Centre for Biodiversity and Conservation Science
The University of Queensland
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The Committee Secretary
State Development, Natural Resources and Agricultural Industry Development Committee
sdnraidc@parliament.qld.gov.au

22 March, 2018

Dear Committee,

**RE: Submission to the Vegetation Management and Other Legislation Amendment Bill 2018 Parliamentary Inquiry**

We are writing to you on behalf of the University of Queensland's Centre for Biodiversity and Conservation Science (CBCS), a dynamic team of multidisciplinary conservation scientists, with expertise in ecology, biogeography, decision science, mathematics, economics, spatial analysis, social science and climate modelling. The team has a worked extensively with state and federal governments to develop and refine environmental policy.

It is well established that and clearing rates in Queensland have increased dramatically over the past five years, in particular after the changes in vegetation laws under the Newman government in 2013[1].

There is a strong evidence base that land clearing causes myriad problems for Queensland's environment[1] as detailed in the attached submission (#504) originally made by a group of 28 concerned senior Queensland environmental scientists to the 2016 Parliamentary Inquiry on a related Bill, and a scientific paper authored by CBCS scientists. We would appreciate the opportunity to re-table that background material as Appendices to our current submission; please find it attached to this email.

We understand the proposed Bill would achieve the following key changes, and we provide brief comments on each:

**Removal of 'High-Value Agriculture' as an allowable purpose for broadscale clearing of remnant vegetation.**

*Comment:* This is a crucial component of the bill. Genuine high-value agricultural land has long since already been cleared in Queensland[2,3]. There is clear evidence that remaining remnant vegetation is of very high value as habitat for wildlife[1,4], including many species listed as Endangered in Queensland and threatened nationally[5], and provides myriad other services for people, such as carbon sequestration and storage, sediment retention and water quality and flow regulation[1,6].

**Changes to the Self-Assessable Codes to restrict the circumstances under which self-assessed 'thinning' and other clearing is allowed.**

*Comment*: Analysis of ground-truthed satellite imagery shows that a large proportion of vegetation clearing occurring from 2013-2016 has been done under self-assessable codes[7,8]. This makes it clear that this change is essential in reducing overall rates of land clearing. It is important that thinning is only permitted in circumstances in which the impacts of thinning on environmental values of the affected ecosystem are minimal. Ecological thinning, a process used in some very specific situations to improve vegetation condition (e.g. removal of individual stems by hand[9]), is a very different exercise to the 'thinning' that has been recently recorded to occur in Queensland under these codes, which is ecologically damaging. If thinning is allowed in future, it should only be permitted in places where it can be demonstrated that substantial vegetation thickening has occurred, and only where thickening threatens the ecological functioning and biodiversity of the Regional Ecosystem at that locality[10].

**Protections of high-conservation value regrowth older than 15 years and along streams in all GBR catchments**

*Comment*: For many extensively cleared ecosystems, the only way they can return to a non-threatened status is by allowing regrowth to mature to an age at which their condition approaches that of remnant. Therefore, older regrowth of such ecosystems needs protection to achieve this. Native vegetation, both remnant and regrowth, plays a vital role in stabilising streambanks and controlling sediment inputs to the Great Barrier Reef, thus it is important that it is protected[1]. However, it is not clear yet whether new self-assessable codes contained in the Bill will allow for additional clearing of this important habitat. We recommend amending this to clearly provide the protection of high-conservation value regrowth.

**Expansion of exemptions, and approaches to 'lock in' new exemptions, from the new regulations for high-value regrowth, but no ability to reverse existing exemptions where they allow for further destruction of threatened ecosystems and threatened species habitat**.

*Comment:* A large proportion of existing clearing is done under exemptions[7]. It is likely that a portion of the vegetation currently under exemptions are critical habitats for endangered wildlife and/or and provides myriad other services for people, such as carbon sequestration and storage, sediment retention and water quality and flow. It seems sensible that all exceptions be reviewed and assessed against their current environmental value before they are locked in (especially considering the impact of the enormous rates of land clearing that have occurred in the previous decade).

In summary, the new Bill contains provisions that appear likely to reduce the damage currently accumulating to Queensland's biodiversity, inland and coastal waterways, soils and climate. However, there remain elements that, if not carefully managed, will permit ongoing losses of critically important habitats and vegetation.

Thank you for considering our submission.

Associate Professor Martine Maron
Centre for Biodiversity & Conservation Science

**References**


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5 Black-throated Finch Recovery Team. Submission #2008 - Mio College Vegetation Clearing for High Value Agriculture, Barratta Road, Clare QLD. (Submission to the Department of the Environment and Energy, Canberra, 2017).

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29 April, 2016

**Research Director**
Agriculture and Environment Committee
Parliament House, BRISBANE QLD 4000

**To: Agriculture and Environment Committee**

**Re: Vegetation Management (Reinstatement) and Other Legislation Amendment Bill 2016**

**From: Concerned group of senior Queensland environmental scientists**

We are a group of 28 expert independent environmental scientists based at Universities and research institutions across Queensland. Collectively, our expertise covers biodiversity and ecology (land and water), land degradation, climate change, carbon accounting, remote sensing, environmental policy and resource management. Each of us has a distinguished scholarly reputation, and holds a senior position of responsibility in our organisations.

We make this submission to demonstrate the strong scientific consensus about the multiple important ecological functions of retained native vegetation, and the wide range of adverse undesirable and long-term consequences for land, water, climate and biodiversity that result from increased land clearing.

Attempts to reverse these consequences after clearing has occurred are not only expensive, but often of limited effectiveness. It is far more cost-effective to avoid land clearing in the first instance, rather than later to attempt repair of the resulting environmental damage.

The purpose of the Vegetation Management Act 1999 (henceforth "VMA") is to regulate the clearing of vegetation in order to achieve specified ecological outcomes, including: preventing loss of remnant regional ecosystems, avoiding land degradation, preventing loss of biodiversity, maintaining ecological processes, reducing greenhouse gas emissions and allowing for ecologically sustainable land use (VMA Section 3[1]). This Section of the Act also specifies application of the precautionary principle: "*lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment if there are threats of serious or irreversible environmental damage*"[1].

**We submit that increased clearing of native woody vegetation enabled by the current VMA (as amended in 2013) has outcomes that are contrary to the Act's purpose.** Re-strengthening Queensland's ability to regulate the clearing of native vegetation across all land tenures, through legal mechanisms, is a crucial component of any effective policy framework for ensuring future environmental and economic sustainability.

We support the currently proposed amendments outlined in the Bill, but note they are unlikely to address fully the recently-observed very large increases in clearing of native vegetation.

We also request an opportunity to provide evidence in person at the Committee's public hearing on this matter. If invited to attend the hearing, selected representatives will attend.

The following section provides a summary of relevant specific issues, with reference to key scientific sources.

# Specific issues related to vegetation clearing and the Queensland VMA

Below we explain the basis of our submission. The current form of the Act is referred to as "VMA 2013". Details of the scientific publications and data supporting each point are provided at the end of this submission, cross-referenced to the relevant section. These documents are available on request; most are provided at: https://drive.google.com/folderview?id=0BxprmX5WkYonTllxT01xdzd1am8&usp=sharing_eid&ts=5719739b.

**First, we consider the evidence that VMA 2013 has enabled a substantial increase in vegetation clearing.**

**Second, we outline different ecological functions of native vegetation cover**: for terrestrial biodiversity and ecosystems, streambank stability and stream quality, coastal waters and biodiversity (including the Great Barrier Reef), regional climate, atmospheric carbon and climate change. For these functions, we also outline the adverse consequences of increased vegetation loss.

**Third, we explain the significance of regrowth vegetation for various functions**, and **finally we comment on achieving sustainable land use**. We also highlight the high **costs of repairing the damage** caused by broadscale vegetation clearing.

## Evidence that the 2013 VMA amendments increased vegetation clearing

The Statewide Land and Trees Survey (SLATS) monitors change in woody vegetation extent in Queensland[2a]. The recent SLATS report[2b] for the years 2012-13 and 2013-2014 showed that, while annual rates of land clearing had steadily reduced over the decade 2000-2010, they are now increasing steeply. For example, 296,000 ha of native vegetation were cleared in 2013-14 compared with 78,000 ha in 2009-10.

This report[2b] also shows that:

- this recent clearing was of both remnant vegetation and regrowth, including mature regrowth of threatened ecosystems. The cleared remnant vegetation included all threat categories ('Least Concern', 'Of Concern' and 'Endangered'; and
- clearing was spread across the state, being particularly high in the Brigalow Belt, which is a national biodiversity hotspot.

Recent independent analysis[2c] of the Queensland government's data has shown that, between 2011-12 and 2013-14, annual clearing increased by:

- 270% for 'Least Concern' Regional Ecosystems (REs);
- 309% for 'Of Concern' REs; and
- 58% for 'Endangered' REs.

Such high clearing rates have not been seen since prior to the phasing out of broadscale clearing in 2006[2d].

Much of the native vegetation cleared after VMA 2013 was in areas mapped as potential habitat for threatened species[2e].

This evidence indicates a **failure of the VMA in its current form to meet two of its stated purposes** – conserving regional ecosystems that are "Endangered" and "Of Concern"; and preventing the loss of biodiversity.

## Ecological functions and current status of Queensland's native woody vegetation

Native woody vegetation supports the health of Queensland's environment through a diverse range of ecological functions, all of which are placed at risk by increased land clearing. Below we outline the scientific basis of, and evidence for, the need to strengthen the VMA's ability to meet its stated purposes of: ensuring that clearing does not cause land degradation; preventing the loss of biodiversity; and maintaining ecological processes.

We do this for five important ecological functions.

### *1. Terrestrial biodiversity and ecosystems*

The total extent of native vegetation in a landscape is the most important factor in determining how many species that the landscape can support[3a].

Native vegetation also contributes to species' ability to move or disperse through the landscape; without this movement threatened species in Australia are at much greater risk of extinction[3b]. Movement capacity will become even more crucial as climate change forces species to shift their ranges[3c].

Old-growth vegetation has especially high biodiversity values because regrowth vegetation after clearing lacks certain important habitat features that are essential to sustain some species (for example, tree hollows, which can take centuries to form)[3d].

Additionally, increased cover of native vegetation reduces the impact of invasive predators (such as feral cats) on threatened fauna, and is likely to be crucial in enabling native fauna to escape cat predation. This reduces the amount (and financial cost) of predator control[3e].

Queensland has a lower percentage of its land in protected areas (conservation reserves) than any other Australian State or Territory[3f]. Therefore, Queensland's vegetation outside of these reserves is especially important to biodiversity and ecosystem function. However, the Brigalow Belt and Mulga Lands bioregions, both of which have less than 5% of land in protected areas, had the greatest clearing rates in 2012-2014[3g].

### *2. Catchment erosion, water security and aquatic ecosystem health*

Riparian condition (the amount and quality of forest vegetation cover along the margins of watercourses) is the main factor that influences the water quality and ecosystem heath of Queensland's rivers[4a]. Vegetation clearing is a major cause of riparian land degradation (loss of condition), and therefore the single most important management preventive action is to protect (and restore) riparian vegetation[4b].

Recent research in several of Queensland's major coastal catchments has shown that most of the sediment entering water storages and coastal environments originated from erosion of stream banks and gullies[5b]. This erosion often accounts for more than 90% of the sediment[4c], and it has been caused mainly by degradation of riparian lands.

This degradation of riparian lands by vegetation clearing threatens water security. For example, during the 2011 flood, Brisbane came within 6 hours of running out of water when the Mt Crosby treatment plant was overwhelmed with sediment; the estimated cost of sedimentation to water storage capacity and treatment in SEQ is over $7M pa, and could increase by more than $32M pa by 2031 if not addressed[4d].

Road infrastructure and valuable farmland are at risk from riparian land degradation[4e]. For example, 477,670 tonnes of soil, with estimated value $14.3M, were eroded from a single 278 hectare farm during the 2011 Brisbane river flood[4f]; protecting and restoring riparian vegetation is essential to reduce the risk of such erosion during extreme weather events.

Several of Queensland's endangered freshwater species depend on protecting riparian vegetation[4g]. Riparian vegetation is also particularly important for terrestrial wildlife. For example, more than 50% of all the koalas in the nationally significant Mulga Lands population are found in the 1% of the vegetation that is along river and stream banks[4h].

### *3. Coastal waters and biodiversity, including the Great Barrier Reef*

Pollution of rivers with sediment and nutrients resulting from riparian degradation affects both the rivers themselves (as described in the previous section) and the coastal environments into which they flow. Therefore the amount and quality of forest vegetation cover near to watercourses is also a major factor influencing Queensland's coastal environments, including Moreton Bay and the Great Barrier Reef.

*A. Moreton Bay*

Coastal inputs from runoff when catchment vegetation has been cleared are much greater than for the same catchment if vegetation was retained: for Moreton Bay this is estimated to be 50-200 times greater for soil; 25-60 for phosphorus and 1.6-4.1 times greater for nitrogen [5a]. Sedimentation of Moreton Bay has increased since historical vegetation clearing in its catchment[5b]. During the 2011 floods, a 3- to 10-fold increase in sediment deposition into the Bay required months of costly additional dredging works[5c].

*B. Great Barrier Reef*

Maintaining and improving water quality and condition of biodiversity in the coastal waters of the Great Barrier Reef (GBR) lagoon are central to the success of the Reef 2050 Plan[5d].

Retaining sufficient native vegetation cover, especially in riparian zones and steeper topography, is crucial to limiting soil erosion (see previous section) and consequent runoff to the GBR, and evidence has shown clearly the impact of soil stability in GBR catchments on reef water quality[5e].

Deterioration of water quality in the GBR lagoon resulting from loss of catchment vegetation cover threatens a wide range of GBR ecosystems. For example, increased fine sediment loads due to catchment runoff affect seagrasses and corals by increasing turbidity and reducing light penetration[5f].

However, 38% of the clearing under VMA 2013 was done in catchments that drain to the Great Barrier Reef[5g].

Such losses risk reversing the beneficial effects of recent investments in improving reef water quality; the estimated cost of counteracting the water quality decline (based on estimates included in regional Water Quality Improvement Plans) over ten years is as high as $5-10 billion[5h].

Queensland's Auditor-General recently recommended that stronger legislation would be essential to reducing harmful catchment runoff to the Great Barrier Reef[5i].

### *4. Atmospheric carbon and climate change*

Queensland's native vegetation cover is vital to limiting Australia's greenhouse gas emissions, because retained woody vegetation can store large amounts of carbon, whereas clearing this vegetation will release the carbon into the atmosphere[6a].

Carbon emissions from land clearing in Queensland in 2013-14 were 35.8 million tonnes per year under VMA 2013: more than double the emissions rate from land clearing in 2009-10, when clearing rates were lowest (77,590 ha/year)[6b].

Note that these estimates, from Queensland's SLATS data, are more reliable than those of Australia's National Carbon Accounting System (which has produced lower emissions estimates for 2013-14)[6c].

At the average cost of $13/tonne, Emissions Reduction Fund payments required to counter just the increase in Queensland's land clearing emissions since 2009-10 would be approximately $257 million per year were the most recent rates of land clearing to continue[6d].

Retaining native vegetation provides an enormous opportunity for avoiding potential carbon emissions[6e].

### *5. Regional climate*

The loss of native vegetation from the landscape affects not only the global climate through carbon emissions, but also regional climate and drought severity. For example, the extensive clearing of native woody vegetation for crops and improved pastures in Queensland's inland regions has been shown to cause increased temperature (especially in summer) and decreased rainfall, as well as reduced soil moisture [7a].

This has important implications for agriculture and the environment under an already warming climate, because vegetation management policies that allow the further conversion of woody vegetation will exacerbate this trend and result in more severe and more frequent droughts and heatwaves.

## Roles of regrowth and restored vegetation

Older regrowth vegetation has acquired a partial range of important ecological functions and is on track to develop others over time. For restoring native vegetation, it is more cost effective to retain older regrowth than to invest in tree planting projects. Clearing of high value regrowth risks loss of biodiversity, ecological degradation, and financial waste because it then becomes necessary to invest in active restoration, as outlined below.

### *Values of regrowth to ecological functions*

Very young regrowth vegetation typically has fewer species and a simpler structure than old-growth vegetation, and therefore supports fewer species[8a]. However, within a few decades, regrowth vegetation starts to make important contributions to biodiversity and ecological processes. For example, brigalow regrowth older than about 30 years supports similar bird diversity to old-growth brigalow, and retaining regrowth also helps to increase the number of species that a landscape can support[8a].

Allowing regrowth to mature is important to biodiversity and threatened species because some old-growth habitat features, such as hollow trees, large flowering/fruiting trees, coarse woody debris, and the functions they perform, require many more decades to develop, if the regrowth is protected[8b].

Carbon stocks also accumulate over time as regrowth matures. Older, larger trees hold more carbon than young, dense regrowth. Allowing regrowth to mature is a highly efficient way to sequester carbon, especially in Queensland[8c], because carbon stocks also accumulate over time as regrowth matures

Within a few decades, regrowth vegetation can also contribute substantially to catchment protection[8d].

Category C "high value" regrowth (as used in the VMA) is now likely to be more than 30 years old, and is therefore likely to have a range of habitat values and ecological functions partly or well-developed. However, clearing will revert these values to zero, resulting in loss of present biodiversity and function, and of the important potential for further recovery (see also next section)

### *Cost of replacement through active restoration*

Australia spends millions of dollars each year on tree planting projects. For example, Caring for our Country and Biodiversity Fund grants reported just over 42,000 hectares of replanting since 2013[9a], yet nearly 300,000 ha of Queensland's native vegetation were cleared in 2013-14[2b]. The Commonwealth is currently investing A$50 million to replace 20 million trees over five years by 2020, as part of the '20 million trees' Program[9a]. However, at current rates, just one year of land clearing in Queensland removes more than 20 million trees.

And furthermore, the cost per hectare to successfully replant native vegetation is so large that only small areas can be restored, and even then the result after 2-3 decades is inferior in biodiversity and ecosystem function to intact remnant vegetation. For example, woodland replanting costs up to $20K per hectare, to partially restore vegetation structure and diversity[9b], and tropical rainforest replanting costs $20-30K (and up to $50k) per hectare with only partial success at recovering forest-like biodiversity and function after 2-3 decades[9c]. Smaller per hectare investments, using cheaper plantings of lower diversity and tree density, result in even poorer function and slower development [9d]. The cost of effectively stabilising river-banks following deforestation can range from A$16,000 to A$5 million per kilometre[9e].

Retaining already-established regrowth vegetation achieves a range of environmental benefits (see previous section), for a fraction of what it would cost to later compensate for vegetation clearing by funding tree-planting projects. Many Queensland ecosystems can readily regenerate passively through unassisted regrowth, and this capacity provides a significant opportunity to achieve the same restoration goals at a substantially reduced cost.

## Sustainable land use

A large proportion of land suitable for intensive agricultural cropland has already been cleared, and provides a basis for Australia's food production. Regulation of the clearing of native vegetation does not restrict existing agricultural productivity, but rather it seeks to make it more sustainable. Retained trees have benefits for the amelioration of many environmental risks that hamper agricultural productivity, including animal health, long-term pasture productivity and hydrological risks[10].

Recent pastoral production has suffered from drought, but land clearing cannot be an effective quick-fix drought remedy, because such a solution leads to environmental degradation in the longer term – for example, drought risks will increase with further tree clearing, as described previously[7].

Sustainable land use requires the retention of native vegetation, not its ongoing destruction.

Signed:

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## Signatories to this submission

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| 3 | **Professor Marc Hockings** | Deputy Head, School of Geography, Planning and Environmental Management; Vice-Chair (Science) IUCN World Commission on Protected Areas | The University of Queensland | Protected area management, environmental policy, conservation monitoring and evaluation |
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| 16 | **Professor Stuart Phinn** | Director, Remote Sensing Research Centre, Australian Earth Observation Community Coordination Group | The University of Queensland | Application of satellite and airborne images with field data for mapping and monitoring environmental change in terrestrial and marine environments. |
| 17 | **Professor Karen Hussey** | Deputy Director, Global Change Institute | The University of Queensland | Environmental policy and economics, specifically in relation to water resource management, energy policy, waste, climate adaptation, agriculture and international trade. |
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| 19 | **Professor Bob Pressey** | Distinguished Research Professor and Program Leader, Conservation Planning | James Cook University | Biodiversity, conservation science, conservation policy |
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## Cited information sources (these sources match the superscript numbers in the submission's text)

**1 Vegetation Management Act 1999.** Current as at 11 September 2015.< www.legislation.qld.gov.au>

**2. Supporting information re "Evidence that the 2013 VMA amendments increased vegetation clearing"**

2a. The mapping in the SLATS process is recognised as international best practice for detecting woody vegetation removal. It is highly labour intensive and has been developed over a 15 year period, using ongoing fieldwork across the state, a growing archive of satellite image and vegetation maps now produced yearly, and gradually improved methods to reduce error levels.

The SLATS mapping process is for clearing only, and does not produce a product from which regrowth extent can be inferred as its methodology does not reliably identify young regrowth as distinct from changes in foliage density except in producing its data on clearing (total foliage removal).

2b. SLATS report 2012-14:

Department of Science Information Technology Innovation and the Arts. (2015). Land Cover Change in Queensland 2012-13and 2013-14. Statewide Landcover and Trees Study (SLATS) Report. Department of Science Information Technology Innovation and the Arts, Brisbane, Australia.

This report presents details of the following information.

- From a low of less than 100,000 hectares cleared in 2009-10, 296,000 hectares of native woody vegetation were cleared in 2013-14, the most recent year for which data are available.
- These 296,000 hectares included 103,308 ha of remnant native vegetation and 27,721 hectares of high-value regrowth (mature regrowth of threatened ecosystems).
- Continued loss of mature regrowth of 'Of Concern' and 'Endangered' ecosystems has occurred, which prevents their recovery and removal from the threatened list.
- The rate of loss of 'Of Concern' remnant ecosystems has increased, further threatening the persistence of these ecosystems and preventing their recovery.
- The vegetation loss was spread across the state, with particularly high rates of clearing in the Brigalow Belt north and south bioregions, which are national biodiversity hotspots.

2c. Recent independent analysis of annual clearing (by Assoc. Prof. J. R. Rhodes) for 'Not Of Concern', 'Of Concern' and 'Endangered' Regional Ecosystems has used GIS to overlay the SLATS data on land clearing and the previously-known distribution of regional ecosystems. The results show that between 2011/12 and 2013/14 the anthropogenic clearing rate of 'Of Concern' Regional Ecosystems more than tripled (rising from 33 $km^2$ in 2011/12 to 102 $km^2$ in 2013/14) and the clearing rate of 'Endangered' Regional Ecosystems increased 58% (rising from 12 $km^2$ in 2011/12 to 19 $km^2$ in 2013/14), with clearing of 'Least Concern' Regional Ecosystems increasing 270%(rising from 310 km2 in 2011/12 to 837 km2 in 2013/14).

To perform this analysis, SLATS land clearing data and the regional ecosystem mapping version 9.0 provided by Department of Science Information Technology Innovation and the Arts were used. Raster data sets of the proportion of each VMA Class in 25m x 25m resolution cells were generated to match the resolution of the corresponding FPC data. This produced raster layers of the distribution of Least Concern, Of Concern, and Endangered vegetation communities across Queensland. Next the raster cells cleared in each year based on the SLATS woody vegetation clearing data were identified and the proportion of each cell cleared that was classified as Least Concern, Of Concern, and Endangered under the VMA was identified from the previously created raster layer. This was used to calculate the area cleared (km2) of each VMA Class (Least Concern, Of Concern and Endangered) in each year in Queensland (tree loss). To ensure only anthropogenic was considered clearing, natural disaster damage and natural tree death were excluded from these estimates.

2d. These recent clearing rates have not been seen since prior to the phasing out of broadscale clearing in 2006. There is a huge scientific literature on this subject. See for example:

Department of Science Information Technology Innovation and the Arts (2015) *Land Cover Change in Queensland 2012-13 and 2013-14. Statewide Landcover and Trees Study (SLATS) Report*.. Vegetation clearing rates in Queensland. Supplementary report. Department of Science Information Technology Innovation and the Arts, Brisbane, Australia.

2e. http://www.wwf.org.au/?15660/More-than-40000-hectares-of-koala-habitat-cleared

**3. Supporting information re "Terrestrial biodiversity and ecosystems"**

3a. The total extent of vegetation in a landscape is the most important factor in determining how many species that landscape can support. See:

Pimm, S.L., Raven, P. (2000) Biodiversity: extinction by numbers. Nature 304: 843-843

Fahrig, L., (2001) Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management 61: 603–610.

Radford, J.Q., Bennett, A.F., Cheers, G.J. (2005) Landscape-level thresholds of habitat cover for woodland-dependent birds. Biological Conservation 124: 317-337.

3b. Native vegetation also contributes to these species' ability to move or disperse through the landscape; without this movement, threatened species in Australia are at much greater risk of extinction. There is a very large literature on this subject; for example, see:

Brooker, L., Brooker, M., Cale, P. (1999) Animal dispersal in fragmented habitat: measuring habitat connectivity, corridor use, and dispersal mortality. Conservation Ecology [online] 3(1): 4. URL: http://www.consecol.org/vol3/iss1/art4/.

Soulé, M.E., Mackey, B.G., Recher, H.F., Williams, J.E., Woinarski, J.C.Z., Driscoll, D., Dennison, W., Jones, M., 2004. The role of connectivity in Australian conservation. Pacific Conservation Biology 10, 266-279.

3c. Movement capacity will become even more crucial as climate change forces species to shift their ranges. See:

Travis, J.M.J., Delgado, M., Bocedi, G., Baguette, M., Bartoń, K., Bonte, D., Boulangeat, I., Hodgson, J.A., Kubisch, A., Penteriani, V., Saastamoinen, M., Stevens, V.M., Bullock, J.M. (2013) Dispersal and species' responses to climate change. Oikos 122: 1532-1540

Reside, A.E., VanDerWal, J., Kutt, A.S. (2012) Projected changes in distributions of Australian tropical savanna birds under climate change using three dispersal scenarios. Ecology and Evolution 2:705-718

3d. Supporting evidence or ref(s) for "Old-growth vegetation has especially high biodiversity values, because regrowth vegetation after clearing lacks certain important habitat features that are essential to sustain some species features (for example tree hollows, which can take centuries to form). See:

Department of Sustainability and Environment (2003) Loss of hollow-bearing trees from Victorian native forests and woodlands Action Statement No. 192, State of Victoria

Remm J, Lohmus A (2011) Tree cavities in forests - The broad distribution pattern of a keystone structure for biodiversity. Forest Ecology and Management 262: 579–585.

3e. There is strong evidence that invasive predators such as cats are only able to have such severe effects on threatened fauna because clearing and vegetation degradation gives invasive species an advantage when hunting(Doherty et al. 2015). Retaining intact savanna vegetation gives threatened tropical mammals a chance against cats (Woinarski et al. 2015). See:

Doherty, T. S., Davis, R., van Etten, E., Algar, D., Collier, N., Dickman, C., Edwards, G., Masters, P., Palmer, R., & Robinson, S., 2015. A continental-scale analysis of feral cat diet in Australia. Journal of Biogeography, 42: 964-975

Woinarski, J.C.Z., Burbidge, A.A., Harrison, P.L., 2015. Ongoing unraveling of a continental fauna: Decline and extinction of Australian mammals since European settlement. Proceedings of the National Academy of Sciences. 112: 4531-4540 doi:10.1073/pnas.1417301112

3f. Only 8.16% of Queensland is in protected areas (CAPAD 2014 data). All jurisdictions in Australia have committed to establishing a comprehensive, adequate and representative system of protected areas (National Reserves System Task Group, 2009) that conserve the full diversity of biogeographic regions.

However, only four of the 18 biogeographic regions that occur in Queensland have greater than 15% of the area in reserves. See:

CAPAD (2014) Collaborative Australian Protected Areas Database . Department of the Environment, Canberra. http://www.environment.gov.au/land/nrs/science/capad.

National Reserve System Task Group (2009) Australia's Strategy for the National Reserve System 2009-2030. Canberra: Department of the Environment, Water, Heritage and the Arts.

3g. However, the Brigalow Belt and Mulga Lands bioregions, both of which have less than 5% of land in protected areas, had the greatest clearing rates in 2012-2014. See:

Department of Science Information Technology Innovation and the Arts (2015) *Land Cover Change in Queensland 2012-13 and 2013-14. Statewide Landcover and Trees Study (SLATS) Report*. Department of Science Information Technology Innovation and the Arts, Brisbane, Australia.

**4. Supporting information re "Catchment erosion, water security and aquatic ecosystem health"**

4a. River health in Queensland (measured in terms of water quality, biodiversity and ecosystem processes) is primarily influenced by riparian condition (i.e. the extent and quality of forest vegetation cover along the margins of watercourses), especially in rural lands. See information in:

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

Peterson, E.E., Sheldon, F., Darnell, R., Bunn, S.E. and Harch, B.D. (2011). A comparison of spatially explicit landscape representation methods and their relationship to seasonal stream conditions. Freshwater Biology 56, 590-610.

Sheldon, F., Peterson, E.E., Boone, E.L., Sippel, S., Bunn, S.E. and Harch, B.D. (2012). Identifying the spatial scale of land-use that most strongly influences overall river ecosystem health score. Ecological Applications 22, 2188–2203.

4b. protection and, where necessary, targeted rehabilitation of riparian vegetation is the single most important management action to address the threat of degradation resulting from poor riparian land management. See information in:

Allan, J.D.(2004).Landscape and riverscapes:the influence of land use on river ecosystems. Annual Review of Ecology, Evolution and Systematics 35, 257–284.

Lovett, S. & Price, P. (eds.) (2007). Principles for riparian lands management. Land and Water Australia, Canberra.

4c. Studies conducted in several catchments along the Queensland coast have confirmed that most (often exceeding 90%) of the sediment entering water storages and coastal environments comes from channel erosion (i.e. stream banks and gullies). See information in:

Caitcheon, G., Olley, J., Pantus, F., Hancock, G., and Leslie, C., (2012). The dominant erosion processes supplying fine sediment to three major rivers in tropical Australia, the Daly (NT), Mitchell (Qld) and Flinders (Qld) Rivers. Geomorphology 151, 188-195.

Olley, J.M., Brooks, A., Spencer, J.S., Pietsch, T., Borombovits, D.K., (2013a). Subsoil erosion dominates the supply of fine sediment to rivers draining into Princess Charlotte Bay, Australia. Journal of Environmental Radioactivity 124, 121-129.

Olley, J.M., Burton, J., Smolders, K., Pantus, F., Pietsch, T. (2013b) The application of fallout radionuclides to determine the dominant erosion process in water supply catchments of subtropical South-East Queensland, Australia. Hydrological Processes 27, 885-895.

Burton, J., Furuich,i T., Lewis, S., Olley, J., Wilkinson, S. (2014). Identifying Erosion Processes and Sources in the Burdekin Dry Tropics Catchment - Synthesis Report. Department of Science, Information Technology and Innovation, Brisbane.

4d. In the 2011 flood, Brisbane was within 6 hours of running out of water because the Mt Crosby treatment plant was overwhelmed with sediment. The loss of water storage capacity in SEQ from sedimentation and sediment removal at the treatment plant is estimated to cost over $7M pa, and water treatment costs could increase by in excess of $32M pa by 2031 if this is not addressed. See:

Marsden Jacob Associates (2011). The future of our bay. Report to Queensland Department of Environment and Resource Management.

4e. Road infrastructure and valuable farmland are at risk from riparian land degradation. See:

Thornton, C.M., Cowie, B.A., Freebairn, D.M. Playford, C.L. (2007) The Brigalow Catchment Study: II. Clearing brigalow (*Acacia harpophylla*) for cropping or pasture increases runoff. Australian Journal of Soil Research 45: 496-511.

4f. LiDAR analysis of a 278 hectare farm area in Tenthill by SEQ Catchments after the 2013 flood showed that 477,670 tonnes of soil were lost. Using a replacement cost of $30 per tonne, this was estimated as a loss of $14.3M of productive soil from a single event. Unpublished data. SEQ Catchments.

4g. Protection and rehabilitation of riparian lands is recognized as a key management action to reduce the threats to several endangered freshwater species in Queensland. For example:

http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=83806

4h. More than 50% of all the koalas in the nationally significant Mulga Lands population are found in the 1% of the vegetation that is along river and stream banks. See:

Sullivan, B.J., Baxter, G.S., Lisle, A.T., Pahl, L. & Norris, W.M. (2004) Low-density koala (*Phascolarctos cinereus*) populations in the mulgalands of south-west Queensland. IV. Abundance and conservation status. Wildlife Research, 31, 19-29.

**5. Supporting information re "Coastal waters and biodiversity, including the Great Barrier Reef"**

5a. Modelling of water quality data from Moreton Bay catchments has shown that the sediment yield per unit area from a catchment containing no remnant riparian vegetation is predicted to be between 50 and 200 times that of a fully vegetated channel network; total phosphorus between 25 and 60 times; total nitrogen between 1.6 and 4.1 times. See:

Olley, J., Burton, J., Hermoso, V., Smolders, K., McMahon, J., Thomson, B., Watkinson, A., (2015) Remnant riparian vegetation, sediment and nutrient loads, and river rehabilitation in subtropical Australia, Hydrological Processes 29, 2290-2300.

5b. The infilling of Moreton Bay with sediment has been greatly accelerated by historical clearing of catchment vegetation. See:

Coates-Marnane, J., Olley, J., Burton, J., Sharma, A. (submitted). Catchment clearing accelerates the infilling of a shallow sub-tropical bay in east coast Australia. Estuarine, Coastal and Shelf Science. Draft available to Committee on request.

5c. In an average year, 100,000-300,000 $m^3$ of sediment is dredged from the Port of Brisbane and Moreton Bay to ensure navigable shipping channels. However, the floods in January 2011 deposited more than 1 million m3 of additional material into the channels and berths, which added several extra months of work to the dredging schedule. See:

Marsden Jacob Associates (2011). The future of our bay. Report to Queensland Department of Environment and Resource Management.

5d. Reef 2050 Plan:

Commonwealth of Australia (2015) Reef 2050 Long-Term Sustainability Plan http://www.environment.gov.au/marine/gbr/publications/reef-2050-long-term-sustainability-plan.

5e. Evidence has shown clearly the impact of soil stability in GBR catchments on reef water quality; see:

Waters, D.K., Carroll C., Ellis, R., Hateley L., McCloskey J., Packett R., Dougall C., Fentie B. (2014) Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR, Technical Report, Volume 1, Queensland Department of Natural Resources and Mines, Toowoomba, QLD

5f. Fine sediment loads entering the lagoon cause extra turbidity and reduced light, which affect seagrasses and corals.

Fabricius, K.E., Logan, M., Weeks, S., Brodie, J. (2014) The effects of river run-off on water clarity across the central Great Barrier Reef. Marine Pollution Bulletin 84: 191-200

Fabricius, K.E., Logan, M., Weeks, S.J., Lewis, S.E., Brodie, J. (2016) Changes in water clarity in response to river discharges on the Great Barrier Reef continental shelf: 2002–2013. Estuarine, Coastal and Shelf Science http://dx.doi.org/10.1016/j.ecss.2016.03.001.

5g. Data from SLATS report to show that 38% of the clearing under VMA 2013 was done in catchments that drain to the Great Barrier Reef. See:

Department of Science Information Technology Innovation and the Arts (2015) *Land Cover Change in Queensland 2012-13 and 2013-14. Statewide Landcover and Trees Study (SLATS) Report*. Department of Science Information Technology Innovation and the Arts, Brisbane, Australia.

5h. The estimated cost of investment to counteract declining GBR health is about $5-10 billion to fully solve GBR water quality issues, based on costs included in recent Water Quality Improvement Plans, available at https://www.ehp.qld.gov.au/water/policy/water_quality_improvement_plans.html

Brodie J., Pearson, R. In review. Management of ecosystem health of the Great Barrier Reef, Australia: Time for reprioritisation and action on the basis of triage. Estuarine, Coastal and Shelf Science

5i. Queensland's Auditor-General reported in 2015 that stronger legislation would be essential to reducing harmful catchment runoff to the Great Barrier Reef; see:

Queensland Audit Office (2015) Managing water quality in Great Barrier Reef catchments Report 20: 2014–15.

**6. Supporting information re "Atmospheric carbon and climate change"**

6a. See information in:

Johnson, I. and Coburn, R. 2010. Trees for carbon sequestration. Climate in Primary Industries, Government of New South Wales.

Butler, D.W. and Halford, J. (2015) Opportunitites for greenhouse benefits from land use change in Queensland. Department of Science, Information Technology and Innovation, Queensland Government.

6b. Land clearing was the lowest in 2009-10 (78,378 ha/year) since the SLATS program began recording clearing. In 2013-14 the annual clearing rate was 296,324 ha/year. See:

Department of Science Information Technology Innovation and the Arts (2015) *Land Cover Change in Queensland 2012-13 and 2013-14. Statewide Landcover and Trees Study (SLATS) Report*. Department of Science Information Technology Innovation and the Arts, Brisbane, Australia.

6c. Estimates from Queensland's SLATS data are more reliable than those of Australia's National Accounting System (NCAS), which has produced lower emissions estimates for 2013-14. The SLATS and NCAS used different methods of estimation. SLATS methods are more reliable (and considered world's best practice – see also supporting information under (2a) above), because they incorporate background year-to-year fluctuations in satellite-sensed measurements due to changes in foliage density associated with environmental factors unrelated to land clearing or regrowth, such as the effects of wet vs dry years. Changes in foliage density have negligible influence on carbon storage, because most carbon is stored in wood (stems and branches). See information in:

Department of Science Information Technology Innovation and the Arts (2015) *Land Cover Change in Queensland 2012-13 and 2013-14. Statewide Landcover and Trees Study (SLATS) Report*. Department of Science Information Technology Innovation and the Arts, Brisbane, Australia.

Commonwealth of Australia (2016) Quarterly Update of Australia's National Greenhouse Gas Inventory: September 2015. http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/quarterly-update-australias-national-greenhouse-gas-inventory-sep-2015

6d. http://www.cleanenergyregulator.gov.au/ERF/Auctions-results

6e. By 2050, potential carbon abatement through avoided deforestation and regrowth in Australia is estimated to be in the range of 4-50 Mt $CO_2e$/year, and 7-10 Mt $CO_2e$/year; see:

Battaglia, M. (2011) Greenhouse gas mitigation: sources and links in agriculture and forestry. In H. Cleugh, M. Stafford-Smith, M. Battaglia, P Graham (eds) Climate Change: Science and Solutions for Australia. CSIRO Publishing, Collingwood, Australia pp.97-108.

**7. Supporting information re "Regional climate"**

7a. Reduced native vegetation cover in eastern Australia has been shown to increase temperatures and decrease rainfall. The extensive clearing of native woody vegetation for crops and improved pastures in the inland regions of Queensland has resulted in a warming, most prominent in summer, of between 0.5 and 2.0°C. Also, modelling shows that soil moisture is reduced by 5-30% because of a reduction in convective rainfall and cloud cover. See:

McAlpine C.A., Syktus J.I., Ryan, J.G., Deo R.C., McKeon, G.M., McGowan H.A. & Phinn S.R. (2009) A continent under stress: interactions, feedbacks and risks associated with impact of modified land cover on Australia's climate. Global Change Biology. 15: 2206–2223.

Syktus J.I. and McAlpine C.A. More than carbon sequestration: Biophysical climate benefits of restored semi-arid woodlands. Nature Scientific Reports. – under review [Confidential copy of submitted draft available to Committee on request].

**8. Supporting information re "Values of regrowth to ecological functions"**

8a. See information in:

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

Bruton, M.J., McAlpine, C.A., Maron, M. (2013). Regrowth woodlands are valuable habitat for reptile communities. *Biological Conservation* 165, 95-103.

8b. See information in:

Vesk, P.A., Nolan, R., Thomson, J.R., Dorrough, J.W., Mac Nally, R., 2008. Time lags in provision of habitat resources through revegetation. *Biological Conservation* 141, 174-186.

Shoo, L.P., Freebody, K., Kanowski, J. and Catterall, C.P. (2016) Slow recovery of tropical old field rainforest regrowth and the value and limitations of active restoration. *Conservation Biology* 30: 121–132.

8c. See information in:

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.

Evans, M.C., Carwardine, J., Fensham, R.J., Butler, D.W., Wilson, K.A., Possingham, H.P., Martin, T.G. (2015). Carbon farming via assisted natural regeneration as a cost-effective mechanism for restoring biodiversity in agricultural landscapes. Environmental science & policy 50, 114-129.

Bryan, B.A., Runting, R.K., Capon, T., Perring, M.P., Cunningham, S.C., Kragt, M.E., Nolan, M., Law, E.A., Renwick, A.R., Eber, S., Christian, R., Wilson, K.A. (2016). Designer policy for carbon and biodiversity co-benefits under global change. Nature Clim. Change 6, 301-305.

8d. See information in:

Lovett, S. & Price, P. (eds.) (2007). *Principles For Riparian Lands Management*. Land and Water Australia, Canberra.

**9. Supporting information re "Cost of replacement through active restoration"**

9a. The Commonwealth is investing A$50 million to replace 20 million trees over five years by 2020, as part of the '20 million trees' program. However, just one year of increased land clearing in Qld removes more than 20 million trees. Caring for our Country and Biodiversity Fund grants reported just over 42,000 hectares of replanting since 2013; see:

Australian Government (2016) 20 Million Trees. http://www.nrm.gov.au/national/20-million-trees.

Australian Government (2016) Field capture https://fieldcapture.ala.org.au/home/projectExplorer. [This website shows that in Queensland the Green Army program has revegetated 93.75 ha of land and planted up to 55,000 plants.]

9b. In woodland ecosystems, tree planting for ecosystem restoration costs can cost as much as A$20,000 per hectare, and still result in ecosystems inferior to intact native vegetation[9b]; see:

Schirmer, J. and Field, J. (2000) *The Cost of Revegetation*. Final report. ANU Forestry and Greening Australia.

Munro, N., Fischer, J., Wood, J. and Lindemayer, D.B. (2009) Revegetation in agricultural areas: the development of structural complexity and floristic diversity. *Ecological Applications* 19: 1197-1210.

9c. In the Wet Tropics, active "biodiversity plantings" of plant communities during Natural Heritage Trust projects (1997-2003) required $20- $30K/ha on average, with ecological outcomes after two decades that were significantly inferior to intact remnant vegetation in many of the measured properties; see:

Catterall, C.P. and Harrison, D.A. 2006. *Rainforest Restoration Activities in Australia's Tropics and Subtropics*. Rainforest CRC, Cairns. Online via: http://www.jcu.edu.au/rainforest/reports.htm.

Catterall, C.P., Freeman, A.N.D, Kanowski, J. and Freebody, K. (2012) Can active restoration of tropical rainforest rescue biodiversity? a case with bird community indicators. *Biological Conservation* 146: 53–61.

Shoo, L.P., Freebody, K., Kanowski, J. and Catterall, C.P. (2016) Slow recovery of tropical old field rainforest regrowth and the value and limitations of active restoration. *Conservation Biology* 30: 121–132.

9d. Smaller per hectare investments, using cheaper plantings of lower diversity and tree density, result in poorer function and slower development; see:

Catterall, C.P., Kanowski, J. and Wardell-Johnson, G.W. 2008. Biodiversity and new forests: interacting processes, prospects and pitfalls of rainforest restoration. Pp 510-525 in: Stork, N. and Turton, S. (eds.) *Living in a Dynamic Tropical Forest Landscape*. Wiley-Blackwell, Oxford.

9e. Bartley, R., Henderson, A. Wilkinson, S., Whitten, S and Rutherfurd, I. (2015) Stream Bank Management in the Great Barrier Reef Catchments: A Handbook. Report to the Department of Environment. CSIRO Land and Water, Australia.

**10. Supporting information re "Sustainable land use"**

See information in:

Mitchell, C.D., Harper, R.J., Keenan, R.J., 2012. Current status and future prospects for carbon forestry in Australia. *Australian Forestry* 75, 200-212.

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**Review**

# Ecological consequences of land clearing and policy reform in Queensland

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**Abstract.** Land clearing threatens biodiversity, impairs the functioning of terrestrial, freshwater, and marine ecosys tems, and is a key contributor to human induced climate change. The rates of land clearing in the State of Queensland, Australia, are at globally significant levels, and have been the subject of intense and polarised political debate. In 2016, a legislative bill that aimed to restore stronger controls over land clearing failed to pass in the Queensland Parliament, despite the clear scientific basis for policy reform. Here, we provide a short history of the recent policy debate over land clearing in Queensland, in the context of its global and national ecological significance. Land clearing affects regional climates, leading to hotter, drier climates that will impact on the Queensland economy and local communities. Loss of habitat from land clearing is a key threatening process for many endangered animals and plants. Runoff from land clearing results in sediment and nutrient enrichment, which threatens the health of the Great Barrier Reef. Australia has made national and international commitments to conserve biodiversity and reduce our greenhouse gas emissions, but current land clearing policies are not consistent with these commitments. Stronger regulation is needed to reduce vegetation loss, such as target based regulation, which sets a cap on land clearing and could effectively halt vegetation loss over the long term. Lasting policy reform is required, and we recommend an effective policy mix that restricts clearing, provides economic opportunities for vegetation retention, and informs the Australian community about the value of native vegetation.

**Additional keywords:** agriculture, Australia, Brigalow Belt, Cape York Peninsula, deforestation, Great Barrier Reef, habitat loss, land use change, threatened species, woodlands

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## Introduction

Land use change poses the single greatest threat to species and ecosystems worldwide due to the resulting habitat loss, frag mentation, and degradation (Vié *et al.* 2009). In Oceania habitat loss is a key threat for over 80% of threatened species (Kingsford *et al.* 2009). Australia has one of the highest rates of land clearing in the world, having cleared 5 896 300 ha of tree cover between 2000 and 2012 (Hansen *et al.* 2013). Over 40% of Australia's forests and woodlands have been cleared since European colonisation, and much of the remainder is degraded and fragmented (Bradshaw 2012). Widespread land clearing across Victoria, New South Wales and South Australia had already occurred by the early 20th century, with clearing in some states ceasing when little was left to clear (Evans 2016). Over 43% (19 million ha) of south west Western Australia has been deforested, with little of the remaining in protected areas (Wardell Johnson *et al.* 2016). Queensland has become the contemporary land clearing hotspot, contributing 50 65% of Australia's total loss of native forest over each of the last four decades, dwarfing other states (Evans 2016). Eastern Australia is projected to continue to be a global land clearing hotspot over 2010 30, due to changes to regulations in both Queensland and New South Wales (Taylor 2015). Queensland's land clearing has ramifications for local terrestrial, freshwater, and marine ecosystems, including the World Heritage listed Great Barrier Reef and intact wilderness areas of Cape York Peninsula, and for regional and global climate. The sheer scale of Queensland's land clearing is undermining investments made by the Australian and Queensland Governments in conservation of biodiversity and the Great Barrier Reef, and in greenhouse gas emission reductions (Table S1 available as supplementary material to this paper).

Recent policy changes around native vegetation in Queensland have been the subject of intensive political debate (Evans 2016; Reside *et al.* 2016). The public face of this debate has been characterised by two broad groups: those who oppose restrictions on native vegetation clearing, including many in the agricultural sector and the conservative Liberal National party, versus those who support clearing controls, including environmental groups, ecological scientists, and the Labor Party. In August 2016, a bill that aimed to restore regulations on native vegetation clearing under the *Vegetation Management Act 1999* (VMA) (Table 1) failed to pass the Queensland Parliament by one vote, after the Labor State Government failed to secure cross bench support of the bill. In the absence of strong regulations on vegetation clearing, the rate of woody vegetation loss in Queensland is now over 295 000 ha year$^{-1}$, the highest since 2005 06.

Land clearing controls, including legislation, codes of practice under legislation, and enforcement of the laws, were all substantially weakened by the previous State Government from 2012 to 2014. Yet, the original purpose of the VMA was purportedly retained: to regulate clearing such that it conserves 'remnant' (intact or mature) forest or woodland, prevent land degradation and biodiversity loss, maintain ecological processes, and reduce greenhouse gas emissions. However, in reality, the dilution of the land clearing controls has led to a rapid increase in land clearing (Fig. 1), resulting in a backwards trajectory for each of the intended outcomes of the VMA.

It remains unclear how and when Queensland may again increase regulatory controls on land clearing. Although the ensuing political debate over this issue was highly polarised (Reside *et al.* 2016), the scientific basis for controlling land clearing remains sound. Greater regulation of land clearing in Queensland was endorsed by a public declaration highlighting concerns over the rapid loss of forest and woodland in Australia signed by over 400 scientists and four scientific societies (SCB Oceania 2016). The scientific basis for concern around native vegetation loss in Australia is wide ranging, covering impacts relating to terrestrial, freshwater and marine ecosystems, threatened species, soil health and salinity, on farm productivity, and regional and global climate. There are policy implications for all of these issues, which subsequently impact on multiple stakeholder groups (including agricultural, tourism, recreational and residential). The sheer complexity of this issue and the ongoing debate creates a need for a clear synthesis of the ecological impacts of land clearing, and policy options for reducing ongoing vegetation loss. In this paper we: (1) outline the policy background of land clearing in Queensland; (2) provide an overview of the history of land clearing in Queensland; and (3) review the impacts on climate, species and ecosystems in terrestrial, freshwater and marine realms. We conclude by outlining recommendations for policy reform.

## Policy background

The VMA regulates clearing of vegetation[1] in Queensland on freehold and leasehold land. Prior to the amendments to the VMA in 2004, land clearing in Queensland occurred at a rate of over 400 000 ha year$^{-1}$ (Fig. 1). These amendments instituted a ban on broad scale clearing of remnant vegetation, which took effect in 2006. Later amendments in 2009 extended regulation of clearing to 'high value' (i.e. advanced age) regrowth forests (Evans 2016). At this time, legislative protection for native vegetation in Queensland was among the strongest in the world. The Liberal National party came to power in Queensland in 2012, and passed The *Vegetation Management Framework Amendment Act 2013* (Queensland Government 2013). The 2013 amendments included provisions that:

- removed restrictions on clearing of high value regrowth vegetation on freehold and indigenous land;
- introduced codes to allow landholders to self assess clearing activities such as fodder harvesting and vegetation 'thinning'; and
- reversed the 2006 ban by allowing clearing of remnant vegetation for 'high value' agriculture (i.e. crops and irrigated pastures).

Elected in 2015, the minority Labor Queensland Government introduced a legislative amendment bill to reverse most of these 2013 amendments to the VMA (Table 1), which failed to pass in August 2016. It remains unclear when the Queensland Government may again attempt to restore legislative controls on land clearing.

## Land clearing overview

Changes to land clearing rates are closely aligned with changes to governments, and subsequent changes to policy and legislation (Fig. 1). Over the period of tightened regulation, woody vegetation clearing rates dropped from 715 481 ha year$^{-1}$ to 83 749 ha year$^{-1}$ (DSITI 2016). However, clearing rates increased to 295 556 ha year$^{-1}$ (~1.5 times the size of Brisbane Local Government Area) after compliance investigations and penalties were suspended in 2013 (DSITI 2016).

Over 92% of woody vegetation cleared since 1999 has been to create or retain pasture (Table S2). Around 37% of land cleared since 2012 occurred in the Great Barrier Reef catchment area (Fig. 2) (DSITI 2016), mostly in the Brigalow Belt bioregion (44% of the State's total clearing) (IBRA 2012), followed by the Mulga Lands (22%) (Fig. 3). The rate of woody vegetation clearing for settlement (i.e. imminent urban development) roughly doubled in the post 2013 period (DSITI 2016). While a substantially smaller area than that cleared for pasture, clearing in urban areas has implications for many threatened species, including the 97 threatened species occurring in Brisbane, and threatened species occurring in 17 other cities across Queensland (Ives *et al.* 2016).

Clearing of remnant woody vegetation has nearly doubled since 2012, from 58 000 ha year$^{-1}$ to 114 000 ha year$^{-1}$ (Fig. 1), and over one third of clearing now occurs in remnant woodland

[1]Under the *Vegetation Management Act 1999*, 'vegetation' is a native tree or plant other than the following: (a) grass or non-woody herbage; (b) a plant within a grassland Regional Ecosystem prescribed under a regulation; (c) a mangrove.

**Table 1. Key reforms in the *Vegetation Management (Reinstatement) and Other Legislation Amendment Bill 2016* (Reinstatement Bill) put to the Queensland Parliament on 18 March 2016**

The bill: https://www.legislation.qld.gov.au/Bills/55PDF/2016/B16 0035 Vegetation Management (Reinstatement) and Other Legislation Amendment Bill 2016.pdf. Explanatory notes: https://www.legislation.qld.gov.au/Bills/55PDF/2016/B16 0035 Vegetation Management (Reinstatement) and Other Legislation Amendment Bill 2016E.pdf

| Acts | Key Reforms |
|---|---|
| *Amendment of the Vegetation Management Act 1999* (VMA) | • Reinstatement of the protection of high-value regrowth on freehold and indigenous land (Category C). |
| | • Removal of the provisions that permit vegetation clearing for high-value agriculture and irrigated high-value agriculture. |
| | • Broadening the protection of regrowth vegetation watercourse areas (Category R) to mean within 50 m of a watercourse or drainage feature located in the Great Barrier Reef catchments (Burnett Mary, Eastern Cape York, Fitzroy). |
| | • Reverse the onus of proof for vegetation clearing offences: '… contravention of a vegetation clearing provision is taken to have been done by an occupier of land in absence of evidence to the contrary'. |
| | • The amendments to have retrospective effect (from 17 March 2016 when the Bill was introduced) to prevent panic clearing of areas proposed for reregulation. |
| *Sustainable Planning Act 2009* | Operational works and material change of use development applications must be for a relevant clearing purpose under section 22A of the VMA. |
| *Amendment of the Water Act 2000* | Requirement for a riverine protection permit for the destruction of vegetation in a watercourse. |
| *Amendment of the Environmental Offsets Act 2014* | • Removal of 'significant' in defining 'purpose and achievement', 'offset condition' and 'residual impact', so that offsets are required for any residual impact. |
| | • Provide ability to legally secure offset areas. |

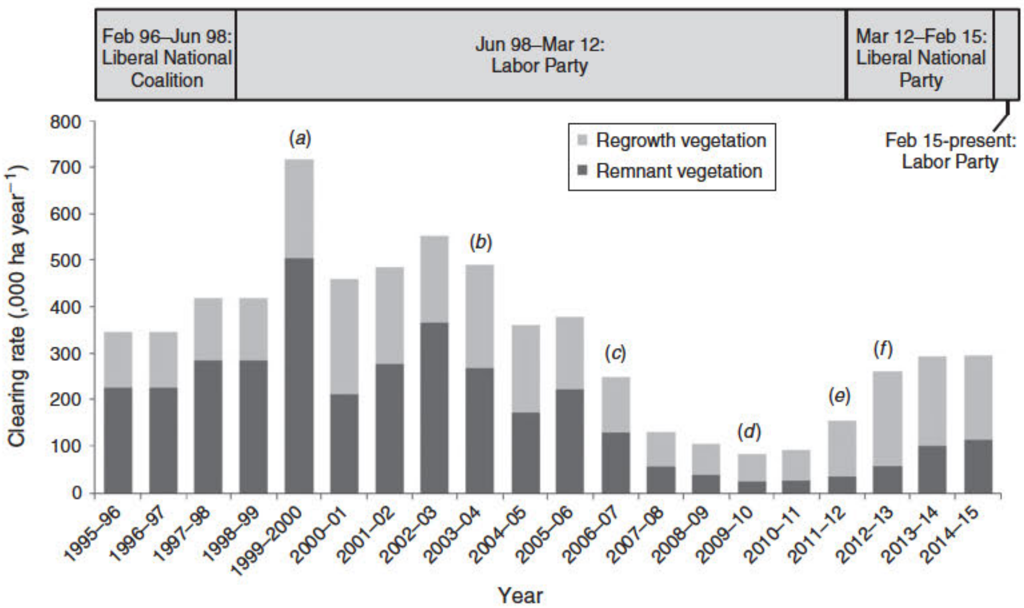


**Fig. 1.** Annual rate of clearing of regrowth and remnant woody vegetation in Queensland with corresponding political and legislative changes. (*a*) The *Vegetation Management Act 1999* (VMA) entered into force September 2000 to regulate clearing of all vegetation on freehold land in Queensland. This initially produced a spike in clearing rates due to panic clearing (McGrath 2007). (*b*) May 2004: VMA was extended to leasehold land; later that year, broad-scale clearing was capped (Kehoe 2009). (*c*) December 2004: VMA amended to effectively end broad-scale clearing of remnant vegetation for agricultural purposes and financial compensation was offered to affected landholders, to come into effect in 2006. (*d*) October 2009: VMA amended to regulate clearing of high-value regrowth vegetation. (*e*) April 2012: Review ordered into the enforcement of the VMA; all investigations into non-compliance suspended. (*f*) May 2013: the *Vegetation Management Framework Amendment Act 2013* was passed by Parliament. Graph adapted from DSITI (2016) and State of Queensland (2015).

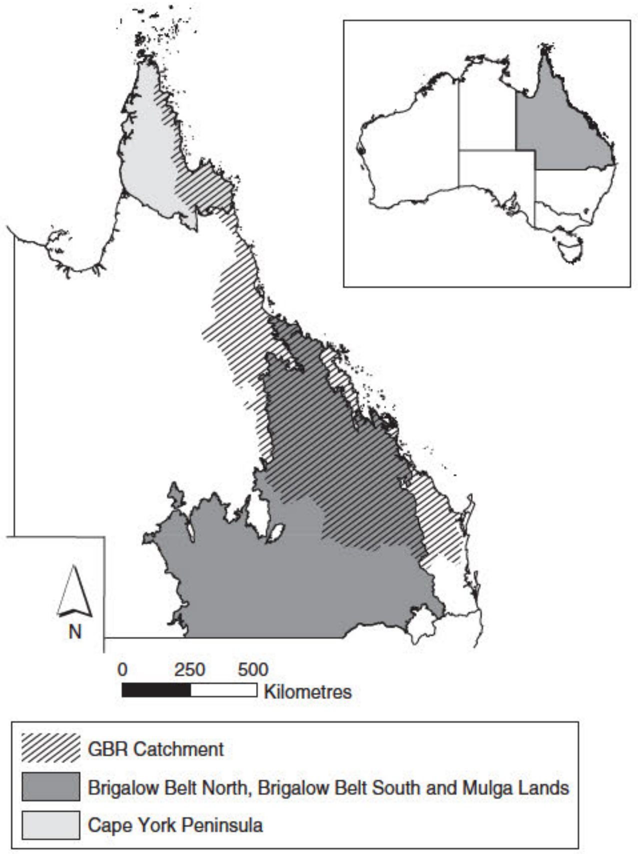


**Fig. 2.** Important regions of Queensland impacted by land clearing: Cape York Peninsula bioregion (far north) (Environment Australia 2000), which consists of intact wilderness at threat of broad-scale clearing (light grey); the Brigalow Belt bioregions (North and South) and the Mulga Lands bioregion, which have had the highest rate of broad-scale clearing and contain threatened species impacted by land clearing (dark grey), and the Great Barrier Reef (GBR) Catchments (hashed area). Data were provided by the State of Queensland (Department of Science, Information Technology and Innovation) 2016. GBR Catchment data were provided by State of Queensland (Department of Natural Resources and Mines) 2016. Updated data are available at http://qldspatial.information.qld.gov.au/catalogue//.

and forest (DSITI 2016). There are many circumstances under which landholders may clear vegetation without a permit, guided by self assessable codes (Queensland Government 2014*a*). These include managing woody plant encroachment in grasslands, knocking down mulga (*Acacia aneura*) and eight other tree species to feed livestock on foliage ('fodder harvest'), forestry, operational efficiency of agriculture and vegetation 'thinning' (reduction in woody vegetation density). These self assessable codes require only a notification to clear, and leave room for considerable interpretation over the definition and extent of thinning. Since the failure of the *Vegetation Manage ment (Reinstatement) and Other Legislation Amendment Bill 2016* in August 2016, 273 000 ha of remnant or high value regrowth, including eight nationally threatened ecological com munities, have been notified for clearing under the self assess able codes (Queensland Government 2017). Many of these notifications are in threatened species habitat (WWF 2017). Landholders may also obtain development approval to clear for high value agriculture, which includes crops and irrigated pastures (DSITI 2016).

## Impacts of land clearing

### *Regional and global climate*

Broad scale clearing modulates regional climate by altering fluxes of energy and water vapour, specifically via reduced evapotranspiration and altered albedo effects (Deo 2011; Alkama and Cescatti 2016). Forests have an evaporative cooling effect on the landscape that promotes moisture cycling, cloud formation, and convective precipitation (Syktus and McAlpine 2016). Trees absorb solar radiation while deforested areas reflect more of the radiation back into the atmosphere (Berbet and Costa 2003). This reflected radiation decreases latent heat on the ground surface which reduces water vapour and cools the atmosphere, resulting in less cloud formation and precipitation (Berbet and Costa 2003). Thus, deforested landscapes generate warmer, drier weather at local and regional scales, as seen across the area delimited by the 750 km rabbit fence of Western Australia (Ray *et al.* 2003). Land clearing on the western side of the fence has likely contributed to the ongoing reduction in rainfall in south west Western Australia (Pitman *et al.* 2004).

These changes to the regional climate are likely to be exacerbated by global climate change, which is partly fuelled by carbon emissions released from vegetation and soils upon clearing. An estimated 35.8 million tonnes of carbon dioxide were released by land clearing in Queensland during 2013/14 alone approximately one quarter of the State's annual green house gas emissions (State of Queensland 2015; Common wealth of Australia 2016). The agricultural sector is expected to be especially vulnerable to climate change due to an antici pated increase in the frequency of especially hot years and longer, more frequent droughts (Hennessy *et al.* 2008). Land management by the way of avoided loss of vegetation is an effective strategy to both mitigate climate change and adapt to it (Eady *et al.* 2009; Martin and Watson 2016).

### *Threatened species and ecosystems*

Maintaining substantial areas of native vegetation is essential for the persistence of terrestrial biodiversity (Pimm and Raven 2000; Radford *et al.* 2005), yet large intact ecosystems are increasingly rare (Watson *et al.* 2016). Extensive tracts of vegetation are important for facilitating species dispersal (Soulé *et al.* 2004), and for species that must track resources that shift seasonally or interannually, such as the honeyeaters and granivores of Queensland's woodlands (Woinarski *et al.* 1992). Retaining intact ecosystems is the best climate change adaptation strategy in many cases (Martin and Watson 2016); for example, retaining extensive tracts of vegetation is the best option for enabling species to adjust their ranges to track their suitable habitat (Travis *et al.* 2013). The loss and fragmentation of habitat resulting from land clearing interacts with other threats such as invasive species, pathogens and altered fire regimes (Doherty *et al.* 2015). The interactions between these threats can be synergistic, with amplifying feedbacks that greatly accelerate species declines (Brook *et al.* 2008). For example, loss of native vegetation increases the impact of invasive predators such as cats and foxes

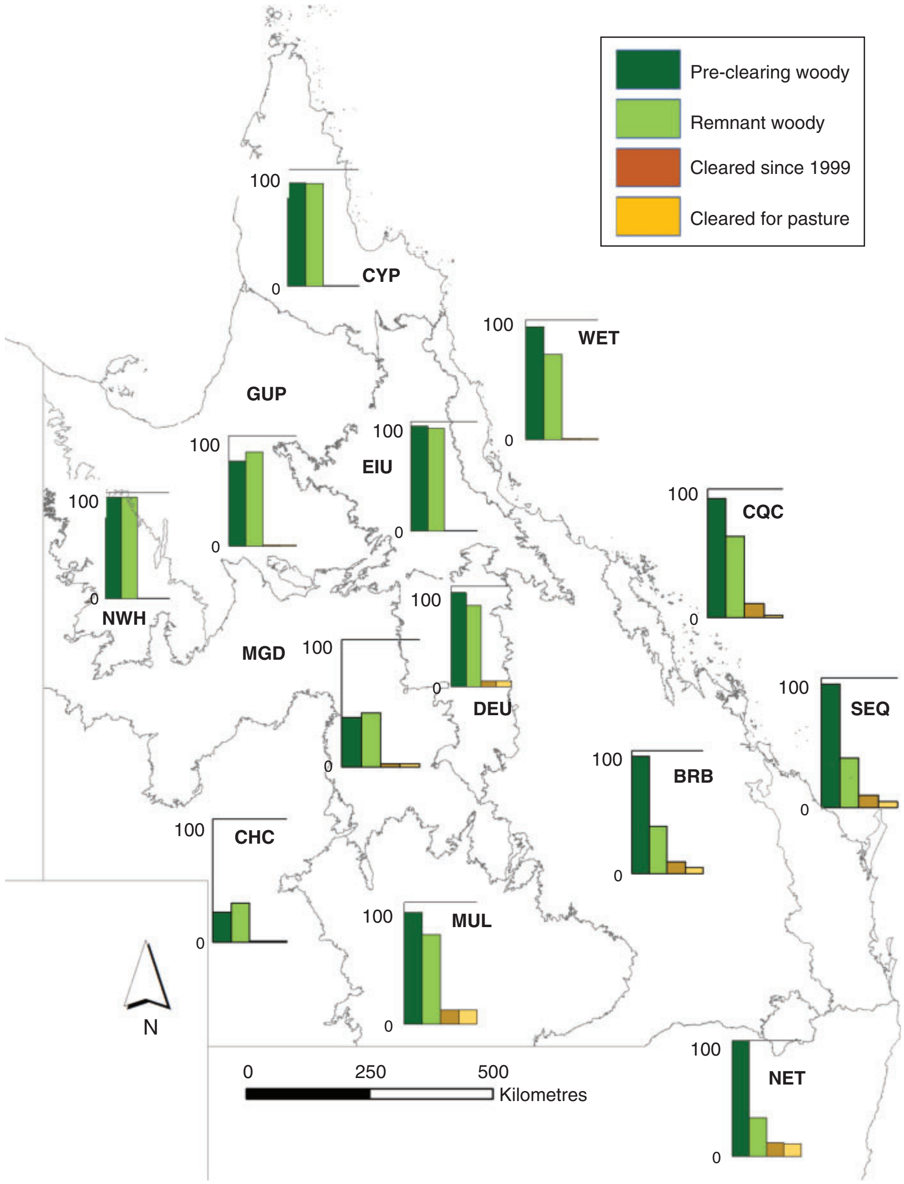


**Fig. 3.** Percentage area of woody vegetation for each of Queensland's bioregions. Bar charts from left to right: (*a*) (dark green) reconstructed preclearing Regional Ecosystems dominated by woody vegetation. For example, WET, EIU and SEQ were almost 100% covered in woody vegetation before clearing began, but MGD and CHC mainly consisted of grass-dominated Regional Ecosystems, (*b*) (Light green) remnant Regional Ecosystems remaining in 1999 dominated by woody vegetation (a subset of (*a*)), (*c*) (orange) woody vegetation (including remnant, disturbed and regrowth) cleared between 1999 and 2016, and (*d*) (yellow) woody vegetation cleared for pasture between 1999 and 2016 (a subset of (*c*)). The top bar marks the 100% level. See Text S1 and Fig. S1 (available as supplementary material to this paper) for details of the methodology. Bioregions are: BRB, Brigalow Belt; CYP, Cape York Peninsula; CQC, Central Queensland Coast; CHC, Channel Country; DEU, Desert Uplands; EIU, Einasleigh Uplands; GUP, Gulf Plains; MGD, Mitchell Grass Downs; MUL, Mulga Lands; NET, New England Tableland; NWH, North-west Highlands; SEQ, South Eastern Queensland; WET, Wet Tropics.

by removing protection for native fauna (Doherty *et al.* 2015; McGregor *et al.* 2015). Vegetation clearing facilitates invasion of introduced grasses (Gilbert and Levine 2013), leading to eco system transformation and resulting in substantial biodiversity loss (Cook and Grice 2013). Vegetation clearing has exacerbated the overabundance of noisy miners (*Manorina melanocephala*), resulting in substantial decreases in richness and abundance of woodland birds in the IBRA bioregions in Queensland: Gulf Plains, Einasleigh Uplands, Brigalow Belt South and South Eastern Queensland (Thomson *et al.* 2015).

**Table 2. Terrestrial fauna in Queensland listed as endangered under the *Nature Conservation Act 1992* (Queensland) where loss of habitat containing woody vegetation is a key threatening process**

Excludes extinct animals, sea or shore birds, amphibians, marine mammals, and fish. All but four species are also listed under the *Environment Protection and Biodiversity Act 1999* (EPBC Act). CE, critically endangered; EN, endangered; VU, vulnerable

| Subgroup | Scientific name | Common name | EPBC Act status | Location |
|---|---|---|---|---|
| Bird | *Amytornis barbatus barbatus* | Grey grasswren (bulloo) | EN | SW Qld |
| Bird | *Anthochaera phrygia* | Regent honeyeater | CE | SE Qld, Brigalow Belt |
| Bird | *Casuarius casuarius johnsonii* (southern population) | Southern cassowary (southern population) | EN | Wet Tropics, Cape York |
| Bird | *Epthianura crocea macgregori* | Yellow chat (Dawson) | CE | Central Qld |
| Bird | *Erythrotriorchis radiatus* | Red goshawk | VU | Wet tropics, Cape York |
| Bird | *Erythrura gouldiae* | Gouldian finch | EN | North Qld |
| Bird | *Lathamus discolor* | Swift parrot | EN | Migratory to south Qld |
| Bird | *Neochmia ruficauda ruficauda* | Star finch (eastern subspecies) | EN | Inland Qld |
| Bird | *Pezoporus occidentalis* | Night parrot | EN | Inland Qld |
| Bird | *Poephila cincta cincta* | Black-throated finch (southern subspecies) | EN | Central and north Qld |
| Invertebrate | *Adclarkia dawsonensis* | Boggomoss snail | CE | Central Qld |
| Invertebrate | *Adclarkia dulacca* | Dulacca woodland snail | EN | Central Qld |
| Invertebrate | *Argyreus hyperbius inconstans* | Australian fritillary butterfly | Not listed | SE Qld |
| Invertebrate | *Hypochrysops piceata* | Bulloak jewel butterfly | Not listed | Brigalow Belt |
| Mammal | *Bettongia tropica* | Northern bettong | EN | Wet Tropics |
| Mammal | *Dasyurus maculatus gracilis* | Spotted-tailed quoll (northern subspecies) | EN | Wet Tropics |
| Mammal | *Hipposideros semoni* | Semon's leaf-nosed bat | VU | Wet Tropics, Cape York |
| Mammal | *Lasiorhinus krefftii* | Northern hairy-nosed wombat | EN | Brigalow Belt |
| Mammal | *Onychogalea fraenata* | Bridled nailtail wallaby | EN | Brigalow Belt |
| Mammal | *Petaurus gracilis* | Mahogany glider | EN | Wet Tropics |
| Mammal | *Petrogale persephone* | Proserpine rock-wallaby | EN | Central coast Qld |
| Mammal | *Rhinolophus philippinensis* | Greater large-eared horseshoe bat | VU | Wet Tropics, Cape York |
| Mammal | *Saccolaimus saccolaimus nudicluniatus* | Bare-rumped sheathtail bat | CE | Wet Tropics, Cape York |
| Reptile | *Anomalopus mackayi* | Long-legged worm-skink | VU | SE Qld |
| Reptile | *Hemiaspis damelii* | Grey snake | Not listed | Brigalow Belt |
| Reptile | *Lerista allanae* | Allan's lerista | EN | Brigalow Belt |
| Reptile | *Nangura spinosa* | Nangur skink | CE | SE Qld |
| Reptile | *Phyllurus kabikabi* | Oakview leaf-tailed gecko | Not listed | SE Qld |
| Reptile | *Tympanocryptis condaminensis* | Condamine earless dragon | EN | Brigalow Belt |

### *Threatened terrestrial fauna*

Out of a total of 121 terrestrial fauna species listed as vulnerable or endangered in Queensland that use forest or woodland as part of their habitat, vegetation clearance is cited as a key threatening process for 97 (80%) under Queensland and Australian threatened species legislation (Table 2, Table S3) (DEE 2016; DEHP 2016). Habitat loss is also implicated in the demise of half of the 10 extinct fauna species in Queensland (DEE 2016).

Retention of old growth remnant vegetation is particularly important for terrestrial fauna because it can take centuries for features such as tree hollows and coarse woody debris such as fallen trees to develop (Remm and Lohmus 2011). Increased competition for tree hollows following land clearing is implicated in the decline of several birds including the eclectus parrot (*Eclectus roratus*), the Macleay's fig parrot (*Cyclopsitta diophthalma macleayana*), the Major Mitchell's cockatoo (*Lophochroa leadbeateri*), and the swift parrot (*Lathamus discolor*) (DEE 2016). Many reptile species rely on leaf litter and woody debris for suitable habitat (Woldendorp and Keenan 2005). However, where remnant vegetation has been almost entirely removed, such as in the Brigalow Belt, regrowth vegetation is also crucial for species survival, particularly regrowth older than 20 30 years (Bowen *et al.* 2009; Bruton *et al.* 2013).

### *Threatened terrestrial flora*

Plant species threatened by land clearing are those confined to small remnants of native vegetation that are unable to survive in the modified habitat created after clearing. Although Queensland has more than 200 plant species listed as endangered under State and/or Federal legislation, the only bioregion where large numbers of threatened species coincide with ongoing land clearing is the Brigalow Belt, which accounts for one quarter of endangered plant species. Most of these have been much diminished in range and abundance through past habitat loss. At least 12 occur on fertile soils and are threatened by ongoing habitat loss due to land clearing (Table 3), including four endangered *Solanum* species. Most *Solanum* populations are on roadsides heavily infested by exotic grasses, and the remaining populations in brigalow (*Acacia harpophylla*) remnants on private property are essential to the long term survival of these highly threatened species. For many threatened species, there is little information on their total population numbers or trends, and the lack of comprehensive surveys mean that unknown populations continue to be affected by clearing.

**Table 3. Terrestrial flora listed as endangered under the *Nature Conservation Act 1992* (Queensland) that are threatened by ongoing land clearing in the Brigalow Belt bioregion**

All have suffered extensive habitat loss in the past for agriculture and now persist in small, fragmented populations, but only current/ongoing threats are shown. *Phebalium distans* (CR), *Xerothamnella herbacea* (EN), and *Homopholis belsonii* (VU) are also listed under the EPBC Act. Lifeforms: PG, perennial grass; AH, annual herb; PH, perennial herb

| Species | Family | Habitat summary | Life-form | No. of populations (estimate) | Current threats and notes |
|---|---|---|---|---|---|
| *Callicarpa thozetii* | Lamiaceae | Tall eucalypt woodland and vine forest in valleys and steep slopes. | Shrub | 4 (??) | Ongoing habitat loss. |
| *Capparis humistrata* | Capparaceae | Shrubby woodland; also in pasture and non-remnant woodland. | Shrub | 10 (>500) | Ongoing habitat loss; weeds (buffel grass); changed fire regimes. |
| *Homopholis belsonii* | Poaceae | Dry woodlands, including brigalow and belah. | PG | ~30 (>1000) | Ongoing habitat loss (agriculture and mining); weed invasion. |
| *Phebalium distans* | Rutaceae | Semi-evergreen vine thicket on red volcanic soils. | Tree | 10 (1000) | Land clearing for agriculture or urban development grows on highly fertile, heavily cleared soils (Forster 2003). |
| *Ptilotus brachyanthus* | Amaranthaceae | Sandy loams in mixed open woodland, with buffel grass understorey. | AH | 3 (350) | Weed invasion (buffel grass); ongoing habitat loss. Rare, cryptic and ephemeral species (Silcock *et al.* 2014). |
| *Ptilotus extenuatus* | Amaranthaceae | Grassland on silty clay loam soils, sometimes in brigalow mosaic. | AH | 3 (??) | Weed invasion; ongoing habitat loss. Last collected in 1996; surveys required. |
| *Solanum adenophorum* | Solanaceae | Brigalow and gidgee woodland (remnant and regrowth) on deep cracking clay soils. | PH | 8 (<500) | Weed invasion (buffel, green panic); cryptic and element of temporal rarity, but probably most threatened Brigalow Belt solanum. |
| *Solanum dissectum* | Solanaceae | Open forests to woodlands dominated by brigalow sometimes with belah on heavy clay soils. | PH | 5 (>3000) | Weed invasion (buffel, green panic); ongoing habitat loss (clearing). Most secure population is on private property remnant if this is cleared, it would be disastrous for long-term prospects of species. |
| *Solanum elachophllym* | Solanaceae | Remnant and regrowth brigalow; less commonly eucalypt woodland. | PH | 25 (>5000) | Weed invasion (buffel, green panic); ongoing habitat loss (clearing). |
| *Solanum johnsonianum* | Solanaceae | Open forests to woodlands dominated by brigalow sometimes with belah on heavy clay soils. | PH | 16 (>10000) | Weed invasion (buffel, green panic); ongoing habitat loss (clearing). |
| *Xerothamnella herbacea* | Acanthaceae | Brigalow forests, often associated with shady gilgais. | PH | 20 (>2000) | Weeds; ongoing habitat loss. |
| *Zieria inexpectata* | Rutaceae | Eucalypt woodland in sandy soil derived from duricrust. | Shrub | 6 (<1000) | Ongoing habitat loss and fragmentation (bush blocks, forestry). Insufficient data to determine population trends. |

The South Eastern Queensland and Wet Tropics bioregions were extensively cleared in the past (Fig. 4), and have high numbers of threatened plant species. The largely intact Cape York Peninsula also has many listed species due to high levels of narrow ranged endemism (Australian Government 2012). These three bioregions together accounted for <10% of land clearing in Queensland in 2014/15, although the northern bioregions, particularly Cape York Peninsula, could be threatened by future clearing (Australian Government 2015). On the other hand, the Mulga Lands accounts for 22% of total clearing but none of its eight endangered species are threatened by land clearing (Silcock *et al.* 2014). Past clearing has resulted in high proportions of Regional Ecosystems becoming endangered in the Wet Tropics, New England Tableland, Central Queensland Coast, South Eastern Queensland, and Brigalow Belt bioregions (Fig. 4).

### *Freshwater species and ecosystems*

Intact riparian vegetation is the main factor that influences the water quality and ecosystem health of Queensland's rivers (Bunn *et al.* 1999). Land clearing impacts freshwater systems by increasing light, nutrients, sediment load, and water temperatures (reviewed in Allan 2004). Most of the sediment (>90%) entering water storages and coastal environments in Queensland's major coastal catchments originated from erosion of stream banks and gullies (Bartley *et al.* 2014), primarily caused by degradation of riparian areas from land clearing and livestock grazing. The increased sediment load can result in scouring and abrasion, impaired substrate suitability for periphyton (algae and detritus attached to submerged surfaces), decreased primary productivity, decreased food quality, infilling of interstitial

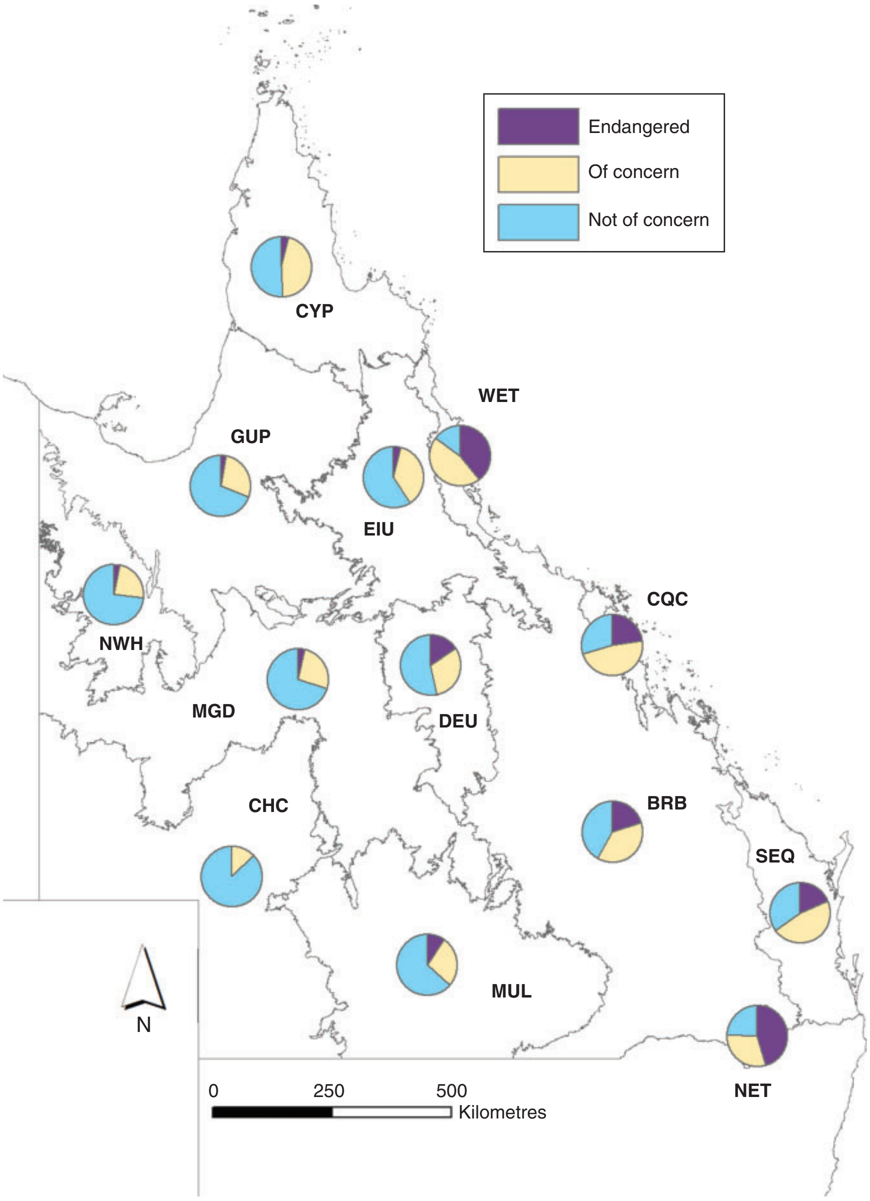


**Fig. 4.** Percentage of the total number of remnant Regional Ecosystems (REs) in each bioregion in Queensland according to their conservation status (Source: https://data.qld.gov.au/dataset/soe2015-extent-of-endangered-of-concern-and-no-concern-at-present-regional-ecosystems/resource/indicator-1-1-0-4-1). Purple shows 'endangered' REs (<10% remaining), yellow shows 'of concern' (10 30% remaining), and blue shows 'not of concern' REs (>30% remaining). For example, the Brigalow Belt (BRB) contained 353 REs, of which 20% are endangered, 38% are of concern and 42% are not of concern. Bioregions are: BRB, Brigalow Belt; CYP, Cape York Peninsula; CQC, Central Queensland Coast; CHC, Channel Country; DEU, Desert Uplands; EIU, Einasleigh Uplands; GUP, Gulf Plains; MGD, Mitchell Grass Downs; MUL, Mulga Lands; NET, New England Tableland; NWH, North-west Highlands; SEQ, South Eastern Queensland; WET, Wet Tropics.

habitat, and reduced stream depth heterogeneity (Allan 2004). It can also decrease the reproductive success of fish (Burkhead and Jelks 2001). Streams draining from cleared agricultural lands generally have poorer habitat quality and bank stability, and contain fewer species of invertebrates and fish. The early wet season floods flush high concentrations of contaminants that have accumulated during the dry season into freshwater systems, impacting function through acute exposure (Davis *et al.* 2016). Small freshwater systems are particularly vulnerable to water quality issues such as ammonia toxicity and hypoxia caused by nutrient runoff (Davis *et al.* 2016). This, in combination with other impacts of clearing such as reduced canopy cover and increased weeds, such as para grass (*Urochloa mutica*), has a severe impact on freshwater ecosystem function and river health (Bunn *et al.* 1998, 1999).

Several of Queensland's threatened freshwater species depend on protecting riparian vegetation, such as the Mary River turtle (*Elusor macrurus*), the giant barred frog (*Mixophyes iteratus*), the cascade treefrog (*Litoria pearsoniana*), the Mary River cod (*Maccullochella peelii mariensis*), the Oxleyan pygmy perch (*Nannoperca oxleyana*), the Australian lungfish (*Neoceratodus forsteri*), the tusked frog (*Adelotus brevis*), and the giant spiny crayfish (*Euastacus hystricosus*).

### *Marine ecosystems and the Great Barrier Reef*

Over 90% of the sediment entering coastal environments in several of Queensland's major coastal catchments originated from erosion of stream banks and gullies (Bartley *et al.* 2014), caused mainly by degradation of riparian lands and catchment wide increases in runoff resulting from land clearing (Siriwardena *et al.* 2006). Sediment runoff into both Moreton Bay and the Great Barrier Reef has increased several fold since historical vegetation clearing in their catchments (Kroon *et al.* 2012), and continues to threaten these systems through recent and ongoing vegetation clearing (DSITI 2016).

Deterioration of water quality in Moreton Bay and the Great Barrier Reef lagoon resulting from loss of catchment vegetation cover impacts a wide range of ecosystems. Both chronic and acute influxes of sediment into the marine environment can alter seagrass and coral reef communities and reduce coral cover (Fabricius 2005; Wenger *et al.* 2016). Sediment destabilises coral communities in two ways. Increased fine sediment loads in suspension increase turbidity and reduce light penetration (Fabricius *et al.* 2014), which decreases the photosynthetic abilities of corals (Fabricius 2005) and seagrass (Walker and McComb 1992). Suspended sediment can bind to coral egg bundles and limit successful fertilisation (Ricardo *et al.* 2016). Sedimentation onto coral reefs can also smother corals, increasing their energetic demands through mucous production to remove sediment, and can result in mortality of small benthic organisms (Fabricius and Wolanski 2000).

Sediments delivered to the marine environment can also increase nutrient levels, leading to increased susceptibility to bleaching (Wiedenmann *et al.* 2013) and prevalence in coral disease, which undermines the protection afforded by marine reserves (Lamb *et al.* 2016). This highlights the importance of enacting measures that increase the resilience of the Great Barrier Reef, such as improving water quality.

### *Northern Australia's intact ecosystems*

The Gulf Plains and Cape York Peninsula bioregions of Far North Queensland have had limited agricultural or urban development, and as a result support globally significant intact ecosystems. Cape York Peninsula has been nominated for World Heritage status on the basis of outstanding cultural and natural values, including many restricted and endemic species (Australian Government 2012). For example, threatened species such as the buff breasted buttonquail (*Turnix olivii*) and the red goshawk (*Erythrotriorchis radiatus*) require the large intact woodland areas on Cape York Peninsula. Furthermore, almost half of the Regional Ecosystems on Cape York are 'of concern' (defined as 10 30% or less than 10 000 ha remaining: https://www.qld.gov.au/environment/plants animals/plants/ecosystems/biodiversity status/, accessed 7 May 2017) (Fig. 4). Yet lifting of the 2006 ban on broad scale clearing for high value agriculture in 2013, combined with the $5 billion *Northern Australia Infrastructure Facility Act 2016*, have enabled broad scale land clearing in these regions, despite their marginal agricultural value (Russell Smith *et al.* 2015). These recent clearings highlights the inadequacy of the current legal framework to protect areas of outstanding natural heritage.

## Options for policy reform

If land clearing in Queensland is to be controlled over the long term, better policies are needed to reduce the rate of vegetation loss to a more sustainable level. Regulation is an essential component of an effective policy mix, alongside long term incentives, education, and self regulation for low risk activities (Gunningham and Sinclair 1999; Evans 2016). Achieving environmental goals in a way that is equitable, efficient, and socially and politically feasible will remain an ongoing policy challenge, but is essential for effective long term outcomes (Dovers and Hussey 2013).

Re establishing regulatory controls on remnant and high value regrowth vegetation clearing, tightening provisions on self assessable codes, and the reinstatement of monitoring and compliance activities are high priorities for reducing the current alarming rate of land clearing. However, it should be noted that while strong regulation likely decreased the rate of clearing in Queensland during the years 2004 13, there was still an overall decline in native vegetation during this time. The VMA, working alongside Queensland's environmental offsets scheme (Queensland Government 2014*b*), implicitly enables incremental clearing to continue indefinitely (Maron *et al.* 2015). An alternative approach is a 'target based' regulation that would set a cap on overall land clearing, alongside regional retention targets for each vegetation type. Such a regime could operate alongside tradeable clearing rights. The use of explicit targets allows for an open and concrete representation of objectives (Carwardine *et al.* 2009) and currently operates for land clearing regulation in Brazil (Soares Filho *et al.* 2014) and the Cape Floristic Region of South Africa (Brownlie and Botha 2009) (albeit with variable outcomes, due to loopholes and exemptions: e.g. Soares Filho *et al.* 2014).

Regulation can be balanced with incentives that provide economic opportunities for land holders. Land clearing in Queensland predominantly occurs on private land to create pasture (Evans 2016). Under an effective carbon pricing scheme, there are opportunities for land holders to gain income by surrendering any residual valid right to clear vegetation (for example, young regrowth) in exchange for carbon offset payments, potentially resulting in greater economic and environmental outcomes (Evans *et al.* 2015). Other options include payments for ecosystem services, where incentives are offered to manage native vegetation to improve biodiversity values (Binning and Young 2000). Queensland has the lowest percentage of land within protected areas of any Australian State or Territory (DEE 2014); thus, retaining and managing native vegetation for biodiversity on privately managed land is partic ularly important. The Brigalow Belt and Mulga Lands biore gions, both of which have less than 5% of land in protected areas, had the greatest woody vegetation clearing rates in Queensland in 2012 14 (DSITI 2016).

### Implications for existing investments

Australia is bound to national and international commitments to protect biodiversity and reduce greenhouse gas emissions. However, the lack of consistency between Queensland and Federal laws grossly undermines these commitments, and high lights the regulatory dissonance in Australia's environmental policy agenda. For example, since 2014, the Federal Government has spent over $130 million on projects promoting threatened species recovery, yet these investments are effectively nullified by loss of critical habitat through land clearing (Table S1). Likewise, many more trees are lost through Queensland's land clearing than are planted nationally by the Federal Government revegetation programs. Restoring cleared land, while important, is expensive and a less effective conservation measure than avoiding vegetation loss, and can fail to restore ecological values (Kanowski 2010; Suding 2011). Continued land clearing in Queensland will also undermine the recent State and Federal Government investments in improving water quality in the Great Barrier Reef, and will increase the cost of counteracting water quality decline, already estimated at $5 10 billion over 10 years (Brodie and Pearson 2016) (Table S1). Land clearing contributed ~8% to Australia's greenhouse gas emissions in 2013, and these were projected to rise from 47 Mt $CO_2$ e year$^{-1}$ (generated) to 53 Mt $CO_2$ e year$^{-1}$ by 2020 due to changes in land clearing reg ulations (DIICCSRTE 2013). Increased emissions from increased land clearing make it far more difficult for Australia to meet its targets under the Paris Agreement (UNFCCC 2015).

### Conclusion

Queensland's ongoing land clearing, and lack of effective policy and regulation, are of major national and international concern. Areas of Queensland with the highest historical clearing rate have the highest ongoing clearing rates, with substantial impacts to already threatened vegetation communities and species. Intact areas with high biodiversity values are now also at risk of being cleared, with Federal Government support. Poorly regu lated and escalating rates of clearing are contributing to sedi mentation and accelerating climate change, which are threatening the already imperilled Great Barrier Reef. Policy reform to stem land clearing is urgently required, but requires effective policy and political will.

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