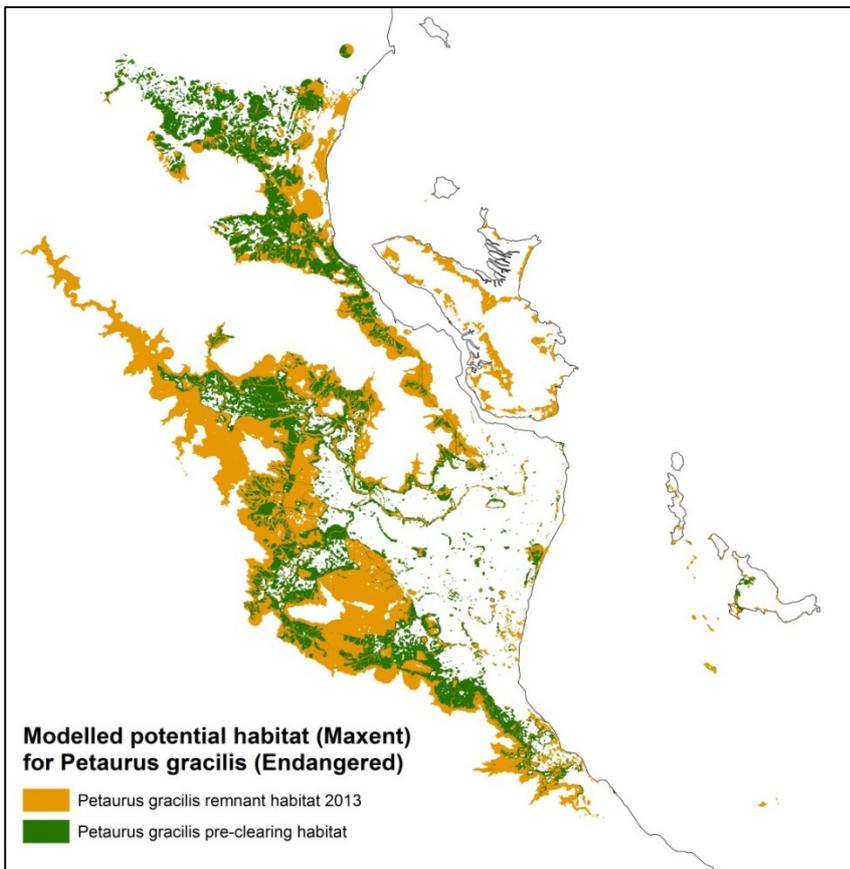
Figure 23 Modelled potential pre-clearing and remnant 2013 habitat for the endangered mahogany glider *Petaurus gracilis* based on 397 presence records

Case Study 6. *Tympanocryptis condaminensis* **(Condamine earless dragon)**

Photo 11 Condamine earless dragon *Tympanocryptis condaminensis.* **Photo M.T. Mathieson.**

The Condamine earless dragon (*Tympanocryptis condaminensis)* and closely related Roma earless dragon (*T. wilsonii)* occur in both agricultural (converted grasslands, including those sown to sorghum and wheat) and remnant grassland areas (Starr and Leung 2006). Grassland or cropping areas adjacent to roadsides or tracks, fallow fields, or other open ground may provide the necessary microhabitat for the dragons to shelter in. The natural habitat of *T. condaminensis* is the EPBC listed critically endangered regional ecosystem 11.8.11 (grassland dominated by *Dichanthium sericeum, Aristida* spp., *Astrebla* spp. and *Panicum decompositum* on soils derived from Cainozoic igneous rocks) which occurs on the Darling Downs, but only 1% of it remains in its remnant state. *Tympanocryptis condaminensis* is able to coexist with the mixed farming operations of cropping and grazing in the Darling Downs area. However soil structure decline which occurs with too-frequent cultivation, overgrazing (especially compaction on wet soil), and lack of plant cover or crop stubble is a major threat to these species. Any reduction in the roadside or paddock remnant grasslands is also a major threat; 30% of this potential habitat (805 ha) was lost between 1997 and 2013.

Modelled potential habitat (Maxent) for Tympanocryptis condaminensis (Endangered)

- Tympanocryptis condaminensis remnant habitat 2013
- Tympanocryptis condaminensis pre-clearing habitat
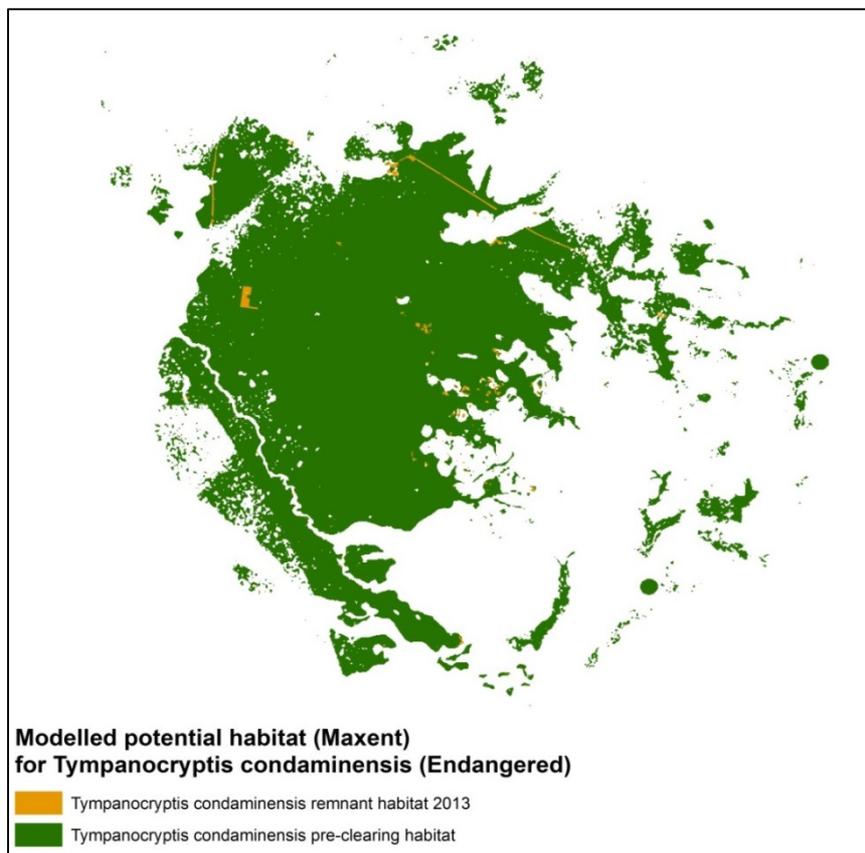
Figure 24 Modelled potential pre-clearing and remnant 2013 habitat for the endangered Condamine earless dragon *Tympanocryptis condaminensis* **based on 38 presence records**

Case Study 7. *Melaleuca irbyana* (swamp tea-tree)

Melaleuca irbyana is listed as endangered species under the EPBC and NCA. *M. irbyana* forests/ thickets of Southeast Queensland are also listed as a critically endangered ecological community under the EPBC It is comprised of RE 12.9-10.11, which had been reduced to 7.7% of its pre-clearing distribution by 2013 (Accad and Neldner 2015) and RE 12.3.3.c. Only seventeen percent of the potential habitat remained in 2013, and similarly only 20 percent of the 35 presence records were still in remnant vegetation in 2013. The main identified threats to this ecological community are clearing and fragmentation, and edge effects and weed invasion from surrounding pastoral and peri-urban lands (DEWHA 2016c).

Photo 12 Swamp tea-tree *Melaleuca irbyana* thicket. Photo T.S. Ryan.
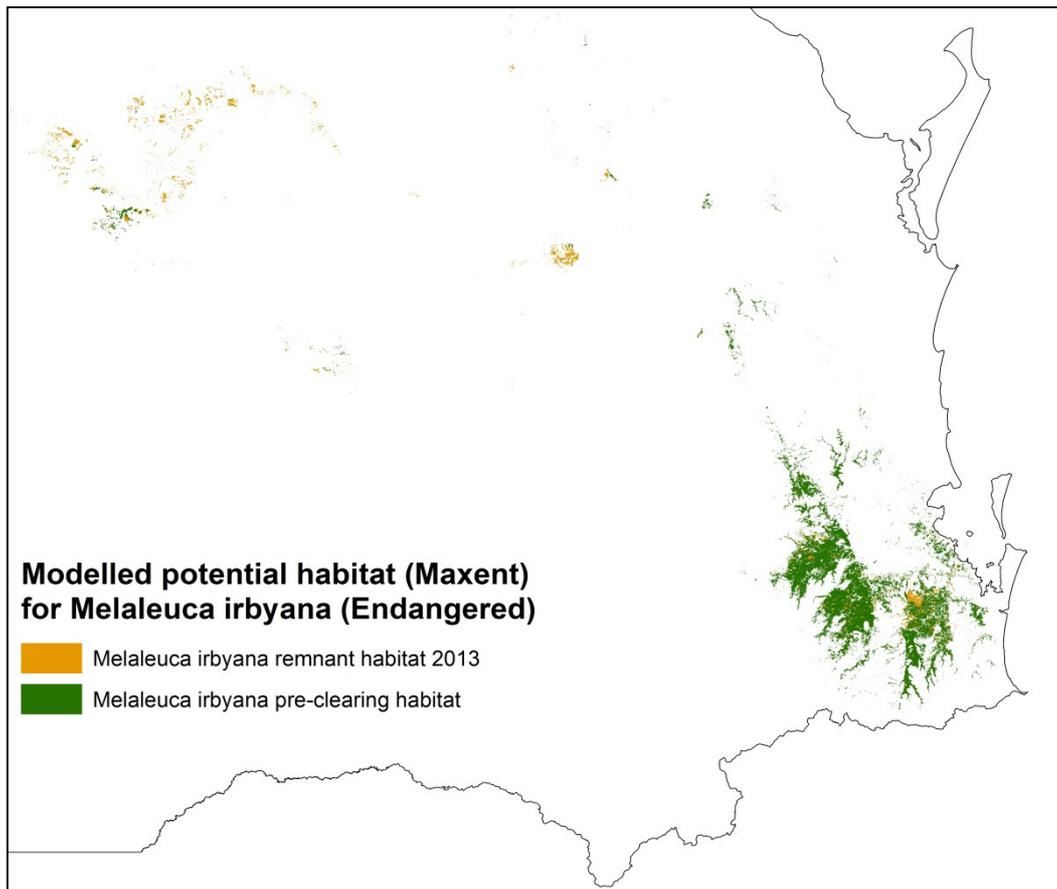
Figure 25 Modelled potential pre-clearing and remnant 2013 habitat for endangered swamp tea-tree *Melaleuca irbyana* based on 35 presence records.

Case Study 8. *Jalmenus eubulus* (pale imperial hairstreak butterfly)

Jalmenus eubulus is a small butterfly in the Lycaenidae family. It is restricted to vegetation communities comprising brigalow-dominated old-growth open-forests and woodlands in the Brigalow Belt in Queensland, and has been found in five sites in New South Wales (NSW Government 2014). The larvae are monophagous on *Acacia harpophylla* (brigalow), and attended by several species of ants (Valentine and Johnson 2012). Nationally, the geographic range has an estimated area of occupancy of less than 2000 km², is severely fragmented, and the extent or quality of its habitat, which is poorly conserved, continues to decline (Eastwood *et al.* 2008). Only 23 percent of the potential habitat remained in 2013, and only 46 percent of the 46 presence records were still in remnant vegetation in 2013. Remaining fragments of brigalow are so small and isolated that they may not ensure the long term survival of the species and will make genetic continuity difficult (Valentine and Johnson 2012).

Photo 13 Pale imperial hairstreak butterfly *Jalmenus eubulus*. Photo Bruce Thomson.

Modelled potential habitat (Maxent) for Jalmenus eubulus (Vulnerable)

- Jalmenus eubulus remnant habitat 2013
- Jalmenus eubulus pre-clearing habitat
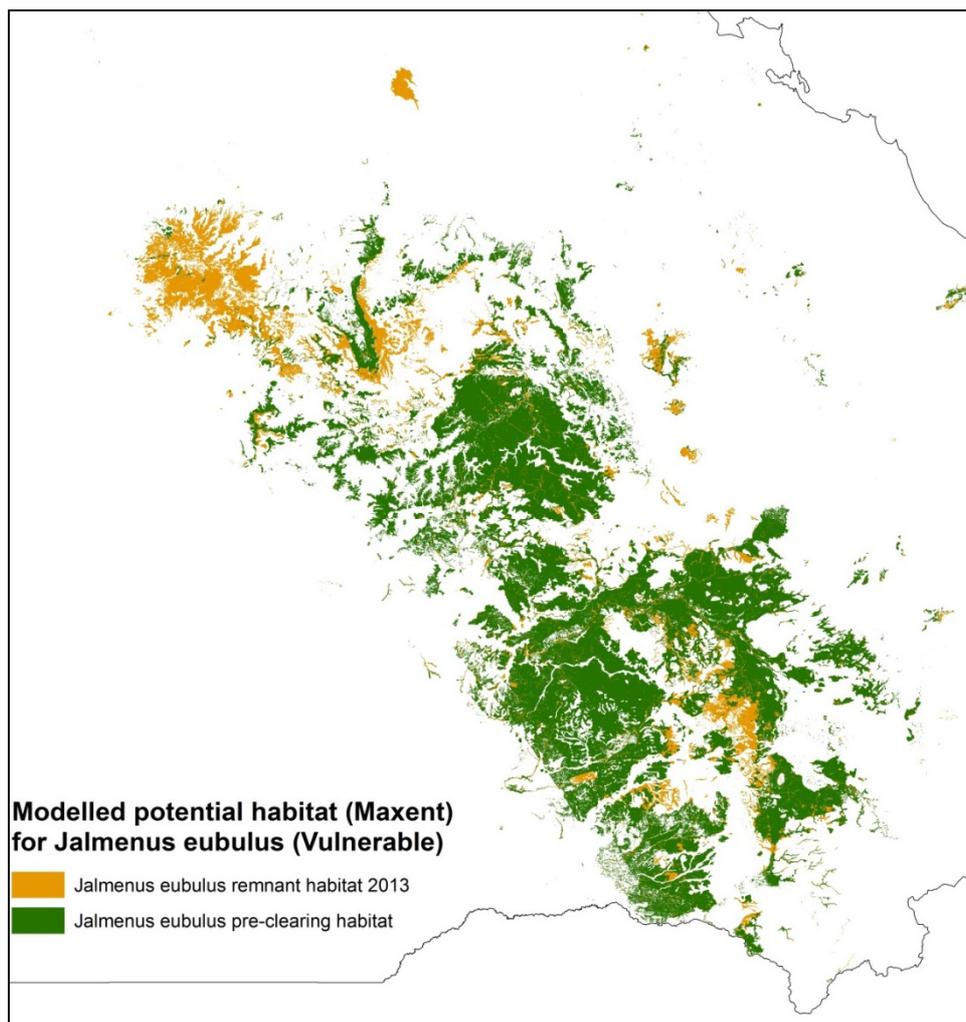
**Figure 26 Modelled potential pre-clearing and remnant 2013 habitat for Queensland for the vulnerable pale imperial hairstreak butterfly *Jalmenus eubulus* based on 46 presence records.**

Case Study Conclusions

Collectively the eight case studies illustrate the impact of a major reduction in the area and quality of habitat that historic and recent land clearing has caused. The impact affects all levels of biodiversity with examples of mammals, a bird, a reptile, a butterfly and three vascular plants.

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