Spatial modelling for koalas in South East Queensland

Koala Habitat Areas (KHA) v4.0

Locally Refined Koala Habitat Areas (LRKHA) v4.0

Koala Priority Areas (KPA) v1.0

Koala Habitat Restoration Areas (KHRA) v1.0

Report version 4.0

Queensland Government

Prepared by: Biodiversity Assessment Team, Queensland Herbarium and Biodiversity Science, Science Division, Department of Environment and Science

Citation

Department of Environment and Science (DES) 22 November 2023. Spatial modelling for koalas in South East Queensland: Report version 4.0. Koala Habitat Areas (KHA) v4.0, Locally Refined Koala Habitat Areas (LRKHA) v4.0, Koala Priority Areas (KPA) v1.0, Koala Habitat Restoration Areas (KHRA) v1.0. Brisbane: Department of Environment and Science, Queensland Government.

Acknowledgements

The project team would like to acknowledge the invaluable contribution of the Koala Expert Panel, namely Associate Professor Jonathan Rhodes, Dr Alistair Melzer, Ms Antra Hood and Mr Al Mucci, and a specially formed Koala Advisory Group of koala ecologists and spatial modelling experts including Associate Professor Jonathan Rhodes, Dr Alistair Melzer, Dr Hawthorne Beyer, Professor Clive McAlpine, and Dr Bill Ellis. The project team would like to acknowledge the time and effort taken by local government staff to compile and provide information. Members of the Biodiversity Assessment Team, DES significantly contributed to the project including Courtney Miles, Lindsey Lenneberg, Stephen Trent, Chris Sanderson, Jeremy Anderson and Steven Howell. Members of the Queensland Herbarium and Biodiversity Science contributed to the regional ecosystem and high value regrowth update including Tim Ryan, Andrew Franks, Chris Appelman, Ron Booth, John Neldner, Hans Dillewaard, Dale Richter and Dean Orrick.

Please contact biodiversity.planning@qld.gov.au for any queries relating to the habitat mapping.

Please contact SEQKoalaStrategy@des.qld.gov.au for any queries relating to the Koala Strategy.

Revision history

Version	Release Date	Description
1.0	7 February 2020[1]	This release includes the following: Koala habitat areas (KHA v1.0), based on: - Regional ecosystem mapping version 11, produced by the Department of Environment and Science, Queensland Herbarium. December 2018. Updated January 2020. - High Value Regrowth mapping, produced by the Department of Environment and Science, Queensland Herbarium. November 2019. Updated January 2020 - Removal of core habitat from islands (other than North Stradbroke, South Stradbroke and Bribie), that either don’t contain koala records or would not be able to sustain a koala population. - Core koala habitat area defined by twelve rules (koala habitat suitability categories 4–10). - Study area boundary based on South East Queensland Regional Plan 2017 “Shaping SEQ” (DILGP 2017). Locally refined koala habitat areas (LRKHA) mapping (v1.0). Report v1.0. [1] Previous versions of this report indicated the date as the 20/1/2020 which was when the results were finalised and not the actual release date.
1.1	22 August 2020	This release includes the following: Locally Refined Koala Habitat Areas (LRKHA v1.1): - Based on a review of high value regrowth across the study area. - Areas of HVR were assessed against a preclear model to determine core habitat and subsequent areas were included where they met the model rules for inclusion. Koala Habitat Areas (KHA v1.0) – no changes. Koala Priority Area (KPA) mapping (v1.0) – no changes. Koala Habitat Restoration Areas (KHRA) mapping (v1.0) – no changes. Report v1.1 updated to include: - LRKHA v1.1 results. - Minor editorial updates to improve readability. - Inclusion of KPA and KHRA documentation for completeness.
2.0	8 September 2021	This release includes the following: Koala habitat areas (KHA v2.0), based on: - Regional ecosystem mapping version 12 (with some small remnant additions, supplied 2 June 2021), produced by the Department of Environment and Science, Queensland Herbarium. - Reviewed and updated where appropriate the koala suitability rank of regional ecosystems and utility of tree species. - High Value Regrowth (HVR) mapping, produced by the Department of Environment and Science, Queensland Herbarium (supplied 26/02/2021).

Version	Release Date	Description
		- HVR attributed to better reflect historical clearing and maintain consistency between remnant and HVR. Locally refined koala habitat areas (LRKHA) mapping (v2.0) is a product of LRKHA v1.1 with the following removed: - LRKHA v1.1 areas which have now become KHA v2.0. - Areas of HVR which didn't meet the criteria for remnant or high value regrowth. - PMAV on Cat X (certified on or before 7/2/2020) (mainly slivers). - Small areas and slivers. Koala Priority Area (KPA) mapping (v1.0) – no changes. Koala Habitat Restoration Areas (KHRA) mapping (v1.0) - No changes to the delineation of KHRA. - KHRA map background updated with latest KHA. Report v2.0 - Updated KHA and LRKHA maps and results. - Updated RE suitability and koala tree utility tables. - Minor editorial updates to improve readability.
3.0	7 September 2022	This release includes the following: Koala habitat areas (KHA v3.0), based on: - Regional ecosystem mapping version 12.2. - High Value Regrowth (HVR) mapping (supplied 16 February 2022). - Approved Map Amendment Requests up to the 28 January 2022. - Small areas and slivers removed. Locally refined koala habitat areas (LRKHA) mapping (v3.0) is a product of LRKHA v2.0 with the following removed: - LRKHA v2.0 areas which have now become KHA v3.0. - Areas of HVR which didn't meet the criteria for remnant or high value regrowth. - PMAV on Cat X (certified on or before 7/2/2020) (mainly slivers). - Small areas and slivers. Koala Priority Area (KPA) mapping (v1.0) – no changes. Koala Habitat Restoration Areas (KHRA) mapping (v1.0): - No changes to the delineation of KHRA. - KHRA map background updated with latest KHA. Report v3.0: - Updated KHA and LRKHA maps and results. - Minor editorial updates to improve readability.

Version	Release Date	Description
4.0	22 November 2023	This release includes the following: Koala habitat areas (KHA v4.0), based on: - Regional ecosystem mapping version 13. - High Value Regrowth (HVR) mapping version 13. - Approved Map Amendment Requests up to the 1 March 2023. - Small areas and slivers removed. Locally refined koala habitat areas (LRKHA) mapping (v4.0) is a product of LRKHA v3.0 with the following removed: - LRKHA v3.0 areas which have now become KHA v4.0. - Areas of HVR which didn’t meet the criteria for remnant or high value regrowth. - PMAV on Cat X (certified on or before 7/2/2020) (mainly slivers). - Small areas and slivers. Koala Priority Area (KPA) mapping (v1.0) – no changes. Koala Habitat Restoration Areas (KHRA) mapping (v1.0): - No changes to the delineation of KHRA. - KHRA map background updated with latest KHA. Report v4.0: - Updated KHA and LRKHA maps and results.

Table of contents

List of tables

List of figures

List of maps

List of results

Description	Version	GIS Name
Koala Habitat Areas (KHA): Remnant and regrowth, core habitat	v4.0	koala_habitat_areas_v4_0
Locally Refined Koala Habitat Areas (LRKHA)	v4.0	locally_refined_koala_habitat_areas_v4_0
Koala Priority Areas (KPA)	v1.0	koala_priority_areas_v1_0
Koala Habitat Restoration Areas (KHRA)	v1.0	koala_habitat_restoration_areas_v1_0

List of abbreviations

Abbreviation	Description
AKF	Australian Koala Foundation
AUC	Area under the ROC (receiver operating characteristic) curve
CEC	Cation exchange capacity
CKHA	Core koala habitat area
DEM	Digital elevation model
DES	Department of Environment and Science
DILGP	Department of Infrastructure, Local Government and Planning
DSITI	Department of Science, Information Technology and Innovation
EHP	Department of Environment and Heritage Protection
FPC	Foliage projection cover
GDE	Groundwater dependent ecosystem
ha	Hectare(s)
HSM	Habitat suitability model
HVR	High value regrowth
KAG	Koala Advisory Group
KEP	Koala Expert Panel
kg	Kilogram(s)
KHA	Koala Habitat Areas
KHRA	Koala Habitat Restoration Areas
km	Kilometre(s)
KPA	Koala Priority Areas
LGA	Local government area
LRKHA	Locally Refined Koala Habitat Areas
m	Metre(s)
MASL	Metres above sea level
Maxent	Maximum entropy modelling
mm	Millimetre(s)

Abbreviation	Description
NDVI	Normalised difference vegetation index
PDA	Priority development areas
RE	Regional Ecosystem
REDD	Regional Ecosystem Description Database
ROC	Receiver operating curve
SDM	Species distribution model
SEQ	South East Queensland
SIR	Queensland Government’s spatial information resource
SISP	Spatial imagery subscription plan
SLATS	Statewide Landcover and Trees Study
SMPK	Spatial modelling and planning for koalas in southern South East Queensland project
SRTM	Shuttle radar topography mission
VM Act	*Vegetation Management Act 1999 (Qld)*

Executive summary

One of the key recommendations of the Koala Expert Panel (KEP) was to develop targeted and high-quality koala habitat and threat mapping that can be used to underpin a more coordinated and strategic approach to koala conservation in South East Queensland. The KEP recommended that the new koala habitat mapping should be suitable for monitoring changes in koala ecological values and threats over time and be suitable for supporting future policy and management decisions while addressing the limitations of previous mapping.

This report describes the development of new koala habitat mapping, locally refined koala habitat areas (LRKHA), the delineation of broad koala priority areas (KPAs) for koala conservation and habitat restoration areas (KHRA).

New tenure-blind koala habitat mapping was developed to use state-of-the-art modelling coupled with the Queensland government's expertise in state-wide, comprehensive vegetation mapping. The approach integrated a species distribution model with the Queensland Herbarium's regional ecosystem (RE) mapping and validated koala occurrence records to produce a comprehensive map that ranked koala habitat values across the South East Queensland (SEQ) study area. The new approach used a set of key biophysical variables to construct a distribution model linked to the regional ecosystem mapping. Linking the new koala habitat mapping with the government's existing vegetation and landcover mapping allows the modelling to be updated and refined as newer data becomes available.

To ensure the adequacy of any new mapping, the spatial modelling and planning for koalas in southern South East Queensland project (SMPK) received input and advice from the KEP and a specially formed koala advisory group (KAG) consisting of koala ecologists and spatial mapping specialists.

The new koala habitat mapping divided habitat into three categories (core habitat, non-core habitat, and non-habitat) across pre-clearing, remnant and non-remnant (regrowth) vegetation as delineated by the Queensland Herbarium, Department of Environment and Science (DES). Core habitat represents the best habitat for koalas, based on the combination of biophysical measures, suitable vegetation and koala occurrence records. Non-core habitat includes marginal or rainforest habitat that koalas may use as refuges from heat or fire, for thermoregulation (shade), or for dispersal and connectivity between populations. Non-habitat refers to areas that are very unlikely to provide suitable conditions for supporting koala populations.

Koala habitat occurring in regrowth vegetation was delineated using the best source data currently available, which was the high value regrowth mapped by the Queensland Herbarium. Incorporating non-remnant habitat recognises the importance of these areas for koala conservation. Datasets that are better able to reliably detect and map regrowth and even individual trees are likely to be available in the future with additional research and development by the Statewide Landcover and Tree Study (SLATS) program and other groups within DES including the Queensland Herbarium.

This project identified 645,822ha of core koala habitat (consisting of 511,085ha remnant core koala habitat and 134,737ha regrowth core koala habitat), from a pre-clearing extent of 1,834,796ha. This means 72% (1,323,711 ha) of core koala habitat has previously been cleared; 7% has regrown to high value regrowth. Of the best quality koala habitat, approximately 90% has been cleared, with much of it situated on the high fertility, highly modified alluvial plains. Additionally, there were 60,779ha of locally refined koala habitat areas.

In addition to developing new koala habitat mapping, the KEP recommended that there was a need to undertake comprehensive threat mapping and to identify priority areas for koala conservation across rural and urban landscapes in SEQ. To achieve this, a set of threats, constraints, opportunities and resilience measures were combined with the habitat mapping to assist with identifying priority areas that will be the focus of koala conservation measures. Spatial prioritisation software, Marxan, was used to identify broad priority areas for koala habitat protection and restoration based on the presence of existing remnant or regrowth vegetation or the potential for restoration based on former habitat. Areas with a combination of low threats and constraints, and high conservation opportunities were identified where koala conservation measures would be more likely to achieve desired outcomes. Both habitat protection and areas targeted for restoration were focused within the KPAs. Areas for prioritising threat management were also identified to help guide targeted management actions.

1 Introduction

In Queensland, koala populations are in decline with the species listed as vulnerable by the Queensland Government under the *Nature Conservation Act 1992* and by the Australian Government under the *Environment Protection and Biodiversity Conservation Act 1999*. In South East Queensland (SEQ), despite existing protection strategies, koala numbers have decreased by 50–80% in key habitat areas over the last 20 years with this rate of decline possibly accelerating (Rhodes et al. 2015). Increases in the number of people living in SEQ and the associated loss of habitat is putting added pressure on koala populations already subject to high mortality caused by vehicle collisions, dog attacks and disease.

New approaches are, therefore, needed to better protect koalas, especially in the south-east, where the state's largest koala population is living in close proximity to large urban centres. In May 2016 the then Minister for Environment and Heritage Protection, National Parks and the Great Barrier Reef announced the establishment of a Koala Expert Panel (KEP) and consultation with specialists with a diversity of expertise in relation to koala population dynamics, genetics, captive breeding, translocation, disease management, threat mitigation, rescue and rehabilitation, town planning and behavioural science. The consultation identified a number of key ongoing issues which threaten koala populations in SEQ, including matters relating to strategic policy settings, threat management, planning processes, monitoring and mapping (Rhodes et al. 2017).

Reviews of earlier koala habitat mapping identified a number of strengths and limitations of previous approaches (Neldner and Accad 2013; Rhodes 2014; EHP 2017). Major limitations included a lack of comprehensiveness, coarse resolution, simplistic habitat associations, and no update mechanisms (Rhodes et al. 2017). Previous mapping has used broad landcover associations and biophysical properties such as land zone, slope and elevation with koala occurrence records to characterise habitat quality (GHD 2009). Other mapping has used tree species preferences as the primary driver of koala habitat quality and often ignored landscape-level processes such as fragmentation (Rhodes 2014). The KEP highlighted the strengths and complementarity of earlier methods and recommended that future mapping could benefit from using state-of-the-art species habitat modelling and adopting the best aspects of the previous landcover and vegetation-centred approaches (Rhodes et al. 2017).

The spatial modelling and planning for koalas in southern South East Queensland project was established to deliver koala habitat mapping based on the latest scientific modelling principles and data. The project set out to develop a tenure-blind koala habitat mapping framework based on the integration of biophysical variables with an expert derived vegetation classification and records of koala occurrence. The approach integrated a species distribution model (Guisan and Thuiller 2005) with the Queensland Herbarium's regional ecosystem (RE) mapping and validated koala occurrence records to produce a comprehensive map that ranks koala habitat values across the study area.

The model used the machine learning program, Maxent (Phillips et al. 2006), and a set of decision rules (matrix) to determine which areas were considered core habitat, non-core habitat and non-habitat across pre-clearing, remnant and non-remnant (regrowth) vegetation in SEQ. Linking the new koala habitat mapping with the government's existing vegetation and landcover mapping programs allows the modelling to updated and refined as updated high resolution remnant and non-remnant data becomes available. The potential habitat values of cleared or partially cleared areas can be derived from the pre-clearing modelling and used as a valuable tool for targeting restoration measures in areas of the highest koala habitat suitability.

Comprehensive threat mapping was also carried out to support the identification of broad-scale priority areas for koalas across rural and urban landscapes in SEQ. Threats, constraints, opportunities and resilience measures were evaluated and used as inputs to spatial prioritisation software (Marxan) to identify broad priority areas to target koala habitat conservation. Koala Priority Areas (KPAs) were delineated from the Marxan models to support policy for koala conservation around habitat protection and habitat restoration opportunities.

The project received input and advice from the KEP and a specially formed project-specific koala advisory group (KAG) consisting of koala ecologists and spatial mapping specialists. The study area for the project was defined by the SEQ regional planning area, represented by 12 local government areas (LGAs).

1.1 Project Scope

The project involved:

- Collation of literature, koala occurrence records, spatial data and approaches for modelling habitat suitability for koalas.

- Evaluation of koala habitat suitability using a repeatable, transparent modelling approach that included a suite of biophysical, habitat and threat drivers of koala distribution and density.
- Consultation with relevant local governments, state government, universities and natural resource management groups to acquire data on threats, constraints, opportunities and resilience relevant to koala conservation to inform the identification of priority areas for koala conservation.
- Engagement with internal and external experts (KEP and KAG).
- Application of the method to the SEQ regional planning area.
- Identification of areas for future monitoring and field surveys to evaluate and validate the results.

1.2 Study area

The study area (2,300,042ha) corresponds to the South East Queensland Regional Plan 2017 "Shaping SEQ" (DILGP 2017), encompassing 12 local government areas: Noosa, Sunshine Coast, Moreton Bay, Brisbane, Redland, Logan, Ipswich, Gold Coast, Somerset, Lockyer Valley, Scenic Rim, and a portion of Toowoomba (Figure 1).

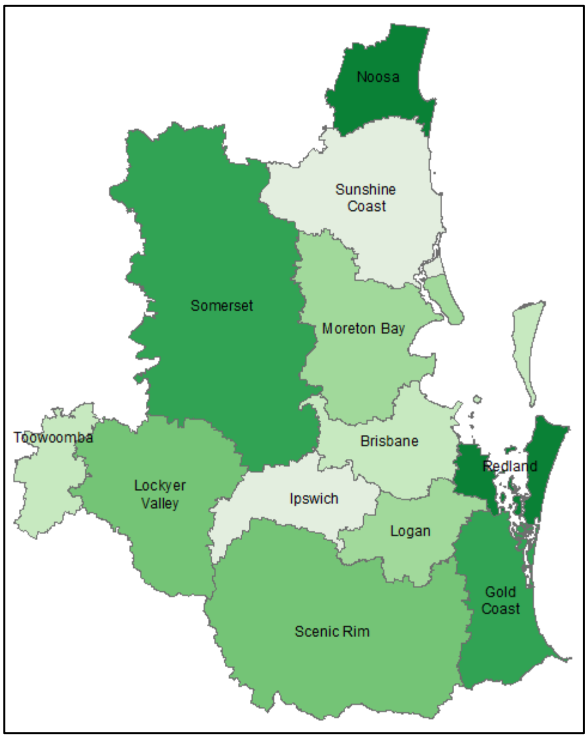


Figure 1: SEQ study area showing the twelve local government areas within the regional planning area.

1.3 Consultation

The project undertook consultation with the 12 local governments within the study area, in order to acquire the most current data available. The consultation targeted the acquisition of specific koala conservation and occurrence data relevant to the project. Consultation included requesting information about koala conservation measures, programs and data specific to each of the LGAs, including:

- Koala records – additional occurrence records not held currently in the Department of Environment and Science (DES) databases. These records will be provided to WildNet.
- Koala conservation areas – spatial layers or descriptions of areas where local governments are investing in koala conservation to ensure the project took into account identified priority areas for on-ground works, or where the councils have identified priority areas for koalas or biodiversity corridors.
- Parks and reserves – including other conservation covenant and agreement lands such as Land for Wildlife properties that could provide synergies with koala conservation measures.

- Conservation constraints – areas identified for future urban development or other constrained areas that would reduce the success of implementing koala conservation measures.

A larger consultation process was undertaken on broader koala conservation issues by DES and was reported in the KEP final report (Rhodes et al. 2017).

1.4 Conceptual model

A conceptual model was developed for the project with components including: spatial modelling, modelling summary, deliverables and decision framework (Figure 2). The spatial modelling component was used to identify the three main criteria in the project:

1. Koala habitat
2. Threats and constraints
3. Opportunities and resilience

Koala habitat mapping was the first major component of the project followed by modelling of threats, constraints, opportunities and resilience. The outputs were combined and incorporated in a decision framework to identify broad-scale priority areas for koala habitat protection, restoration and threat management.

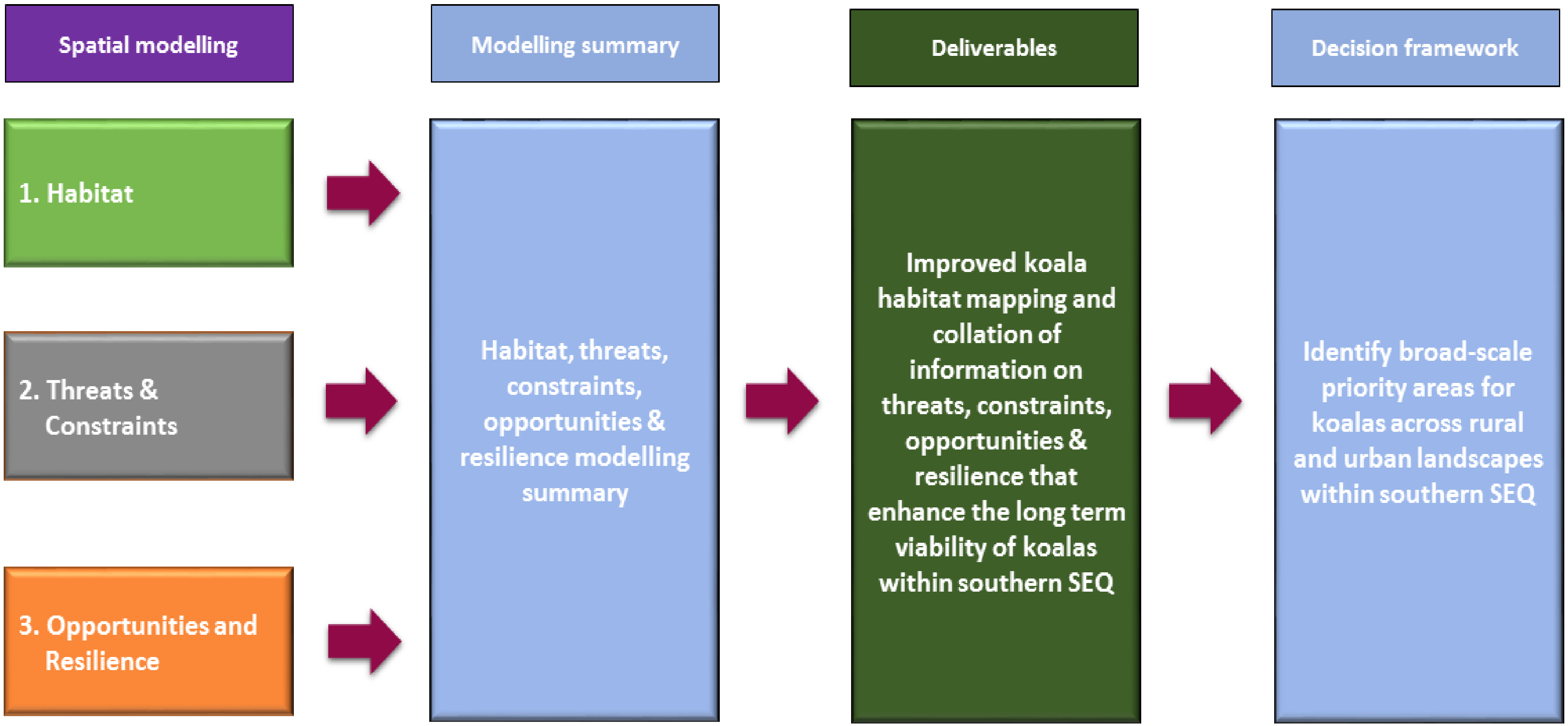


Figure 2: Conceptual model.

2 Core koala habitat areas

The new koala habitat mapping was developed to represent the habitat niche or habitat most suitable for the species (Araújo and Guisan 2006). The method was developed to be robust, easily repeatable and to ensure outputs were as up-to-date and transparent as possible. The method used state-of-the-art modelling coupled with the Queensland government's expertise in state-wide, comprehensive vegetation mapping. It integrated a species distribution model with the Queensland Herbarium's RE mapping and validated koala occurrence records to produce a comprehensive map that ranked koala habitat values across the SEQ study area.

The new approach used a set of key biophysical variables to construct a distribution model linked to the RE mapping. Linking the new koala habitat mapping with the government's existing RE mapping overcame the coarse resolution issues and major limitations of the previous approaches by allowing for regular revisions tied to updates by the Queensland Herbarium.

The method was developed to be easily adaptable to other regions through the inclusion of regionally specific datasets and rules. To ensure consistency and repeatability, no manual editing was undertaken. To ensure transparency, users are able to drill down though the attributes for each polygon to obtain the values from each phase of the modelling. The project builds on data and approaches used in previous koala habitat mapping and reviewed prior to this modelling project (EHP 2017).

2.1 Approach

Koala habitat was modelled using a three stage approach. In the first stage, a RE suitability classification was developed that used expert knowledge of koala habitat preference to identify the type of habitat that koalas prefer. In the second stage, a species distribution model (SDM) was developed using Maxent (Phillips et al. 2006) and key biophysical variables. In the third stage a decision matrix was developed to integrate both the RE suitability classification from the first stage and the Maxent model from the second stage, in combination with koala occurrence records. Figure 3 illustrates how each stage feeds into the decision matrix and contributes to identifying the habitat categories.

The new koala habitat mapping divided habitat into three categories: (1) core habitat, (2) non-core habitat and (3) non-habitat. The mapping was applied across pre-clearing, remnant and non-remnant (regrowth) vegetation. Incorporating non-remnant habitat into the mapping recognises the importance of these areas for koala conservation as koalas do not discriminate between intact or regrowth habitat and are known to use landcover ranging from remnant forests to individual trees in urban or rural settings.

Datasets that are better able to reliably detect and map regrowth and individual trees will be available in the future with additional research and development by the Statewide Landcover and Tree Study (SLATS) program and other groups within DES. Establishing a mapping framework which includes regrowth was considered important in order to provide scope for future technological and methodological improvements.

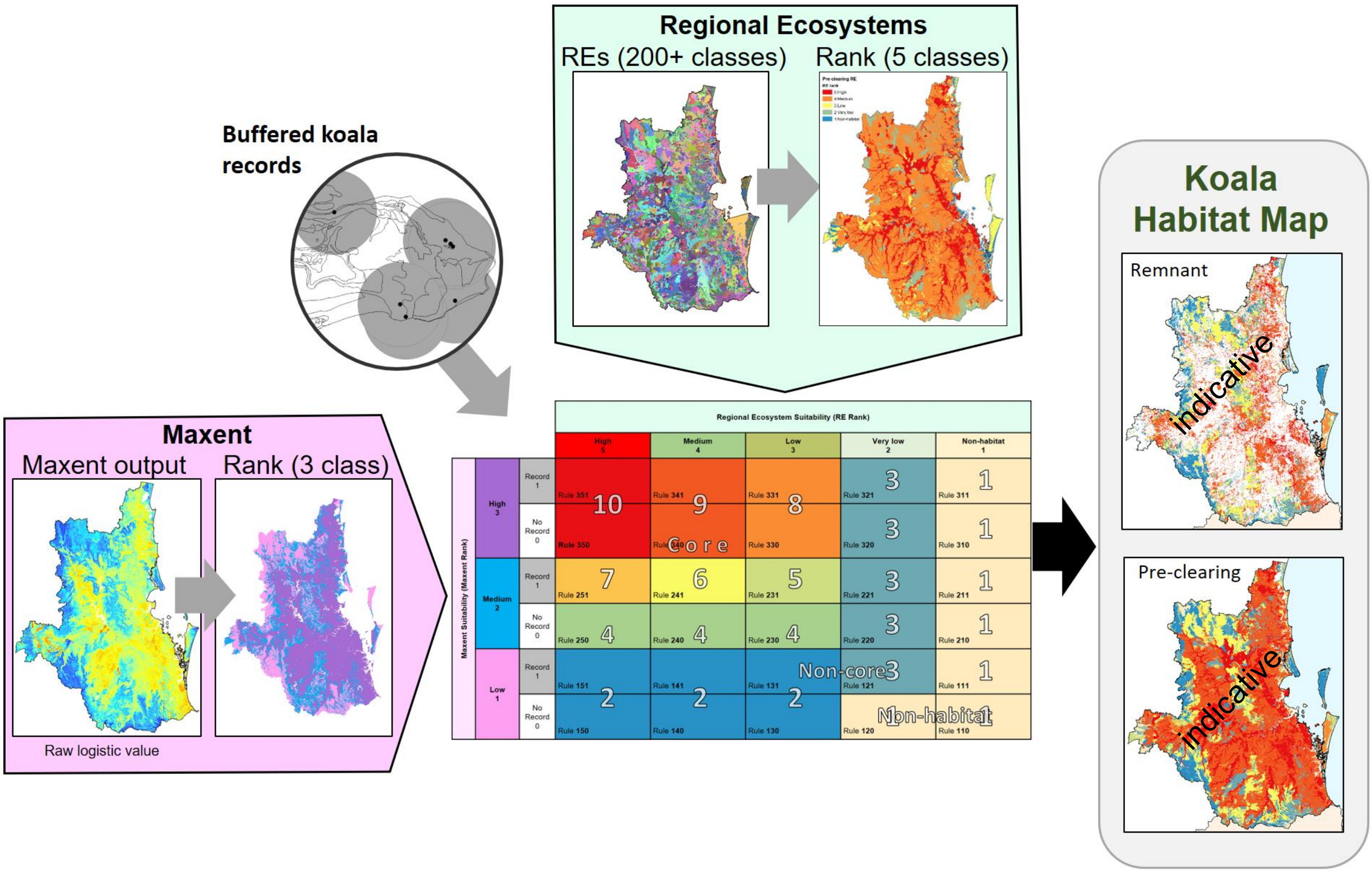


Figure 3: Modelling approach used in identifying koala habitat suitability. (Note, maps are indicative only).

2.2 Data sources

The mapping used an extensive set of spatial data layers that were chosen based on their known and potential relationships with koala distribution and abundance. The data layers represented key biophysical drivers of koala habitat. To ensure the method was repeatable, transparent and more broadly applicable, a further consideration for inclusion of data layers was based on availability and the need for datasets to be broadly mapped across the whole study area, approved and published on the Queensland Government Spatial Information Resource (SIR) data repository and hence likely to be available should they be needed for future analysis. All data sets were prepared using ArcGIS software (ESRI Redlands, CA, USA).

To undertake the analysis, data was organised into three tiers: criteria, indicators, and measures. For the koala habitat criterion, environmental measures (variables) represented indicators of vegetation, terrain, soil, climate, landcover, and groundwater (Figure 4).

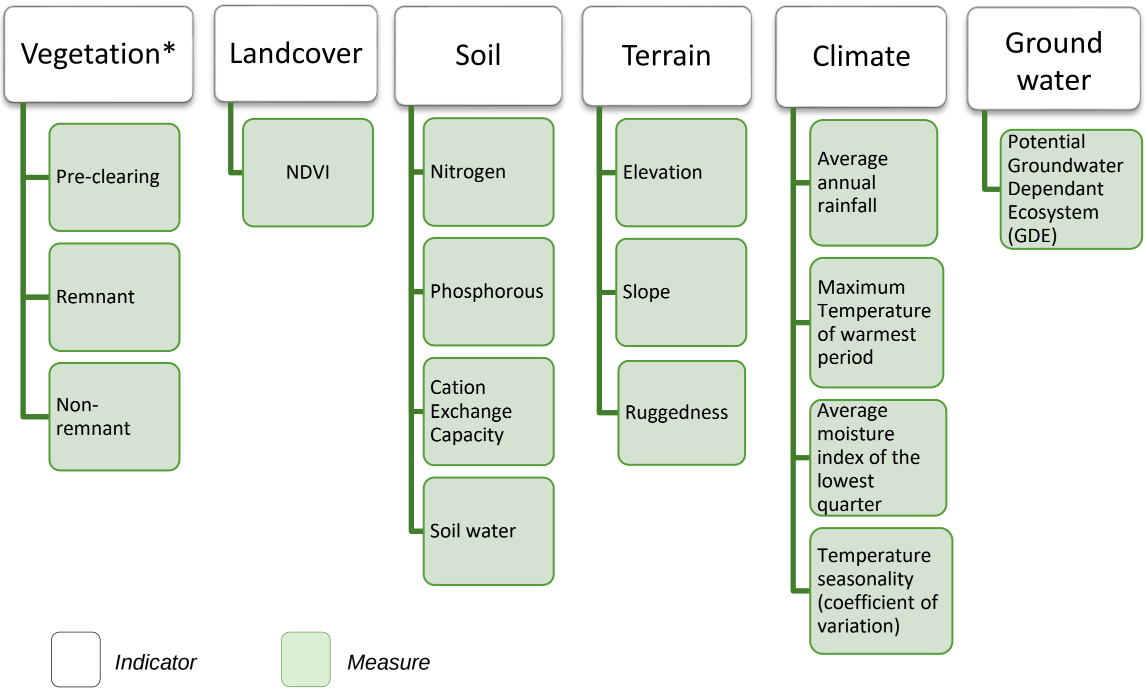


Figure 4: Indicators and measures used for the habitat criterion in the koala habitat spatial model.

*Vegetation was considered in the matrix stage; all other measures were considered in the Maxent modelling.

2.3 Koala occurrence records

Koala occurrence records were collated and vetted prior to producing a dataset with 94,878 records with coordinate precision ≤ 900m and year of observation between 1975 and 2022 (inclusive)[1]. Of the records used, 95% were collected after 1995. Records were vetted for spatial accuracy and duplicates removed before being subset to obtain a dataset for the SEQ study area (Figure 5). The majority of the records had a recorded coordinate precision better than 500m. Records were collated from numerous sources, including WildNet, KoalaBase, DES databases, Local Governments, Community Action Groups, Atlas of Living Australia and research papers. A much smaller, random subset of spatially filtered records was used to reduce survey bias during the development of the Maxent model (Appendix 4).

To construct the habitat matrix the koala records were buffered by 900m to create a polygon dataset representing the full set of vetted occurrence records. The buffered koala records dataset was then intersected with regional ecosystem polygons. The presence (1) or absence (0) of the koala record buffer was recorded in the attributes for every regional ecosystem polygon to facilitate interrogation and increase data transparency. A 900m buffer was used because it is equivalent to the coordinate precision used in the record vetting process and in other habitat suitability models (EPA 2004). The buffer diameter of 1800m is close to the median dispersal distance of approximately 2km recorded for koalas in South East Queensland (Dique et al. 2003) and representative of a home range of 254ha, similar to a large home range of 296ha recorded for koalas in central Queensland (Ellis et al. 2002).

[1] Using fauna records collected since (and including) 1975 and with a coordinate precision less than and including 900m is consistent with existing habitat suitability modelling and the biodiversity assessment mapping methodology (EPA 2004; DEHP 2014).

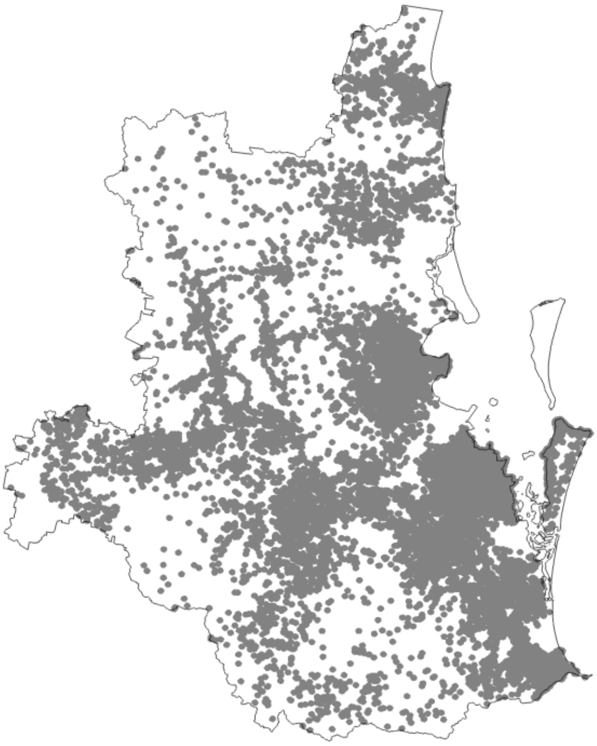


Figure 5: Koala occurrence records buffers.

2.4 Regional ecosystem suitability categorisation

The regional ecosystem classification ranked the koala habitat suitability of every regional ecosystem occurring in the study area. This was achieved by consulting koala experts from the KAG and assisted by information relating to the presence and relative dominance of trees used by koalas (utility), the number of koala records for each regional ecosystem, the percentage of regional ecosystem polygons with koala records and a number of other metrics.

2.4.1 Regional ecosystem suitability classification

The presence and relative dominance of high utility koala tree species within the regional ecosystem was used to help experts classify each regional ecosystem into one of five suitability classes: high, medium, low, very low and non-habitat. The initial regional ecosystem description and details of the tree species were obtained from the Regional Ecosystem Description Database (REDD version 10; Queensland Herbarium 2016). The experts were also supplied with a number of metrics to further assist with their categorisation. It was recognised that any proportional metric (such as the proportion of polygons with koala records) would favour a smaller denominator, consequently a number of metrics were supplied, including: the number of koala records within each regional ecosystem (favours large regional ecosystems); total area of regional ecosystem; number of koala records per hectare (favours small regional ecosystems); number of polygons per regional ecosystem; proportion of polygons with koala records (favours regional ecosystems with fewer polygons).

For example, if a regional ecosystem consisting of 150 polygons had 60 koala records recorded from 30 polygons, then the percentage of polygons with koala records would be 20%. To ensure consistency, the regional ecosystem suitability classification obtained from the experts was checked against previous rankings obtained from other koala habitat models (EHP 2016). Any discrepancies were flagged for further detailed examination and provided to the KAG for feedback. See Appendix 2 for the results of the regional ecosystem classification.

2.4.2 Tree species utility

The tree species utility classification ranked the usefulness to koalas of every tree species occurring in the study area. The process involved classifying the tree species listed in the full regional ecosystem descriptions from the Regional Ecosystem Description Database into one of four utility classes (Table 1). The classification used published literature as a definitive source, secondary sources, anecdotal, expert opinion and published factsheets. The initial assessment was conducted using REDD v10 (Queensland Herbarium, 2016) and subsequently updated. See Appendix 3 for the results of the tree utility classification and information sources.

Table 1: Koala tree species utility classes used by the experts to help rank the suitability of regional ecosystems.

Tree species utility class	Description
Higher	Species referred to in a variety of reports and literature, the majority of which were definitive studies, described as being an important utility species for koala.
Medium	Species referred to in some reports and literature, can be secondary or anecdotal reference to species used by koalas e.g. species included in a factsheet.
Lower	Species not referred to in any literature or considered a trace food species for koalas from a definitive study, and/or eucalypt.
None or unknown	Species not referred to in any literature, not eucalypt, melaleuca or lophostemon.

2.4.3 Vegetation cover classes

Recognising the importance of both remnant and non-remnant habitat to koalas, the habitat model was applied to pre-clearing and remnant vegetation (as delineated by the Queensland Herbarium, DES) and non-remnant regrowth vegetation (Appendix 1). Recent and historical clearing has often focussed on the low-lying alluvial, highly productive areas in the landscape which frequently coincided with the best habitat for koalas. As a result, much of the remnant vegetation now only occurs in lower productivity areas, such as the dry hills and ranges, which are often less suitable habitat for koalas. Koalas are known to prefer palatable vegetation and may in fact preferentially select individual trees or regrowth vegetation because these areas often have a larger proportion of young trees with more palatable leaves and higher nutritional value than mature remnant forest with large trees (Braithwaite et al. 1984; Cork et al. 1990; Cork and Braithwaite 1996; Cork et al. 2000; Moore et al. 2004; Lunney et al. 2000). The ability to identify different vegetation cover classes was considered important for management where areas of regrowth could be focal points for potential habitat restoration efforts. Consequently, the koala habitat mapping was applied across three different vegetation datasets, as follows:

1. **Pre-clearing**

   Pre-clearing vegetation is defined as the vegetation present before clearing and represents the pre-European vegetation prior to major impacts by non-indigenous people. Pre-clearing vegetation is mapped by the Queensland Herbarium, DES, using historical aerial photographs in conjunction with field surveys as described in Neldner et al. (2019).

2. **Remnant**

   Woody vegetation is mapped as remnant where the dominant canopy has greater than 70% of the height and greater than 50% of the cover relative to the undisturbed height and cover of that stratum and is dominated by species characteristic of the vegetation's undisturbed canopy. Remnant vegetation is mapped by the Queensland Herbarium, DES, using aerial photography and Landsat TM satellite imagery supplied by SLATS in conjunction with field surveys as described in Neldner et al. (2019).

3. **Regrowth**

   Regrowth is non-remnant vegetation that has a significant woody component but fails to meet the structural and/or floristic characteristics of remnant vegetation. It includes vegetation that has regrown after clearing or vegetation that has been heavily thinned or logged but may retain significant biodiversity values (Neldner et al. 2019). High Value Regrowth (HVR) mapping represents high conservation value native woody vegetation that has not been cleared for at least 15 years. The regrowth layer was attributed with the regional ecosystems and koala habitat suitability rankings from the pre-clearing RE mapping.

2.5 Species distribution modelling

2.5.1 Maxent modelling

Koala habitat suitability was modelled using maximum entropy species geographic distribution modelling software (Maxent). Other species modelling approaches were investigated, however, Maxent was recommended by the KEP and considered to be the most applicable approach given that the majority of records across the study region were non-systematic and consisted of occurrence records rather than systematic surveys that include absence data and information on prevalence. Maxent is a widely used machine learning program for generating species distribution models based on presence-only species records (Elith et al*.* 2006; Phillips et al. 2006). It has gained popularity for use in species modelling due to its ability to make predictions from incomplete information, such as the common scenario where systematic survey data is not available. Maxent predicts species occurrences by comparing the biophysical attributes at presence locations with a large sample of background point locations randomly generated across the study area.

In consultation with the KEP and KAG, the project team undertook an extensive process of compiling environmental variables (measures) on the basis of known or hypothesised links to koala habitat and ecology (see Rhodes et al 2015). Additionally, data sources needed to be available and mapped at an appropriate resolution (scale) across the study area. The environmental measures represented indicators of terrain, soil, climate, landcover, vegetation and groundwater (Table 2). An examination of correlations among the candidate measures and a pilot Maxent analysis were used to reduce the initial set of 18 variables to a final set of 13 measures used to build the model (Appendix 4). Following trials using a bias grid and spatial filtering at three spatial scales, a 2km hexagon grid (400ha) was used to reduce survey bias in the occurrence records prior to modelling using a 1ha (100m x 100m) grid cell with 1364 presence records and 10,000 randomly generated background points. For details of the Maxent modelling see Appendix 4.

Table 2: The final set of explanatory measures used in the Maxent model.

Indicator	Measure	Measure code	Short description
Soil	Nitrogen	hsnit	Mean mass fraction of total nitrogen in the soil by weight (%)
Soil	Phosphorous	hspho	Mean mass fraction of total phosphorus in the soil by weight (%)
Soil	Cation Exchange Capacity (CEC)	hscec	Concentrations of cations (cmol (+)/kg)
Soil	Soil water	hswat	Mean plant available water (mm)
Terrain	Elevation	htele	Mean altitude (m)
Terrain	Slope	htslo	Mean slope (degrees)
Terrain	Ruggedness	htrug	Topographic ruggedness (index)
Climate	Rainfall	hcapr	Annual average mean precipitation per year (mm/year)
Climate	Temperature	hctem	Maximum temperature of warmest period (°C)
Climate	Moisture index	hcmil	Moisture index - lowest quarter mean (index)
Climate	Temperature seasonality	hctsv	Temperature coefficient of variation (index)
Landcover	Normalised Difference Vegetation Index (NDVI)	hlndv	Representing living green vegetation (index)
Ground water	Groundwater Dependant Ecosystem (GDE)	hgpot	Ecosystems which require access to groundwater on a permanent or intermittent basis (category)

To construct the habitat matrix, the Maxent logistic values[2] from the model output were categorised into three classes (high, medium and low) representing koala habitat suitability based on a high and low logistic threshold (Table 3).

Table 3: Classification of Maxent logistic values used for constructing the habitat matrix.

Maxent classification rank	Maxent logistic value
3. High	0.460 – 1
2. Medium	0.299 – 0.459
1. Low	0 – 0.298

2.5.2 Maxent model validation

The accuracy of the Maxent model was assessed by creating a confidence map using 100 repetitions of the Maxent model (from a random sample of koala records) and repeated sub-sampling. Sub-sampling was undertaken whereby the presence points were repeatedly split into random training and testing subsets, with 80% of occurrence records used to train the model and 20% used to test the model (an approach cautiously supported by Araújo et al. 2005). Assessments were made using: (a) area under the ROC (receiver operating characteristic) curve (AUC) as a measure of model performance, (b) analysis of the variability associated with the predictor variables, (c) analysis of the response curves of the predictor variables, (d) mean habitat suitability and standard deviation, (e) visual interpretation of mapped predictions. For results of model validation see Appendix 4.

2.6 Koala habitat decision matrix

A koala habitat decision matrix (Stage 3) was used to create the koala habitat map by integrating the categorised output from the Maxent model (Stage 2) with the RE suitability classification and buffered koala records (Stage 1). The decision matrix established the rules for categorising different classes of koala habitat and to designate **core habitat** based on the application of the koala habitat decision matrix rules (Figure 6).

These rules were based on those applied in other koala habitat models (EPA 2004, EHP 2016) and through consultation with the KAG. The koala occurrence records, buffered by 900m, were used to confirm the likelihood of known and possible koala habitat and differentiate between core habitat and non-core habitat. The original 30 rules were grouped into 10 ranked from lowest suitability (rank 1) to the highest (rank 10)[3] (Figure 7).

Core habitat – matrix categories 4 to 10

Core habitat refers to the best habitat for koalas, based on the combination of biophysical measures, suitable vegetation and koala occurrence records. Core habitat was delineated where there was

---

[2] The threshold between high and medium suitability was defined using the logistic value at which the sum of sensitivity and specificity is maximized (Liu et al. 2005; 2013). This approach minimizes the mean error rate for positive observations and the error rate for negative observations (false positives and false negatives) and is equivalent to finding the point on the receiver operating characteristic (ROC) curve whose tangent has a slope of one (Cantor et al. 1999; Freeman and Moisen 2008). The threshold between medium and low suitability was defined using the logistic threshold representing the 10 percentile training presence (Liu et al. 2005; 2013). This threshold defines the minimum probability of suitable habitat and using this threshold defines suitable habitat to include 90% of the data used to develop the model (Liu et al. 2005; Young et al. 2011). Low suitability was defined as logistic values below the 10 percentile training presence.

[3] The full koala habitat model included **Non-core (marginal habitat) - matrix category 2 which r**epresents areas of lower quality habitat that koalas can use but which are unlikely to sustain koala populations in the long term because of limiting environmental conditions; **Non-core (rainforest habitat) - matrix category 3** which **r**epresents habitat used by koalas for shelter and short-term refuge from threats and stressors such as heat and fire; and **Non-habitat– matrix category 1,** which refers to areas such as rock pavements, grasslands and mangroves that are considered very unlikely to provide habitat or contain koalas. Koalas may occasionally be present in these areas, however, the areas do not represent koala habitat.

agreement between the REs ranked high, medium or low suitability by the KAG and Maxent areas ranked high or medium suitability (with or without a koala record).

2.6.1 Koala habitat map

To produce the final koala habitat map (see Figure 3), the koala habitat categories from the decision matrix were allocated to the current regional ecosystem mapping units. Every regional ecosystem polygon was assigned a koala habitat value according to the rules in the decision matrix. The regional ecosystem mapping units and line-work were not altered, instead, each polygon was attributed with values associated with its utility to koalas. Using the regional ecosystem mapping as the point of truth ensured consistency with existing statutory instruments, such as Essential Habitat under the VM Act, which designates regional ecosystems as a mandatory essential habitat factor for koalas.

To increase the transparency of the model, each regional ecosystem polygon was attributed with its decision rule, regional ecosystem suitability (rank 1–5), Maxent suitability (rank 1–3) and presence or absence of a koala record buffer (1 or 0 respectively). For homogenous regional ecosystem polygons (containing only a single regional ecosystem), it was a straightforward process of assigning the regional ecosystem suitability designated by the experts directly to the polygon (see Appendix 2).

For heterogeneous polygons (containing more than one regional ecosystem), assigning the regional ecosystem suitability was achieved by attributing the polygon with the highest regional ecosystem suitability category represented in the polygon. Given that the Queensland Herbarium prescribe that a vegetation unit must occupy at least 5% of a polygon in order to be mapped, this effectively means that the regional ecosystem suitability given to a heterogeneous polygons was achieved using a 5% allocation threshold. For example, a heterogeneous polygon that consisted of 5% high and 95% low ranked regional ecosystems would be categorised as high rank. From an ecological perspective, if a polygon was heterogeneous then a koala is likely to use the favourable habitat components even if they occupy only a small proportion of the polygon. Consequently, using a precautionary approach, heterogeneous polygons containing small proportions of favourable conditions should be regarded as koala habitat.

The translation of raster Maxent values into vector regional ecosystem polygons was achieved using a 20% allocation threshold, so that each regional ecosystem polygon was populated with the highest Maxent ranked component that occupied 20% or more of that polygon. For example, a regional ecosystem polygon that consisted of 20% high and 80% low Maxent ranked components would be categorised as high Maxent rank.

The 20% Maxent allocation threshold was chosen to ensure that the majority of known habitat, (i.e. habitat confirmed by buffered koala records) was represented in the mapping. The 20% Maxent threshold captured 95% of the highest suitability koala habitat class and balanced the amount of habitat captured with the amount of known habitat not captured as core habitat. A higher threshold would decrease the total area designated as core habitat at the expense of known high value habitat confirmed by koala records[4]. In this scenario we chose precautionary thresholds to ensure that areas of known habitat were, in the majority of cases, represented in the mapping.

To process the rules, the Maxent output was vectorised (converting the three raster classes into polygons) and intersected with the regional ecosystems and point record buffers. The koala habitat categories were then allocated using the 20% Maxent allocation threshold and the rules established in the habitat matrix.

Recording the matrix components and proportions within the polygon attributes increased the transparency of the model and allows users to drill down though the data table for each regional ecosystem polygon to obtain all the information used by the decision rules to allocate the core koala habitat categories[5].

[4] Other approaches such as simple majority were also examined. Populating the regional ecosystem polygons with the Maxent class occupying the largest proportion of a polygon resulted in the failure of significant areas of known koala habitat being designated as core habitat. For example, if a regional ecosystem polygon was 45% high and 55% low Maxent rank then that polygon would not be designated as core habitat – even though it contained a large proportion of highly suitable habitat.

[5] Processing was undertaken using ArcGIS (version 10.4) and a python script (“fauna – Phascolarctos SEQ political region” in the HSM_Toolbox) developed for this project.

Maxent Suitability (Maxent Rank)		Regional Ecosystem Suitability (RE Rank): High 5	Medium 4	Low 3	Very low 2	Non-habitat 1
High 3	Record 1	Rule 351	Rule 341	Rule 331	Rule 321	Rule 311
High 3	No Record 0	Rule 350	Core Rule 340	Rule 330	Rule 320	Rule 310
Medium 2	Record 1	Rule 251	Rule 241	Rule 231	Rule 221	Rule 211
Medium 2	No Record 0	Rule 250	Rule 240	Rule 230	Rule 220	Rule 210
Low 1	Record 1	Rule 151	Rule 141	Rule 131	Rule 121	Rule 111
Low 1	No Record 0	Rule 150	Rule 140	Non-core Rule 130	Non-habitat Rule 120	Rule 110

Figure 6: Decision matrix and model rules used to define core habitat, non-core habitat and non-habitat.

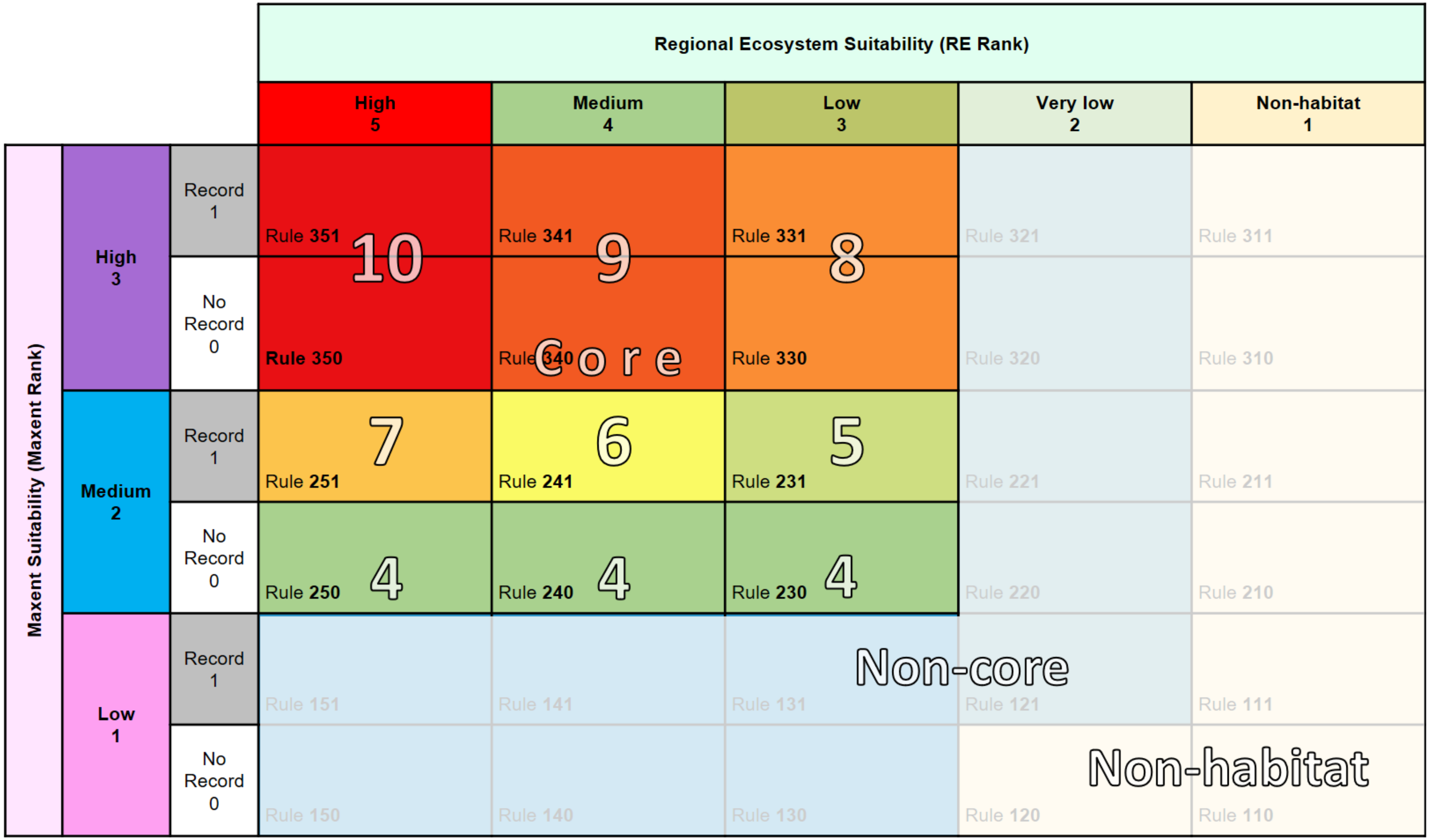


Figure 7: Koala habitat decision matrix and ranked habitat suitability categories.

Decision matrix classes are ordered into 10 categories from (1) lowest suitability to (10) highest suitability. Categories 4–10 represent core habitat, with categories 4 and 5 the lowest suitability core habitat and category 10 the highest suitability core habitat.

2.6.2 Validation of koala habitat mapping

The following approaches were used to assess the accuracy of the draft koala habitat mapping:

1. Point validation – compared an independent set of koala records (n = 264) with the mapped habitat using supplementary koala survey records (not used in model development) sourced from:
   a) GHD field verification (GHD 2009) – 490 points (96 presence, 394 absence).
   b) McAlpine Noosa data (McAlpine et al. 2008) – 300 points (114 presence, 186 absence).
   c) Rhodes SEQ data (Rhodes et al. 2006) – 133 points (54 presence, 74 absence).
2. Stratified random sampling – compared the mapped habitat with high-resolution digital photography using a set of random points. The accuracy of the Koala Habitat Map was assessed using a set of 200 random points which were allocated to the mapped cover types using stratified random sampling as follows: 100 points in remnant and 100 points in non-remnant. Accuracy assessment was made by manually comparing the mapped cover classes representing trees with high resolution, recent imagery provided through the Spatial Imagery Subscription Plan (SISP).

2.7 Results

2.7.1 Regional ecosystem suitability categorisation

The 209 REs occurring in the SEQ study area were classified according to their suitability as koala habitat into five suitability classes shown in Figure 8. The koala habitat suitability of each RE in the SEQ study area and the RE description is given in 0. The extent of each RE class emphasises the strong relationship between high RE suitability and lowland or alluvial landforms, which are preferentially cleared for human uses. For estimates of changes in koala habitat see section 2.7.4.

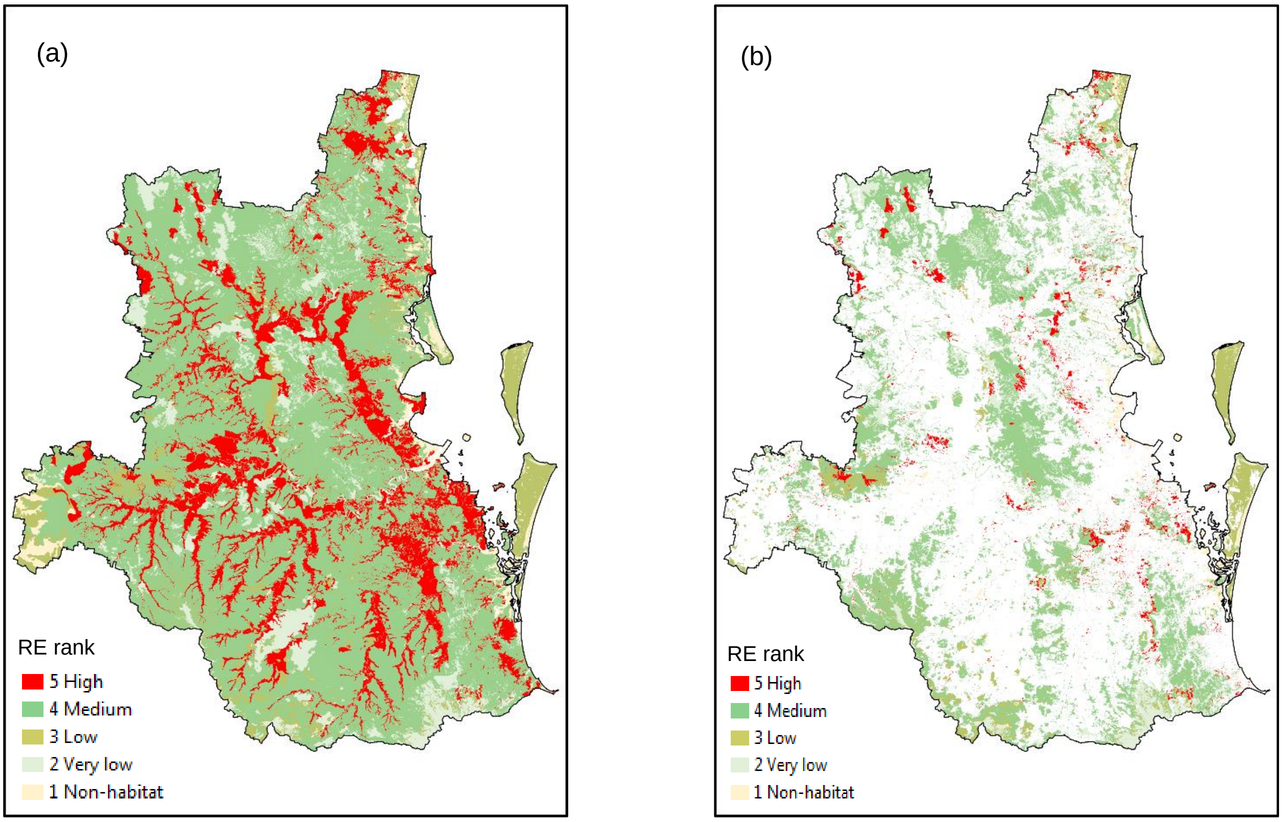


Figure 8: Regional ecosystem suitability classified into five classes. (a) Pre-clearing and (b) and remnant.

2.7.2 Species distribution modelling

Maxent modelling

The AUC in the final Maxent model was 0.737. AUC is a rank-based statistic with values ranging from 0 to 1. A random ranking has, on average, an AUC of 0.5 and a perfect ranking achieves the best possible AUC of 1.0 (Phillips and Dudı´k 2008). Models with an AUC > 0.7 are regarded as having good discriminatory power, although the AUC should not be used as a comparison between species or study areas (Anderson et al. 2011). In the final

Maxent model, elevation (htele) was the largest single predictor of koala habitat suitability, contributing 40% to the model. Elevation is known to be related to temperature and rainfall and is likely to have a distal relationship with the species (i.e. an indirect relationship to the species through correlation with limiting environmental factors; Bradie and Leung 2017). Elevation is likely to be a proxy for the physical drivers of distribution and is still regarded as a useful variable given the aim of this project was to produce the best possible model rather than determine the key drivers of distribution.

The top eight measures contributed 88% to the model and consistently ranked higher than the remaining five measures in all model runs. The remaining five measures each contributed between 2% and 4% to the final model (Table 4).

Table 4: Contribution of the measures to the final Maxent model.

Measure	Measure code	Contribution (%)
Elevation	htele	40.4
Seasonality	hctsv	12.3
Slope	htslo	9.5
Soil water	hswat	5.6
Ruggedness	htrug	5.4
Phosphorus	hspho	5.1
Temperature	hctem	5
GDE	hgpot	4.2
Moisture index	hcmil	3.7
NDVI	hlndv	2.6
Rainfall	hcapr	2.1
Nitrogen	hsnit	2
Cation exchange capacity	hscec	1.9

The modelled koala habitat suitability showed the highest ranked koala habitat was concentrated in the lowland regions of the study area extending along the alluvial flats from the coastal regions through the inland river valleys of the Brisbane, Bremer and Lockyer (Figure 9). Habitat suitability logistic values ranged from low suitability = 0.008 to high suitability = 0.964, mean suitability = 0.453 and standard deviation of suitability = 0.178.

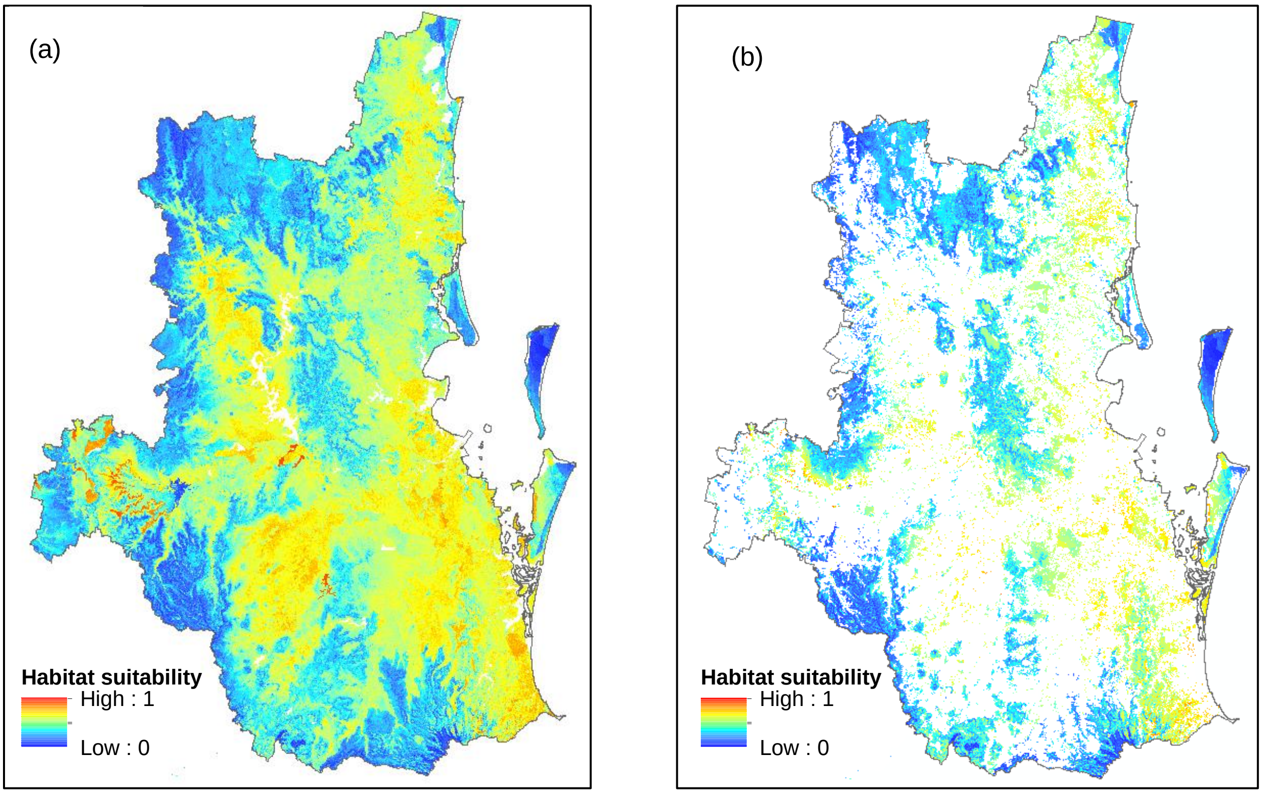


Figure 9: Maxent koala habitat suitability logistic values. (a) Pre-clearing and (b) remnant.

The Maxent model for pre-clearing and remnant habitat, categorised into 3 classes (using the thresholds in Table 3), emphasises the strong relationship between high Maxent suitability and areas of low elevation as well as the extensive clearing of high Maxent suitability areas (Figure 10). The confidence model indicates the confidence associated with the designation of high suitability, medium suitability and low suitability (non-habitat) (Figure 11). The confidence model (map) needs to be viewed in association with the three class Maxent model output (Figure 10). The confidence map shows high confidence in the Maxent model, particularly in the highest koala suitability areas (given a Maxent ranking of 3. High) and low suitability (non-habitat) areas such as Moreton Island.

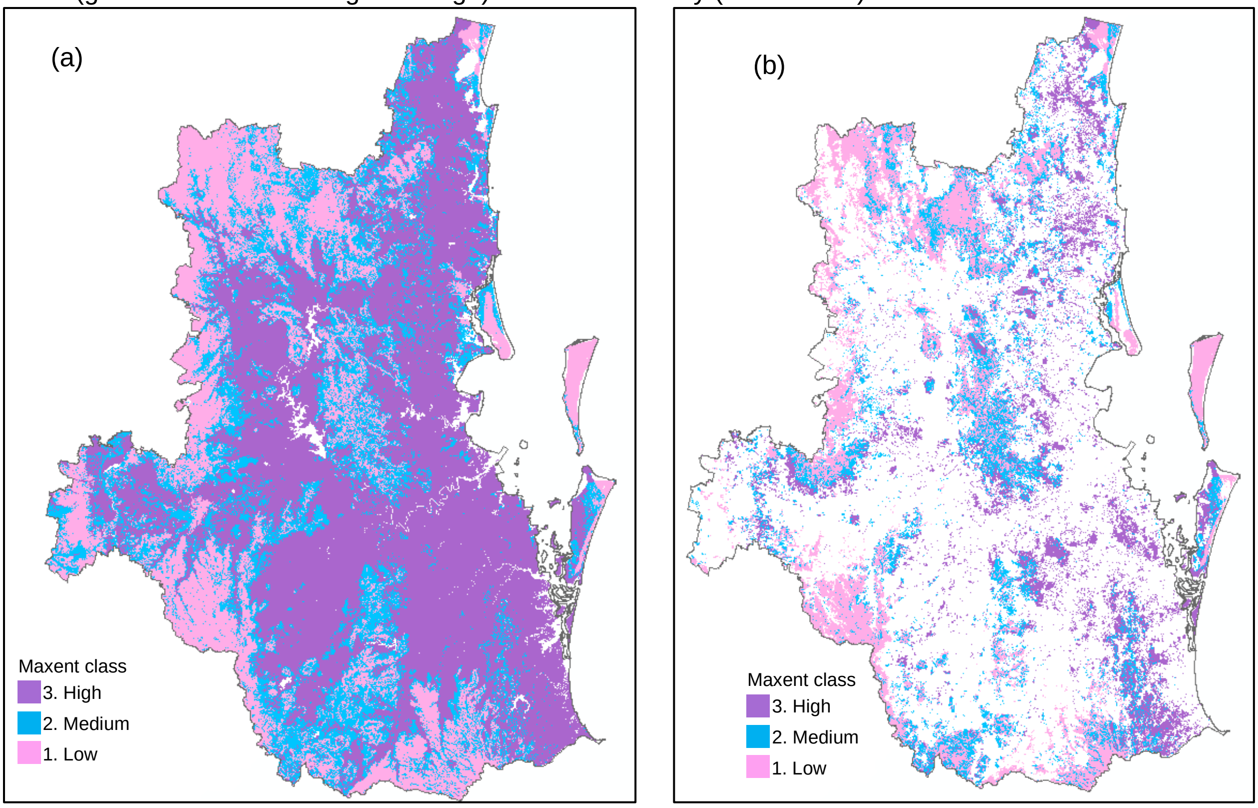


Figure 10: Maxent koala habitat suitability classified into three classes. (a) Pre-clearing and (b) remnant.

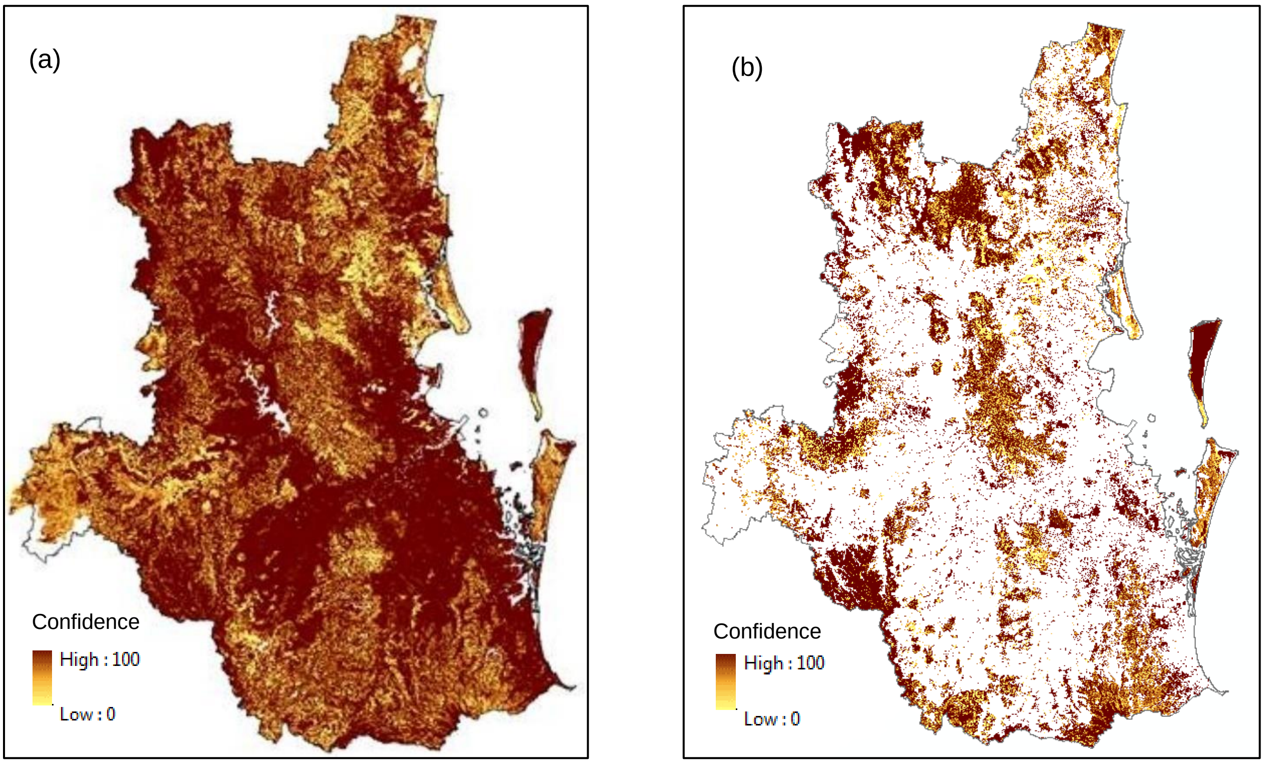


Figure 11: Confidence in Maxent model (version 11.17). (a) Pre-clearing and (b) remnant -

The confidence map was obtained from 100 repetitions of the Maxent model using a random sample of koala records.

2.7.3 Koala habitat decision matrix

The habitat decision matrix areas for pre-clearing and current core koala habitat (remnant and regrowth combined) are shown in Appendix 5.

2.7.4 Koala habitat map

The koala habitat mapping identified 645,822ha of core koala habitat (Map 1), consisting of 511,085ha remnant core koala habitat and 134,737ha regrowth core koala habitat (Map 2 and Table 5). The suitability ranking of the current core koala habitat (from very high suitability to very low suitability) is shown in Map 3. The area of pre-clearing core koala habitat was 1,834,796 (Map 4). This means 72% (1,323,711ha) of core koala habitat has been cleared with 7% regrowing and identified as high value regrowth (Figure 12). The suitability ranking of the pre-clearing core koala habitat (from very high suitability to very low suitability) is shown in Map 5. Of the best quality habitat (ranked very high suitability–category 10), approximately 90% has been cleared, with much of it situated on the high fertility, highly modified alluvial plains (see Map 3, Map 5 and Appendix 5).

Table 5: Extent of pre-clearing and current koala habitat within South East Queensland.

Habitat	Pre-clearing area		Current area		Change[6]	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Remnant core	1,834,796	100%	511,085	28%	-1.323.711	-72%
Regrowth core			134,737	7%	+134,737	+7%
Total core			645,822	35%	-1,189,125	-65%

Due to rounding, numbers may not add up precisely to the totals provided in this table. Area calculated using MGA56.

Due to refinements in the underlying pre-clearing mapping between versions, direct comparisons with previous versions should be treated with caution.

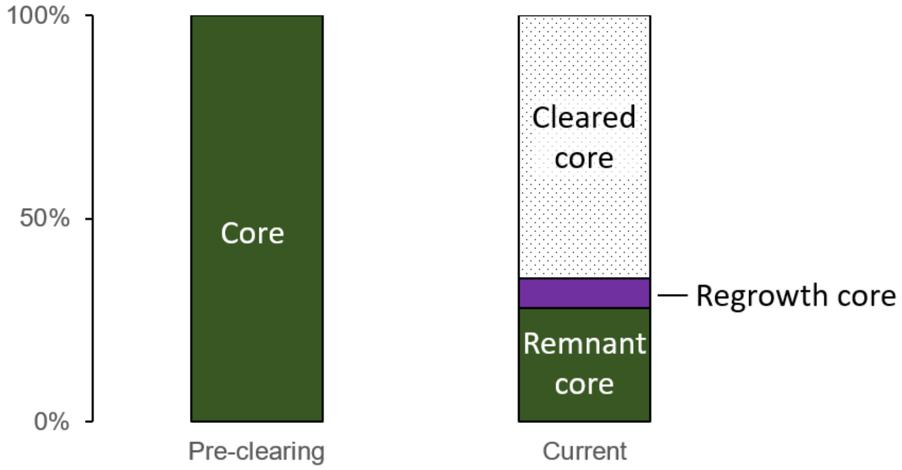
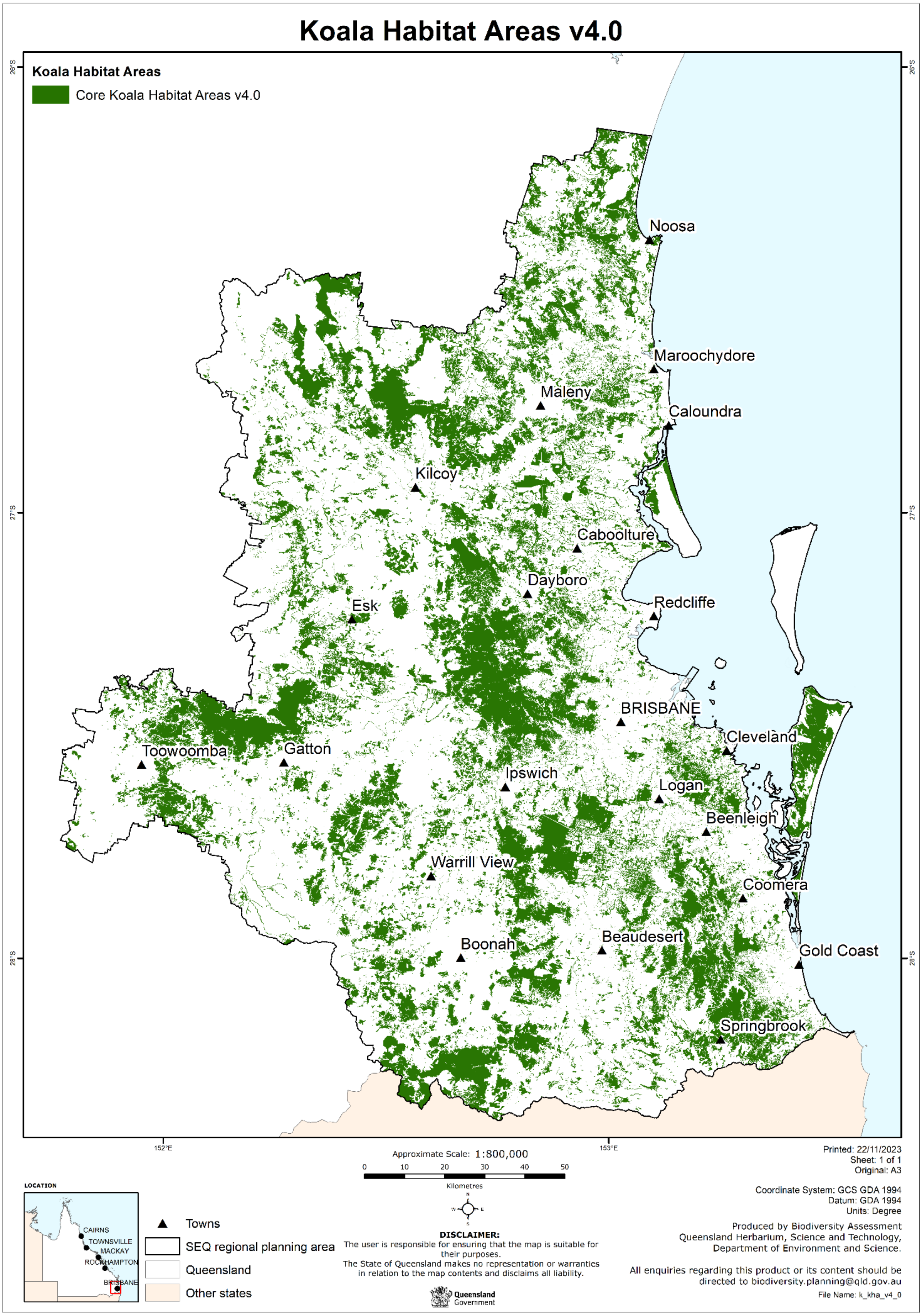
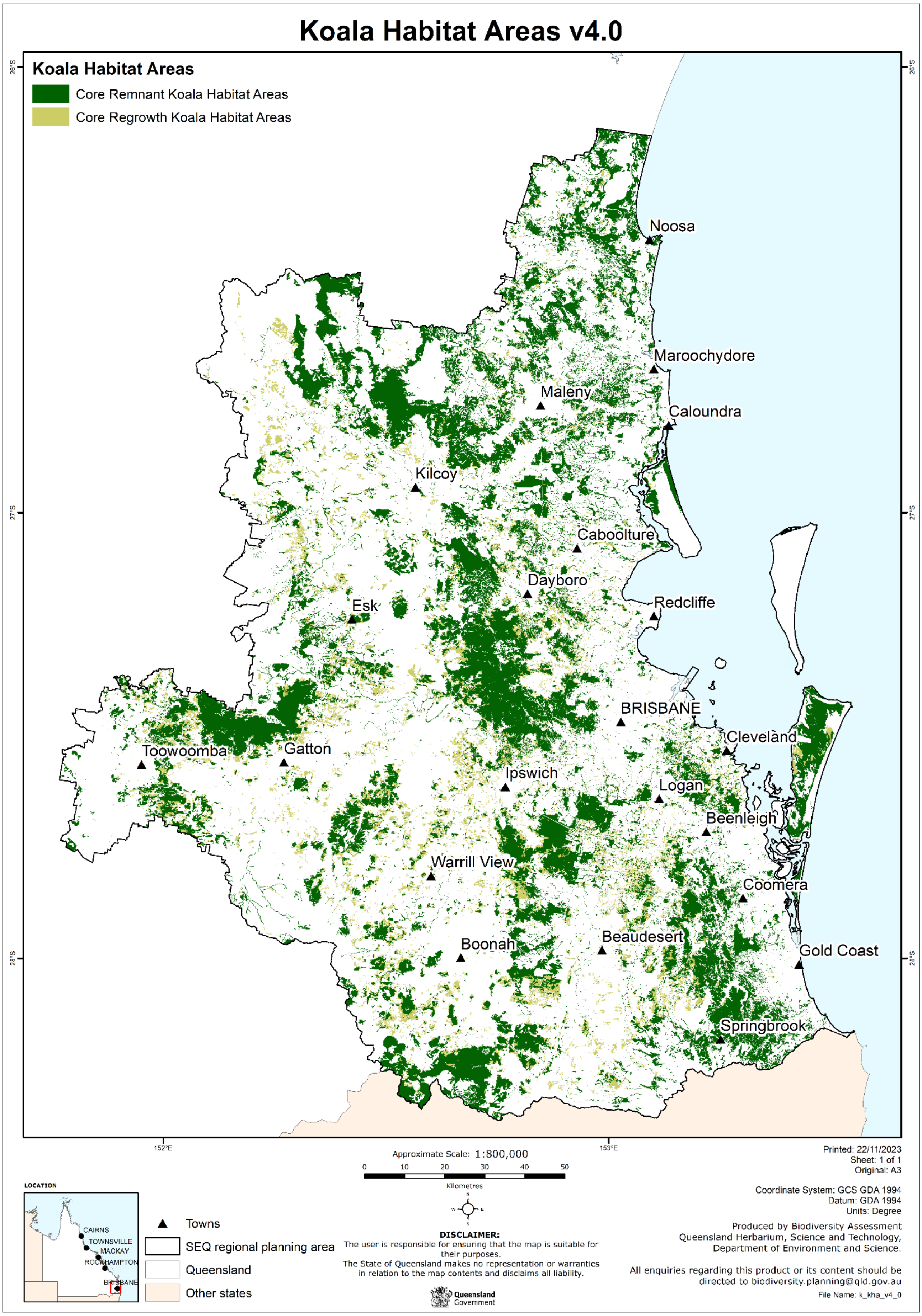


Figure 12: Comparative area of pre-clearing koala habitat and current koala habitat in SEQ.

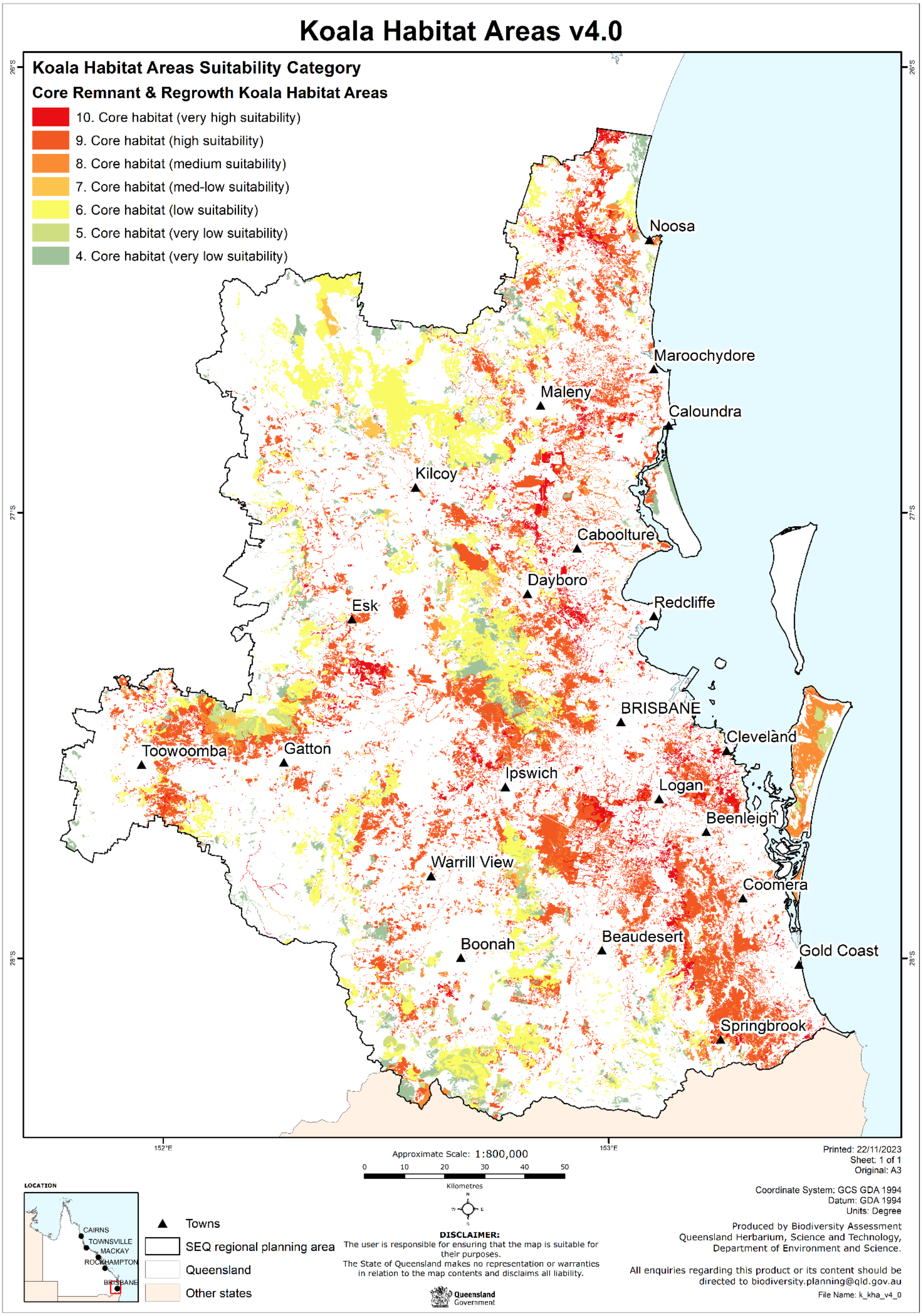
[6] *Difference between pre-clearing and current area.*



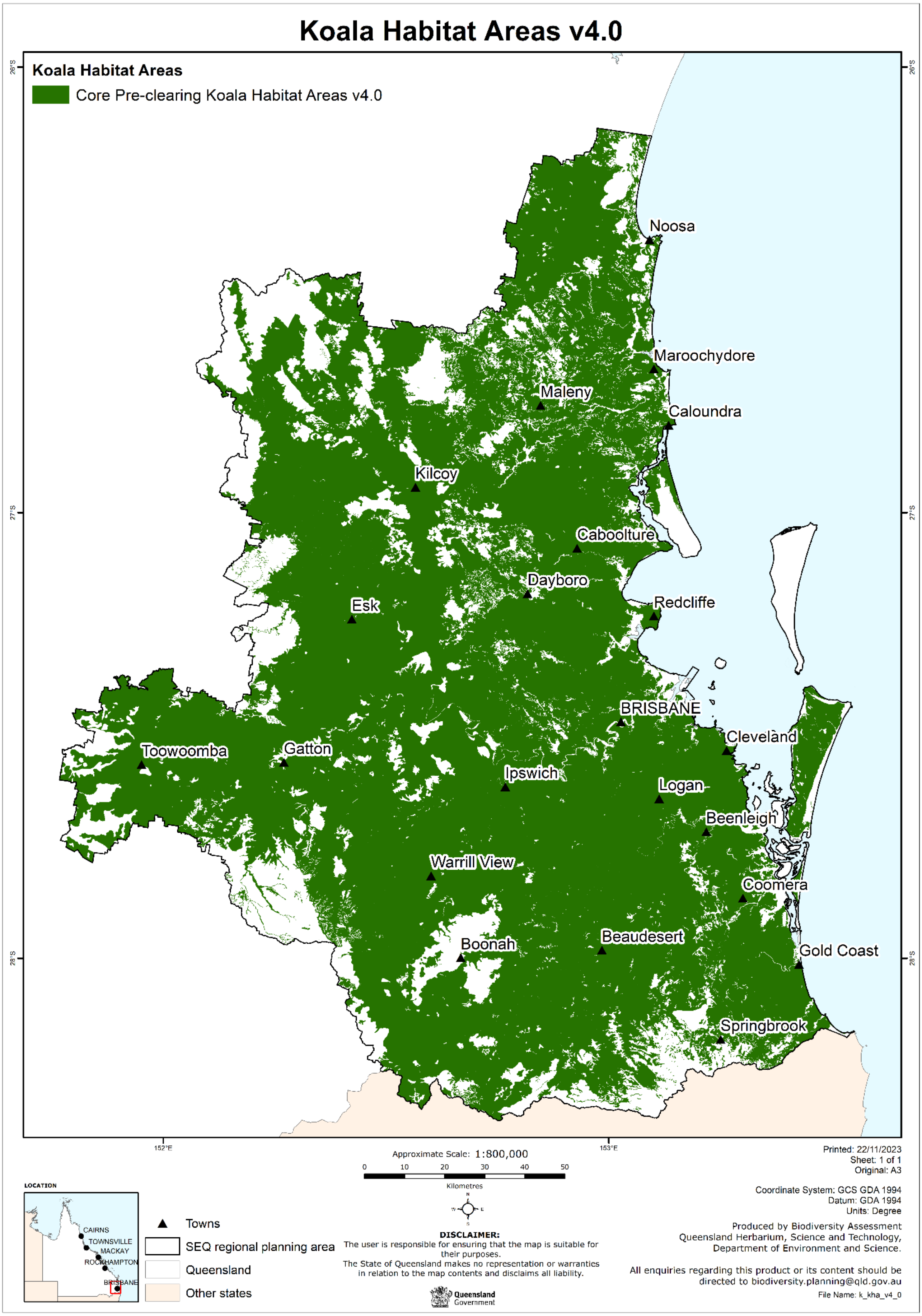
Map 1: Extent of core koala habitat areas (remnant and regrowth combined).



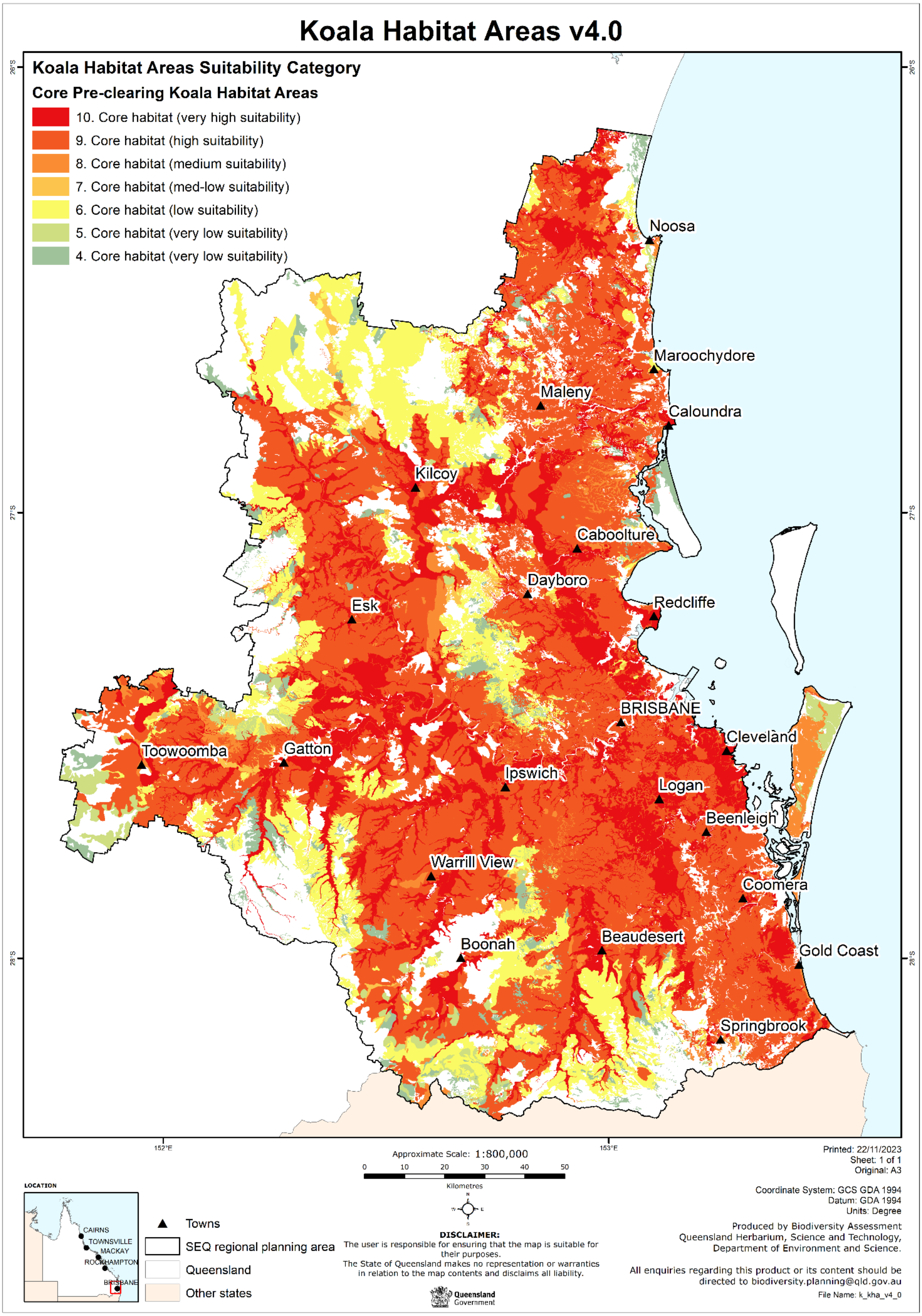
Map 2: Extent of remnant and regrowth core koala habitat areas.



Map 3: Extent of ranked habitat suitability categories for remnant and regrowth core koala habitat areas.



Map 4: Extent of pre-clearing core koala habitat areas.



Map 5: Extent of ranked habitat suitability categories for pre-clearing core koala habitat areas.

2.7.5 Validation of koala habitat mapping

2.7.5.1 Map accuracy: Point validation

Overall map accuracy assessed using point validation from independent koala records supplied by supplementary sources showed a 95% agreement (251/264) with 251 of the 264 field records of koala presence falling in areas mapped as koala habitat (Table 6). Map accuracy was assessed for version 1.0 and is expected to be the same or very similar for subsequent versions.

Table 6: Map accuracy using independent koala records.

Source	Number of koala records falling in areas mapped as habitat (n)	Total number of koala records (n)	Agreement (%)
GHD	88	96	92%
McAlpine	110	114	96%
Rhodes	53	54	98%
Total	**251**	**264**	**95%**

2.7.5.2 Map accuracy: Stratified random sampling

Overall map accuracy for identifying tree cover was 86% (see Table 7). The accuracy of identifying remnant cover was 100% and non-remnant cover was 71%. Combined accuracy for remnant and regrowth cover was 89%. The 100% accuracy in identifying remnant cover is attributed to the Queensland Herbarium's expertise in state-wide, comprehensive vegetation mapping.

Table 7: Map accuracy assessment using stratified random sampling.

Cover	Remnant and non-remnant
Remnant	100% (100/100)
Non-remnant	71% (51/70)
Total	**89% (151/170)**

Values in brackets represent sample size

3 Locally Refined Koala Habitat Areas (LRKHA)

3.1 Approach

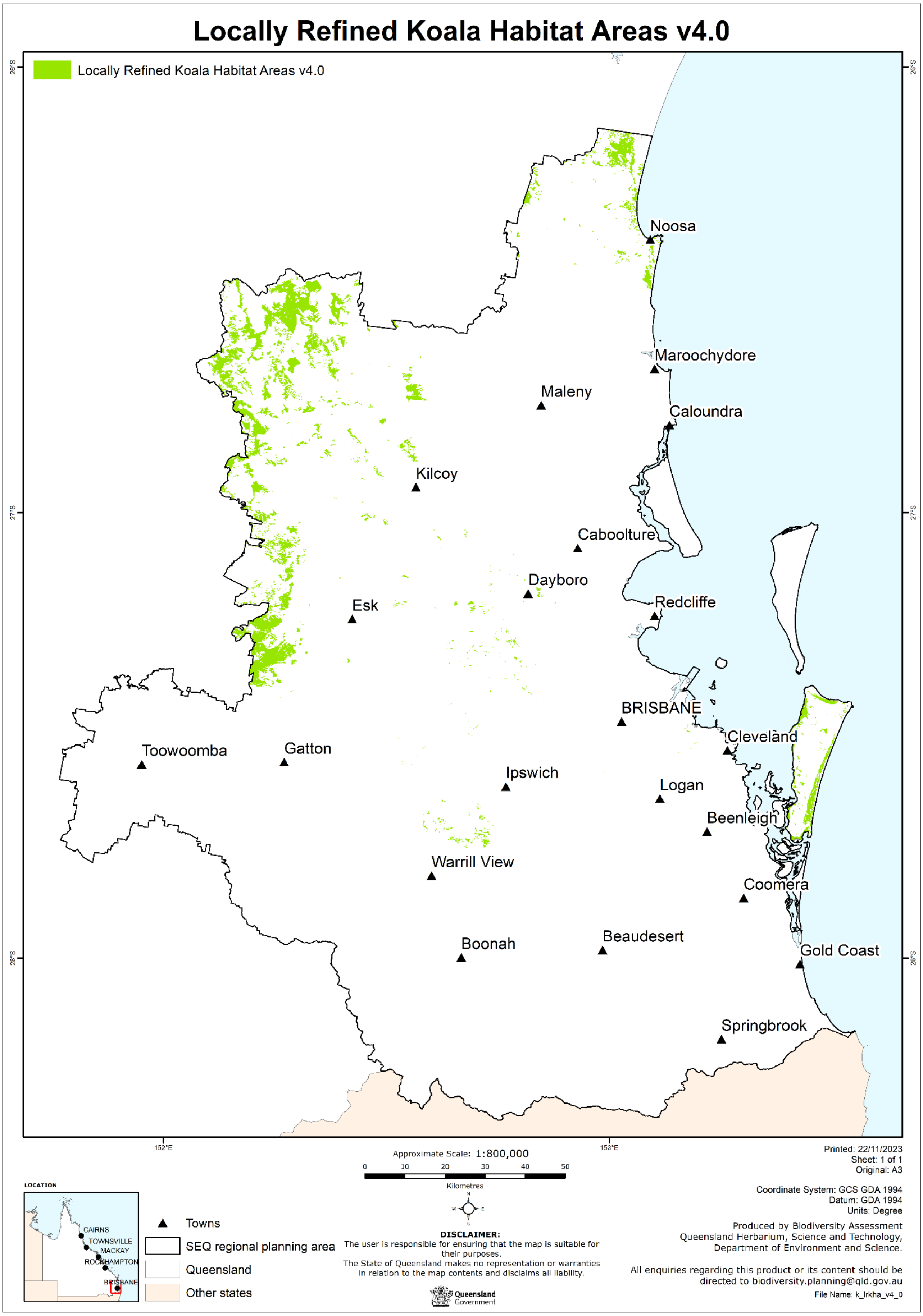
To address the transition of responsibility for koala habitat conservation from local government to state government, local governments were asked to provide locally significant koala habitat areas that formed part of their koala conservation efforts. These areas contributed to the identification of locally refined koala habitat areas (LRKHA).

The datasets from the different LGAs were aligned to remnant and high value regrowth. For version 4.0 the LRKHA layer was updated by removing the following areas from LRKHA v3.0: areas from v3.0 which have now become KHA v4.0 (136ha); areas of HVR which were assessed by the Herbarium in 2021 and didn’t meet the criteria for remnant or high value regrowth and hence were not incorporated into the KHA (49ha); and small areas (less than 0.25ha) and slivers (~2ha). LRKH areas within the Gold Coast City Council boundary have been removed from v4.0 of the mapping at the request of council (132ha) as these areas will be identified and managed through other processes by the council.

The results were attributed with the LGA, source, regulated vegetation management category (RVM v3.05, 27/11/2019) and property map of assessable vegetation (PMAV 07/02/2020). The koala habitat area mapping was used to erase any overlap with the LRKHA. Minor slivers and isolated polygons were removed.

3.2 Results

The area of LRKHA was 60,779ha. The spatial distribution of LRKHA areas is shown in Map 6.



Map 6: Locally refined koala habitat areas (LRKHA)

4 Modelling priority areas for koala conservation

The Koala Expert Panel final report (Rhodes et al. 2017) recommended a more strategic approach to conserving koalas in SEQ, including identifying a network of priority areas in the landscape for koala habitat conservation. Identification of these priority areas included the mapping of threats, constraints, opportunities, and resilience measures, and the use of spatial prioritisation modelling to identify the optimum areas for koala habitat conservation to enhance the long-term viability of koalas within the southern SEQ bioregion. This section focuses on the methods used to identify and select the priority areas.

Spatial data sets that represent direct measures or proxies of threats such as urban development, land clearing, dog attacks, vehicle collisions, fire management, climate change, disease, and reductions in genetic diversity were included in the analyses (Rhodes et al. 2017). Opportunities and resilience measures, such as existing conservation areas and climate refugia, were also considered for their potential to help leverage conservation actions to support viable koala populations.

The spatial modelling and planning for koalas (SMPK) project developed a three part approach to help guide the identification of priority areas for koala conservation in southern SEQ which included:

1. Development of a habitat model in which vegetation, including pre-clearing and remnant regional ecosystems (REs), and non-remnant high value regrowth layers, were ranked based on their suitability for koala habitat (shown in section 2). This model was used to provide the target features to be conserved in prioritisation modelling.
2. Mapping of key threats, constraints and opportunities that may either help or hinder koala survival in a particular patch of habitat. Spatial data sets that represented direct measures or proxies of threats such as urban development, land clearing, dog attacks, vehicle collisions, fire management, climate change, disease, and reductions in genetic diversity (Lee et al. 2010) were included in the analyses (Preece 2007; Rhodes et al. 2017). Opportunities and resilience measures, such as existing conservation areas and climate refugia, were also considered for their potential to help leverage conservation actions to support viable koala populations. These formed an ecological cost layer for prioritisation modelling.
3. Identification of priority areas for koala habitat conservation, using prioritisation software. Marxan was used for prioritisation because it is the most widely used systematic conservation planning software in the world. It allows policy makers and planners to explore different management options and scenarios to design effective conservation areas in mixed-use landscapes (Ardron et al. 2010). The software uses a reserve selection algorithm that optimises the spatial selection of areas based on their contribution to meeting one or more ecological targets at a minimum cost.

4.1 Approach

4.1.1 Threats and constraints

Threats are considered direct and immediate factors that could do physical harm to koalas, while constraints are factors that can limit an area’s ability to support habitat. A conceptual diagram of threats and constraints is shown in Figure 13.

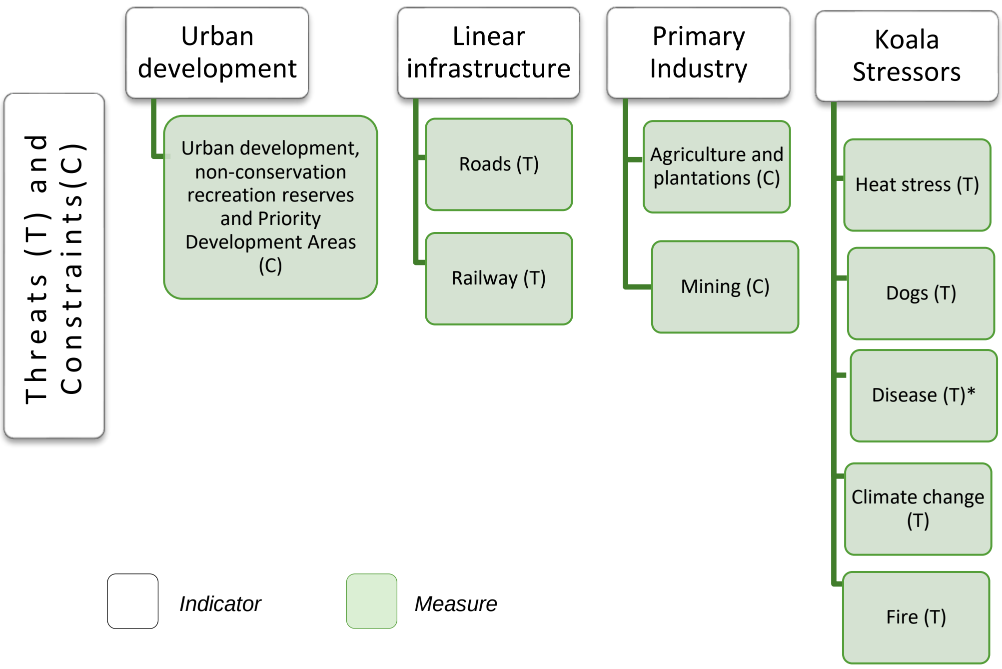


Figure 13: Threats (T) and constraints (C) indicators and measures.

** Not implemented due to absence of spatial data representing koala disease threat*

4.1.2 Opportunities and resilience

Opportunities and resilience represent areas that in combination achieve conservation outcomes by increasing the likelihood of long-term persistence of koalas. Opportunities include existing reserves or areas managed with a conservation intent that offer longer term retention of habitat where koalas can persist. Refugia include areas where koalas can shelter when their wider geographic distribution becomes uninhabitable from the longer-term impacts of climate change and shorter term impacts of bushfires, clearing or extreme weather events such as heatwaves. A conceptual diagram of opportunities and resilience is shown in Figure 14.

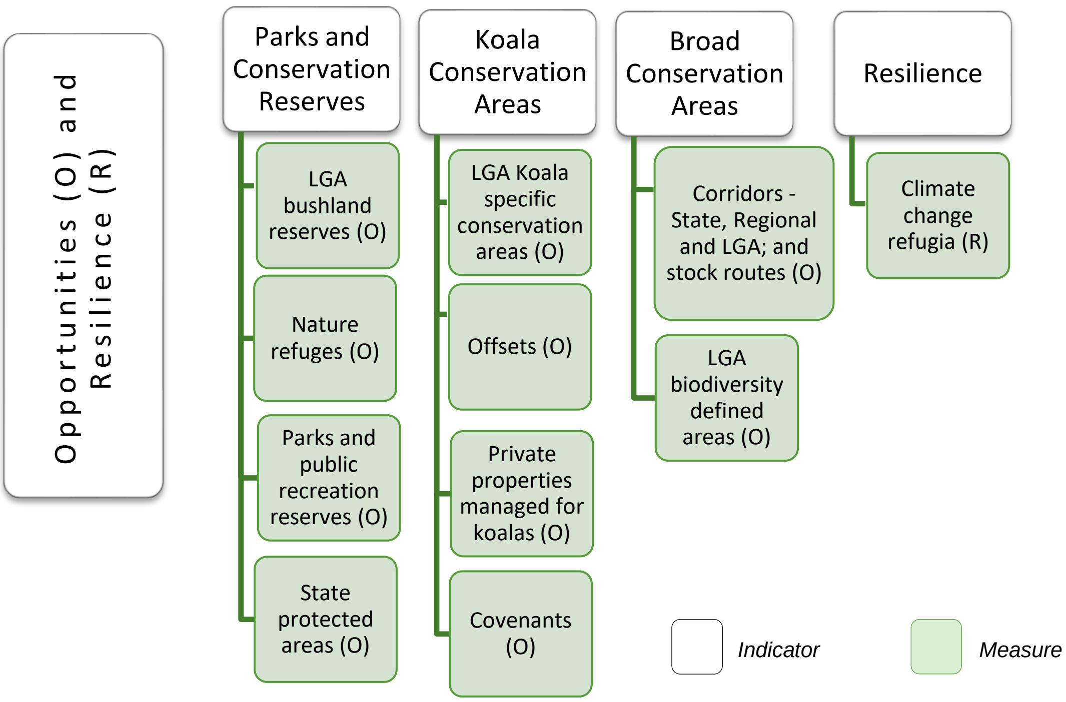


Figure 14: Opportunities (O) and resilience (R) indicators and measures.

4.2 Marxan modelling

A variety of scenarios were explored with Marxan, using different combinations of conservation feature targets and ecological costs, based on threats, constraints and opportunities. Here, we focus on the scenario chosen by DES to identify priority areas for koala conservation (see section 4) using a subset of key variables.

4.2.1 Marxan inputs

The essential inputs for Marxan are conservation features and costs, which are allocated to a set of spatial planning units. Marxan uses a technique called simulated annealing to find near-optimal solutions that meet the conservation target with the minimum number of spatial units and the lowest cost. The simulated annealing algorithm compares spatial units and progressively discards those that do not lower the overall cost while meeting the targets until close-to-optimal solutions are reached. The overall workflow is shown in Appendix 7.

4.2.2 Planning units

To identify the priority areas recommended by the KEP report, the SEQ planning region was divided into 100 ha hexagons (total of 23,929 planning units). The choice of hexagon size was a balance between providing enough detail for meaningful planning and keeping the total number of units at a reasonable level for subsequent spatial analysis.

4.2.3 Conservation features

The conservation features in the chosen scenario were ~230,000 ha of core koala habitat from the koala habitat model developed by the SMPK project. Table 8 shows the conservation targets and Figure 15 shows the distribution of core habitat conservation features. 0 shows details of the habitat suitability decision matrix and habitat mapping used to generate the target conservation features.

Table 8: Conservation targets and habitat types used in Marxan conservation modelling scenario.

Category	Description	Remnant and non-remnant (ha)	Percentage remaining (%)	Marxan targets (ha)	Marxan targets (%)	Penalty factor used in Marxan
10	Very high quality koala habitat with or without sightings	98,025	24.4	63,716	65	20
9	High quality koala habitat with or without sightings	378,307	38.9	94,576	25	10
8	Medium-high quality koala habitat with or without sightings	38,146	66.1	9,536	25	10
7	High quality koala habitat with sightings	11,882	57.6	4,753	40	10
6	Medium-high quality koala habitat with sightings	202,099	74.8	40,419	20	10
5	Very low suitability koala habitat with sightings	20,650	63.1	2,065	10	10
4	Very low suitability koala habitat without sightings	87,725	90.7	13,158	15	10
Totals†		**836,834**	**45.2**	**228,223**		

†Marxan conservation scenario 112, run 3. Based on a draft koala habitat model. Inputs: remnant habitat, regrowth from the offsets program (EHP 2015) and scattered trees koala habitat. Core habitat (suitability categories 4–10).

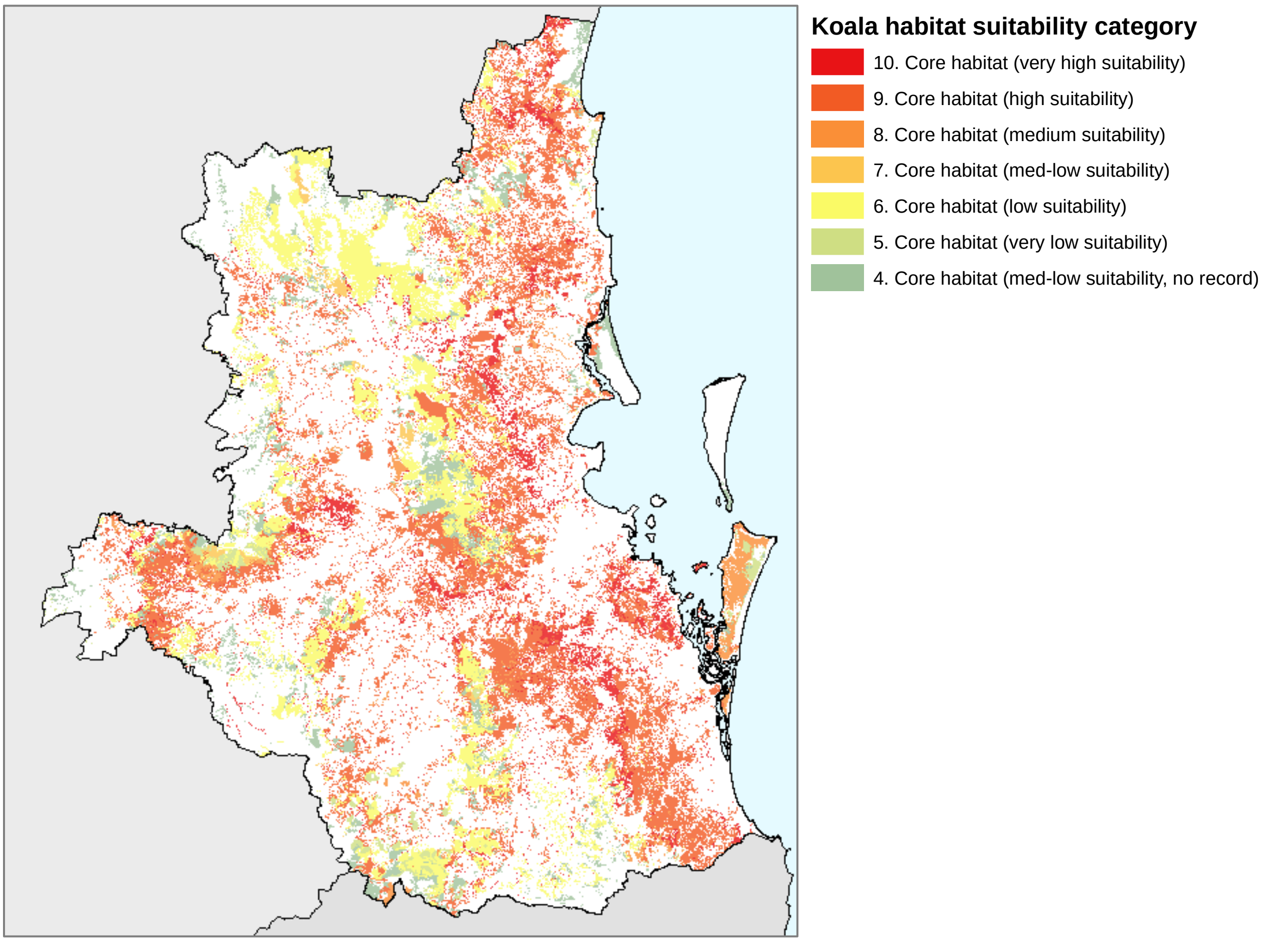


Figure 15: Potential core habitat conservation features available for selection. (Based on a koala habitat model draft).

4.2.4 Ecological cost layer

The cost layer in Marxan can either be monetary, e.g. land value or lost economic opportunity, or non-monetary such as ecological threats from changes in land and resource use (Rebelo et al. 2011; Lötter et al. 2010). The cost layer used in Marxan to identify priority areas for koala habitat conservation was an ecological cost, or a trade-off between threats/constraints and opportunities/resilience (TCOR). Threats are direct and immediate factors that could do physical harm to koalas, such as dog attacks and heat stress, while constraints are factors that could limit an area's ability to support appropriate habitat such as urban development or cropping. Opportunities included existing reserves or areas managed with a conservation intent that offer longer term retention of core habitat where koalas can persist. Resilience identified areas where climate change was less likely to affect koala habitat, from the Maxent model. The ecological cost in Marxan was a single value, comprising different combinations of TCOR elements. Each TCOR variable was normalised to a similar scale with a range of 0 – 1. In the chosen scenario, variables were ranked and weighted, with the weights summing to 1. This is a common method of combining multiple factors with comparable scores (Lötter et al. 2010). Table 9 shows the range of threats, constraints and opportunities that were considered in the chosen scenario. Figure 16 illustrates the spatial distribution of the ecological costs. Maps of the individual costs for the chosen scenario are shown in Appendix 8.

Table 9: Threats (T), constraints (C) and opportunities (O), ranking and weighting.

Threats or Constraints	Ranking	Weighting
• Heat stress (T)	Medium	0.75
• Climate change (T)	Low	0.5
• Urban development (C)	High	1.0
• Extractive industry (C)	Low	0.5
Opportunities		
• Conservation & environmental management (O)#	High	1.0
• Current bushland habitat in KADA and PKADA areas** - all classes (high, medium, low bushland and high and medium rehabilitation) #	High	0.5*
• Habitat adjacent to protected areas (within 5 km)	Low	0.5

Scores for these two opportunities were reversed, so that a high opportunity reflected a low cost, since Marxan preferentially choses lower cost planning units.

* Current bushland opportunities were weighted at 0.5, although they were ranked as highly important, because they covered very limited parts of the region.

** Koala Assessable Development Areas (KADA) and Priority KADA (PKADA)

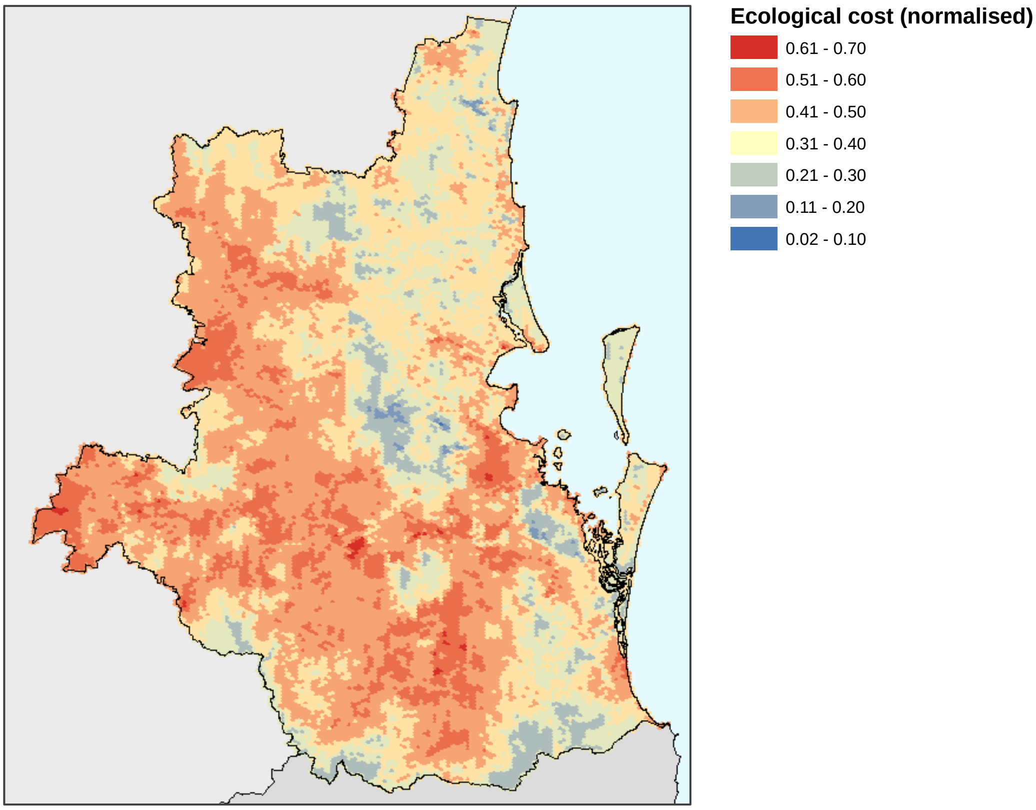


Figure 16: Ecological cost for conservation scenario. Reds represent high ecological costs and blues low ecological costs.

4.2.5 Marxan outputs

The Marxan prioritisation output shows the selection frequency which represents how often each planning unit (100ha hexagon) was included in the solution based on 100 runs, with 10 million iterations for annealing and a boundary length modifier of 10 (Figure 17). This gave a (summed) solution that was moderately clumped but still provided enough choice for stakeholders to tailor on-ground conservation outcomes to the optimisation results. The other input parameter factors were kept as standard. See Appendix 9 for examples of how the conservation targets and ecological costs were calculated, and the resulting Marxan selection frequency.

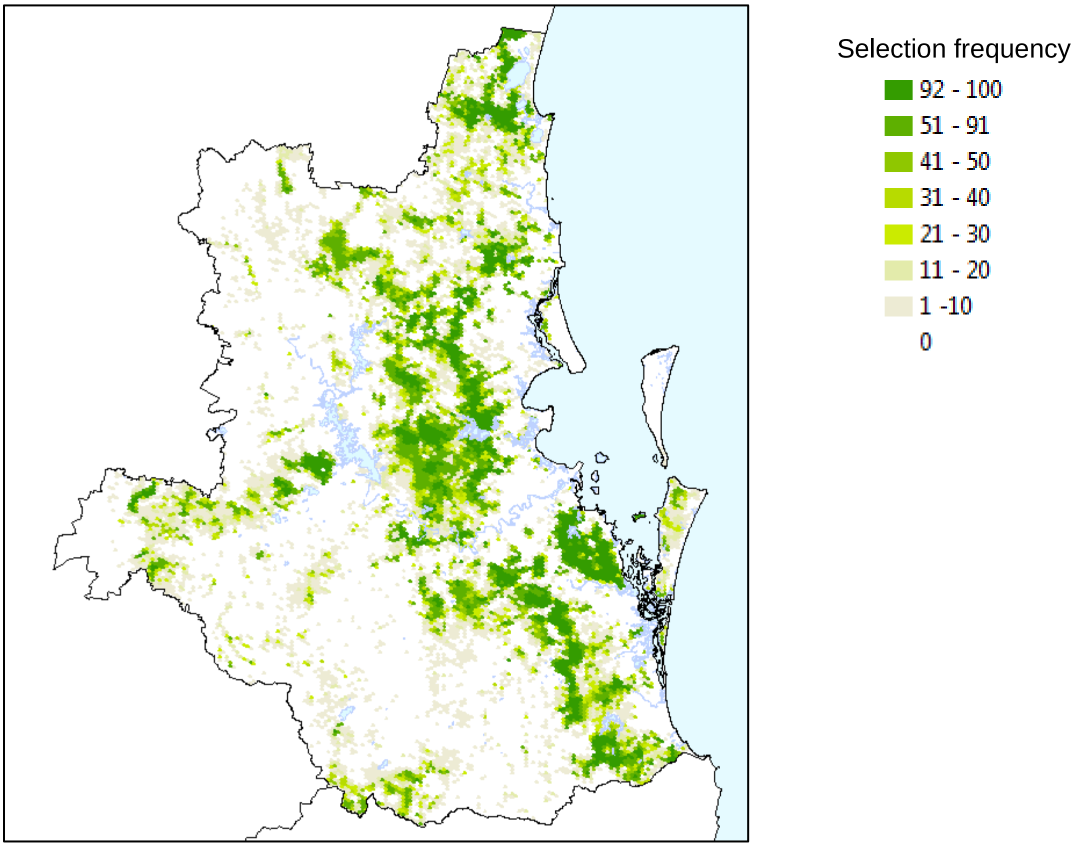


Figure 17: Marxan output showing selection frequencies for the koala habitat conservation scenario.

5 Koala Priority Areas (KPA)

5.1 KPA boundary development

The conservation of koalas depends on conserving areas of habitat that are large enough and/or well-connected enough to maintain viable populations of hundreds or thousands of koalas (Rhodes et al., 2017). The Koala Expert Panel (2017, p. 8) recommended protecting priority areas of “100,000s of hectares” of koala habitat. The Department of Environment and Science aimed to identify a network of priority areas in the landscape for koala habitat conservation where stronger regulatory control over habitat clearing could be implemented. The koala priority areas (KPA) were identified using Marxan prioritisation to develop a habitat protection model where the emphasis was on protecting the highest value remnant and regrowth habitat with low threats (especially urban development) and good opportunities. The Marxan prioritisation output was used as the basis to develop the koala priority areas (KPAs).

5.2 Methodology

The method used interpolation to convert the Marxan model (run 112, scenario 3) from integer cells to a continuous surface and then summarised each cadastral parcel by the interpolated Marxan values found within.

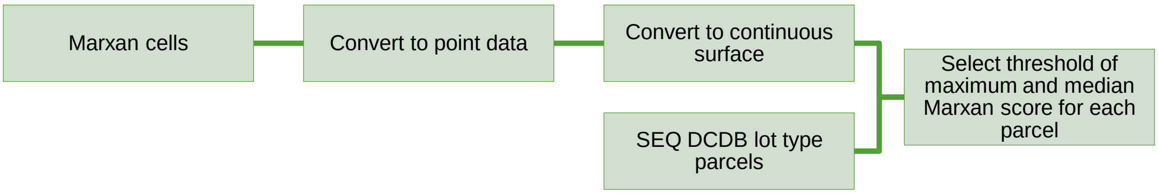


Figure 18: Flowchart of process to develop KPA boundaries.

The selection frequencies in Marxan outputs are a measure of how often a particular cell contributes to meeting the target—in this case, core remnant and regrowth koala habitat. Therefore, a cell with a selection frequency of 50 was chosen 50 times in our 100 run scenario (meaning the cell was chosen 50% of the time). A selection frequency cut off of 40 was used to identify the initial KPA boundaries. The Marxan hexagons were converted into points and a TIN surface was used to interpolate the points into a continuous surface. The TIN surface was converted to the 10 x 10 m grid, and zonal statistics were used to summarise the grid values within each cadastral parcel. Cadastral boundaries for SEQ were taken from the Queensland DCDB spatial data. The maximum score threshold (the highest raster cell value in each parcel) was used to identify whether the property should be inside or outside the KPA area. Parcels with selection frequencies of 40-100 were then aggregated and snapped to the cadastre using a fully automated procedure to produce the first draft (March 2019) KPA boundaries (Figure 19).

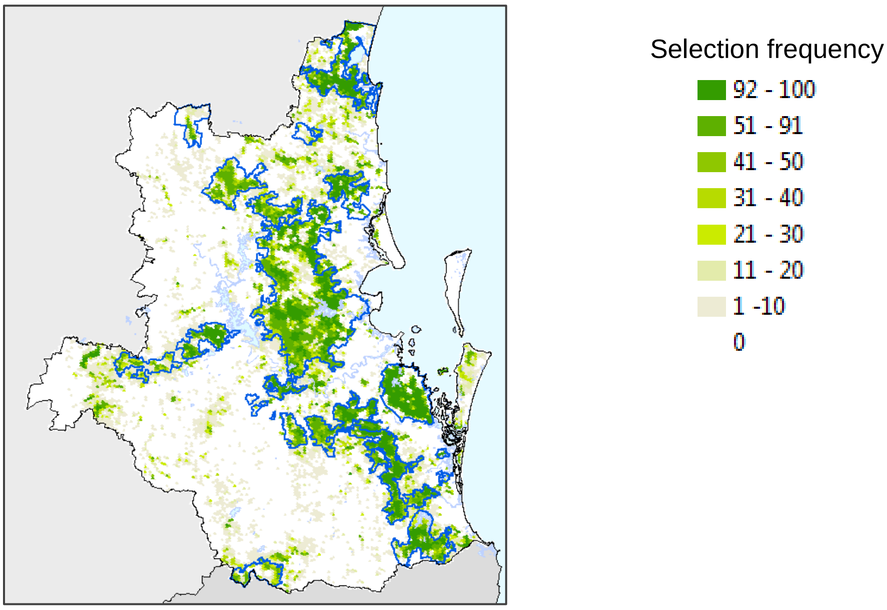
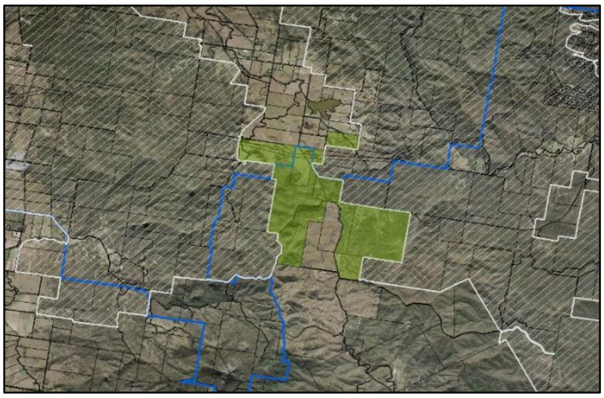


Figure 19: Marxan selection frequencies and first pass of Koala Priority Areas (KPAs) (outlined in blue).

5.3 KPA boundary refinement rules

The initial KPA boundaries were adjusted using a set of decision rules to improve connectivity, address anomalies in the KPA boundaries and take into account feedback from local governments (see Map 7).

1. Link together KPAs where they were connected by suitable koala habitat:
   - KPAs were connected along cadastral boundaries where contiguous suitable koala habitat was present or where KPAs are separated by small slivers of land not within KPAs.

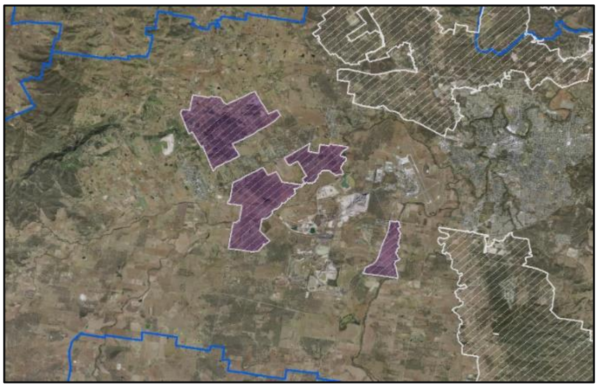


2. Adjust anomalous KPA boundaries to achieve boundary smoothing:
   - Where KPA boundaries were coarse (positioned ambiguously through communities or land uses, or created bisections of koala habitat), boundaries were adjusted and aligned to clear and recognisable features (such as rivers, roads, protected area boundaries).
   - Care was taken to not exclude smaller patches of important koala habitat in the urban landscape during this process.
   - This rule also applies to areas that were selected to delete from the KPA boundary in cases where there was geographical boundaries separating habitat, a lack of mapped habitat, extensive non-native plantation uses and areas that were not suitable for koalas (zoning, lack of habitat).

3. Avoid bisecting koala habitat:
   - KPA areas were adjusted to incorporate areas of connected habitat where the boundary was bisecting this habitat. This can involve retracting or expanding adjacent areas of connected koala habitat where the Marxan output attributes a similar cost.

4. Adjust small cadastral errors or removal of isolated KPA areas:
   - Removal of KPAs where isolated protected areas were selected and were not contributing to larger, connected areas of suitable koala habitat.
   - Small boundary errors associated with computer generated outputs snapped to the cadastral boundaries were adjusted with guidance from the Marxan scenario, koala habitat and land use data.

5. Koala Assessable Development Areas (KADAs) were retained within KPA areas:
    - An exception was where KADAs were removed if they were considered small and/or isolated areas that did not contribute towards significant areas of connected suitable koala habitat, e.g. in the Ipswich LGA.



6. Priority Koala Assessable Development Areas (PKADAs) were retained within KPA areas.

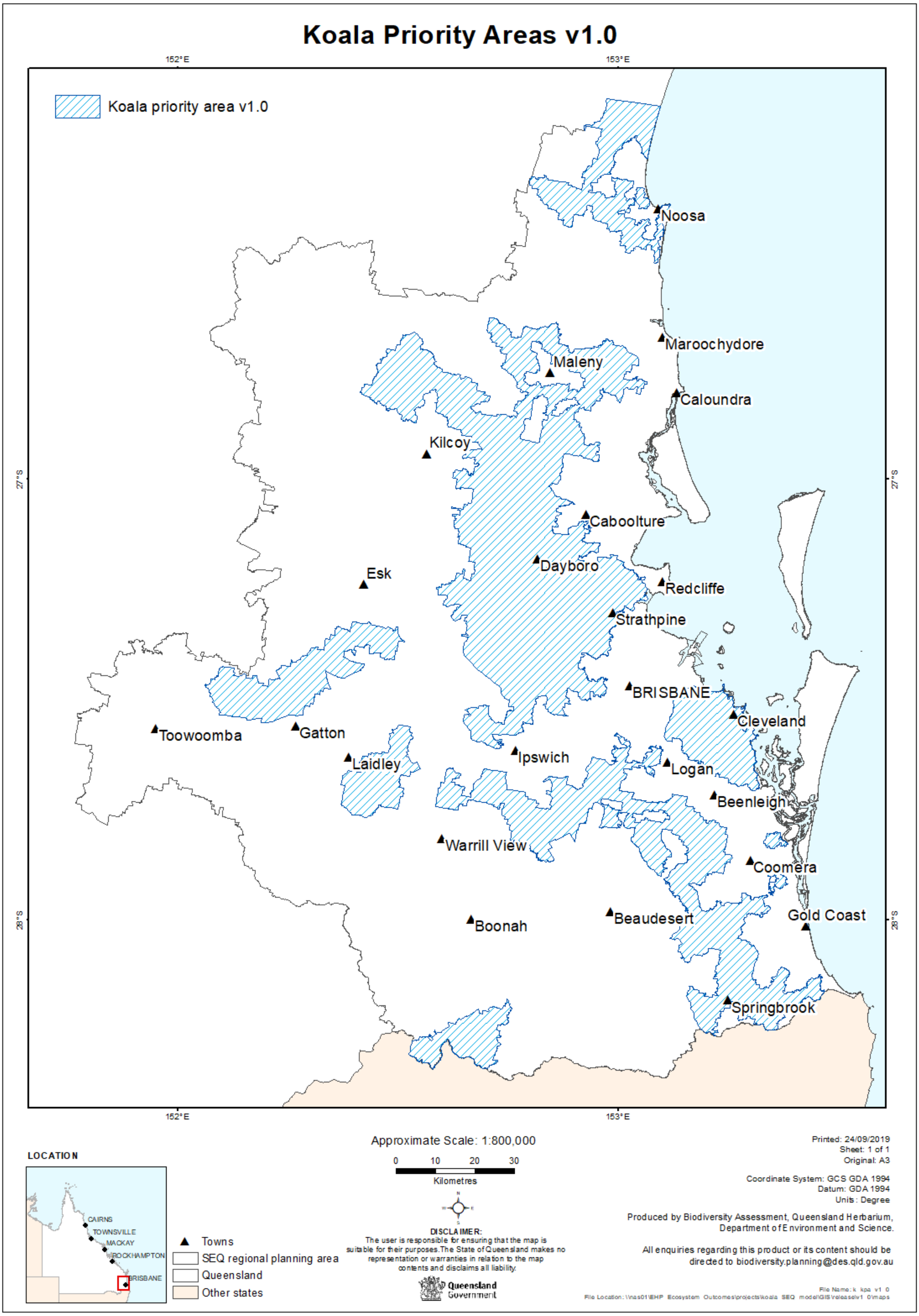
7. Extension of KPAs to include areas that **local governments requested** where they are investing ongoing koala conservation initiatives that contribute towards koala conservation outcomes:
    - This was considered to support the Koala Expert Panel's recommendation to direct coordinated conservation efforts across levels of government into identified priority areas.
    - Councils exposed areas where local koala populations are maintained through koala conservation initiatives (monitoring, threat abatement, restoration, citizen science etc.).
    - Areas suggested by council were considered for inclusion as KPAs using sightings data, local government policy and regulations (corridors, precincts), conservation program areas (LFW, Covenants, local reserve networks).
    - Areas suggested by council were considered for inclusion as KPAs also by their proximity to existing KPAs (where the patch size is small), presence and connectivity of suitable koala habitat using the v1.0 koala habitat mapping and the Marxan and TCOR modelling for the KPAs.
    - Priority Development Areas were removed from KPAs where they bordered the edges of draft KPAs.

Rules 1 to 5 were also guided by:

- Available koala sightings
- Marxan ecological cost data
- Land zones from local government mapping online resources or advice provided from local government consultation
- Koala habitat suitability mapping
- Local government conservation areas if provided during the local government consultation process.

5.4 Results

The area of KPA was 577,174ha. The spatial distribution of KPA areas is shown in Map 7.



Map 7: Koala Priority Areas (KPAs).

6 Koala habitat restoration areas (KHRA)

6.1 Approach

Koala habitat restoration area mapping identifies cleared habitat where potential restoration activities for koalas are preferred to support remnant and regrowth koala habitat. The areas are located both inside and outside the KPA to acknowledge that restoration of degraded habitat occurs across SEQ. Koala habitat restoration areas are intended to be indicative and may be used to inform planning decisions, offsets policy and the koala program delivery decisions.

Restoration areas relied on a separate Marxan analysis to the KPA Marxan analysis (‘restoration’ scenarios). The purpose was to identify viable areas for koala habitat restoration using a target and considering a range of threats, constraints and opportunities for restoration. Cleared habitat in SEQ that previously contained very highly and highly suitable koala habitat was used in the Marxan restoration analysis (Figure 20) which determined a target scenario of 90,000 ha (~6%) of habitat being restored (Table 10). A threats, opportunities and constraints layer (Marxan ecological cost) was applied to the scenario (Figure 21). A final scenario was produced which identified the most viable areas for restoration represented by the highest selection frequency (Figure 22). Modelling was based on a draft koala habitat model.

Like the initial KPA analysis, the final Marxan scenario base unit was 100 ha hexagons which was too broad for realistic interpretation. Therefore, the mapping was re-applied to mapped cleared habitat which formerly contained highly suitable habitat. These were mapped only where Marxan identified suitable restoration areas.

After feedback from local government, further refinement removed areas in the mapping where restoration was considered unsuitable in certain planning scheme zones or areas. However, relevant areas were retained where an environmental corridor (or biodiversity area) was present.

Table 10: Conservation targets and habitat types used in Marxan restoration modelling scenario.

Scenario	Habitat type	Marxan target (ha)
Koala habitat restoration targeted mapping	Cleared habitat on former very high and high suitability regional ecosystems under matrix rules R351, R350, R341 and R340.	90,000

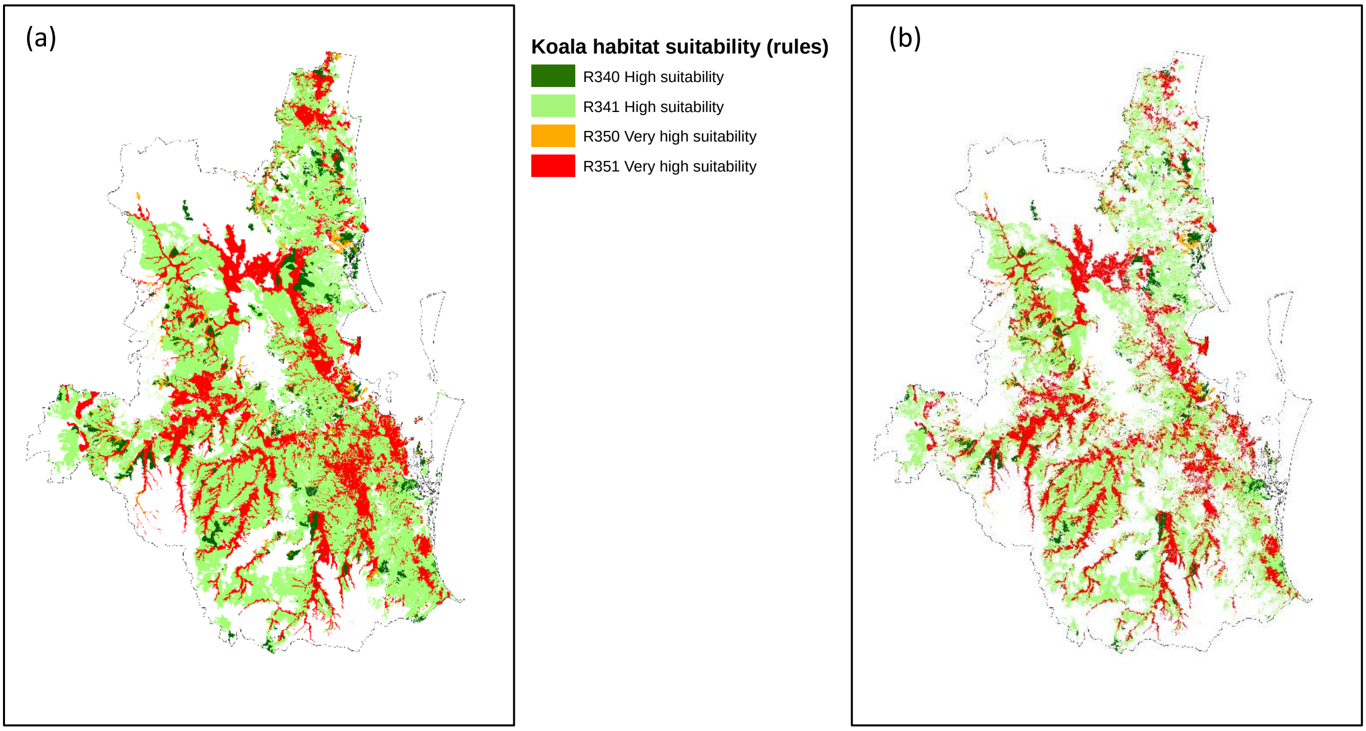


Figure 20: High and very high suitability koala habitat (a) pre-clearing, (b) cleared habitat input into the restoration scenario.

The threats, constraints, opportunities and resilience (TCOR) layers were weighted and normalised, consequently, each layer had different relative importance. To encourage selection, the scores for all opportunity variables (except distance to frequently selected hexagons for protection) were reversed so high opportunities were given a low score because Marxan preferentially picks cells with lower costs. The ecological cost layer was made up from ten weighted threats, constraints, opportunities and resilience layers (Table 11). Results are shown in Figure 21.

Table 11: Variables and rankings for the ecological cost layer in the koala habitat restoration scenario.

Available Threats or Constraints	**Ranking***
• Roads (T)	Medium
• Heat stress (T)	Medium
• Climate change (T)	Low
• Urban development (C)	High
• Extractive industry (modified) (C)	High
Opportunity	
• Conservation & Environmental management (O)	High
• Draft KPA mapping scenarios	High
• Current bushland habitat in PKADA and KADA areas (high, medium, low bushland and high and medium rehabilitation) (O)	Medium
• Areas with cleared high value habitat within 1-5 km of Marxan frequently selected areas for habitat protection (O)	High
Resilience	
• Refugia resilient to climate change (R)	Medium

* These equate to a weighting of 100% for high, 75% for medium and 50% for low ranking.

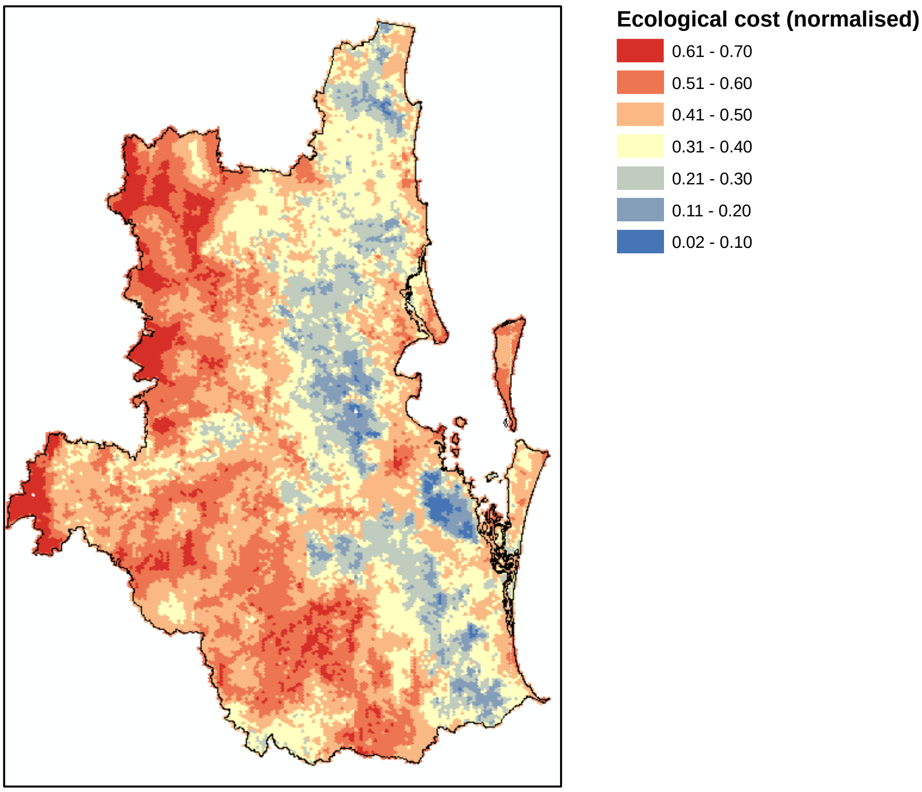


Figure 21: Marxan ecological cost input layer.

After local government feedback, a further refinement process removed areas that were potentially unsuitable for koala restoration. The refinement removed areas where zoning was considered unsuitable (such as urban zoning including centre, residential, industry and other zones associated with urban infrastructure). However, areas were retained where a state or local environment corridor occurs over the zoning (or suitable biodiversity area if an environment corridor was not available). Areas of existing koala restoration activities were also retained (where available) if they occurred in these areas. Consideration was given to remove intensive use areas in rural zones but was not applied in this version. The refinement used currently available planning scheme zoning and precinct zoning and applied to standardised zoning under Schedule 2 of the Planning Regulation 2017. The refinement also sourced regional and local government biodiversity data either directly from local government request or through open data platforms.

Potential restoration areas based on a target of 90,000 ha of cleared very high and high suitability koala habitat are shown in Figure 22.

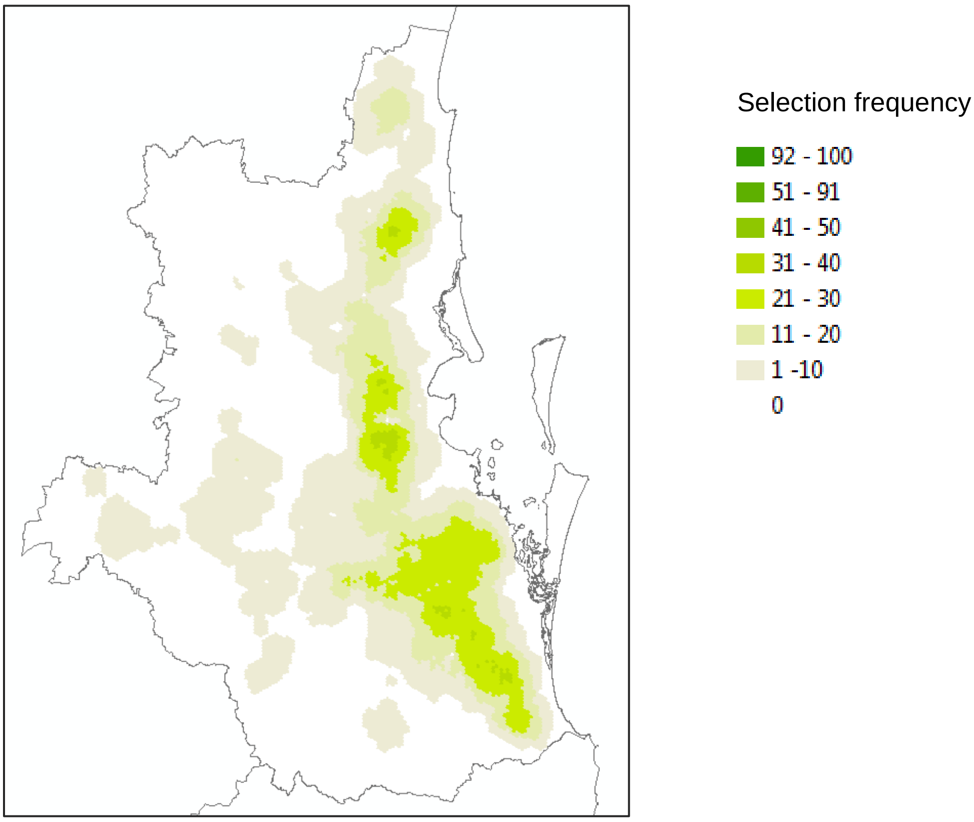
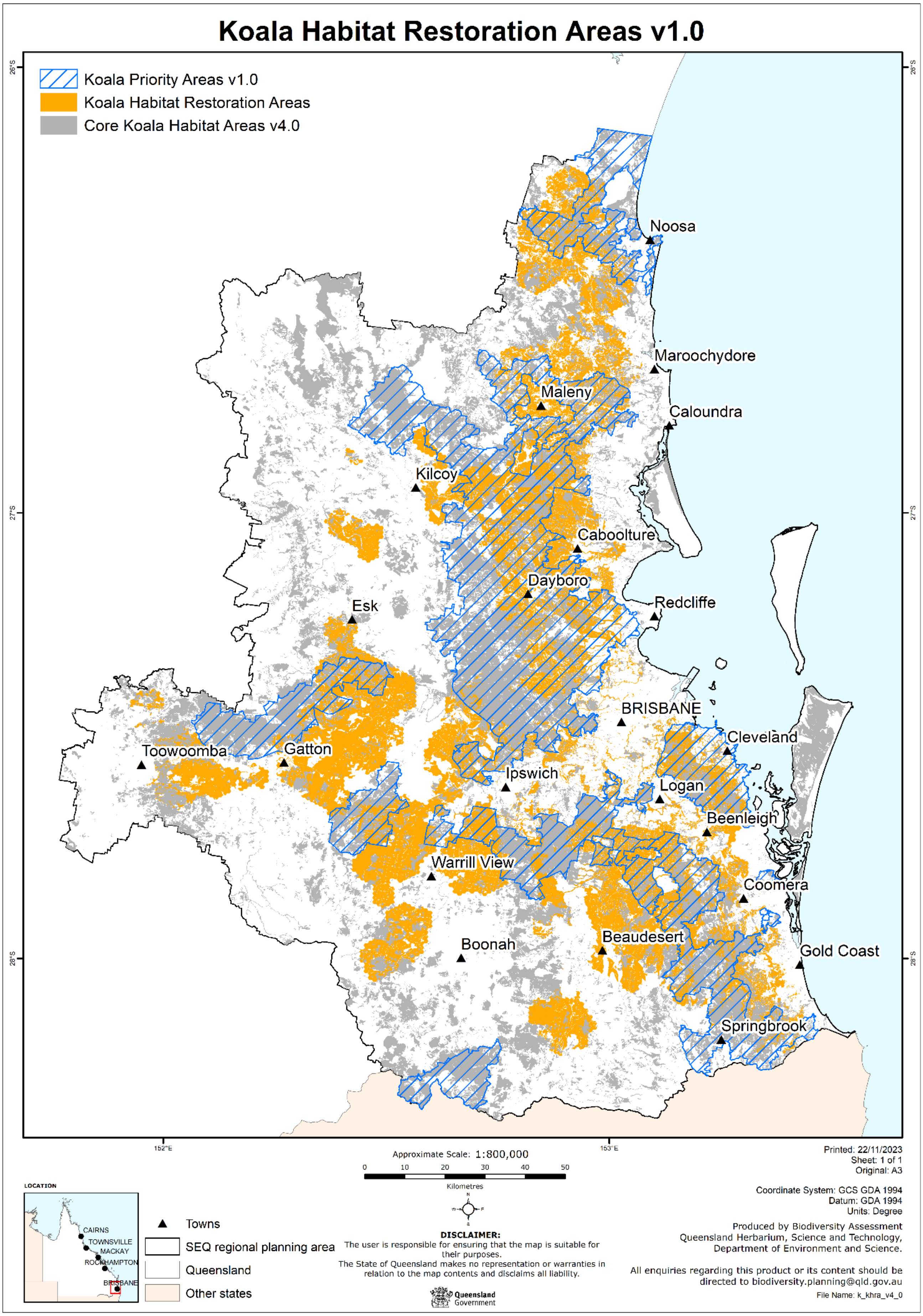


Figure 22: Marxan selection frequency used to identify KHRA.

6.2 Results

The potential for koala habitat restoration areas across SEQ was 446,846ha. The spatial distribution of KHRA areas is shown in Map 8.



Map 8: Koala Habitat Restoration Areas (KHRA).

7 Discussion

The project developed a tenure blind koala habitat mapping framework by uniquely integrating a species distribution model with an expert derived regional ecosystem classification and validated records of koala occurrence to produce a comprehensive map that ranks koala habitat values across the SEQ regional planning area. Threat mapping was also undertaken and used in spatial prioritisation modelling (with Marxan software) to identify potential areas for koala habitat protection and restoration with lower ecological costs (low threats and constraints with high opportunities and resilience). The Marxan output was then used by the Koala Policy and Oversight team to identify priority areas for koala conservation (KPAs).

The new habitat modelling approach used a set of key biophysical variables with statistically tested relationship to koalas to construct a distribution model linked to the RE mapping with a set of decision rules (matrix) to determine which areas were considered 'core habitat', 'non-core habitat' and 'non-habitat' across pre-clearing, remnant and regrowth vegetation in the SEQ study area, and to rank these areas based on habitat quality for koalas.

The project uniquely integrated robust mathematical modelling, with the use of Maxent, and the practical strengths and flexibility of an expert-driven assessment of vegetation suitability, to produce a koala habitat map based on a transparent and repeatable method. Areas predicted by the Maxent modelling to be highly suitable for koalas, corresponding with suitable vegetation types and confirmed by occurrence records, were mapped with a high degree of certainty. The creation of a decision matrix enabled the customisation of decision rules used to rank habitat predicted from the combination of the Maxent model and RE classification. As a result, core habitat was designated with a high level of confidence with 88% of remnant core confirmed by the presence of koala records.

Koalas are an easily identifiable species and consequently there exists a large number of incidental occurrence records where koalas have been reported across the state. Until recently it has been difficult to make use of this data due to statistical issues in dealing with potential observer bias and the lack of absence data. Technological advances, such as the development of machine learning programs like Maxent, now make it possible to use presence-only data in a robust modelling environment. This study was able to draw together a large number of koala occurrence records, not previously compiled, to confirm the presence of habitat and support the designation of core koala habitat areas.

Alternative approaches, such as the Bayesian state-space statistical models developed by Rhodes et al. (2015), were investigated for this study, however there was insufficient systematic survey data and very little absence data suitable for other methods. Rhodes et al. (2015) used 20 years of systematic survey data (which is expensive and time-consuming to collect) and found that sufficient systematic koala survey data for developing distribution models were only available from seven of the 12 LGAs in SEQ and trend data were only available from two regions (Koala Coast and Pine Rivers) where long term koala monitoring has been in place since 1995. Consequently, following a review and advice from the KEP, Maxent was chosen for the current project.

A detailed review and analysis of previous approaches to koala habitat mapping allowed the strengths and limitations of these approaches to be taken into account. Approaches previously undertaken to map koala habitat in Queensland have either focused their assessment on a set of landcover or vegetation attributes. In a review of previous koala habitat mapping, Rhodes (2014) found that there were strengths and weaknesses in both approaches and recommended that future mapping should combine the strengths of earlier approaches with robust statistical models such as Maxent. Rhodes (2014) also highlighted the need to take into account the impact of sampling and spatial bias in koala occurrence records obtained from non-systematic datasets. In this project, bias in the koala occurrence records was addressed using spatial filtering to select a subsample of records for modelling purposes. Maxent was then used to take into account a broad suite of biophysical attributes, known to be predictors of koala habitat, including terrain, soil, landcover, climate and vegetation.

Undertaking modelling using remnant and pre-clearing RE mapping value-adds to the koala mapping and ensures that it can be readily updated in line with changes to the base mapping. These links to statutory products also provide robust quality assurance and an ability to amend the mapping according to already established protocols. Similarly, improvements in non-remnant mapping and the identification of regrowth used by koalas can be incorporated as it becomes available.

Modelling was undertaken in non-remnant vegetation as these areas are considered critical for koala conservation given the significant loss of core habitat to date. These areas often represent the only habitat left where food and shelter trees remain in an otherwise cleared landscape. As long as there are sufficient trees available to meet their energy requirements, regrowth or cleared areas with some trees represent little impediment to koalas as they move across the ground (rather than through the canopy) to find forage trees (White 1999). Koalas can use non-remnant vegetation and may preferentially select these areas because they often occur on fertile soils supporting a larger proportion of young trees with more palatable foliage than in remnant areas (Braithwaite et al. 1984; Cork et al. 1990; Moore et al. 2004; Lunney et al. 2000). However, over-clearing resulting in habitat loss and fragmentation not only reduces the amount of habitat, but also increases the amount of time koalas must spend moving on the ground, which increases their risk of death from threats such as vehicles strikes or dog attacks (McAlpine et al.

2015).

The threat (TCOR) mapping showed that in addition to the direct impact of over-clearing of the highest suitability koala habitat, that some areas, particularly in the west of SEQ, will be significantly affected by additional threats such as climate change heat stress and bushfires, although this is somewhat offset by less intensive development and therefore constraints from urban development, for example, may be lower. This emphasises the importance of protecting and restoring koala habitat in the eastern LGAs even though these are facing more pressure from urban development. The Marxan spatial optimisation provided decision support for the identification of areas where koala habitat protection and restoration should be targeted.

7.1 Future monitoring and field surveys

7.1.1 Koala habitat monitoring

Changes in the extent of koala habitat identified in this project could be monitored over time using data from the existing woody vegetation change monitoring program conducted by the SLATS program. SLATS monitors woody vegetation loss due to land clearing on an annual basis for the entire state and could be used to assess change in the remnant core habitat modelled by this project. However, the SLATS program is generally limited to those areas where FPC is above 10 – 11% and therefore currently may not map loss of habitat from small patches of regrowth.

The project recognised the importance of non-remnant habitat for koala conservation and the recommendations of the KEP that non-remnant vegetation could be used to help redress some of the habitat loss that has occurred to date. Consequently, the project initially attempted to represent the extent of non-remnant regrowth through the use of the best data available at the time. This focused on statutory high value regrowth mapping (from the Queensland Herbarium)[7]. Current difficulties in reliably detecting and mapping non-high value regrowth should be addressed as new technology and remote sensing data becomes available in the future and with additional research and development by SLATS and other programs.

The Remote Sensing Centre, previously undertook ‘bushland extent mapping’ (Muir et al*.* 2013) based on a combination of FPC greater than 10% (20% canopy cover) and tree height of greater than 2m, using SPOT 5, 10m multispectral imagery. This approach was considered to represent the extent of non-remnant vegetation better than the existing SLATS data. Unfortunately, this analysis was not available for the whole of the SEQ study area, as it excluded two LGAs (Noosa and Toowoomba) and therefore was not suitable for this project. It is recommended that, to improve monitoring of koala habitat change over time, additional research and development is undertaken to determine the best way to detect changes in non-remnant regrowth habitat. This could include creating updated ‘bushland extent mapping’ (Muir et al*.* 2013) based upon satellite imagery that is part of a long term strategy such as the Landsat or Sentinel-2 programs. Such data could also be useful for modelling a range of other species distributions in addition to koalas.

7.1.2 Koala field surveys

The koala habitat model was developed for the 12 LGAs in the SEQ regional planning area. Currently, systematic koala survey data is mostly available for the seven coastal LGAs. The Southern Wildlife Operations group of DES operate a koala survey and monitoring program across SEQ and are using the new habitat mapping, in combination with the collated koala occurrence records, to stratify and prioritise koala field surveys and identify sampling data gaps.

Additional systematic surveys, particularly in the five LGAs lacking systematic surveys, would provide koala density data across all of SEQ which would increase the robustness of the current model and results. Similarly, with repeat survey data, currently only available for the Koala Coast and Pine Rivers, it might be possible to determine koala population trends (*sensu* Rhodes et al*.* 2015) so that the success of koala conservation measures can be evaluated.

The primary source of presence data used in the modelling was incidental records (obtained from WildNet, citizen science and koala hospital records). Pellet survey data from DES and other sources of incidental records could also be used in future modelling reviews. Koala surveys and monitoring are critical in providing validation of the koala habitat model and can be used as inputs into future models. Additional field survey data could be used in the following ways:

- Presence-absence or presence-only data

[7] Only the statutory high value regrowth mapping from the Queensland Herbarium was used in the koala habitat model.

- Direct input into reviewed Maxent and habitat modelling
- Validation of the habitat model
- Repeat surveys to determine true absence

Density data (from systematic repeat surveys)

- Koala distribution
- Koala abundance
- Identification of koala hotspots (high density koala population areas and key areas for protection)
- Koala population trends

Pellet surveys

- Koala presence-absence
- Koala distribution.

7.2 Recommendations for future work

- In future modelling, apply purpose-built, high resolution, high accuracy non-remnant regrowth and scattered trees vegetation mapping, as this becomes available.
- Conduct further landscape analyses of the spatial modelling outputs to identify conservation values and management options that will enhance the long term viability of koalas within SEQ.
- Undertake field validation of the habitat mapping.
- Undertake targeted koala field surveys that establish what proportion of identified core and non-core habitat is currently occupied by koalas.
- Develop and implement monitoring procedures to quantify changes to the extent and quality of koala habitat over time.
- Investigate approaches for including confidence measures in future mapping.
- Extend the current koala habitat mapping methodology across the koalas’ range in Queensland.

7.3 Limitations of the study

The aim of the project was to map areas of koala habitat based on the best available spatial data and knowledge available at the time of production. However, the project team acknowledges the following limitations:

- Some biophysical and climatic datasets were only available at coarse scales thereby reducing the reliability and operating scale of some modelled outputs.
- Given the project timeframes and confidential nature of the work, it was not possible to undertake further consultation (outside the KAG) on the model outputs or engage with local governments, local experts and other stakeholders.
- Given the project timeframes it was not possible to undertake field validation of the modelled outputs. However, the large number of koala records and the large proportion of records falling within mapped koala habitat areas, increased confidence in the model.

.

8 Conclusion

The project has developed a new habitat mapping framework and produced a tenure-blind koala habitat map for the SEQ regional planning area, based on the latest scientific modelling principles and data. Comprehensive threat mapping was integrated with the habitat mapping to delineate priority areas that will be the focus of koala conservation. The project used advice and input from the Koala Expert Panel and a specially formed group of koala ecologists and spatial mapping specialists (KAG). A review of previous koala mapping projects and approaches to modelling was undertaken and a significant data collation and consultation phase took place with local governments to ensure that the model represented the most comprehensive data inputs to date.

The major strength of the approach was the development of a transparent and repeatable method that can be replicated when additional or updated spatial data (such as updates to the RE and landcover mapping) becomes available. In addition, the method was developed to be adaptable to other regions, through the inclusion of relevant regionally specific datasets and rules.

In addition to the habitat mapping, the project collated a substantial range of spatial data (representing threats, constraints, opportunities and resilience) and koala occurrence records sourced from local governments and natural resource management groups. It is anticipated that integrating the koala habitat mapping with threats, constraints, opportunities and resilience measures will be useful in the identification of priority areas for koalas and for the stratification of potential future field surveys.

9 References

ABS Census: Australian Population Grid 2011 - http://www.abs.gov.au/ausstats/abs@.nsf/mf/1270.0.55.007.

Adams-Hosking, C, Grantham, HS, Rhodes, JR, McAlpine, CA and Moss, PT 2011. 'Modelling climate-change induced shifts in the distribution of the koala'. *Wildlife Research*, vol. 38, pp. 122–30.

Adams-Hosking, C, McAlpine, C, Rhodes, JR, Grantham, HS and Moss, PT 2012. 'Modelling changes in the distribution of the critical food resources of a specialist folivore in response to climate change'. *Diversity and Distributions*, vol. 18, pp. 847-60.

Anderson, RP, & Gonzalez, I 2011. 'Species-specific tuning increases robustness to sampling bias in models of species distributions: An implementation with Maxent'. Ecological Modelling, 222(15), 2796–2811. https://doi.org/10.1016/j.ecolmodel.2011.04.011

Araújo, MB, Pearson, RG, Thuiller, W and Erhard, M 2005. 'Validation of species–climate impact models under climate change'. *Global Change Biology*, vol. 11, pp. 1504–13.

Araújo, MB and Guisan, A 2006. 'Five (or so) challenges for species distribution modelling'. *Journal of Biogeography*, vol. 33, pp. 1677–88.

Ardron, JA, Possingham, HP, and Klein, CJ (eds) 2010. Marxan Good Practices Handbook, Version 2. Pacific Marine Analysis and Research Association, Victoria, BC, Canada. 165 pages. www.pacmara.org.

Boria RA, Olson LE, Goodman SM and Anderson RP 2014. 'Spatial filtering to reduce sampling bias can improve the performance of ecological niche models'. *Ecological Modelling*, vol. 275, pp. 73–7.

Bradie J, Leung B 2017. 'A quantitative synthesis of the importance of variables used in MaxEnt species distribution models'. *Journal of Biogeography* vol. 44, pp.1344–1361 doi:10.1111/jbi.12894

Braithwaite, LW, Turner, J and Kelly, J 1984. 'Studies on the arboreal marsupial fauna of eucalypt forests being harvested for pulpwood at Eden, NSW. III. Relationships between faunal densities, eucalypt occurrence and foliage nutrients, and soil parent materials'. *Australian Wildlife Research* 11: 41-8.

Briscoe, NJ, Handasyde, KA, Griffiths, SR, Porter, WP, Krockenberger, A and Kearney, MR 2014. 'Tree-hugging koalas demonstrate a novel thermoregulatory mechanism for arboreal mammals'. *Biology Letters*, vol. 10(6), 20140235 http://dx.doi.org/10.1098/rsbl.2014.0235.

Briscoe, NJ, Kearney, MR, Taylor, CA and Wintle, BA 2016. 'Unpacking the mechanisms captured by a correlative species distribution model to improve predictions of climate refugia'. *Global Change Biology*, vol. 22, pp. 2425-39.

Callaghan, J, McAlpine, C, Mitchell, D, Thompson, J, Bowen, M, Rhodes, J, de Jong, C, Domalewski, R and Scott, A 2011. 'Ranking and mapping koala habitat quality for conservation planning on the basis of indirect evidence of tree-species use: a case study of Noosa Shire, south-eastern Queensland'. *Wildlife Research*, vol.38, pp.89-102.

Cantor, SB, Sun, CC, Tortolero-Luna, G, Richards-Kortum, R and Follen, M 1999. 'A comparison of C/B ratios from studies using Receiver Operating Characteristic Curve Analysis'. *Journal of Clinical Epidemiology*, vol. 52, pp 885-92.

Cork, SJ 1986. 'Foliage of *Eucalyptus punctata* and the maintenance nitrogen requirements of koalas, *Phascolarctos cinereus'*. *Australian Journal of Zoology*, vol. 34, pp. 17–23.

Cork, SJ, CR Margules, and LW Braithwaite. 1990. Implications of koala nutrition and the ecology of other arboreal marsupials in south-eastern New South Wales for the conservation management of koalas. Pages 48–57 in: D Lunney, CA Urquhart, and P Reed, editors. *Koala summit. Managing koalas in New South Wales*. New South Wales National Parks and Wildlife Service, Sydney.

Cork, SJ and Braithwaite, LW 1996. 'Resource availability, eucalypt chemical defences, and habitat quality for leaf eating marsupials'. Pages 9-16 in: G. Gordon, editor. *Koalas: Research for Management. Brisbane Koala Symposium 22–23 September 1990.* World Koala Research, Brisbane.

Cork, SJ, Hume, ID and Foley, WJ 2000. 'Improving habitat models and their utility in koala conservation'. *Conservation Biology*, vol. 14, pp. 660-668.

Crowther, MS, McAlpine, CA, Lunney, D, Shannon, I, and Bryant, JV 2009. 'Using broad-scale, community survey data to compare species conservation strategies across regions: A case study of the koala in a set of adjacent 'catchments''. *Ecological Management and Restoration*, vol. 10, pp. S88-S96.

Cristescu RH, Rhodes, J, Frére, C and Banks, PB (2013), Is restoring flora the same as restoring fauna? Lessons learned from koalas and mining rehabilitation. Journal of Applied Ecology, 50: 423-431. doi:10.1111/1365-2664.12046

Degabriele, R 1981. ‘A relative shortage of nitrogenous food in the ecology of the koala (*Phascolarctos cinereus*)’ *Australian Journal of Ecology*, vol. 6, pp. 139–41.

Department of Environment and Heritage Protection (EHP) 2014. Biodiversity Assessment and Mapping Methodology. Version 2.2., Conservation and Sustainability Services, Department of Environment and Heritage, Queensland Government, Brisbane.

Department of Environment and Heritage Protection (EHP) 2015. Woody cover raster data (offsets regrowth mapping). Biodiversity Implementation and Offsets Team, Conservation and Sustainability Services, Department of Environment and Heritage Protection, Brisbane.

Department of Environment and Heritage Protection (EHP) 2016. *Phascolarctos cinereus* (Koala) Taxon Profile - Habitat Suitability Modelling for South East Queensland. (Internal report) Department of Environment and Heritage, Queensland Government, Brisbane.

Department of Environment and Heritage Protection (EHP) 2017. Spatial modelling and planning for koalas in southern South East Queensland – Review of koala habitat mapping. (Internal report v1.3) Department of Environment and Heritage Protection, Queensland Government.

Department of Infrastructure, Local Government and Planning (DILGP) 2017. ShapingSEQ South East Queensland Regional Plan 2017. The State of Queensland.

Department of Science, Information Technology and Innovation (DSITI) 2015. Queensland Groundwater Dependent Ecosystem Mapping Method: A method for providing baseline mapping of groundwater dependent ecosystems in Queensland, Department of Science, Information Technology and Innovation, Brisbane

Dique, DS, Thompson, J, Preece, HJ, Penfold, GC, de Villiers, DL and Leslie, RS 2003. ‘Koala mortality on roads in south-east Queensland: The koala speed-zone trial’. *Wildlife Research*, vol. 30, pp. 419-26.

Elith, J 2008.Threatened species map updates: Species distribution Modelling, Part 2: Additional details – submitted to the Department of the Environment, Water, Heritage and Arts. University of Melbourne, Victoria.

Elith, J, Graham, CH, Anderson, RP et al. 2006. ‘Novel methods improve prediction of species distributions from occurrence data’. *Ecography*, vol. 29, pp. 129-51.

Elith, J, Kearney, M and Phillips, S 2010. ‘The art of modelling range-shift species’. *Methods in Ecology and Evolution*, vol. 1, pp. 330-42.

Elith, J, Phillips, S, Hastie, T, Dudı´k, M, Chee, Y and Yates, C 2011. ‘A statistical explanation of Maxent for ecologists’. *Diversity and Distributions*, vol. 17, pp. 43-57.

Ellis, W, Melzer, A, Carrick, F, & Hasegawa, M (2002). ‘Tree Use, Diet and Home Range of the Koala (Phascolarctos Cinereus) at Blair Athol, Central Queensland’. In *Wildlife Research* (Vol. 29, Issue 3, pp. 303–311).

Ellis, W, Melzer, A, Clifton, I and Carrick, F 2010. ‘Climate change and the koala *Phascolarctos cinereus*: water and energy’. *Australian Zoologist,* vol. 35, pp. 369-77.

Environmental Protection Agency (EPA). 2004. Koala Habitat Map Methodology, Version 1, released 24th May 2004. Internal report, Biodiversity Planning Division.

Fischer, DT, Alidina, HM, Steinback, C, Lombana, AV, Ramirez de Arellano, PI, Ferdana, Z & Klein, CJ 2013, ‘Ensuring robust analysis’, in JA Ardron, HP Possingham, & CJ Klein (eds), *Marxan Good Practices Handbook*, Pacific Marine Analysis and Research Association, Victoria, BC, Canada, pp. 75–96.

FitzGibbon, S, Ellis, W and Carrick, F 2013. ‘The Koala Venture Research Partnership: an overview of 24 years of regional koala research in central Queensland’. Pages 16-19 in N. Flint and A. Melzer, editors. *Conserving Central Queensland’s Koalas.* Koala Research Centre of Central Queensland, CQ University Australia, Rockhampton, Queensland.

Fourcade, Y, Engler, JO, Rodder, D and Secondi, J 2014. ‘Mapping species distributions with Maxent using a geographically biased sample of presence data: A performance assessment of methods for correcting sample bias’. *PLoS ONE*, vol. 9(5): e97122. doi:10.1371/journal.pone.0097122.

Freeman, E and Moisen, GG 2008. ‘A comparison of the performance of threshold criteria for binary classification in terms of predicted prevalence and kappa’. *Ecological Modelling*, vol. 217, pp. 48-58.

Garden, JG, O’Donnell, T and Catterall, CP 2015. ‘Changing habitat areas and static reserves: Challenges to species protection under climate change’. *Landscape Ecology*, vol. 30, pp. 1959-73.

GHD. 2009. South East Queensland koala habitat assessment and mapping project final report. Report for the Department of Environment and Resource Management South East Queensland Koala Habitat Assessment and Mapping Project. May 2009. GHD, Brisbane, Australia.

Gordon, G, Brown, AS and Pulsford, T 1988. ‘A koala (*Phascolarctos cinereus* Goldfuss) population crash during drought and heatwave conditions in south-western Queensland’. *Austral Ecology*, vol. 13, pp. 451–61.

Graham, CH, Elith, J, Hijmans, RJ, Guisan, A, Townsend Peterson, A, Loiselle, BA 2008. ‘The influence of spatial errors in species occurrence data used in distribution models.’ *Journal of Applied Ecology*, vol. 45, pp. 239–247. doi:10.1111/j.1365-2664.2007.01408.x

Guisan, A, and Thuiller, W, 2005. ‘Predicting species distribution: offering more than simple habitat models’. *Ecology Letters*, vol. 8, pp. 993–1009.

Hasegawa, M 1995. ‘Habitat utilisation by koalas (*Phascolarctos cinereus*) at Point Halloran, Queensland’. Masters of Science Thesis, the University of Queensland, Brisbane.

Houlder, DJ, Hutchinson, MF, Nix, HA and McMahon, JP 2000. ‘ANUCLIM User Guide, Version 5.1’. Centre for Resource and Environmental Studies, Australian National University, Canberra.

Kavanagh, RP, Stanton, MA, Brassil, TE 2007. ‘Koalas continue to occupy their previous home-ranges after selective logging in *Callitris–Eucalyptus* forest.’ *Wildlife Research* 34, 94-107. https://doi.org/10.1071/WR06126

Laidlaw, MJ and Butler, DW 2012. Potential habitat modelling methodology for Queensland’s threatened flora and fauna, Queensland Herbarium, Brisbane.

Law, B, Caccamo, G, Wimmer, J, Truskinger, A, McConville, A, Brassil, T, Stanton, M and Gonsalves, L 2017. *A predictive habitat model for koalas* Phascolarctos cinereus *in north-east New South Wales: Assessment and field validation*. New South Wales Department of Industry – Land and Forestry.

Lee, K E, Seddon, JM, Corley, SW, Ellis, WAH, Johnston, SD, de Villiers, DL, Preece, HJ, & Carrick, FN (2010). ‘Genetic variation and structuring in the threatened koala populations of Southeast Queensland’. *Conservation Genetics*, 11(6), 2091–2103. https://doi.org/10.1007/s10592-009-9987-9

Liu, C, Berry, PM, Dawson, TP and Pearson, RG 2005. ‘Selecting thresholds of occurrence in the prediction of species distributions’. *Ecography*, vol. 28, pp. 385-93.

Liu, C, White, M and Newell, G 2013. ‘Selecting thresholds for the prediction of species occurrence with presence-only data’. *Journal of Biogeography*, vol. 40, pp. 778-89.

Lötter, M, Lieberknecht, L, Ardron , JA, Wells, R, Ban, NC Nicolson, DJ and Gerhartz JL. 2010. Reserve design considerations. Pp. 39–48 in J.A. Ardron , H.P. Possingham , and C.J. Klein , eds., *Marxan Good Practices Handbook*, Version 2. Pacific Marine Analysis and Research Association, Victoria, BC

Lunney, D, Matthews, A, Moon, C and Ferrier, S 2000. ‘Incorporating habitat mapping into practical koala conservation on private lands’. *Conservation Biology*, vol. 14, pp. 669-80.

Lunney, D, Crowther, MS, Wallis, I, Foley, WJ, Lemon, J, Wheeler, R, Madani, G, Orscheg, C, Griffith, JE, Krockenberger, M, Retamales, M and Stalenberg, E 2012. ‘Koalas and climate change: a case study on the Liverpool Plains, north-west New South Wales’. Pages 150-68 in D. Lunney and P. Hutchings, editors. *Wildlife and Climate Change. Toward Robust Conservation Strategies for Australian Fauna*. Royal Zoological Society of New South Wales, Mosman, Australia.

Lunney, D, Stalenberg, E, Santika, T and Rhodes, JR 2014. ‘Extinction in Eden: Identifying the role of climate change in the decline of the koala in south-east NSW’. *Wildlife Research*, vol 41, pp. 22-34.

Martin, RW, Handasyde, KA and Krockenberger, A 2008. ‘Koala *Phascolarctos cinereus* (Goldfuss, 1817)’. Pages 198-201 in S. van Dyck and R. Strahan, editors. *The Mammals of Australia*. New Holland: Chatswood, NSW.

Matthews, A, Lunney, D, Gresser, S, Maitz, W, 2007, ‘Tree use by koalas (*Phascolarctos cinereus*) after fire in remnant coastal forest.’ *Wildlife Research* 34, 84-93.

McAlpine, CA, Callaghan, J, Lunney, D, Bowen, ME, Rhodes, JR, Mitchell, DL and Possingham, HP 2005. ‘Conserving South-east Queensland koalas: how much habitat is enough?’ Pages 11-17 in G. Siepen and D. Jones, editors. *Proceedings of the SEQ Biodiversity Conference*, Gatton, Queensland, 30th June - 2nd July 2004 The University of Queensland, Gatton, Australia.

McAlpine, CA, Bowen, ME, Callaghan, JG, Lunney, D, Rhodes, JR, Mitchell, DL, Pullar, DV and Possingham, HP 2006. ‘Testing alternative models for the conservation of koalas in fragmented rural-urban landscapes’. *Austral Ecology*, vol. 31, pp. 529-44.

McAlpine, CA, Rhodes, JR, Peterson, A, Possingham, HP, Callaghan, JG, Curran, T, Mitchell, DL, Lunney, D Dan 2007. ‘Planning guidelines for koala conservation and recovery: A guide to best planning practice’. Australian Koala Foundation and The University of Queensland. Brisbane, Australia.

McAlpine, CA, Rhodes, JR, Bowen, ME, Lunney, D, Callaghan, JG, Mitchell, DL and Possingham, HP 2008. ‘Can multi-scale models of species' distribution be generalised from region to region? A case study of the koala'. *Journal of Applied Ecology*, vol. 45, pp. 558-67.

McAlpine, C, Lunney, D, Melzer, A, Menkhorst, P, Phillips, S, Phalen, D, Ellis, W, Foley, W, Baxter, G, de Villiers, D, Kavanagh, R, Adams-Hosking, C, Todd, C, Whisson, D, Molsher, R, Walter, M, Lawler, I and Close, R 2015. 'Conserving koalas: A review of the contrasting regional trends, outlooks and policy challenges'. *Biological Conservation*, vol. 192, pp. 226-36.

Melzer, A, Carrick, F, Menkhorst, P, Lunney, D and St John, B 2000. 'Overview, critical assessment, and conservation implications of koala distribution and abundance'. *Conservation Biology*, vol. 14, pp. 619-28.

Melzer, A and Houston, W 2001. 'An overview of the understanding of koala ecology: how much more do we need to know?' Pages 6–45 in K. Lyons, A. Melzer, F. Carrick, and D. Lamb, editors. *The Research and Management of Non-urban Koala Populations*. Koala Research Centre of Central Queensland, Central Queensland University, Rockhampton.

Melzer, A, Cristescu, R, Ellis, W, FitzGibbon, S and Manno, G 2014. 'The habitat and diet of koalas (*Phascolarctos cinereus*) in Queensland'. *Australian Mammalogy*, vol.36, pp.189-99.

Merow, C, Smith, MJ and Silander Jr, JA 2013. 'A practical guide to Maxent for modelling species distributions: What it does, and why inputs and settings matter'. *Ecography*, vol. 36, pp. 1058-69.

Moore, BD, Wallis, IR, Marsh, KJ and Foley, WJ 2004. 'The role of nutrition in the conservation of the marsupial folivores of eucalypt forests'. Pages 549-575 in D. Lunney, editor. *Conservation of Australia's Forest Fauna*. Royal Zoological Society of New South Wales, Mosman, Australia.

Moore, BD and Foley, WJ 2005. 'Tree use by koalas in a chemically complex landscape'. *Nature*, vol. 435, pp. 488-90.

Muir, J, Tindall, D and Armston, J 2013. *South East Queensland Bushland Extent Mapping: Final Report*. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Neldner, VJ and Accad, A 2013. *Review of Methodologies used in producing the Queensland Government Koala Habitat Maps and those produced by the Australian Koala Foundation*. Queensland Herbarium, DSITIA, Brisbane.

Neldner, VJ, Wilson, BA, Dillewaard, HA, Ryan, TS, Butler, DW, McDonald, W.J.F. Addicott, E.P. and Appelman, C.N. 2019 *Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland*. Version 5.0. Updated March 2019. Queensland Herbarium, Department of Science, Brisbane.

NSW 2018. A review of koala tree use across New South Wales. Office of Environment and Heritage.

O'Donnell, MS, and Ignizio, DA 2012. 'Bioclimatic predictors for supporting ecological applications in the conterminous United States' *U.S. Geological Survey Data Series*, 691, 10pp.

Pfeiffer, A, Melzer, A, Tucker, D, Clifton, D and Ellis, W 2005. 'Tree use by koalas (*Phascolarctos cinereus*) on St Bees Island, Queensland – report of a pilot study'. *Proceeding of the Royal Society of Queensland*, vol. 112, pp. 47-51.

Phillips, SJ, Anderson, RP and Schapire, RE 2006. 'Maximum entropy modelling of species geographic distributions'. *Ecological Modelling*, vol. 190, pp. 231-59.

Phillips, SJ, and Dudı´k, M, 2008. 'Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation'. *Ecography*, vol. 31(2), pp. 161–175.

Preece, HJ 2007. Monitoring and modelling threats to koala populations in rapidly urbanising landscapes: Koala Coast, South East Queensland, Australia. PhD Thesis. The University of Queensland, Brisbane, Australia.

Queensland Herbarium 2016. Regional Ecosystem Description Database (REDD). Version 10.0 (December 2016). Department of Science, Information Technology and Innovation. Toowong, Brisbane.

Rhodes, JR 2014. *Review of Methodologies used in producing the Queensland Government Koala Habitat Maps and those produced by the Australian Koala Foundation*. UniQuest Report no: C01785.

Rhodes, JR, Wiegand, T, McAlpine, CA, Callaghan, J, Lunney, D, Bowen, M and Possingham, HP 2006. 'Modeling species' distributions to improve conservation in semiurban landscapes: koala case study'. *Conservation Biology,* vol. 20, pp. 449-59.

Rhodes, JR, McAlpine, CA, Peterson, A, Callaghan, JG, Lunney, D, Possingham, HP, Mitchell, DL and Curran, T 2008. 'Lining landscape ecology to planning for koala conservation'. *Australian Planner*, vol. 45, pp. 24-5.

Rhodes, JR, Beyer, HL, Preece, HJ and McAlpine, CA 2015. *South East Queensland Koala Population Modelling Study*. UniQuest – internal report for EHP, Brisbane, Australia.

Rhodes, JR, Hood, A, Melzer, A and Mucci, A 2017. *Queensland Koala Expert Panel: A new direction for the conservation of koalas in Queensland. A report to the Minister for Environment and Heritage Protection*. Queensland Government, Brisbane.

Santika, T, McAlpine, CA, Lunney, D, Wilson, KA and Rhodes, JR 2014. 'Modelling species distributional shifts across broad spatial extents by linking dynamic occupancy models with public-based surveys'. *Diversity and Distributions*, vol. 20, pp. 786-96.

Seabrook, L, McAlpine, C, Baxter, G, Rhodes, J, Bradley, A and Lunney, D 2011. 'Drought-driven change in wildlife distribution and numbers: a case study of koalas in south west Queensland'. *Wildlife Research*, vol. 38, pp. 509-24.

Smith, AP 2004. 'Koala conservation and habitat requirements in a timber production forest in north-east New South Wales'. Pages 591-611 in D. Lunney, editor. *Conservation of Australia's Forest Fauna*. 2nd edn. Royal Zoological Society of New South Wales: Sydney.

Stalenberg, E, Wallis, IR, Cunningham, RB, Allen, C and Foley, W. 2014. 'Nutritional correlates of koala persistence in a low-density population'. *PLoS ONE*, vol. 9, e113930. https://doi.org/10.1371/journal.pone.0113930.

Sullivan, BJ, Norris, WM, Baxter, GS 2003. 'Low-density koala (*Phascolarctos cinereus*) populations in the mulgalands of south-west Queensland. II. Distribution and diet.' *Wildlife Research* 30, 331-338.

Thompson, JA 2006. The comparative ecology and population dynamics of koalas in the koala coast region of south-east Queensland. PhD Thesis, School of Integrative Biology, University of Queensland.

Ullrey, D, Robinson, P and Whetter, P 1981. 'Composition of preferred and rejected eucalyptus browse offered to captive koalas, *Phascolarctos cinereus* (Marsupialia)'. *Australian Journal of Zoology*, vol. 29, pp. 839-46.

White, NA 1999. 'Ecology of the Koala (*Phascolarctos cinereus*) in rural south-east Queensland, Australia'. *Wildlife Research*, vol. 26, pp. 731-44.

Woodward, W, Ellis, WA, Carrick, FN, Tanizaki, M, Bowen, D and Smith, P 2008. 'Koalas on North Stradbroke Island: diet, tree use and reconstructed landscapes'. *Wildlife Research* vol. 35, pp. 606-11.

Wu, H, McAlpine, CA and Seabrook, LM 2012. 'The dietary preferences of koalas, *Phascolarctos cinereus*, in southwest Queensland'. *Australian Zoologist*, vol. 36, pp. 93-102.

Xu, T and Hutchinson, MF 2011. ANUCLIM Version 6.1. Fenner School of Environment and Society, Australian National University, Australia.

Xu, T and Hutchinson, MF 2013. 'New developments and applications in the ANUCLIM spatial climatic and bioclimatic modelling package'. *Environmental Modelling and Software*, vol. 40, pp. 267-79.

Yackulic, CB, Chandler R, Zipkin, EF, Royle, JA, Nicols, JD, Campbell Grant, EH and Veran, S 2013. 'Presence only modelling using Maxent: when can we trust the inferences?' *Methods in Ecology and Evolution*, vol. 4, pp. 236-43.

Young N, Carter, L and Evangelista, P 2011. A Maxent model v3.3.3e Tutorial (ArcGIS v10). Natural Resource Ecology Laboratory, Colarad State University, USA.

Youngentob, KN, Yoon, H-J, Stein, J, Lindenmayer, DB and Held, AA 2015. 'Where the wild things are: Using remotely sensed forest productivity to assess arboreal marsupial species richness and abundance'. *Diversity and Distributions*, vol. 21, pp. 977–90.

Appendix 1. **Vegetation data layers description and rationale**

Name	Summary description and data range	Rationale for inclusion
Pre-clearing, remnant	**Pre-clearing** vegetation is defined as the vegetation present before clearing. **Remnant** woody vegetation is defined as vegetation that has not been cleared or vegetation that has been cleared but where the dominant canopy has greater than 70% of the height and greater than 50% of the cover relative to the undisturbed height and cover of that stratum and is dominated by species characteristic of the vegetation's undisturbed canopy. Regional ecosystems represent vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil. Remnant vegetation was mapped using aerial photography and satellite imagery supplied by the State Land and Tree Study (SLATS) in conjunction with field surveys as described in Neldner et al. (2019). Map scale range: 1:25,000–100,000. Map scales: 1:25,000 for Brisbane and Gold Coast; 1:50,000 for Moreton Bay, Redland, Sunshine Coast, Noosa, Lockyer Valley, Toowoomba and the pre-amalgamation portion of Logan; and 1:100,000 for Scenic Rim, Ipswich and Somerset. A map scale of 1:25,000 is generally used in areas covered by a property map of assessable vegetation (PMAV) (Tim Ryan 2019 pers. comm. 21 February). The minimum mapping unit ranges from 1ha and 35m width for linear features in areas mapped at 1:25,000 and 1:50,000 to 5ha and 75m width for linear features in areas mapped at 1:75,000 and 1:100,000.	Throughout their range, koalas are primarily associated with eucalypt forests (Martin et al. 2008) with some eucalypt communities, such as *Eucalyptus tereticornis* dominated woodlands which contain one of the koalas preferred browse species (Queensland blue gum), known to support high koala densities (McAlpine et al 2006; Melzer et al. 2014). The proportion of the landscape occupied by eucalypt and melaleuca forests and woodlands has been shown to be an important determinant of koala occurrence in Noosa Shire Council (McAlpine et al. 2006) and elsewhere across its geographic range (Melzer & Houston 2001; Rhodes et al. 2206; McAlpine et al. 2008). Koalas are more likely to persist in landscapes with >50% high quality habitat configured in large patches, greater than 100 ha (McAlpine et al. 2005).
Regrowth	**High value regrowth** (HVR) mapping represents high conservation value native woody vegetation that has not been cleared for at least 15 years. High value regrowth was attributed with the regional ecosystems and koala habitat suitability rankings from the pre-clearing regional ecosystem mapping using differential clearing (rempercent) to better reflect historical clearing and maintain consistency between remnant and HVR. Differential clearing takes into consideration differences in clearing of vegetation communities or sub-units within a mixed (heterogeneous) pre-clearing regional ecosystem polygon. Note: The proportion of regional ecosystems occurring in a heterogeneous pre-clearing polygon may be different to the proportions of derived remnant polygons on the remnant regional ecosystem map, due to the differential clearing of specific regional ecosystems for a range of historical and current land management purposes (Tim Ryan, 8/6/2021). Processing High value regrowth was produced by the Queensland Herbarium from an initial automated process that identified vegetation with a woody foliage projective cover of at least 11% on a consecutive sequence of satellite images indicating that it had not been cleared for at least 15 years and excluded: areas of cropping, plantation, orchards or intensive land use and tenures not covered by VMA (e.g. national parks, state forests). The output of this process was subject to manual visual checking and editing of boundaries using high resolution imagery by botanists from DES to remove errors such as small plantations, houses and areas dominated by weedy non-native vegetation. Potential overlaps with the remnant layer were removed by erasing the regrowth layer with the current remnant regional ecosystem mapping.	Incorporating non-remnant habitat such as regrowth into the modelling was considered important because koalas utilise trees in fragmented landscapes and do not discriminate between remnant habitat or regrowth habitat (White 1999; Lunney et al. 2000; and Melzer et al. 2000).

Appendix 2. **Regional ecosystem koala suitability**

The regional ecosystems and associated vegetation communities were classified and ranked by experts for their suitability to koalas.

RE	Description (Queensland Herbarium REDD version 12)	RE rank
11.3.2	Eucalyptus populnea woodland to open woodland. E. melanophloia may be present and locally dominant. There is sometimes a distinct low tree layer dominated by species such as Geijera parviflora, Eremophila mitchellii, Acacia salicina, Acacia pendula, Lysiphyllum spp., Cassia brewsteri, Callitris glaucophylla and Acacia excelsa. The ground layer is grassy dominated by a range of species depending on soil and management conditions. Species include Bothriochloa decipiens, Enteropogon acicularis, Aristida ramosa and Tripogon loliiformis. Occurs on Cainozoic alluvial plains with variable soil types including texture contrast, deep uniform clays, massive earths and sometimes cracking clays. (BVG1M: 17a)	Medium
11.3.2	Eucalyptus populnea woodland to open woodland. Occasionally, E. melanophloia or E. crebra may be present. A secondary tree layer may occur and include species such as Geijera parviflora, Eremophila mitchellii, Acacia salicina, Cassia brewsteri, and Acacia excelsa. The ground layer is dominated by a range of tussock grasses, including Chloris spp., Enteropogon spp., and Aristida spp. Occurs on Cainozoic alluvial plains with variable soil types including texture contrast, deep uniform clays, massive earths and sometimes cracking clays. (BVG1M: 17a)	Medium
11.3.4	Eucalyptus tereticornis woodland to open forest. Other tree species that may be present include E. camaldulensis, Corymbia tessellaris, C. clarksoniana, E. melanophloia, E. platyphylla or Angophora floribunda. E. crebra and Lophostemon suaveolens may be locally common. A shrub layer is usually absent, and a grassy ground layer is prominent, and may include any of Bothriochloa bladhii subsp. bladhii, Aristida spp., Heteropogon contortus, Dichanthium spp. and Themeda triandra. Occurs on Cainozoic alluvial plains and terraces. Occurs on variety of soils, including deep cracking clays, medium to fine textured soils, and deep texture-contrast soils. (BVG1M: 16c)	High
11.3.21	Dichanthium sericeum and/or Astrebla spp. (A. lappacea, A. elymoides and A. squarrosa) tussock grassland. Frequently occurring species include the grasses Aristida leptopoda, A. latifolia, Bothriochloa bladhii subsp. bladhii, Brachyachne convergens, Heteropogon contortus, Panicum decompositum, Eriochloa spp., Sporobolus mitchellii and Thellungia advena and the forbs Abelmoschus ficulneus, Corchorus trilocularis, Commelina ensifolia, Euphorbia coghlanii, Ipomoea lonchophylla, Neptunia gracilis, Phyllanthus maderaspatensis, Sida trichopoda and Trichodesma zeylanicum var. latisepaleum. Scattered emergent trees and shrubs may occur, including Eucalyptus coolabah, E. populnea, E. tereticornis and Acacia spp. Occurs on Cainozoic alluvial plains on flats associated with rivers and creeks, including back-plains, terraces, low levees and back-swamps. Associated soils are usually heavy cracking clays. (BVG1M: 30a)	Non-habitat
11.3.24	Themeda avenacea +/- Eleocharis pallens tussock grassland sometimes with scattered Duma florulenta shrubs. Occurs on depressions on Cainozoic alluvial plains. (BVG1M: 30a)	Non-habitat
11.3.24a	Grassland +/- Eleocharis pallens grassland sometimes with scattered Duma florulenta shrubs.	Non-habitat
11.3.25	Eucalyptus tereticornis or E. camaldulensis woodland to open forest. Other tree species, including Casuarina cunninghamiana, E. coolabah, Melaleuca bracteata, Melaleuca viminalis, Livistona spp. (in north), Melaleuca spp. and Angophora floribunda, may occur. An tall shrub layer may occur, including Acacia salicina, A. stenophylla and Lysiphyllum carronii. Low shrubs are present, but rarely form a conspicuous layer. The ground layer is open to sparse and dominated by perennial grasses, sedges or forbs. Occurs on fringing levees and banks of major rivers and drainage lines of alluvial plains throughout the region. Soils are very deep, alluvial, grey and brown cracking clays with or without some texture contrast. These are usually moderately deep to deep, (BVG1M: 16a)	High
11.3.26	Eucalyptus moluccana or E. woollsiana +/- E. populnea +/- E. melanophloia open forest to woodland +/- Allocasuarina luehmannii low tree layer and a grassy ground layer. In northern subregions, there may be shrub layer of any of Eremophila mitchellii, Flindersia dissosperma, Citrus glauca or Petalostigma pubescens, with a sparse grassy ground layer. Occurs on margins of Cainozoic alluvial plains on deep texture contrast soils. (BVG1M: 13d)	Low
11.5.2a	Allocasuarina luehmannii low tree layer with or without emergent woodland. (BVG1M: 24a)	Non-habitat
11.8.2a	Eucalyptus tereticornis and E. melliodora woodland occurring on low hills. Occurs on low hills (subregion 31 and 32) formed from basalt. The soils are generally shallow (< 60 cm deep), brown to grey-brown, gradational, clay-loams and clays. Basalt stones and boulders can occur on the surface. (BVG1M: 11a)	Medium
11.8.3	Semi-evergreen vine thicket which may have emergent Acacia harpophylla, Casuarina cristata and Eucalyptus spp. Occurs on Cainozoic igneous rocks. Generally restricted to steeper, rocky hillsides. (BVG1M: 7a)	Very low
11.8.4	Eucalyptus melanophloia and/or E. crebra +/- E. orgadophila +/- Corymbia erythrophloia woodland to open woodland. Macrozamia moorei is a conspicuous element of the mid layer in the Central Highlands. Localised patches of Corymbia citriodora occur on volcanic plugs such as Minerva Hills. Generally occurs on slopes of mountains and hills formed from Cainozoic igneous rocks usually with shallow stony soils and extensive outcropping. (BVG1M: 11a)	Low
11.8.5a	Eucalyptus orgadophila woodland with a dense understorey of low trees species including Geijera parviflora, Callitris glaucophylla, Pittosporum angustifolium, Casuarina cristata, Alectryon oleifolius, Psydrax odorata and Notelaea microcarpa. (BVG1M: 11a)	Medium
11.8.5	Eucalyptus orgadophila open woodland. Eucalyptus orgadophila predominates and forms a distinct but discontinuous canopy sometimes with other sub-dominant species such as Corymbia erythrophloia, E. melanophloia and occasionally E. crebra. Shrubs are usually scarce and scattered although a well-defined shrubby layer does develop in some areas. On the lower slopes at better sites, softwood scrub species may form tall and low shrub layers under the canopy of Eucalyptus orgadophila. The ground layer is moderately dense to dense, and dominated by species that include the grasses Aristida lazaridis, A. ramosa, Bothriochloa ewartiana, Dichanthium sericeum, Chrysopogon fallax, Heteropogon contortus, Enneapogon gracilis, Themeda triandra and Tragus australianus and the herbs Brunoniella australis, Evolvulus alsinoides, Galactia tenuiflora and Indigofera linnaei.	Low

RE	Description (Queensland Herbarium REDD version 12)	RE rank
	Occurs on undulating plains, rises, low hills or sometimes flat tablelands on top of mountains, formed from basalt. Generally soils are shallow to moderately shallow, often rocky or stony clays. (BVG1M: 11a)	
11.8.8	Woodland usually dominated by either Eucalyptus albens or E. crebra. Eucalyptus tereticornis is an associated species that becomes locally dominant on creek lines. Other tree species that may be present include Callitris baileyi, Angophora subvelutina, Brachychiton populneus, E. melliodora, E. orgadophila, Angophora floribunda, E. moluccana, E. microcarpa, E. biturbinata, E. melanophloia and Corymbia clarksoniana. There is often a sparse low tree layer dominated by similar species to the canopy. The shrub layer is absent or sparse and consisting of species such as Cassinia laevis, Olearia elliptica, Acacia implexa, Xanthorrhoea glauca or Jacksonia scoparia. The ground layer is usually dominated by grasses of variable composition. Common species include Themeda triandra, Bothriochloa decipiens, Dichanthium sericeum, Cymbopogon refractus, Aristida spp. Fords or sedges such as Gahnia aspera, Asperula conferta or Desmodium varians frequently occur. Occurs on hilltops and sides formed from Cainozoic basaltic rocks. (BVG1M: 11a)	Medium
11.8.11	Grassland dominated by Dichanthium sericeum, Aristida spp., Astrebla spp. and Panicum decompositum with or without trees such as Eucalyptus orgadophila, E. melanophloia, Corymbia erythrophloia and Acacia salicina. However, dominance and cover may vary with seasonal and other environmental conditions. Frequently occurring and sometimes locally dominant, species include the grasses Aristida lazaridis, A. ramosa, Bothriochloa ewartiana, Dichanthium sericeum, Chrysopogon fallax, Heteropogon contortus, Enneapogon gracilis, Themeda triandra and Tragus australianus and the herbs Brunoniella australis, Evolvulus alsinoides, Galactia tenuiflora and Indigofera linnaei. Isolated emergent trees (tree height 12+/-4 m - species including Eucalyptus orgadophila, E. melanophloia and Corymbia erythrophloia) or small areas of open woodland may also be present. Occurs on Cainozoic igneous rocks, particularly fresh basalt, and is generally associated with undulating to gently undulating rises. It usually occurs on the crests and middle and upper slopes (slopes 2-6%), although also present on lower slopes and flat (BVG1M: 30b)	Non-habitat
11.9.5	Acacia harpophylla and/or Casuarina cristata or Acacia harpophylla open forest to woodland. Casuarina cristata is more common in southern parts of the bioregion. A prominent low tree or tall shrub layer dominated by species such as Geijera parviflora and Eremophila mitchellii, and occasionally with semi-evergreen vine thicket species is often present. The latter include Flindersia dissosperma, Brachychiton rupestris, Excoecaria dallachyana, Macropteranthes leichhardtii and Acalypha eremorum in eastern areas, and species such as Carissa ovata, Owenia acidula, Croton insularis, Denhamia oleaster and Notelaea microcarpa in south-western areas. Melaleuca bracteata may be present along watercourses. Occurs on fine-grained sediments. The topography includes gently undulating plains, valley floors and undulating footslopes and rarely on low hills. The soils are generally deep texture-contrast and cracking clays. The cracking clays are usually black or (BVG1M: 25a)	Very low
11.9.9	Eucalyptus crebra grassy woodland. Eucalyptus moluccana sometimes conspicuous on lower slopes. Occurs on Cainozoic to Proterozoic consolidated, fine-grained sediments. (BVG1M: 13c)	Low
12.1.1	Casuarina glauca open forest to low open woodland. Occurs on margins of Quaternary estuarine deposits. (BVG1M: 28a)	Non-habitat
12.1.2	Saltpan vegetation comprising Sporobolus virginicus grassland and samphire herbland. Grasses including Zoysia macrantha subsp. macrantha sometimes present in upper portions of tidal flats. Includes saline or brackish sedgelands. Usually occurs on hypersaline Quaternary estuarine deposits. Marine plains/tidal flats. (BVG1M: 35b)	Non-habitat
12.1.3f	Estuarine water bodies often with groundwater connectivity. Occurs on Quaternary estuarine deposits with groundwater connectivity. (BVG1M: 34a)	Non-habitat
12.1.3b	Avicennia marina subsp. australasica dominated shrubland to low closed forest. Occurs on Quaternary estuarine deposits. (BVG1M: 35a)	Non-habitat
12.1.3	Mangrove shrubland to low closed forest. Occurs on Quaternary estuarine deposits. (BVG1M: 35a)	Non-habitat
12.1.3g	Mangrove dieback area leaving bare soil or ponding. Occurs on Quaternary estuarine deposits. (BVG1M: 35a)	Non-habitat
12.1.3e	Rhizophora stylosa dominated shrubland to low closed forest. Occurs on Quaternary estuarine deposits. (BVG1M: 35a)	Non-habitat
12.2.1	Notophyll/evergreen notophyll vine forest generally with abundant Archontophoenix cunninghamiana or A. alexandrae in north of bioregion. The plant families Lauraceae, Myrtaceae and Elaeocarpaceae are diagnostic of the type. Occurs on moist/wet, valley floors of parabolic dunes. (BVG1M: 4a)	Very low
12.2.2	Microphyll/notophyll vine forest. Characteristic species include Cupaniopsis anacardioides, Acronychia imperforata, Flindersia schottiana, Alectryon coriaceus, Elaeocarpus obovatus, Polyalthia nitidissima, Diospyros spp., Pleiogynium timorense and Mallotus discolor. Melaleuca spp. and eucalypt emergents may be present, e.g. Melaleuca dealbata and Corymbia tessellaris. Occurs on Quaternary coastal dunes and beaches. (BVG1M: 3a)	Very low
12.2.3	Araucarian microphyll/notophyll vine forest. Backhousia myrtifolia common in understorey on Fraser Island and Cooloola and forms low canopy in places. Occurs on parabolic dunes. (BVG1M: 3a)	Very low
12.2.5	Open forest to low closed forest. Species can include Corymbia intermedia, Lophostemon confertus, Banksia integrifolia subsp. integrifolia, B. aemula, Callitris columellaris, Acacia spp., Livistona spp. and Endiandra sieberi. Melaleuca quinquenervia in swales. Understorey generally shrubby and can include vine forest species. Occurs on Quaternary coastal dunes, beach ridges and sandy banks of coastal streams. (BVG1M: 9f)	Low
12.2.6	Eucalyptus racemosa subsp. racemosa, Corymbia intermedia, C. gummifera, Angophora leiocarpa and E. pilularis shrubby or grassy woodland to open forest. Occurs on Quaternary coastal dunes and beaches. Dunes with deeply leached soils. (BVG1M: 9g)	Low
12.2.7c	Melaleuca quinquenervia, Eucalyptus robusta, Melicope elleryana open forest with understorey of Todea barbara. Occurs along watercourses on Quaternary coastal dunes and beaches and seasonally waterlogged sandplains. (BVG1M: 22a)	Low
12.2.7	Melaleuca quinquenervia or rarely M. dealbata open forest. Other species include Eucalyptus tereticornis, Corymbia intermedia, E. bancroftii, E. latisinensis, E. robusta, Lophostemon suaveolens and Livistona decora. A shrub layer may occur with frequent species including Melastoma malabathricum subsp. malabathricum or Banksia	Medium

RE	Description (Queensland Herbarium REDD version 12)	RE rank
	robur. The ground layer is sparse to dense and comprised of species including the ferns Pteridium esculentum and Blechnum indicum the sedges Schoenus brevifolius, Baloskion tetraphyllum subsp. meiostachyum, Machaerina rubiginosa and Gahnia sieberiana and the grass Imperata cylindrica. Occurs on Quaternary coastal dunes and seasonally waterlogged sandplains usually fringing drainage system behind beach ridge plains or on old dunes, swales and sandy coastal creek levees. (BVG1M: 22a)	
12.2.7a	Melaleuca quinquenervia low woodland with Gahnia sieberiana ground layer. Occurs on Quaternary coastal sand dunes fringing swamps. (BVG1M: 22a)	Low
12.2.8	Eucalyptus pilularis, E. microcorys, E. resinifera and Syncarpia hillii open forest. Occurs on parabolic high dunes. (BVG1M: 8b)	Low
12.2.9	Banksia aemula low open woodland. Mallee eucalypts sometimes present, e.g. Eucalyptus latisinensis. Occurs on Quaternary coastal dunes and sandplains with deeply leached soils. (BVG1M: 29a)	Non-habitat
12.2.10	Eucalyptus planchoniana +/- Corymbia gummifera, E. racemosa subsp. racemosa, Banksia aemula low woodland to low open forest. Occurs on deeply leached Quaternary coastal dunes and sandplains. (BVG1M: 29a)	Low
12.2.12	Closed or wet heath +/- stunted emergent shrubs/low trees. Characteristic shrubs include Banksia spp. (especially B. robur) Boronia falcifolia, Epacris spp., Baeckea frutescens, Schoenus brevifolius, Leptospermum spp., Hakea actites, Melaleuca thymifolia, M. nodosa, Xanthorrhoea fulva with Baloskion spp. and Sporadanthus spp. in ground layer. Occurs on poorly drained Quaternary coastal dunes and sandplains. Low part of sand mass coastal landscapes where water collects from both overland flow and infiltration from adjoining sand dunes. (BVG1M: 29a)	Non-habitat
12.2.13	Open or dry heath. Characteristic shrubs include stunted Banksia aemula and Allocasuarina littoralis as well as Xanthorrhoea johnsonii, Leptospermum semibaccatum, Phebalium woombye, Dillwynia retorta and Caustis recurvata. Usually occurs on Pleistocene dunes and beach ridges. (BVG1M: 29a)	Non-habitat
12.2.14	Strand and fore dune complex comprising Spinifex sericeus grassland Casuarina equisetifolia subsp. incana low woodland/open forest and with Acacia leiocalyx, A. disparrima subsp. disparrima, Banksia integrifolia subsp. integrifolia, Pandanus tectorius, Corymbia tessellaris, Cupaniopsis anacardioides, Acronychia imperforata and Hibiscus tiliaceus. Occurs mostly on frontal dunes and beaches but can occur on exposed parts of dunes further inland. (BVG1M: 28a)	Non-habitat
12.2.15	Closed sedgeland in coastal swamps and associated water bodies. Characteristic species include Gahnia sieberiana, Empodisma minus, Gleichenia spp., Blechnum indicum, Lepironia articulata, Baumea spp., Juncus spp., and Eleocharis spp. Occurs on Quaternary coastal dunes and beaches. Low part of coastal landscape where water collects from both overland flow and infiltration from adjoining sand dunes. (BVG1M: 34c)	Non-habitat
12.2.15g	Swamps dominated by Empodisma minus, Gahnia sieberiana, other sedges and forbs and shrubs such as Leptospermum liversidgei. Occurs on depressions in coastal sand masses fed by ground water. (BVG1M: 34c)	Non-habitat
12.2.15a	Permanent and semi-permanent window lakes. Occurs as a window into the water table on Quaternary coastal dunes and beaches. Low part of coastal landscape where water collects from both overland flow and infiltration from adjoining sand dunes. (BVG1M: 34a)	Non-habitat
12.2.15f	Permanent and semi-permanent perched lakes. Occurs perched on Quaternary coastal dunes. (BVG1M: 34a)	Non-habitat
12.2.16	Sand blows largely devoid of vegetation. Sand blows on large sand islands. (BVG1M: 28d)	Non-habitat
12.3.1a	Complex notophyll vine forest. Typical canopy species include Castanospermum australe, Elaeocarpus grandis, Grevillea robusta, Cryptocarya obovata, Beilschmiedia obtusifolia, Dysoxylum mollissimum subsp. molle, Pseudoweinmannia lachnocarpa, Argyrodendron trifoliolatum, Planchonella australis, Ficus watkinsiana, F. macrophylla forma macrophylla, Aphananthe philippinensis, Toona ciliata and Syzygium francisii. Emergent Eucalyptus grandis or Lophostemon confertus may occur. Waterhousea floribunda and Tristaniopsis laurina may occur on banks of stream channels. Typical sub canopy species include Cryptocarya triplinervis, Archontophoenix cunninghamiana, Endiandra pubens, Arytera divaricata, Syzygium moorei and Macadamia spp. Occurs on Quaternary alluvial plains and channels in areas of high rainfall (generally >1300mm). (BVG1M: 4b)	Very low
12.3.2	Eucalyptus grandis +/- E. microcorys, Lophostemon confertus tall open forest with vine forest understorey ('wet sclerophyll'). Patches of Eucalyptus pilularis sometimes present especially in vicinity of sedimentary rocks (e.g. around Palmwoods). Fringing streams and in narrow gullies in high rainfall areas. (BVG1M: 8a)	Medium
12.3.3d	Eucalyptus moluccana woodland. Other frequently occurring species include Eucalyptus tereticornis, E. crebra, E. siderophloia, Corymbia citriodora subsp. variegata, Angophora leiocarpa and C. intermedia. Occurs on margins of Quaternary alluvial plains often adjacent sedimentary geologies. May also occur on stranded Pleistocene river terraces. (BVG1M: 13d)	High
12.3.3a	Eucalyptus crebra, C. tessellaris woodland to open forest. Other species that may be present as scattered individuals or clumps include Corymbia clarksoniana, Eucalyptus melanophloia, E. tereticornis and C. citriodora subsp. variegata. Occurs on high level alluvial plains often of Pleistocene age, terraces and fans where rainfall is usually less than 1000mm/y. (BVG1M: 18b)	Medium
12.3.3	Eucalyptus tereticornis woodland. Eucalyptus crebra and E. moluccana are sometimes present and may be relatively abundant in places, especially on edges of plains and higher level alluvium. Other species that may be present as scattered individuals or clumps include Angophora subvelutina or A. floribunda, Corymbia clarksoniana, C. intermedia, C. tessellaris, Lophostemon suaveolens and E. melanophloia. Occurs on Quaternary alluvial plains, terraces and fans where rainfall is usually less than 1000mm/y. (BVG1M: 16c)	High
12.3.4a	Eucalyptus bancroftii open woodland often with Melaleuca quinquenervia. Occurs on drainage lines and floodplains in coastal areas. (BVG1M: 22a)	Low
12.3.4	Open forest to woodland of Melaleuca quinquenervia and Eucalyptus robusta. Occurs fringing drainage lines and on floodplains in coastal areas. (BVG1M: 22a)	Low
12.3.5	Melaleuca quinquenervia open forest to woodland. Understorey depends upon duration of water logging; sedges and ferns, especially Blechnum indicum, in wetter microhabitats and grasses and shrubs in drier microhabitats. Ground layer species include the grasses Leersia hexandra and Imperata cylindrica, the sedges/rushes,	Medium

RE	Description (Queensland Herbarium REDD version 12)	RE rank
	Machaerina rubiginosa, Gahnia sieberiana, Lepironia articulata, Schoenus brevifolius and Schoenus scabripes and the fern Lygodium microphyllum. Other tree species that may be present as scattered individuals or clumps include Lophostemon suaveolens, Eucalyptus robusta, E. tereticornis, E. bancroftii, E. latisinensis, Corymbia intermedia, Melaleuca salicina, Livistona australis, Casuarina glauca, Endiandra sieberi. Melastoma malabathricum subsp. malabathricum, Glochidion sumatranum and Melicope elleryana are often in understorey. Occurs on Quaternary alluvium in coastal areas. (BVG1M: 22a)	
12.3.6	Melaleuca quinquenervia +/- Eucalyptus tereticornis, Lophostemon suaveolens, Corymbia intermedia open forest to woodland with a grassy ground layer dominated by species such as Imperata cylindrica. Eucalyptus tereticornis may be present as an emergent layer. Eucalyptus seeana may also occur in this ecosystem to the south and east of Brisbane. Occurs on Quaternary floodplains and fringing drainage lines in coastal areas. (BVG1M: 22a)	Medium
12.3.7b	Naturally occurring instream waterholes and lagoons, both permanent and intermittent. Includes exposed stream bed and bars. Occurs in the bed of active (may be intermittent) river channels. (BVG1M: 16d)	Non-habitat
12.3.7	Narrow fringing woodland of Eucalyptus tereticornis, Casuarina cunninghamiana subsp. cunninghamiana +/- Melaleuca viminalis. Other species associated with this RE include Melaleuca bracteata, M. trichostachya, M. linariifolia. North of Brisbane Waterhousea floribunda commonly occurs and may at times dominate this RE . Melaleuca fluviatilis occurs in this RE in the north of the bioregion. Lomandra hystrix often present in stream beds. Occurs on fringing levees and banks of rivers and drainage lines of alluvial plains throughout the region. (BVG1M: 16a)	Medium
12.3.7d	Aquatic vegetation usually fringed with Eucalyptus tereticornis. Closed depressions on alluvial plains. (BVG1M: 34d)	Low
12.3.7c	Billabongs and ox-bow lakes containing either permanent or periodic water bodies. Often fringed with Eucalyptus tereticornis Old river beds now cut off from regular flow. (BVG1M: 34d)	Low
12.3.7a	Melaleuca bracteata open forest +/- emergent Eucalypts tereticornis. Occurs in drainage depressions on Quaternary alluvial plains. (BVG1M: 22c)	Low
12.3.8a	Swamps with characteristic species including Carex appressa, Juncus spp., Persicaria spp., and Cyperus spp. Occurs in closed depressions on the margins of elevated Tertiary basalt landscapes. (BVG1M: 34c)	Non-habitat
12.3.8	Swamps with characteristic species including Cyperus spp., Schoenoplectus spp., Philydrum lanuginosum, Eleocharis spp., Leersia hexandra, Cycnogeton procerus, Nymphaea spp., Nymphoides indica, Persicaria spp., Phragmites australis, Typha spp. and a wide range of sedges grasses or forbs. Emergent Melaleuca spp. may sometimes occur. Occurs in freshwater swamps associated with floodplains. (BVG1M: 34c)	Non-habitat
12.3.9	Eucalyptus nobilis open forest. Occurs at headwaters of streams on Quaternary alluvial plains usually forming a narrow fringing community. (BVG1M: 16c)	Low
12.3.10a	Acacia harpophylla open forest to woodland. Occurs on Quaternary alluvial plains where minor areas of cracking clay soils prevail. (BVG1M: 25a)	Very low
12.3.11b	Eucalyptus tereticornis and/or E. racemosa subsp. racemosa +/- E. siderophloia, Lophostemon suaveolens, E. seeana, E. fibrosa subsp. fibrosa, E. propinqua and Angophora leiocarpa open forest usually with a dense shrub layer dominated by Melaleuca nodosa. Occurs on Quaternary alluvium usually higher Pleistocene plains and terraces. Rainfall usually exceeds 1000mm/y. (BVG1M: 16c)	Medium
12.3.11a	Open forest of Eucalyptus tereticornis and/or E. siderophloia, Lophostemon confertus with vine forest understorey. Other canopy species include Corymbia intermedia, Araucaria cunninghamii and Agathis robusta. Frequently occurring understorey species include Flindersia spp., Lophostemon suaveolens, L. confertus, Cupaniopsis parvifolia, Acronychia spp., Alphitonia excelsa and Acacia disparrima subsp. disparrima. Occurs on sub-coastal Quaternary alluvial plains. Rainfall usually exceeds 1000mm/y. (BVG1M: 16c)	High
12.3.11	Eucalyptus tereticornis +/- E. siderophloia and Corymbia intermedia open forest to woodland. Corymbia tessellaris, Lophostemon suaveolens and Melaleuca quinquenervia frequently occur and often form a low tree layer. Other species present in scattered patches or low densities include Angophora leiocarpa, E. exserta, E. grandis, E. latisinensis, E. tindaliae, E. racemosa and Melaleuca sieberi. Corymbia trachyphloia and/or C. citriodora subsp. Variegata may dominate on areas of Pleistocene alluvia. Eucalyptus seeana may be present south of Landsborough and Livistona decora may occur in scattered patches or low densities in the Glenbar SF and Wongi SF areas. Occurs on Quaternary alluvial plains and drainage lines along coastal lowlands. Rainfall usually exceeds 1000mm/y. (BVG1M: 16c)	High
12.3.13	Closed or wet heathland. Characteristic species include Melaleuca thymifolia, Banksia robur, Xanthorrhoea fulva, Hakea actites, Leptospermum spp. and Baeckea frutescens. Occurs on seasonally waterlogged Quaternary alluvial plains along coastal lowlands. (BVG1M: 29a)	Non-habitat
12.3.14a	Eucalyptus racemosa subsp. racemosa woodland to open forest. Other canopy species may include Corymbia intermedia, C. gummifera, Eucalyptus latisinensis, E. tindaliae and Melaleuca quinquenervia. Occurs on Quaternary alluvial plains in near coastal areas. (BVG1M: 9g)	Low
12.3.14	Banksia aemula low woodland +/- mallee eucalypt low woodland. Associated canopy species include Eucalyptus latisinensis, Corymbia intermedia, E. robusta and Lophostemon confertus. Occurs on Quaternary alluvial plains along coastal lowlands. (BVG1M: 29a)	Low
12.3.16	Complex notophyll to microphyll vine forest. Typical canopy species include Aphananthe philippinensis, Argyrodendron sp. (Kin Kin W.D.Francis AQ81198), Argyrodendron trifoliolatum, Diospyros fasciculosa, Drypetes deplanchei, Dysoxylum mollissimum subsp. molle, Jagera pseudorhus, Mallotus discolor, Melia azedarach, Mischocarpus pyriformis subsp. pyriformis, Planchonella pohlmaniana, Toona ciliata and Vitex lignum-vitae. Casuarina cunninghamiana may occur in scattered patches or low densities along channel banks. Grevillea robusta commonly occurs south of Maryborough. Emergents of Araucaria cunninghamii, Eucalyptus tereticornis and Lophostemon confertus may occur. Typical sub-canopy species include Streblus brunonianus, Cryptocarya triplinervis, Gossia bidwillii, Diospyros australis, Arytera divaricata, Capparis arborea, Cleistanthus cunninghamii and Polyalthia nitidissima. Occurs on Quaternary alluvial plains and channels. (BVG1M: 4b)	Very low

RE	Description (Queensland Herbarium REDD version 12)	RE rank
12.3.17	Simple notophyll fringing forest usually dominated by Waterhousea floribunda. Other typical canopy species include Aphananthe philippinensis and Castanospermum australe. Casuarina cunninghamiana may occur in scattered patches or low densities along channel banks. Often Typical sub-canopy species include Syzygium australe, Cryptocarya triplinervis and Ficus coronata. Fringes channels on Quaternary alluvium. (BVG1M: 4b)	Very low
12.3.18	Melaleuca irbyana low open forest or thicket. Emergent Eucalyptus moluccana, E. crebra, E. tereticornis or Corymbia citriodora subsp. variegata may be present. Occurs on Quaternary alluvial plains where drainage of soils is impeded. (BVG1M: 21b)	Medium
12.3.19	Eucalyptus moluccana and/or Eucalyptus tereticornis and E. crebra open forest to woodland, with a sparse to mid-dense understorey of Melaleuca irbyana. Occurs on margins of Quaternary alluvial plains. (BVG1M: 13d)	Medium
12.3.20	Melaleuca quinquenervia, Casuarina glauca +/- Eucalyptus tereticornis, E. siderophloia open forest. Melaleuca styphelioides is often an associated species in the Wide Bay area. Occurs on lowest terraces of Quaternary alluvial plains in coastal areas. (BVG1M: 22a)	Medium
12.3.21	Complex microphyll vine forest. Typical canopy species include Excoecaria dallachyana, Archidendropsis thozetiana, Polyalthia nitidissima, Drypetes deplanchei, Ficus rubiginosa, Diospyros geminata, Coatesia paniculata, Flindersia australis, Alectryon connatus, Alectryon subdentatus, Diospyros humilis, Planchonella cotinifolia, Bridelia leichhardtii, Croton insularis, Denhamia pittosporoides, Notelaea microcarpa and Siphonodon australis. Casuarina cunninghamiana may occur in scattered patches or low densities along channel banks. Emergents of Araucaria cunninghamii and Eucalyptus tereticornis may occur. Typical sub-canopy species include Mallotus philippensis, Gossia bidwillii, Alangium polyosmoides subsp. Tomentosum, Exocarpos latifolius, Hodgkinsonia ovatiflora, Capparis arborea and Pleurostylia opposita. Typical shrub species include Murraya ovatifoliolata, Alchornea ilicifolia, Turraea pubescens, Alyxia ruscifolia and Psydrax odorata. Occurs on Quaternary alluvial plains and channels in drier western parts of bioregion typically draining from hills and ranges. (BVG1M: 4b)	Very low
12.5.1b	Eucalyptus cloeziana open forest +/- E. microcorys and Corymbia intermedia. Occurs on remnant Tertiary surfaces. Usually deep red soils. (BVG1M: 12a)	Low
12.5.1	Woodland to open forest complex generally with Corymbia trachyphloia, C. citriodora subsp. variegata +/- Eucalyptus crebra, E. longirostrata, C. intermedia, E. major, E. fibrosa subsp. fibrosa (can be locally common) and E. acmenoides. Localised occurrences of Eucalyptus taurina, E. decorticans, E. dura, E. cloeziana and E. melanoleuca. Understorey grassy or shrubby. Occurs on remnant Tertiary surfaces, usually with deep red soils. (BVG1M: 10b)	High
12.5.1g	Eucalyptus planchoniana and/or E. baileyana woodland to open forest +/- C. trachyphloia, E. carnea, Angophora woodsiana, E. psammitica, E. crebra, E. racemosa subsp. racemosa. Occurs on remnant Tertiary surfaces. (BVG1M: 9h)	Low
12.5.1c	Eucalyptus helidonica open forest +/- Corymbia citriodora subsp. variegata, C. trachyphloia, E. planchoniana, E. taurina, E. baileyana, Angophora woodsiana, Lysicarpus angustifolius. Occurs on remnant Tertiary surfaces. (BVG1M: 9h)	Low
12.5.2b	Eucalyptus tereticornis +/- Corymbia intermedia, Lophostemon suaveolens and C. citriodora subsp. variegata open forest. Other species can include Angophora leiocarpa, Eucalyptus acmenoides, E. crebra and Corymbia tessellaris. Eucalyptus exserta is usually present in northern parts of bioregion. Occurs on complex of remnant Tertiary surfaces +/- Cainozoic and Mesozoic sediments in sub-coastal areas. Usually deep red soils. (BVG1M: 9g)	Medium
12.5.2a	Corymbia intermedia, Eucalyptus tereticornis woodland. Other species can include Lophostemon suaveolens, Angophora leiocarpa, Eucalyptus acmenoides or E. portuensis, E. siderophloia or E. crebra, Corymbia tessellaris and Melaleuca quinquenervia (lower slopes). Eucalyptus exserta is usually present in northern parts of bioregion. Occurs on complex of remnant Tertiary surfaces +/- Cainozoic and Mesozoic sediments usually in coastal areas with deep red soils. (BVG1M: 9g)	High
12.5.2x1	Melaleuca irbyana low open forest with emergent Eucalyptus tereticornis. Occurs on remnant Tertiary surfaces, mainly deeply weathered high level Tertiary alluvium. (BVG1M: 21b)	Medium
12.5.3	Eucalyptus racemosa subsp. racemosa woodland with Corymbia intermedia, E. siderophloia +/- E. tindaliae, E. resinifera, E. pilularis, E. microcorys, Angophora leiocarpa. Melaleuca quinquenervia is often a prominent feature of lower slopes. Minor patches (<1ha) dominated by Corymbia citriodora subsp. variegata sometimes occur. Occurs on complex of remnant Tertiary surfaces +/- Cainozoic and Mesozoic sediments. (BVG1M: 9g)	Medium
12.5.3a	Mixed woodland to open forest usually containing Corymbia intermedia, Eucalyptus racemosa subsp. racemosa and at least a presence of Eucalyptus seeana. Other commonly associated species include Angophora leiocarpa, E. siderophloia, E. microcorys, C. citriodora subsp. variegata and Lophostemon suaveolens. Occurs on complex of remnant Tertiary surfaces +/- Cainozoic and Mesozoic sediments. (BVG1M: 9g)	Medium
12.5.4a	Woodland of Melaleuca quinquenervia and/or M. viridiflora var. viridiflora +/- Eucalyptus latisinensis, Corymbia intermedia, Angophora leiocarpa, E. exserta, Lophostemon suaveolens and M. nodosa. Occurs on complex of remnant Tertiary surfaces and Cainozoic and Mesozoic sediments usually lower slopes. (BVG1M: 21a)	Low
12.5.4	Eucalyptus latisinensis +/- Corymbia intermedia, C. trachyphloia subsp. trachyphloia, Angophora leiocarpa, Eucalyptus exserta woodland. Other characteristic species include Eucalyptus siderophloia, Lophostemon suaveolens, Melaleuca viridiflora var. viridiflora, M. quinquenervia, M. cheelii and Grevillea banksii. Patches of Allocasuarina luehmannii or Banksia oblongifolia present locally and Xanthorrhoea johnsonii common in ground layer. Occurs on complex of remnant Tertiary surfaces and Cainozoic and Mesozoic sediments. (BVG1M: 9g)	Low
12.5.6	Eucalyptus siderophloia, E. propinqua and/or E. pilularis open forest +/- Corymbia intermedia, E. microcorys, E. acmenoides, E. tereticornis, E. biturbinata, Lophostemon confertus with E. saligna, E. montivaga at higher altitudes. Occurs on remnant Tertiary surfaces. Usually deep red soils. (BVG1M: 9a)	High
12.5.6a	Eucalyptus saligna or E. grandis open forest, often with vine forest understorey. Occurs on remnant Tertiary surfaces. Usually deep red soils. (BVG1M: 8a)	Low
12.5.6b	Eucalyptus siderophloia, Corymbia intermedia, E. propinqua or E. major or E. longirostrata open forest +/- E. microcorys, E. acmenoides, E. tereticornis, E. biturbinata, E. pilularis, Lophostemon confertus. Occurs on remnant	High

RE	Description (Queensland Herbarium REDD version 12)	RE rank
	Tertiary surfaces. Usually deep red soils. (BVG1M: 9a)	
12.5.6c	Eucalyptus pilularis open forest +/- E. siderophloia, E. propinqua, Corymbia intermedia, E. microcorys, E. acmenoides, E. tereticornis, E. biturbinata, Lophostemon confertus with E. saligna, E. montivaga at higher altitudes. Occurs on remnant Tertiary surfaces. Usually deep red soils. (BVG1M: 8b)	Medium
12.5.7c	Corymbia henryi and/or Eucalyptus fibrosa subsp. fibrosa woodland +/- C. citriodora subsp. variegata, E. major, E. carnea, E. tindaliae, E. siderophloia, Angophora leiocarpa, E. helidonica, E. portuensis, E. latisinensis, C. intermedia and E. moluccana. Occurs on complex of remnant Tertiary surfaces and Tertiary sedimentary rocks. (BVG1M: 10b)	Medium
12.5.7b	Eucalyptus moluccana +/- Corymbia citriodora subsp. variegata open forest. Other species include Eucalyptus siderophloia or E. crebra, E. tereticornis. Understorey generally sparse but can become shrubby in absence of fire. Occurs on complex of remnant Tertiary surfaces and Tertiary sedimentary rocks often on lower slopes. (BVG1M: 13d)	Medium
12.5.7	Corymbia citriodora subsp. variegata +/- Eucalyptus portuensis or E. acmenoides, C. intermedia, E. fibrosa subsp. fibrosa, C. trachyphloia, E. moluccana (lower slopes), E. crebra (drier sub coastal areas) or E. siderophloia, E. exserta open forest. Occurs on complex of remnant Tertiary surfaces and Tertiary sedimentary rocks. Usually deep red soils. (BVG1M: 10b)	Medium
12.5.9a	Melaleuca nodosa low open forest to low closed-forest +/- emergent eucalypts. Occurs on poorly drained areas on remnant Tertiary surfaces including lower slopes. (BVG1M: 21b)	Very low
12.5.9	Sedgeland to heathland often with emergent Eucalyptus latisinensis. Characteristic shrubs include Leptospermum spp., Leucopogon spp., Ricinocarpos pinifolius, Strangea linearis, Brachyloma daphnoides, Persoonia virgata, Xanthorrhoea spp., Styphelia viridis, Monotoca scoparia, Woollsia pungens and stunted Allocasuarina littoralis. Includes minor seepage areas containing Banksia robur and Xanthorrhoea fulva. Occurs on complex of remnant Tertiary surfaces and Tertiary sedimentary rocks. Lower slopes. (BVG1M: 29a)	Very low
12.5.10	Eucalyptus latisinensis and/or Banksia aemula low open woodland +/- Corymbia trachyphloia subsp. trachyphloia. Diverse understorey of heath species. Occurs on complex of remnant Tertiary surfaces and Tertiary sedimentary rocks. (BVG1M: 29a)	Low
12.5.12	Eucalyptus racemosa subsp. racemosa, E. latisinensis +/- Corymbia gummifera, C. intermedia, E. bancroftii, Melaleuca quinquenervia woodland to open woodland with prominent heathy understorey. Other canopy species occasionally present include E. robusta, Angophora leiocarpa and A. woodsiana. Occurs on remnant Tertiary surfaces +/- Cainozoic and Mesozoic sediments. (BVG1M: 9g)	Low
12.5.13a	Microphyll to notophyll vine forest +/- Araucaria cunninghamii. Characteristic species include Araucaria cunninghamii, Cupaniopsis parvifolia, Dendrocnide photiniphylla, Rhodosphaera rhodanthema, Flindersia australis, F. schottiana, F. xanthoxyla, Drypetes deplanchei, Olea paniculata, Diospyros geminata, Gossia bidwillii, Excoecaria dallachyana and Vitex lignum-vitae. Argyrodendron trifoliolatum sometimes present especially in subregion 6. Occurs on remnant Tertiary surfaces especially lateritised basalt. (BVG1M: 5a)	Very low
12.8.1	Eucalyptus campanulata tall open forest with shrubby to grassy understorey. Other canopy species include Eucalyptus microcorys, Syncarpia glomulifera subsp. glomulifera, E. acmenoides, Corymbia intermedia, E. carnea and E. resinifera. Patches of Eucalyptus pilularis sometimes present on ridges and crests. Occurs in high rainfall areas above 580 metres altitude on Cainozoic igneous rocks especially rhyolite. (BVG1M: 8b)	Low
12.8.1a	Eucalyptus montivaga open forest +/- Corymbia intermedia, E. pilularis. Occurs on elevated Cainozoic igneous rocks. (BVG1M: 8b)	Low
12.8.2	Eucalyptus oreades +/- E. campanulata tall open forest. Occurs on Cainozoic igneous rocks. (BVG1M: 8a)	Very low
12.8.3	Complex notophyll vine forest. Characteristic species include Argyrodendron trifoliolatum, Olea paniculata, Castanospermum australe, Cryptocarya obovata, Ficus macrophylla forma macrophylla, Syzygium francisii, Diploglottis australis, Pseudoweinmannia lachnocarpa, Podocarpus elatus, Beilschmiedia obtusifolia, Neolitsea dealbata and Archontophoenix cunninghamiana. Occurs on Cainozoic igneous rocks, especially basalt <600m altitude. (BVG1M: 2a)	Very low
12.8.4	Complex notophyll vine forest with scattered Araucaria bidwillii and A. cunninghamii. Characteristic species include Argyrodendron actinophyllum, Baloghia inophylla, Brachychiton acerifolius, Dendrocnide excelsa, Elaeocarpus kirtonii, Diospyros pentamera, Dysoxylum fraserianum, Toona ciliata, Orites excelsus and Sloanea woollsii. Occurs on Cainozoic igneous rocks especially basalt and lateritised basalt. (BVG1M: 2a)	Very low
12.8.5	Complex notophyll vine forest. Characteristic species include Argyrodendron actinophyllum, Sloanea australis, S. woollsii, Cryptocarya erythroxylon, Ficus watkinsiana, Dysoxylum fraserianum, Ackama paniculosa, Karrabina benthamiana, Orites excelsus, Acmena ingens, Syzygium corynanthum, S. crebrinerve and Citronella moorei. Occurs on Cainozoic igneous rocks especially basalt and lateritised basalt usually >600m altitude. (BVG1M: 6a)	Very low
12.8.6	Simple microphyll fern forest with Nothofagus moorei and/or Doryphora sassafras, Ackama paniculosa, Orites excelsus. Occurs on Cainozoic igneous rocks at high altitudes. (BVG1M: 6a)	Very low
12.8.7	Simple microphyll fern thicket with Acmena smithii. Occurs on Cainozoic igneous rocks at high altitudes. (BVG1M: 6a)	Very low
12.8.8	Eucalyptus saligna or E. grandis tall open forest often with vine forest understorey ('wet sclerophyll'). Other canopy species that may be present and at times locally dominate include Eucalyptus pilularis, E. microcorys, E. acmenoides, Lophostemon confertus and Syncarpia glomulifera subsp. Glomulifera. Occurs on Cainozoic igneous rocks and areas subject to local enrichment from Cainozoic igneous rocks. (BVG1M: 8a)	Medium
12.8.8a	Eucalyptus siderophloia, E. microcorys, Corymbia intermedia +/- Eucalyptus propinqua, E. carnea open forest on Cainozoic igneous rocks. Occurs on Cainozoic igneous rocks and areas subject to local enrichment from Cainozoic igneous rocks. (BVG1M: 9a)	High
12.8.9	Lophostemon confertus open forest often with vine forest understorey ('wet sclerophyll'). Occurs on Cainozoic igneous rocks. Tends to occur mostly in gullies and on exposed ridges on basalt. (BVG1M: 8a)	Low

RE	Description (Queensland Herbarium REDD version 12)	RE rank
12.8.11	Eucalyptus dunnii +/- E. saligna and E. microcorys tall open forest. Occurs on Cainozoic igneous rocks and areas subject to local enrichment from Cainozoic igneous rocks. (BVG1M: 8a)	Low
12.8.12	Eucalyptus obliqua tall open forest. Occurs on Cainozoic igneous rocks. (BVG1M: 8b)	Low
12.8.13	Microphyll and microphyll/notophyll vine forest +/- Araucaria cunninghamii. Characteristic species include Araucaria cunninghamii, A. bidwillii, Cupaniopsis parvifolia, Dendrocnide photiniphylla, Rhodosphaera rhodanthema, Flindersia australis, F. schottiana, F. xanthoxyla, Drypetes deplanchei, Olea paniculata, Diospyros geminata, Gossia bidwillii, Excoecaria dallachyana, Pleiogynium timorense (north of bioregion) and Vitex lignum-vitae. Argyrodendron trifoliolatum sometimes present especially in subregion 6. Occurs on Cainozoic igneous rocks, especially basalt. (BVG1M: 5a)	Very low
12.8.14a	Eucalyptus moluccana open forest +/- E. tereticornis, Eucalyptus siderophloia or E. crebra. Understorey generally sparse but can become shrubby in absence of fire. Occurs on Cainozoic igneous rocks. (BVG1M: 13d)	Medium
12.8.14	Eucalyptus eugenioides, E. biturbinata, E. melliodora +/- E. tereticornis, Corymbia intermedia, E. crebra open forest. Allocasuarina torulosa is a common understorey species. Localised occurrences of Eucalyptus laevopinea, E. quadrangulata and E. banksii may occur. Occurs on Cainozoic igneous rocks, especially basalt. (BVG1M: 11a)	Medium
12.8.14b	Eucalyptus quadrangulata, E. eugenioides +/- E. biturbinata tall open forest. Commonly has a moist ground layer dominated by ferns e.g. Blechnum neohollandicum. Occurs on Cainozoic igneous rocks, especially basalt usually at altitudes >800m. (BVG1M: 11a)	Low
12.8.15	Poa labillardierei var. labillardierei grassland. Occurs on Cainozoic igneous rocks. (BVG1M: 32b)	Non-habitat
12.8.16	Eucalyptus crebra, generally with E. melliodora and E. tereticornis +/- E. albens grassy woodland. Occurs on dry hillslopes on Cainozoic igneous rocks, especially basalt. (BVG1M: 11a)	Medium
12.8.17	Eucalyptus melanophloia +/- E. crebra, E. tereticornis, Corymbia tessellaris, C. intermedia and/or C. clarksoniana, E. melliodora, Angophora subvelutina grassy woodland. Occurs on Cainozoic igneous rocks, especially basalt. (BVG1M: 11a)	Medium
12.8.18	Simple notophyll vine forest, generally with Ceratopetalum apetalum and Lophostemon confertus. Other characteristic species include Ackama paniculosa, Karrabina benthamiana and Orites excelsus. Occurs on Cainozoic igneous rocks, in particular less fertile substrates such as rhyolite. (BVG1M: 6a)	Very low
12.8.19	Heath and rock pavement with scattered shrubs or open woodland. Occurs on Cainozoic igneous rocks especially rhyolite and trachyte. (BVG1M: 29b)	Non-habitat
12.8.20	Woodland to low open woodland complex. Canopy trees include Eucalyptus racemosa subsp. racemosa, E. dura, Corymbia trachyphloia, E. carnea, Allocasuarina littoralis, Acacia spp. and Lophostemon confertus. Occurs on Cainozoic igneous rocks, especially rhyolite. (BVG1M: 9h)	Low
12.8.21	Low microphyll vine forest and semi-evergreen vine thicket +/- Araucaria cunninghamii. Characteristic species include Brachychiton rupestris, Flindersia collina, F. australis, Alectryon diversifolius, A. subdentatus, Elattostachys xylocarpa, Erythroxylum sp. (Splityard Creek L.Pedley 5360), Psydrax odorata forma buxifolia, Diospyros geminata, Planchonella cotinifolia, Croton insularis, Bridelia exaltata and Bursaria incana. Melaleuca bracteata is often present along watercourses. Occurs on Cainozoic igneous rocks, especially basalt. (BVG1M: 7a)	Very low
12.8.23	Acacia harpophylla +/- semi-evergreen vine thicket species +/- Casuarina cristata +/- Eucalyptus populnea tall open forest. Occurs on Cainozoic igneous rocks, especially basalt. (BVG1M: 25a)	Very low
12.8.24	Corymbia citriodora subsp. variegata, Eucalyptus crebra +/- E. moluccana open forest. Occurs on Cainozoic igneous rocks especially lower slopes of rhyolite and trachyte hills (e.g. Moogerah Peaks). (BVG1M: 10b)	Low
12.8.25	Open forest with Eucalyptus acmenoides or E. helidonica +/- E. eugenioides, E. crebra, E. propinqua, Corymbia intermedia, E. biturbinata, E. moluccana and Lophostemon confertus. Occurs on Cainozoic igneous rocks especially trachyte hills. (BVG1M: 9g)	Medium
12.8.27	Grassland of Bothriochloa bladhii, Themeda triandra, Dichanthium sericeum +/- Bothriochloa biloba. Small stands of Eucalyptus melanophloia or Corymbia tessellaris may occur throughout. Occurs on undulating low hills consisting of heavy black clay soil derived from basalt. (BVG1M: 30b)	Non-habitat
12.9-10.1	Tall open forest. Canopy species include Eucalyptus resinifera, E. grandis, E. robusta, Corymbia intermedia +/- E. microcorys, Melaleuca quinquenervia, Syncarpia glomulifera subsp. glomulifera and Lophostemon confertus. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 8a)	Medium
12.9-10.1x1	Tall shrubby open forest. Canopy species include Eucalyptus resinifera, E. grandis, E. robusta, Corymbia intermedia +/- E. microcorys, Melaleuca quinquenervia, Syncarpia glomulifera subsp. glomulifera and Lophostemon confertus. Occurs on coastal remnant Tertiary surfaces +/- Cainozoic and Mesozoic sediments. Not a Wetland (BVG1M: 8a)	Medium
12.9-10.2	Corymbia citriodora subsp. variegata open forest or woodland usually with Eucalyptus crebra. Other species such as Eucalyptus tereticornis, E. moluccana, E. acmenoides and E. siderophloia may be present in scattered patches or in low densities. Understorey can be grassy or shrubby. Shrubby understorey of Lophostemon confertus (whipstick form) often present in northern parts of bioregion. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 10b)	Medium
12.9-10.3	Eucalyptus moluccana open forest. Other canopy species include Eucalyptus siderophloia or E. crebra, E. tereticornis and Corymbia citriodora subsp. variegata. Understorey generally sparse but can become shrubby in absence of fire. Occurs on Cainozoic and Mesozoic sediments, especially shales. Prefers lower slopes. (BVG1M: 13d)	Medium
12.9-10.4a	Eucalyptus racemosa subsp. racemosa woodland to open woodland with a wet ground layer often dominated by Ptilothrix deusta, Lepidosperma laterale and other sedges and grasses. Other canopy species can include Corymbia gummifera, C. intermedia, Melaleuca quinquenervia, Lophostemon suaveolens and Eucalyptus resinifera. A secondary tree layer of Melaleuca quinquenervia, Lophostemon suaveolens, Allocasuarina littoralis may also be present. Occurs on moist lower slopes and discharge areas on Cainozoic and Mesozoic sediments +/- remnant Tertiary surfaces. (BVG1M: 9g)	Medium

RE	Description (Queensland Herbarium REDD version 12)	RE rank
12.9-10.4	Eucalyptus racemosa subsp. racemosa woodland to open forest. Other species can include Angophora leiocarpa, Eucalyptus seeana, E. siderophloia, Corymbia intermedia, E. tindaliae, with Lophostemon suaveolens, Melaleuca quinquenervia, E. tereticornis common on lower slopes. Occurs on Cainozoic and Mesozoic sediments +/- remnant Tertiary surfaces. (BVG1M: 9g)	High
12.9-10.5d	Woodland of Eucalyptus eugenioides, E. biturbinata or E. longirostrata, E. crebra, E. tereticornis and Corymbia trachyphloia. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 9h)	Medium
12.9-10.5	Shrubby woodland complex. More widely distributed and abundant species include Corymbia trachyphloia subsp. trachyphloia, C. citriodora subsp. variegata, Eucalyptus crebra, E. fibrosa subsp. fibrosa, E. major, Angophora leiocarpa, E. helidonica. Understorey of sclerophyllous shrubs. Localised occurrences of Eucalyptus baileyana, E. pilularis, Corymbia henryi, E. dura, E. decorticans (extreme west of bioregion), E. taurina, Angophora woodsiana, Lysicarpus angustifolius and Lophostemon confertus. Tends to shrubland or monospecific woodland of species such as Eucalyptus dura on shallow lithosols. Occurs on quartzose sandstone scarps and crests. (BVG1M: 9h)	Medium
12.9-10.5a	Eucalyptus helidonica, Corymbia citriodora subsp. variegata open forest +/- C. trachyphloia subsp. trachyphloia, Eucalyptus fibrosa subsp. fibrosa, E. taurina, E. dura, E. baileyana, C. gummifera, Angophora woodsiana and Lysicarpus angustifolius. Occurs on quartzose sandstone scarps and crests. (BVG1M: 9h)	Low
12.9-10.6	Acacia harpophylla open forest +/- Casuarina cristata and vine thicket species. Occurs on Cainozoic and Mesozoic sediments, especially fine-grained rocks. (BVG1M: 25a)	Very low
12.9-10.7a	Eucalyptus siderophloia, Corymbia intermedia +/- E. tereticornis and Lophostemon confertus open forest. Occurs on Cainozoic and Mesozoic sediments in near coastal areas. (BVG1M: 12a)	Medium
12.9-10.7	Eucalyptus crebra +/- E. tereticornis, Corymbia tessellaris, Angophora leiocarpa, E. melanophloia woodland. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 13c)	Medium
12.9-10.8	Eucalyptus melanophloia grassy woodland, usually with E. crebra, Eucalyptus tereticornis +/- Corymbia tessellaris, C. erythrophloia and Angophora spp. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 17b)	Medium
12.9-10.10	Melaleuca nodosa low open forest or thicket, usually with Melaleuca sieberi and emergent Eucalyptus spp. Occurs on Cainozoic and Mesozoic sediments in coastal areas. (BVG1M: 21b)	Non-habitat
12.9-10.11	Melaleuca irbyana low open forest or thicket. Emergent Eucalyptus moluccana, E. crebra, E. tereticornis or Corymbia citriodora subsp. variegata may be present. Occurs on Mesozoic sediments where drainage of soils is impeded. (BVG1M: 21b)	Medium
12.9-10.12	Mixed woodland to open forest usually containing Corymbia intermedia, Angophora leiocarpa and at least a presence of Eucalyptus seeana. Other commonly associated species include E. siderophloia, E. tereticornis, E. racemosa subsp. Racemosa and C. citriodora subsp. Variegata. E. seeana and Lophostemon suaveolens are often present as sub-canopy or understorey trees. Occasional Melaleuca quinquenervia on lower slopes. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 9g)	Medium
12.9-10.14	Eucalyptus pilularis tall open forest with shrubby understorey. Other species include Syncarpia glomulifera subsp. glomulifera, S. verecunda, Corymbia intermedia, Angophora woodsiana and Eucalyptus microcorys in coastal areas and species of RE 12.9-10.5 in drier sub coastal areas. Eucalyptus pilularis sometimes extends onto colluvial lower slopes. Occurs on Cainozoic and Mesozoic sediments especially sandstone. (BVG1M: 8b)	Medium
12.9-10.14b	Eucalyptus pilularis open forest. Other canopy species may include Angophora woodsiana, Eucalyptus baileyana, Corymbia henryi, C. trachyphloia, E. taurina, and E. microcorys. Occurs in dry sub coastal areas on Cainozoic and Mesozoic sediments especially quartzose sandstone. (BVG1M: 8b)	Medium
12.9-10.14a	Open forest of Eucalyptus grandis, Lophostemon confertus, E. microcorys, Syncarpia glomulifera subsp. glomulifera +/- E. pilularis. Occurs on Cainozoic and Mesozoic sediments especially sandstone in wet gullies and southern slopes. (BVG1M: 8a)	Medium
12.9-10.15	Low microphyll vine forest +/- Araucaria cunninghamii and semi-evergreen vine thicket. Characteristic species include Brachychiton rupestris, Flindersia collina, F. australis, Alectryon diversifolius, A. subdentatus, Elattostachys xylocarpa, Erythroxylum sp. (Splityard Creek L.Pedley 5360), Psydrax odorata forma buxifolia, Diospyros geminata, Planchonella cotinifolia, Croton insularis, Bridelia exaltata and Bursaria incana. Melaleuca bracteata is often present along watercourses. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 7a)	Very low
12.9-10.16	Microphyll to notophyll vine forest +/- Araucaria cunninghamii. Characteristic species include Argyrodendron sp. (Kin Kin W.D.Francis AQ81198), Araucaria cunninghamii, Agathis robusta, Backhousia myrtifolia, Cupaniopsis parvifolia, Dendrocnide photiniphylla, Rhodosphaera rhodanthema, Flindersia australis, F. xanthoxyla, Drypetes deplanchei, Olea paniculata, Diospyros geminata, Gossia bidwillii, Excoecaria dallachyana and Vitex lignum-vitae. Archontophoenix cunninghamiana often present in gully floors. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 5a)	Very low
12.9-10.17c	Open forest of Eucalyptus carnea and/or E. tindaliae and/or E. helidonica +/- Corymbia citriodora subsp. variegata, Eucalyptus crebra, Eucalyptus major, Corymbia henryi, Angophora woodsiana, C. trachyphloia, E. siderophloia, E. microcorys, E. resinifera and E. propinqua. Lophostemon confertus often present as a sub-canopy or understorey tree. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 9g)	High
12.9-10.17d	Open forest generally containing Eucalyptus siderophloia, E. propinqua or E major, Corymbia intermedia. Other characteristic species include Lophostemon confertus, Eucalyptus microcorys and E. acmenoides or E. portuensis. Other species that may be present locally include Corymbia trachyphloia subsp. trachyphloia, C. citriodora subsp. variegata, E. longirostrata, E. carnea, E. moluccana and occasional vine forest species. Hills and ranges on Cainozoic and Mesozoic sediments. (BVG1M: 9a)	High
12.9-10.17e	Eucalyptus acmenoides, E. propinqua, Corymbia intermedia +/- E. microcorys, Lophostemon confertus open forest. Mixed understorey of grasses, shrubs and ferns. Hills and ranges of Cainozoic and Mesozoic sediments. (BVG1M: 9a)	Medium
12.9-10.17	Open forest to woodland complex generally with a variety of stringybarks, grey gums, ironbarks and in some areas spotted gum. Canopy trees include Eucalyptus siderophloia, E. propinqua or E. major, E. acmenoides or E.	High

RE	Description (Queensland Herbarium REDD version 12)	RE rank
	portuensis, E. carnea and/or E. microcorys and/or Corymbia citriodora subsp. variegata. Other species that may be present locally include Corymbia intermedia, C. trachyphloia, Eucalyptus tereticornis, E. biturbinata, E. moluccana, E. longirostrata, E. fibrosa subsp. fibrosa and Angophora leiocarpa. Lophostemon confertus or Whipstick Lophostemon confertus often present in gullies and as a sub-canopy or understorey tree. Mixed understorey of grasses, shrubs and ferns. Hills and ranges of Cainozoic and Mesozoic sediments. (BVG1M: 9a)	
12.9-10.17b	Corymbia citriodora subsp. variegata mixed open forest to woodland. Other commonly occurring canopy trees include Eucalyptus acmenoides, Angophora leiocarpa, E. siderophloia, E. carnea, E. longirostrata and C. intermedia. Other species that may be present locally include Eucalyptus tereticornis, E. crebra, E. fibrosa subsp. fibrosa and E. exserta. Lophostemon confertus (tree form and whipstick form) often present in gullies and as a sub-canopy or understorey tree. Mixed understorey of grasses and shrubs. Hills and ranges of Cainozoic and Mesozoic sediments usually with > 1000mm rainfall per annum. (BVG1M: 10b)	High
12.9-10.17a	Lophostemon confertus or L. suaveolens dominated open forest usually with emergent Eucalyptus and/or Corymbia species. Occurs in gullies and southern slopes on Cainozoic and Mesozoic sediments. (BVG1M: 28e)	Low
12.9-10.18	Angophora leiocarpa, Eucalyptus crebra woodland +/- E. longirostrata, Corymbia citriodora subsp. variegata. Other species such as Eucalyptus tereticornis, Corymbia trachyphloia subsp. trachyphloia and C. intermedia may be present in scattered patches or in low densities. Understorey can be grassy or shrubby. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 9h)	Medium
12.9-10.19a	Corymbia henryi and/or Eucalyptus fibrosa subsp. fibrosa open forest. Other commonly associated species include, Corymbia citriodora subsp. variegata, E. carnea, E. siderophloia, E. crebra and E. major. Occurs in coastal areas on Cainozoic and Mesozoic sediments. (BVG1M: 10b)	Medium
12.9-10.19	Eucalyptus fibrosa subsp. fibrosa woodland +/- Corymbia citriodora subsp. variegata, E. acmenoides or E. portuensis, Angophora leiocarpa, E. major. Understorey often sparse. Localised occurrences of Eucalyptus sideroxylon. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 12a)	Medium
12.9-10.21	Eucalyptus acmenoides or E. portuensis woodland usually with Corymbia trachyphloia subsp. trachyphloia +/- Angophora leiocarpa, E. major, E. moluccana, E. exserta, Lophostemon confertus (whipstick form). Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 9h)	Medium
12.9-10.22	Closed sedgeland to heathland with emergent trees. Characteristic species include Schoenus brevifolius and/or Machaerina juncea and/or Banksia robur and/or Melaleuca nodosa. Sometimes grading into Banksia aemula woodland on rises. Usually occurs on lower slopes subject to periodic water logging on Cainozoic and Mesozoic sediments. (BVG1M: 34f)	Non-habitat
12.9-10.26	Eucalyptus baileyana and/or E. planchoniana woodland to open forest. Other commonly associated species include Angophora woodsiana, E. tindaliae, E. carnea, E. resinifera. Eucalyptus psammitica may dominate areas of this ecosystem occurring in Toohey Forest. Occurs on quartzose sandstone scarps and crests. (BVG1M: 12a)	Medium
12.9-10.27	Corymbia citriodora subsp. variegata, Eucalyptus crebra and/or E. moluccana, E. tereticornis open forest with a very sparse to mid-dense understorey of Melaleuca irbyana. Occurs on lower slopes and elevated flats with impeded drainage on Mesozoic sediments. (BVG1M: 10b)	Medium
12.9-10.28	Angophora leiocarpa, Eucalyptus interstans +/- Corymbia intermedia, E. tereticornis C. tessellaris, C. clarksoniana, C. gummifera, E. siderophloia, C. citriodora subsp. variegata woodland to open forest. Lophostemon suaveolens is often present as a sub-canopy or understorey tree. Occasional Melaleuca quinquenervia on lower slopes. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 9g)	High
12.9-10.29	Eucalyptus cloeziana +/- E. propinqua, E. acmenoides, E. microcorys and E. grandis tall open forest. Occurs on Cainozoic and Mesozoic sediments. (BVG1M: 8a)	Medium
12.11.1	Evergreen notophyll vine forest and/or Lophostemon confertus closed forest. Archontophoenix cunninghamiana often present in gully floors. The plant families Lauraceae, Myrtaceae and Elaeocarpaceae are characteristic of the type. Occurs in gullies on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 4a)	Very low
12.11.2	Tall open forest with vine forest understorey ('wet sclerophyll'). Canopy species include Eucalyptus saligna or E. grandis, E. microcorys, Corymbia intermedia and Lophostemon confertus. Characteristic understorey species include Ackama paniculosa, Pittosporum undulatum, Synoum glandulosum subsp. Glandulosum and Cryptocarya microneura. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 8a)	Medium
12.11.3b	Eucalyptus pilularis tall open forest. Other frequently occurring species include Eucalyptus microcorys, E. saligna, E. siderophloia, E. carnea, Corymbia intermedia and E. propinqua. Occurs on higher altitude (>300m) subcoastal hills and ranges of Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 8b)	High
12.11.3	Eucalyptus siderophloia and E. propinqua open forest +/- E. microcorys, Lophostemon confertus, Corymbia intermedia, E. biturbinata, E. acmenoides, E. tereticornis, E. moluccana, Angophora leiocarpa, Syncarpia verecunda with vine forest species and E. grandis or E. saligna in gullies. Eucalyptus pilularis and E. tindaliae sometimes present e.g. mid D'Aguilar Range, Conondale Range. Occurs predominantly on hills and ranges of Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 9a)	Medium
12.11.3a	Lophostemon confertus +/- Eucalyptus microcorys, E. carnea, E. propinqua, E. major, E. siderophloia woodland. Occurs in gullies and exposed ridges of Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 9a)	Medium
12.11.5	Corymbia citriodora subsp. variegata open forest to woodland, usually including Eucalyptus siderophloia/E. crebra (sub coastal ranges), E. propinqua and E. acmenoides or E. carnea. Other species that may be present and abundant locally include Corymbia intermedia, C. trachyphloia subsp. trachyphloia, Eucalyptus tereticornis, E. microcorys, E. portuensis, E. helidonica, E. major, E. longirostrata, E. biturbinata, E. moluccana and Angophora leiocarpa. Lophostemon confertus often present in gullies and as a sub-canopy or understorey tree. Mixed	Medium

RE	Description (Queensland Herbarium REDD version 12)	RE rank
	understorey of grasses, shrubs and ferns. Occurs on hills and ranges of Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 10b)	
12.11.5m	Rock pavement to open woodland of Eucalyptus carnea and Corymbia citriodora subsp. variegata, Corymbia intermedia and Lophostemon confertus. Occurs on ridges and crests comprised of chert or other highly resistant Palaeozoic and older moderately to strongly deformed and metamorphosed sediments. (BVG1M: 29b)	Non-habitat
12.11.6	Open forest to woodland of Corymbia citriodora subsp. variegata generally with Eucalyptus crebra. Other species such as Eucalyptus exserta, E. tereticornis, E. moluccana, E. melanophloia, E. acmenoides, Corymbia tessellaris and Angophora leiocarpa may be present in scattered patches or in low densities. Understorey grassy or shrubby. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. Drier habitats than RE 12.11.5. (BVG1M: 10b)	Medium
12.11.7	Eucalyptus crebra woodland. Other species such as Corymbia clarksoniana may be present in low densities or in patches. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 13c)	Low
12.11.8	Eucalyptus melanophloia usually with E. crebra grassy woodland. Other species such as Corymbia erythrophloia, C. tessellaris, C. clarksoniana may be present in low densities or in patches. Restricted occurrence of Callitris glaucophylla south of Gayndah. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 17b)	Low
12.11.9	Open forest to woodland with Eucalyptus tereticornis. Includes both E. tereticornis subsp. tereticornis and E. tereticornis subsp. basaltica. Other canopy species include Eucalyptus biturbinata, E. melliodora, Corymbia intermedia, E. longirostrata, E. eugenioides, Allocasuarina torulosa, E. moluccana, E. saligna, E. siderophloia and Angophora subvelutina. Occurs on ridges and upper slopes especially at higher altitudes on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. These occurrences are often associated with small areas of intermediate and bas (BVG1M: 9g)	Medium
12.11.9x1	Eucalyptus montivaga open forest. Other canopy species can include Corymbia trachyphloia, E. acmenoides, Syncarpia glomulifera subsp. glomulifera and C. intermedia. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. Altitude >500m. (BVG1M: 8b)	Low
12.11.10	Notophyll and notophyll/microphyll vine forest +/- Araucaria cunninghamii. Characteristic species include Argyrodendron trifoliolatum, Argyrodendron sp. (Kin Kin W.D.Francis AQ81198), Backhousia subargentea, Dissiliaria baloghioides, Brachychiton discolor, Beilschmiedia obtusifolia, Diospyros pentamera, Grevillea robusta, Gmelina leichhardtii and Ficus macrophylla forma macrophylla. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 2a)	Very low
12.11.11	Microphyll vine forest +/- Araucaria cunninghamii. Characteristic species include Araucaria cunninghamii, Cupaniopsis parvifolia, Dendrocnide photiniphylla, Rhodosphaera rhodanthema, Flindersia australis, F. xanthoxyla, Drypetes deplanchei, Olea paniculata, Diospyros geminata, Gossia bidwillii, Excoecaria dallachyana and Vitex lignum-vitae. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 5a)	Very low
12.11.14	Eucalyptus crebra, E. tereticornis, Corymbia intermedia grassy woodland. Other species including Eucalyptus melanophloia, Corymbia clarksoniana, C. erythrophloia, C. tessellaris, E. siderophloia, Angophora spp. May be present in low densities or in patches. Mid-layer generally sparse but can include low trees such as Vachellia bidwillii, Capparis spp., Dodonaea triquetra, Alphitonia excelsa and Xanthorrhoea spp. Occurs on mid and lower slopes on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 13c)	Medium
12.11.15	Eucalyptus tereticornis, Corymbia intermedia open woodland +/- E. acmenoides, Allocasuarina torulosa, E. siderophloia, E. crebra, Angophora subvelutina, E. tindaliae and Banksia integrifolia. Xanthorrhoea johnsonii prominent in understorey. Patches of Leptospermum spp. Shrubland occur in places. Occurs on serpentinite. (BVG1M: 9h)	High
12.11.16	Eucalyptus cloeziana +/- E. propinqua, E. acmenoides, E. microcorys and E. grandis open forest. Understory is generally shrubby +/- vine forest species. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics, especially phyllite of the Kin Kin Beds. (BVG1M: 8b)	Low
12.11.17	Eucalyptus acmenoides or E. portuensis, Corymbia trachyphloia open forest to woodland +/- E. crebra, Angophora leiocarpa, E. exserta, C. intermedia, Lophostemon confertus (whipstick form). Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 9h)	Low
12.11.18	Eucalyptus moluccana woodland +/- Corymbia citriodora subsp. variegata, E. tereticornis, E. siderophloia or E. crebra, E. longirostrata, C. intermedia, E. carnea. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. Occurs as scattered occurrences in a range of topographic positions from ridgetops to lower slopes. (BVG1M: 13d)	High
12.11.18a	Eucalyptus moluccana, Eucalyptus tereticornis and Lophostemon confertus open forest. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 13d)	Medium
12.11.22	Angophora leiocarpa, Eucalyptus crebra +/- Corymbia intermedia, E. longirostrata, E. major, E. portuensis, C. citriodora subsp. variegata woodland to open forest. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 9h)	High
12.11.23	Eucalyptus pilularis open forest. Other canopy species include E. microcorys, Corymbia intermedia, Angophora woodsiana, E. tindaliae and E. carnea. E. racemosa subsp. racemosa and Corymbia trachyphloia are prominent in the Venman area whilst C. gummifera and E. resinifera are prominent in the Nerang area. Occurs on low coastal Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics (Neranleigh-Fernvale beds). (BVG1M: 8b)	High
12.11.24	Eucalyptus carnea or E. tindaliae, Corymbia intermedia woodland +/- E. crebra or E. siderophloia, Eucalyptus resinifera, Eucalyptus major, E. helidonica, Angophora woodsiana, C. trachyphloia, E. microcorys, Corymbia citriodora subsp. Variegata, C. henryi. Occurs on Palaeozoic and older moderately to strongly deformed and	Medium

RE	Description (Queensland Herbarium REDD version 12)	RE rank
	metamorphosed sediments and interbedded volcanics usually at altitudes <300 metres. (BVG1M: 9g)	
12.11.25	Corymbia henryi and/or Eucalyptus fibrosa subsp. fibrosa woodland. Other frequently occurring canopy species may include Eucalyptus crebra, E. carnea, E. tindaliae, E. siderophloia, C. citriodora subsp. variegata, Angophora leiocarpa, E. acmenoides, E. helidonica, E. propinqua, C. intermedia and E. seeana. Rarely includes patches of E. dura. Usually occurs on low hills, hills and footslopes of mountains in near coastal areas on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 10b)	Medium
12.11.26	Eucalyptus baileyana and/or E. planchoniana woodland to open forest. Frequently associated canopy species include E. tindaliae and Angophora woodsiana. Other associated canopy species include Corymbia intermedia, C. trachyphloia, E. carnea, E. helidonica and E. resinifera. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics typically on ridges and crests. (BVG1M: 9h)	Medium
12.11.27	Eucalyptus racemosa subsp. racemosa and/or E. seeana and Corymbia intermedia woodland. Other characteristic species include E. siderophloia, Angophora leiocarpa, C. trachyphloia subsp. trachyphloia and rarely E. pilularis. Melaleuca quinquenervia may be present and at times becomes locally co-dominant. Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics, typically at low altitude (<60 metres) in near coastal situations. (BVG1M: 9g)	Medium
12.11.28	Eucalyptus helidonica, Angophora woodsiana, Corymbia gummifera woodland with a heathy shrub layer dominated by Leptospermum trinervium, Xanthorrhoea johnsonii and Banksia spinulosa var. collina. Other commonly occurring canopy species include Eucalyptus tindaliae, E. carnea, E. resinifera, Corymbia intermedia, C. trachyphloia subsp. trachyphloia and Lophostemon confertus. Occurs on crests and upper slopes of hills comprised of Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics. (BVG1M: 9h)	Low
12.12.1	Notophyll and notophyll/microphyll vine forest, sometimes with Archontophoenix cunninghamiana and/or Lophostemon confertus closed forest. The plant families Lauraceae, Myrtaceae and Elaeocarpaceae are diagnostic of the type and Pleioluma queenslandica is common in the northern half of the bioregion. Araucaria cunninghamii is often present on margins. Occurs in gullies on Mesozoic to Proterozoic igneous rocks especially granite and rhyolite. (BVG1M: 4a)	Very low
12.12.2	Eucalyptus pilularis tall open forest with shrubby or grassy understorey. Other canopy species include Syncarpia glomulifera or S. verecunda, Angophora woodsiana, Eucalyptus microcorys, E. resinifera, E. tindaliae, E. propinqua and E. saligna. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 8b)	Medium
12.12.2a	Eucalyptus pilularis tall open forest with subdominant Eucalyptus spp. and Syncarpia spp. and a shrubby or grassy understorey.	Medium
12.12.3	Open forest complex in which spotted gum is a relatively common species. Canopy trees include Corymbia citriodora subsp. variegata, Eucalyptus crebra (drier sub coastal ranges) or Eucalyptus siderophloia, E. major and/or E. longirostrata, E. acmenoides or E. portuensis, E. eugenioides. Hills and ranges. Other species that may be present locally include Corymbia intermedia, C. trachyphloia, Eucalyptus tereticornis, E. propinqua, E. moluccana, E. decolor, E. melliodora, E. carnea, E. fibrosa subsp. fibrosa and Angophora leiocarpa. Lophostemon confertus (tree form and whipstick form) often present in gullies or as a sub-canopy or canopy tree especially on granite. Mixed understorey of grasses, shrubs and ferns. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 10b)	Medium
12.12.3a	Lophostemon confertus open forest. Occurs in moister gullies on Mesozoic to Proterozoic igneous rocks. (BVG1M: 8a)	Low
12.12.4	Eucalyptus acmenoides +/- Syncarpia glomulifera subsp. glomulifera woodland. Other species may be present including Corymbia intermedia, C. trachyphloia, E. major, E. resinifera, Lophostemon confertus (whipstick form). Grades into Eucalyptus montivaga forest at higher altitude. Occurs at high altitude on ranges, on Mesozoic to Proterozoic igneous rocks, especially granite. (BVG1M: 8b)	Low
12.12.5	Open forest to woodland of Corymbia citriodora subsp. variegata, usually with Eucalyptus crebra. Other species such as Eucalyptus exserta, E. moluccana present in scattered patches or in low densities. Understorey generally grassy. Occurs on hills and ranges on Mesozoic to Proterozoic igneous rocks. (BVG1M: 10b)	Low
12.12.6	Eucalyptus montivaga open forest to woodland. Other canopy species can include Eucalyptus acmenoides, Corymbia trachyphloia, C. gummifera, Syncarpia glomulifera subsp. glomulifera and C. intermedia. Occurs on Mesozoic to Proterozoic igneous rocks. Altitude >500 m. (BVG1M: 8b)	Low
12.12.7	Eucalyptus crebra grassy woodland. Other species such as Corymbia erythrophloia, Eucalyptus exserta, E. tereticornis, C. tessellaris, C. citriodora subsp. variegata may be present in low densities or in patches. Mid-layer generally sparse but can include low trees such as Vachellia bidwillii, Alphitonia excelsa, Allocasuarina luehmannii and Petalostigma pubescens. Small areas of Callitris glaucophylla occur in central western parts of bioregion. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 13c)	Medium
12.12.8	Eucalyptus melanophloia, usually with E. crebra +/- Corymbia erythrophloia grassy woodland. Other species such as Eucalyptus exserta, E. tereticornis, C. tessellaris, C. citriodora subsp. variegata may be present in low densities or in patches. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 17b)	Low
12.12.9	Eucalyptus dura woodland (open woodland in rocky areas) +/- Corymbia trachyphloia subsp. trachyphloia, E. acmenoides or E. portuensis, Acacia blakei subsp. blakei, Allocasuarina littoralis, C. intermedia. Eucalyptus montivaga may also be present at higher altitudes. Lophostemon confertus (whipstick form) often present in shrub layer. Usually occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 12a)	Medium
12.12.10	Shrubland or heath sometimes with emergent Eucalyptus acmenoides. Associated with rocky soils derived from Mesozoic to Proterozoic igneous rocks. (BVG1M: 29b)	Non-habitat
12.12.11	Eucalyptus portuensis or E. acmenoides, Corymbia trachyphloia subsp. trachyphloia woodland +/- E. crebra, C. intermedia, E. exserta and Angophora leiocarpa. Whipstick Lophostemon confertus often present in understorey and in gullies. Occurs on hillsides on Mesozoic to Proterozoic igneous rocks. (BVG1M: 9h)	Low
12.12.12	Eucalyptus tereticornis, Corymbia intermedia, E. crebra open forest to woodland. Other species present can include Eucalyptus melanophloia, Corymbia tessellaris, Angophora subvelutina, A. leiocarpa, C. clarksoniana (central and	Medium

RE	Description (Queensland Herbarium REDD version 12)	RE rank
	northern parts) and E. siderophloia with Melaleuca quinquenervia, Lophostemon suaveolens near drainage lines in moister areas. Occurs on Mesozoic to Proterozoic igneous rocks usually on lower slopes, especially granite lowlands and basins. (BVG1M: 9g)	
12.12.13	Microphyll and microphyll/notophyll vine forest +/- Araucaria cunninghamii. Characteristic species include Dendrocnide photiniphylla, Diospyros geminata, Drypetes deplanchei, Ficus virens, Cryptocarya bidwillii, Planchonella myrsinifolia, Vitex lignum-vitae, Hernandia bivalvis, Croton acronychioides, Flindersia spp. Olea paniculata, Excoecaria dallachyana, Gossia bidwillii and on northern half of bioregion Vitex acuminata, Archidendropsis thozetiana, Pleiogynium timorense and Cupaniopsis simulata. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 2a)	Very low
12.12.14	Woodland to open forest characterised by Eucalyptus racemosa subsp. racemosa, Angophora woodsiana, Corymbia gummifera, Syncarpia spp., Eucalyptus helidonica or E. acmenoides and Lophostemon confertus. Other canopy species include Corymbia trachyphloia subsp. trachyphloia, E. carnea, E. tindaliae, E. exserta, E. resinifera and E. microcorys. Usually occurs on rocky near coastal areas on Mesozoic to Proterozoic igneous rocks. (BVG1M: 9g)	Medium
12.12.15	Corymbia intermedia +/- Eucalyptus propinqua, E. siderophloia, E. microcorys, Lophostemon confertus. Other canopy species include E. acmenoides, E. moluccana, Angophora subvelutina and occasional vine forest species. Patches of Eucalyptus pilularis sometimes present. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 9a)	Medium
12.12.15a	Eucalyptus grandis and/or E. saligna tall open forest +/- vine forest understorey. Other canopy species include E. microcorys, E. acmenoides, Lophostemon confertus, E. siderophloia, E. propinqua, Corymbia intermedia, E. tereticornis. Occurs in wet gullies on Mesozoic to Proterozoic igneous rocks. (BVG1M: 8a)	Medium
12.12.15b	Lophostemon confertus open forest +/- Eucalyptus microcorys, E. siderophloia, E. carnea, E. propinqua and vine forest species often present in understorey. Occurs in gullies and exposed ridges on Mesozoic to Proterozoic igneous rocks often amongst vine forest. (BVG1M: 8a)	Medium
12.12.16	Notophyll vine forest. Characteristic species include Araucaria bidwillii, A. cunninghamii, Argyrodendron trifoliolatum, Argyrodendron sp. (Kin Kin W.D.Francis AQ81198), Backhousia subargentea, Brachychiton discolor, Beilschmiedia obtusifolia, Diospyros pentamera, Grevillea robusta, Gmelina leichhardtii, Ficus macrophylla forma macrophylla and Sloanea woollsii. Eucalyptus spp. especially E. siderophloia, E. propinqua and E. grandis may be present as emergents. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 2a)	Very low
12.12.17	Low microphyll vine forest +/- Araucaria cunninghamii and semi-evergreen vine thicket. Characteristic species include Brachychiton rupestris, Flindersia collina, F. australis, Alectryon diversifolius, A. subdentatus, Elattostachys xylocarpa, Erythroxylum sp. (Splityard Creek L.Pedley 5360), Psydrax odorata forma buxifolia, Diospyros geminata, Planchonella cotinifolia, Croton insularis, Bridelia exaltata and Bursaria incana. Melaleuca bracteata is often present along watercourses. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 7a)	Very low
12.12.19x2	Vegetation complex of exposed rocky headlands. Vegetation types include Themeda triandra grassland and wind-sheared shrubland and woodland. Occurs on headlands of Cainozoic and Mesozoic sediments. (BVG1M: 29a)	Non-habitat
12.12.19x3	Vegetation complex of exposed headlands. Vegetation types include Themeda triandra grassland and wind-sheared shrubland and woodland. Occurs on headlands of remnant Tertiary surfaces. (BVG1M: 29a)	Non-habitat
12.12.19	Vegetation complex of exposed rocky headlands. Vegetation types include Themeda triandra grassland and wind-sheared shrubland and woodland. Occurs on Mesozoic to Proterozoic igneous headlands. (BVG1M: 29a)	Non-habitat
12.12.19x5	Vegetation complex of near coastal rocky outcrops. Vegetation is comprised of open shrubland with areas of bare rock grading into a surrounding wind-sheared low open forest. Commonly occurring species include Banksia integrifolia, Leptospermum polygalifolium, Austromyrtus dulcis, Dodonaea triquetra, Pultenaea villosa, Melaleuca quinquenervia, Lophostemon confertus, Allocasuarina littoralis and Corymbia gummifera. Occurs on near coastal outcrops of Mesozoic to Proterozoic igneous rock surrounded by sand dunes. (BVG1M: 29a)	Non-habitat
12.12.23	Woodland to open forest generally with Eucalyptus tereticornis subsp. tereticornis or E. tereticornis subsp. basaltica +/- E. eugenioides. Other species present vary from place to place but commonly include E. crebra, Corymbia intermedia, E. acmenoides, E. biturbinata, E. longirostrata, E. melliodora, C. trachyphloia, C. citriodora subsp. Variegata, Lophostemon confertus (tree form and whipstick form), Angophora subvelutina and Allocasuarina torulosa. Occurs at higher altitudes on crests, upper slopes and elevated valleys and plains on Mesozoic to Proterozoic igneous rocks. (BVG1M: 9g)	Medium
12.12.24	Angophora leiocarpa, Eucalyptus crebra +/- Corymbia intermedia, E. longirostrata, E. major, E. tereticornis, E. acmenoides or E. portuensis, C. citriodora subsp. variegata woodland to open forest. Occurs on Mesozoic to Proterozoic igneous rocks including granite. (BVG1M: 9h)	Medium
12.12.25	Eucalyptus fibrosa subsp. fibrosa woodland +/- Corymbia citriodora subsp. Variegata, Angophora leiocarpa, E. acmenoides, E. decorticans, C. trachyphloia and C. watsoniana in central western part of bioregion. Occurs on Mesozoic to Proterozoic igneous rocks. (BVG1M: 9h)	Low
12.12.28	Eucalyptus moluccana +/- E. crebra, Corymbia citriodora subsp. variegata woodland to open forest. Occurs on broad ridges and lower slopes on Mesozoic to Proterozoic igneous rocks. (BVG1M: 13d)	Medium

Appendix 3. **Tree species utility for koalas**

Tree species utility classes indicating the usefulness of trees for koalas in SEQ (REDD v10, updated with v12.1 Queensland Herbarium).

Tree species	Species utility	Source
Acacia blakei subsp. blakei	none or unknown	
Acacia disparrima subsp. disparrima	none or unknown	
Acacia excelsa	none or unknown	
Acacia harpophylla	none or unknown	
Acacia leiocalyx	none or unknown	
Acacia pendula	none or unknown	
Acacia salicina	none or unknown	
Acacia spp.	none or unknown	Melzer et al. (2014) occasionally eaten
Acacia stenophylla	none or unknown	
Acacia tephrina	Lower	Melzer et al. (2014) minor browse species
Acalypha eremorum	none or unknown	
Acmena ingens	none or unknown	
Acmena smithii	none or unknown	
Acronychia imperforata	none or unknown	
Acronychia spp.	none or unknown	
Agathis robusta	none or unknown	
Alangium villosum subsp. tomentosum	none or unknown	
Alchornea ilicifolia	none or unknown	
Alectryon coriaceus	none or unknown	
Alectryon diversifolius	none or unknown	
Alectryon oleifolius	none or unknown	
Alectryon subdentatus	none or unknown	
Allocasuarina littoralis	Lower	Callaghan et al. (2011) lower use relative to availability.
Allocasuarina luehmannii	none or unknown	Kavanagh et al. (2007 occasionally occupied but usually ignored
Allocasuarina spp.	Lower	R. Cristescu cited in Melzer et al. (2014) occasionally eaten
Allocasuarina torulosa	Lower	Callaghan et al. (2011) lower use relative to availability; Smith (2004) eaten occasionally by captive koalas in northern NSW; Melzer et al. (2014) occasionally eaten
Alphitonia excelsa	none or unknown	
Angophora floribunda	Lower	Kavanagh et al. (2007) daytime shelter especially in summer; NSW (2018) irregular use by koalas
Angophora leiocarpa	Lower	Woodward et al. (2008) used by koalas. MBRC factsheet, koala habitat tree.
Angophora spp.	Lower	
Angophora subvelutina	Lower	NSW (2018) significant use by koalas. MBRC factsheet, koala habitat tree.
Angophora woodsiana	Lower	NSW (2018) little use by koalas.
Aphananthe philippinensis	none or unknown	
Araucaria bidwillii	none or unknown	
Araucaria cunninghamii	none or unknown	
Archidendropsis thozetiana	none or unknown	
Archontophoenix alexandrae	none or unknown	
Archontophoenix cunninghamiana	none or unknown	
Argyrodendron actinophyllum	none or unknown	
Argyrodendron sp. (Kin Kin W.D.Francis AQ81198)	none or unknown	
Argyrodendron trifoliolatum	none or unknown	
Arytera divaricata	none or unknown	
Backhousia myrtifolia	none or unknown	
Backhousia subargentea	none or unknown	
Baloghia inophylla	none or unknown	
Banksia aemula	none or unknown	
Banksia integrifolia subsp. integrifolia	none or unknown	

Tree species	Species utility	Source
Banksia oblongifolia	none or unknown	
Banksia robur	none or unknown	
Banksia spinulosa var. collina	none or unknown	
Baumea juncea	none or unknown	
Beilschmiedia obtusifolia	none or unknown	
Boronia falcifolia	none or unknown	
Brachychiton acerifolius	none or unknown	
Brachychiton discolor	none or unknown	
Brachychiton populneus	none or unknown	
Brachychiton rupestris	none or unknown	
Bridelia exaltata	none or unknown	
Bridelia leichhardtii	none or unknown	
Bursaria incana	none or unknown	
Caldcluvia paniculosa	none or unknown	
Callitris baileyi	none or unknown	
Callitris columellaris	Lower	Callaghan et al. (2011) higher use relative to availability; Woodward et al. (2008) daytime use
Callitris glaucophylla	Lower	Kavanagh et al. (2007) daytime shelter use especially in summer
Capparis arborea	none or unknown	
Cassia brewsteri	none or unknown	
Castanospermum australe	none or unknown	
Casuarina cristata	none or unknown	
Casuarina cunninghamiana	none or unknown	
Casuarina cunninghamiana subsp. cunninghamiana	none or unknown	
Casuarina equisetifolia subsp. incana	Lower	Melzer et al. (2014) minor browse species
Casuarina glauca	none or unknown	
Casuarina spp.	Lower	Melzer et al. (2014) occasionally eaten
Ceratopetalum apetalum	none or unknown	
Citronella moorei	none or unknown	
Citrus glauca	none or unknown	
Coatesia paniculata	none or unknown	
Corymbia citriodora	Medium	Melzer et al. (2014); Thompson (2006); EPA (2004); Lone Pine; EHP factsheet; Mogridge
Corymbia citriodora subsp. variegata	Medium	Thompson (2006); Lone Pine; Mogridge
Corymbia clarksoniana	Lower	Melzer et al. (2014) minor browse species
Corymbia dallachiana	Lower	Melzer et al. (2014) minor browse species
Corymbia erythrophloia	Lower	Melzer et al. (2014) minor browse species
Corymbia gummifera	Lower	NSW (2018) significant use.
Corymbia henryi	Medium	EPA (2004). NSW (2018) irregular use by koalas.
Corymbia intermedia	Medium	Woodward et al. (2008); Callaghan et al. (2011); EHP factsheet; LWA factsheet
Corymbia terminalis	Lower	Sullivan et al. (2003) infrequent use by koalas
Corymbia tessellaris	Lower	Melzer et al. (2014) minor browse species. NSW (2018) little use by koalas. Johnson (2021)
Corymbia trachyphloia	Lower	NSW (2018) little use by koalas.
Corymbia trachyphloia subsp. trachyphloia	Lower	
Corymbia watsoniana	Lower	
Croton acronychioides	none or unknown	
Croton insularis	none or unknown	
Cryptocarya bidwillii	none or unknown	
Cryptocarya erythroxylon	none or unknown	
Cryptocarya microneura	none or unknown	
Cryptocarya obovata	none or unknown	
Cryptocarya triplinervis	none or unknown	
Cupaniopsis anacardioides	none or unknown	
Cupaniopsis parvifolia	none or unknown	
Cupaniopsis simulata	none or unknown	
Dendrocnide excelsa	none or unknown	

Tree species	Species utility	Source
Dendrocnide photinophylla	none or unknown	
Denhamia oleaster	none or unknown	
Denhamia pittosporoides	none or unknown	
Diospyros fasciculosa	none or unknown	
Diospyros geminata	Lower	Melzer et al. (2014) novel species occasionally eaten
Diospyros humilis	none or unknown	
Diospyros pentamera	none or unknown	
Diospyros spp.	none or unknown	
Diploglottis australis	none or unknown	
Dissiliaria baloghioides	none or unknown	
Doryphora sassafras	none or unknown	
Drypetes deplanchei	none or unknown	
Dysoxylum fraserianum	none or unknown	
Dysoxylum mollissimum subsp. molle	none or unknown	
Elaeocarpus grandis	none or unknown	
Elaeocarpus kirtonii	none or unknown	
Elaeocarpus obovatus	none or unknown	
Elattostachys xylocarpa	none or unknown	
Endiandra pubens	none or unknown	
Endiandra sieberi	Lower	Callaghan et al. (2011) use proportional to availability. NSW (2018) irregular use by koalas
Eremophila mitchellii	none or unknown	
Erythroxylum sp. (Splityard Creek L.Pedley 5360)	none or unknown	
Eucalyptus acmenoides	Medium	EPA (2004); Rhodes et al. (2015); AKF; NSW (2018) Significant use in some areas; Callaghan (2011) supplementary
Eucalyptus albens	Lower	NSW (2018) little use by koalas.
Eucalyptus baileyana	Lower	NSW (2018) little use by koalas.
Eucalyptus bancroftii	Medium	EPA (2004); Mogridge; AKF
Eucalyptus banksii	Lower	NSW (2018) little use by koalas.
Eucalyptus biturbinata	Higher	EPA (2004); Lone Pine; Mogridge and based on similarity to Eucalyptus propinqua
Eucalyptus blakelyi	Medium	NSW (2018) local high use in some areas. Granite Belt Wildlife Carers factsheet. Kavanagh et al. (2007) principal food tree in Pilliga study
Eucalyptus brownii	Medium	Based on similarity to Eucalyptus populnea, highly unlikely to occur in the study area.
Eucalyptus camaldulensis	Higher	Wu et al. (2012); Lone Pine; Mogridge; LWA factsheet
Eucalyptus cambageana	Lower	Phillips (1994) included in list of koala food trees. Sullivan et al. (2003) infrequent browse species. Melzer et al. (2014)
Eucalyptus campanulata	Lower	NSW (2018) irregular use by koalas.
Eucalyptus carnea	Medium	EPA (2004); EHP factsheet
Eucalyptus chloroclada	Medium	Baradine red gum or dirty gum. Granite Belt Wildlife Carers Factsheet; Kavanagh et al. (2007) principal food trees in Pilliga study.
Eucalyptus cloeziana	Lower	
Eucalyptus coolabah	Medium	Sullivan et al. (2003) one of the most frequent browse species. Wu et al. (2012); FitzGibbon et al. (2013) (central Queensland)
Eucalyptus crebra	Medium	Melzer et al. (2014); EPA (2004); Hasegawa (1995); FitzGibbon et al. (2013) (central Queensland); LWA factsheet
Eucalyptus dealbata	Medium	NSW (2018) local high use in some areas. Granite Belt Wildlife Carers factsheet.
Eucalyptus decolor	Lower	
Eucalyptus decorticans	Lower	NSW (2018) infrequent use by koalas. Sullivan et al. (2003) infrequent use by koalas
Eucalyptus drepanophylla	Medium	Melzer et al. (2014)
Eucalyptus dunnii	Medium	Lone Pine; Mogridge; LWA factsheet
Eucalyptus dura	Lower	
Eucalyptus eugenioides	Medium	listed in McFarland profile - Habitat Suitability Modelling for South East Queensland
Eucalyptus exserta	Medium	Mogridge; Melzer recommended

Tree species	Species utility	Source
Eucalyptus fibrosa	Medium	Thompson (2006); EPA (2004); EHP factsheet
Eucalyptus fibrosa subsp. fibrosa	Medium	Thompson (2006); EPA (2004); EHP factsheet
Eucalyptus grandis	Medium	Lone Pine; Mogridge; AKF; LWA factsheet
Eucalyptus helidonica	Medium	Based on inference from similar species to Eucalyptus acmenoides
Eucalyptus interstans	Lower	NSW (2018) virtually no evidence of use by koalas.
Eucalyptus laevopinea	Lower	NSW (2018) high use in some areas and irregular use in other areas.
Eucalyptus latisinensis	Medium	Based on inference from similar species to Eucalyptus acmenoides
Eucalyptus longirostrata	Higher	Mogridge, based on similarity to Eucalyptus propinqua
Eucalyptus major	Higher	EHP factsheet; Mogridge, based on similarity to Eucalyptus propinqua; LWA factsheet
Eucalyptus melanoleuca	Lower	
Eucalyptus melanophloia	Medium	EPA (2004)
Eucalyptus melliodora	Medium	Phillips (1994) included in list of koala food trees. NSW (2018) local high use in some areas
Eucalyptus microcarpa	Medium	Based on inference from similar species to Eucalyptus moluccana; NSW (2018) local high use in some areas
Eucalyptus microcorys	Higher	EPA (2004); Thompson (2006); Callaghan et al. (2011); Rhodes et al. (2015); AKF; LWA factsheet; Lone Pine; EHP factsheet; Mogridge
Eucalyptus microtheca	Medium	Based on inference from similar species to Eucalyptus coolabah, Sullivan et al. (2003) one of the most frequent browse species.
Eucalyptus moluccana	Medium	EPA (2004); Lone Pine; EHP factsheet; Mogridge; LWA factsheet
Eucalyptus montivaga	Medium	Based on inference from similar species to Eucalyptus acmenoides
Eucalyptus nigra		Superseded by Eucalyptus tindaliae (Queensland white stringybark) (03/04/2019)
Eucalyptus nobilis	Lower	NSW (2018) local high use in some areas
Eucalyptus obliqua	Lower	NSW (2018) local high use in some areas
Eucalyptus oreades	Lower	NSW (2018) very little evidence of use by koalas.
Eucalyptus orgadophila	Medium	Melzer et al. (2014)
Eucalyptus papuana	Medium	
Eucalyptus pilligaensis		Superseded by Eucalyptus woollsiana (03/04/2019)
Eucalyptus pilularis	Medium	Melzer et al. (2014); Woodward et al. (2008); LWA factsheet
Eucalyptus planchoniana	Lower	Woodward et al. (2008); Melzer et al. (2014) very small component of browse used by koalas.
Eucalyptus platyphylla	Medium	Melzer recommended
Eucalyptus populnea	Medium	Melzer et al. (2014); Wu et al. (2012); Mogridge; FitzGibbon et al. (2013) (central Queensland)
Eucalyptus portuensis	Medium	Based on inference from similar species to Eucalyptus acmenoides
Eucalyptus propinqua	Higher	Callaghan et al. (2011); EPA (2004); Lone Pine; EHP factsheet; Mogridge; Rhodes et al. (2015); AKF; LWA factsheet
Eucalyptus psammitica	Lower	NSW (2018) significant use in some areas
Eucalyptus racemosa	Medium	Thompson (2006); Melzer et al. (2014); EPA (2004); Lone Pine; EHP factsheet; Mogridge; AKF; LWA factsheet
Eucalyptus racemosa subsp. racemosa	Medium	based on inference from base species
Eucalyptus resinifera	Medium	Thompson (2006); Callaghan et al. (2011); AKF; Melzer et al. (2014); Woodward et al. (2008); EPA (2004); Lone Pine; EHP factsheet; LWA factsheet
Eucalyptus robusta	Higher	Callaghan et al. (2011); Melzer et al. (2014); Woodward et al. (2008); EPA (2004); Lone Pine; EHP factsheet; Mogridge; LWA factsheet; AKF
Eucalyptus saligna	Medium	LWA factsheet and based on similarity to Eucalyptus grandis
Eucalyptus saligna subsp. saligna	Medium	LWA factsheet and based on similarity to Eucalyptus grandis
Eucalyptus seeana	Medium	EPA (2004); EHP factsheet; Mogridge; LWA factsheet; Brisbane City Council recommended feed tree
Eucalyptus siderophloia	Medium	Callaghan et al. (2011); EPA (2004); EHP factsheet; AKF; LWA factsheet
Eucalyptus sideroxylon	Medium	Mogridge; NSW (2018) significant use especially in plantings near Gunnedah

Tree species	Species utility	Source
Eucalyptus taurina	Lower	
Eucalyptus tereticornis	Higher	Callaghan et al. (2011); Melzer et al. (2014); Woodward et al. (2008); Pfeiffer et al. (2005); EPA (2004); Lone Pine; EHP factsheet; Mogridge; AKF; LWA factsheet
Eucalyptus tereticornis subsp. basaltica	Higher	based on inference from base species
Eucalyptus tereticornis subsp. tereticornis	Higher	based on inference from base species
Eucalyptus terminalis		Superseded by Corymbia terminalis (03/04/2019)
Eucalyptus tessellaris		Superseded by Corymbia tessellaris
Eucalyptus thozetiana	Medium	
Eucalyptus tindaliae	Medium	Thompson (2006); EHP factsheet; Melzer et al. (2014)
Eucalyptus umbra	Medium	Woodward et al. (2008) diet species on North Stradbroke Island; NSW (2018) irregular use by koalas.
Eucalyptus whitei	Lower	Melzer et al. (2014) very small component of browse used by koalas.
Eucalyptus woollsiana	Lower	NSW (2018) Pilliga box (E. pilligaensis) extensively in the Pilliga Forest
Excoecaria dallachyana	none or unknown	
Exocarpos latifolius	none or unknown	
Ficus coronata	none or unknown	
Ficus macrophylla forma macrophylla	none or unknown	
Ficus rubiginosa	none or unknown	
Ficus virens	none or unknown	
Ficus watkinsiana	none or unknown	
Flindersia australis	none or unknown	
Flindersia collina	none or unknown	
Flindersia dissosperma	none or unknown	
Flindersia schottiana	none or unknown	
Flindersia spp.	none or unknown	
Flindersia xanthoxyla	none or unknown	
Geijera parviflora	none or unknown	
Glochidion sumatranum	none or unknown	
Gmelina leichhardtii	none or unknown	
Gossia bidwillii	none or unknown	
Grevillea banksii	none or unknown	
Grevillea robusta	none or unknown	
Hakea actites	none or unknown	
Hernandia bivalvis	none or unknown	
Hodgkinsonia ovatiflora	none or unknown	
Jagera pseudorhus	none or unknown	
Karrabina benthamiana	none or unknown	
Leptospermum spp.	none or unknown	
Leptospermum trinervium	none or unknown	
Livistona australis	none or unknown	
Livistona decora	none or unknown	
Livistona spp.	none or unknown	
Lophostemon confertus	Medium	EHP factsheet; Mogridge; LWA factsheet. Qld Koala Crusaders factsheet. NSW (2018) irregular use by koalas. Johnson (2021)
Lophostemon suaveolens	Lower	McFarland taxon profile. NSW (2018) irregular use by koalas.
Lysicarpus angustifolius	none or unknown	
Lysiphyllum carronii	none or unknown	
Lysiphyllum spp.	none or unknown	
Macadamia spp.	none or unknown	
Macropteranthes leichhardtii	none or unknown	
Mallotus discolor	none or unknown	
Mallotus philippensis	none or unknown	
Melaleuca bracteata	Lower	Melzer et al. (2014) very small component of browse used by koalas.
Melaleuca cheelii	none or unknown	
Melaleuca dealbata	none or unknown	

Tree species	Species utility	Source
Melaleuca fluviatilis	none or unknown	
Melaleuca irbyana	none or unknown	
Melaleuca leucadendra	Medium	
Melaleuca linariifolia	none or unknown	
Melaleuca nervosa	Lower	Melzer et al. (2014) very small component of browse used by koalas.
Melaleuca nodosa	none or unknown	
Melaleuca quinquenervia	Medium	Callaghan et al. (2011) use proportional to availability; Melzer et al. (2014); EPA (2004); EHP factsheet; LWA factsheet; Johnson (2021)
Melaleuca salicina	none or unknown	
Melaleuca sieberi	none or unknown	
Melaleuca spp.	none or unknown	
Melaleuca thymifolia	none or unknown	
Melaleuca trichostachya	none or unknown	
Melaleuca viminalis	none or unknown	
Melaleuca viridiflora var. viridiflora	none or unknown	
Melastoma labathricum subsp. malabathricum	none or unknown	
Melia azedarach	none or unknown	
Melicope elleryana	none or unknown	
Mischocarpus pyriformis subsp. pyriformis	none or unknown	
Murraya ovatifoliolata	none or unknown	
Neolitsea dealbata	none or unknown	
Notelaea microcarpa	none or unknown	
Nothofagus moorei	none or unknown	
Olea paniculata	none or unknown	
Orites excelsus	none or unknown	
Owenia acidula	none or unknown	
Pandanus tectorius	none or unknown	
Petalostigma pubescens	none or unknown	
Pittosporum angustifolium	none or unknown	
Pittosporum undulatum	none or unknown	
Planchonella australis	none or unknown	
Planchonella cotinifolia	none or unknown	
Planchonella myrsinifolia	none or unknown	
Planchonella pohlmaniana	none or unknown	
Pleiogynium timorense	none or unknown	
Pleioluma queenslandica	none or unknown	
Pleurostylia opposita	none or unknown	
Podocarpus elatus	none or unknown	
Polyalthia nitidissima	none or unknown	
Pseudoweinmannia lachnocarpa	none or unknown	
Psydrax odorata	none or unknown	
Psydrax odorata forma buxifolia	none or unknown	
Rhodosphaera rhodanthema	none or unknown	
Siphonodon australis	none or unknown	
Sloanea australis	none or unknown	
Sloanea woollsii	none or unknown	
Syncarpia glomulifera	Lower	Callaghan et al. (2011) lower use relative to availability. NSW (2018) used extensively in some areas.
Syncarpia glomulifera subsp. glomulifera	none or unknown	
Syncarpia hillii	none or unknown	
Syncarpia verecunda	none or unknown	
Synoum glandulosum subsp. glandulosum	none or unknown	
Syzygium australe	none or unknown	
Syzygium corynanthum	none or unknown	
Syzygium crebrinerve	none or unknown	
Syzygium francisii	none or unknown	

Tree species	Species utility	Source
Syzygium moorei	none or unknown	
Toona ciliata	none or unknown	
Tristaniopsis laurina	none or unknown	
Turraea pubescens	none or unknown	
Vachellia bidwillii	none or unknown	

Species utility classes	Description
Higher	Mentioned in a broad range of reports and literature, the majority of which are definitive studies, and were described as being an important species.
Medium	Mentioned in some reports and literature, can be secondary, anecdotal e.g. included in a factsheet
Lower	Not mentioned in any literature or considered a trace food species from a definitive study, and/or eucalypt species
None or unknown	Not mentioned in any literature, and not a eucalypt

Source	Definitive or Secondary (Anecdotal/Expert derived/Factsheet)	Description
AKF	Secondary	Australian Koala Foundation - in McAlpine et al., 2007 *Planning guidelines for koala conservation and recovery.*
Callaghan et al. (2011)	Definitive	Callaghan et al. 2011. Koala habitat mapping based on tree species use. *Wildlife Research*, vol.38, pp.89-102
EHP factsheet (2012)	Secondary	EHP - Planting trees for koalas factsheet: Coastal South East Queensland
EPA (2004)	Secondary	Environmental Protection Agency (EPA). 2004. Koala Habitat Map Methodology, Version 1, released 24th May 2004. Internal report, Biodiversity Planning Division.
FitzGibbon et al. (2013)	Secondary	The Koala Venture Research Partnership: an overview of 24 years of regional koala research in central Queensland in Flint and Melzer (2013)
Hasegawa (1995)	Definitive	Cited in Callaghan et al. (2011) - Habitat usage by Koalas at Point Halloran - Master's thesis.
Kavanagh et al. (2007)	Definitive	Kavanagh, RP, Stanton, MA, Brassil, TE 2007. 'Koalas continue to occupy their previous home-ranges after selective logging in *Callitris–Eucalyptus* forest.' *Wildlife Research* 34, 94-107. https://doi.org/10.1071/WR06126
Lone Pine	Secondary	Lone Pine Captive koala food preferences e-mail received 04/10/16
LWA factsheet	Secondary	Land for Wildlife (LWA) Queensland :note A4
Mathews et al. (2007)	Definitive	Matthews, A, Lunney, D, Gresser, S, Maitz, W, 2007, 'Tree use by koalas (*Phascolarctos cinereus*) after fire in remnant coastal forest.' *Wildlife Research* 34, 84-93.
McFarland profile	Secondary	*Phascolarctos cinereus* (Koala) Profile - Habitat Suitability Modelling for South East Queensland, Regional Ecosystem Version 7, 2013
Melzer et al. (2014)	Definitive	Melzer et al. 2014. The habitat and diet of koalas (*Phascolarctos cinereus*) in Queensland. *Australian Mammalogy*, vol.36, pp.189-199.

Source	Definitive or Secondary (Anecdotal/Expert derived/Factsheet)	Description
Mogridge	Secondary	Grant Mogridge browse preference list, based on experience at two SEQ captive koala facilities (Lone Pine and Australian Woolshed) and the Cairns Tropical Zoo. Have included species where listed as >90% eaten
NSW (2018)	Definitive	A review of koala tree use across New South Wales. Office of Environment and Heritage.
Pfeiffer et al. (2005)	Definitive	Pfeiffer et al. 2005. Tree use by koalas (*Phascolarctos cinereus*) on St Bees Island, Queensland – report of a pilot study. *Proceedings of the Royal Society of Queensland*, vol.112, pp.47-51.
Rhodes et al. (2015)	Secondary	Rhodes et al. 2015. South East Queensland Koala Population Modelling Study. UniQuest – internal report for EHP, Brisbane, Australia
Smith (2004)	Secondary	Cited in Callaghan et al. (2011)
Sullivan et al. 2003		Sullivan, BJ, Norris, WM, Baxter, GS 2003. 'Low-density koala (*Phascolarctos cinereus*) populations in the mulgalands of south-west Queensland. II. Distribution and diet.' *Wildlife Research* 30, 331-338.
Thompson 2006	Definitive but based on daytime roosting, not faecal pellet study	Thompson, JA 2006. The comparative ecology and population dynamics of koalas in the koala coast region of south-east Queensland. PhD Thesis, School of Integrative Biology, University of Queensland
Woodward et al. (2008)	Definitive	Woodward et al. 2008. Koalas on north Stradbroke Island: Diet, tree use and reconstructed landscapes. *Wildlife Research*, vol.35, pp.606-611.
Wu et al. (2012)	Definitive, however south west Queensland relevant	Wu et al. 2012. The dietary preferences of koalas, *Phascolarctos cinereus*, in southwest Queensland. *Australian Zoologist*, vol.36, pp.93-102.

Appendix 4. **Maxent supplementary information**

Maxent modelling

The koala habitat modelling was conducted using Maximum Entropy Species Distribution Modelling software (Maxent v.3.3.3k) which is a widely used program for generating species distribution models based on presence-only species records (Elith et al. 2006, Phillips et al. 2006; Elith et al. 2011; Young et al. 2011; Yackulic et al. 2013). Maxent has gained popularity for use in species modelling due to its ability to make predictions from incomplete information, such as the common scenario where systematic survey data is not available.

Maxent (which stands for maximum entropy), is a machine learning algorithm that predicts species occurrences by finding the distribution that is most spread out, or closest to uniform (maximum entropy), while taking into account the limits of the environmental variables at known locations. Environmental functions are constructed based upon the environmental variation encountered at presence locations, while taking into account the environmental variation present across the broader study area. The environmental variation present within a study area is estimated via a large random sample of background point locations across the study area (10,000 point locations).

To develop the Maxent model the project team undertook an extensive process of compiling environmental variables (measures) on the basis of known or hypothesised links to koala habitat and ecology (Table 14). Additionally, data sources needed to be available and mapped at an appropriate resolution (scale) across the study area. The environmental measures represented indicators of terrain, soil, climate, landcover, vegetation and groundwater.

Correlations among the candidate measures and a pilot Maxent analysis were used to reduce the initial set of 18 candidate measures to a final set of 13 measures used to build the model (Table 14). Correlations were examined using the Pearson product moment and Spearman's rank correlation (Figure 23) and scatterplots (Figure 24). Some highly correlated landcover measures, such as foliage projective cover (hlfpc) and seasonal persistent green cover (hlpgr) were removed in preference for retaining NDVI (hlndv). Groundwater salinity (hgsal) was removed in favour of groundwater dependent ecosystems (hgpot). Aspect (htasp) and landzones with colluvium (hvlzc) were removed because of very weak responses in the Maxent pilot. Other less strongly correlated measures were retained primarily because the objective was to produce the best possible model and the study was less interested in the coefficients of the measures (i.e. which variables had the greatest impact on model discriminatory capability) and determining the key drivers of koala habitat distribution[8]. In addition, measures were retained if they were of particular interest; if they had been previously been shown to be important in other koala habitat models; or if they may diverge (show lower correlation) in future climate scenarios (Adams-Hosking et al. 2011; 2012; Garden et al. 2015; Santika et al. 2015; Briscoe et al. 2016; Queensland Herbarium 2016; Law et al. 2017). Maxent is less sensitive to correlations between predictor variables (measures) than some other modelling methods because the regularisation method it uses makes it reasonably robust (Elith 2008).

The pilot Maxent analysis was conducted to examine the relative contribution of the 18 candidate variables to model performance. In a stepwise procedure, a number of model runs were undertaken to iteratively remove each explanatory measure and assess the impact on model performance. Estimates of relative contributions of the environmental measures to the model were made using Maxent's percent contribution[9], permutation importance[10] and built-in jackknife[11] tests.

---

[8] Given the potential correlations, care must be taken in interpretation of the model predictors. "If two measures were highly correlated and one made a much greater contribution to the model than the other, this does not necessarily imply that the contributing one is far more important to the species than the other. It's just that it was chosen by the model, and because it was chosen, its correlated pair was rarely selected" (Elith 2008, p44).

[9] While the Maxent model is being trained, it keeps track of which environmental measures are contributing to fitting the model. Each iteration of the algorithm increases the gain (goodness of fit) by modifying the coefficient (weight) for a single environmental measure. The program assigns the increase in the regularised gain to the environmental variable and at the end of the training process calculates the percent contribution (Phillips et al. 2006). The percent contribution values are only heuristically defined–being dependent on the particular path used to get to the optimal solution, and a different algorithm could get the same solution via a different path, resulting in different percent contribution values.

[10] Permutation importance depends only on the final Maxent model, not the path used to obtain it. The contribution for each measure is determined by randomly permuting the values of that variable among the training points (both presence and background) and measuring the resulting decrease in training AUC. A large decrease indicates that the model depends heavily on that measure. Values are normalized to give percentages.

[11] In the jackknife testing Maxent creates a number of models where each measure was excluded in turn, and a model created with the remaining measures. Then a model was created using each variable in isolation and compared to a model created using all measures. The environmental variable with the highest gain when used in isolation provides the most useful information by itself. The variable that the decreases the gain the most when it is omitted indicates that it may have the most information that isn't present in the other measures (Elith et al. 2006; Phillips et al. 2006).

	htasp	hctsv	hcmil	hlndv	htrug	hgsal	hgpot	htele	hscec	htslo	hlpgr	hctem	hcapr	hswat	hspho	hlfpc	hsnit	hvlzc
htasp	**1.00**																	
hctsv	0.01	**1.00**																
hcmil	-0.01	**-0.82**	**1.00**															
hlndv	-0.06	-0.43	0.59	**1.00**														
htrug	0.02	0.09	0.15	0.13	**1.00**													
hgsal	0.01	0.39	-0.36	-0.18	-0.05	**1.00**												
hgpot	0.02	0.40	-0.39	-0.19	-0.02	**0.96**	**1.00**											
htele	0.01	0.31	0.14	0.20	0.50	0.01	-0.01	**1.00**										
hscec	-0.01	0.43	-0.31	-0.23	0.17	0.06	0.03	0.32	**1.00**									
htslo	0.03	0.09	0.15	0.15	**0.94**	-0.03	-0.01	0.50	0.18	**1.00**								
hlpgr	0.03	-0.45	0.63	**0.83**	0.21	-0.20	-0.20	0.22	-0.27	0.23	**1.00**							
hctem	-0.02	0.61	**-0.83**	-0.53	-0.33	0.31	0.34	-0.55	0.07	-0.34	-0.56	**1.00**						
hcapr	-0.02	**-0.82**	**0.94**	0.55	0.03	-0.35	-0.40	-0.05	-0.41	0.03	0.60	-0.66	**1.00**					
hswat	-0.03	0.38	-0.14	-0.09	0.21	0.05	0.00	0.38	**0.73**	0.22	-0.12	-0.01	-0.22	**1.00**				
hspho	0.00	0.04	0.13	0.03	0.18	-0.11	-0.12	0.28	0.30	0.19	0.08	-0.20	0.04	0.38	**1.00**			
hlfpc	0.06	-0.37	0.55	**0.73**	0.23	-0.19	-0.20	0.30	-0.25	0.24	**0.85**	-0.55	0.50	-0.16	0.03	**1.00**		
hsnit	-0.01	-0.10	0.34	0.19	0.29	-0.18	-0.22	0.40	0.32	0.29	0.22	-0.44	0.22	0.44	**0.76**	0.15	**1.00**	
hvlzc	0.01	0.32	-0.24	-0.08	0.18	0.39	0.43	0.14	0.11	0.19	0.00	0.19	-0.25	0.07	0.06	-0.05	-0.03	**1.00**

**Correlations greater than 0.7 or less than -0.7 shown in bold.*

Figure 23: Pearson's correlation matrix.

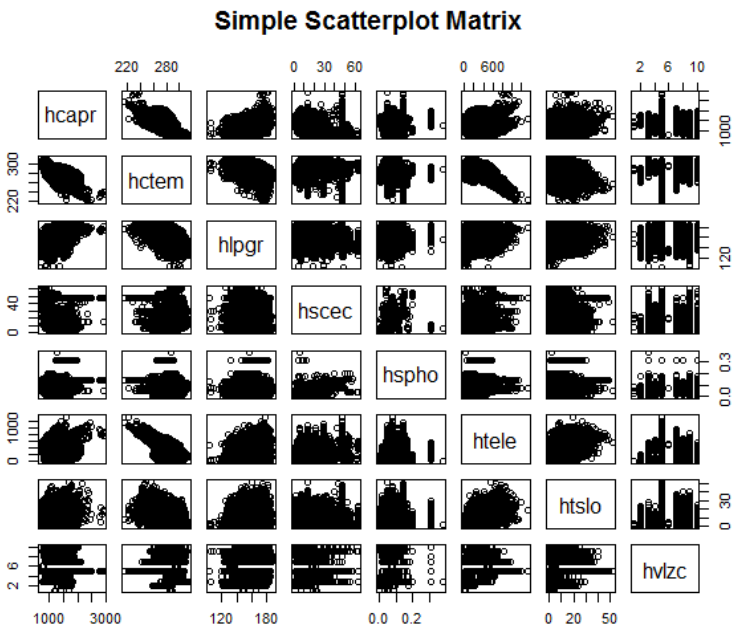


Figure 24: Scatterplot matrix.

Variables were then ranked according to their contribution and permutation importance and examined for natural breaks. Variables that either contributed the most to an increase in the AUC or those that decreased the AUC when omitted and were examined in greater detail for inclusion in the final model. Similarly measures that either contributed the most to model gain in the jackknife tests or those that decreased the gain the most when omitted, tended to be included in the final model. Marginal response curves (partial plots) and variable response curves[12] showing how koala presence varied across the range of each environmental variable were also examined to ensure they reflected expert knowledge of their ecological relationships. Measures that contributed at least 2% to the model result were retained.

A comprehensive analysis of vegetation communities and land zones was undertaken which included using the KAG to categorise and rank the regional ecosystems that occur in SEQ for their suitability to koalas and testing land zones with the inclusion of colluvium. Despite an exhaustive analysis, the contribution of vegetation communities and land zones to model predictions was weak and consequently these variables were excluded from the Maxent model. This is consistent with the work from Garden et al*.* (2015) who found specific floristic types did not increase modelling power. Instead, our approach was to develop a separate RE suitability classification based on expert knowledge and integrate it with the Maxent model using a decision matrix to produce the final koala habitat model. This iterative testing process resulted in the final set of 13 explanatory measures used in the Maxent model.

Training (fitting) the model was done using the remnant and non-remnant RE mapping (Queensland Herbarium, 2016, RE v10.0). Koalas predominantly utilise eucalypt trees for their food requirements although they will utilise non-eucalypt trees for other habitat requirements such as thermoregulation and shelter from fires (Briscoe et al*.* 2014). Consequently, we created a training mask that represented all vegetation communities and included remnant and non-remnant (regrowth only) vegetation while excluding cleared areas. Eliminating koala records from cleared areas during the training process not only decreased the potential sampling bias but also reduced the potential mismatch between when the koala record was obtained and the date of any subsequent clearing and habitat loss. As koalas are a tree dependent species, using a mask that represented vegetation (with trees) prevented the model from being trained in cleared or urban areas (without trees) - thereby reducing temporal and environmental bias.

Survey bias

Two approaches of reducing bias associated with survey effort were investigated: using a bias grid reflective of human population density (Phillips et al*.* 2009; Elith et al*.* 2010; Merow et al*.* 2013) and spatial filtering of occurrence data (Araújo and Guisan 2006; Boria et al*.* 2014). A bias grid is intended to represent sampling probability (i.e. where cell values reflect sampling effort) and is used to modify the background sample data or occurrence records to cancel out impacts associated with survey effort (*sensu* Fourcade et al*.* 2014). In the current project, a bias grid was tested based upon a Gaussian kernel density analysis of human population density (ABS census 2011), which was then rescaled from 1 to 20, following Elith et al*.* (2010) and implemented in the bias file option in Maxent. Other approaches to account for bias, including down-weighting records occurring along roads (Laidlaw and Butler 2012; Briscoe et al. 2016), creating a bias grid based upon known occurrences of the species, or from closely related species (Philips et al*.* 2009) were not used in this study. In koala studies from New South Wales, others have used information on other commonly recorded species to estimate detection bias (Santika et al*.* 2014; Law et al. 2017).

The second approach used spatial filtering to select a subsample of records in geographical space. Although Maxent discards redundant records that occur in a single cell (in our case, 1ha), we removed neighbouring occurrences at a coarser resolution by creating a hexagonal grid and randomly sampling one occurrence record per grid cell (*sensu* Fourcade et al*.* 2014). The grid cell size used to sample the occurrences must be large enough to resolve the bias but not too large to result in a strong loss in resolution (Fourcade et al*.* 2014). We evaluated the resolution of the filtering that provided the optimal trade-off between sampling bias correction and information reduction at three spatial scales (500m, 1km, and 2km). Models fit using a sample bias grid and the alternative approaches of spatial filtering showed very similar spatial predictions and model performance. The 2km spatial filter reduced the density of records in the high density, heavily sampled eastern margins of the study while maintaining sufficient records in lower density less sampled western areas (Figure 25). The 2km spatial filter appeared to provide the best (reduced bias) spatial representation of the koala records and was adopted as the reference grid scale for use in the final Maxent models. Other koala studies have similarly used a filter to ensure koala records were separated by a minimum distance of 2km to reduce spatial aggregation (Law et al. 2017).

[12] The marginal response curves (partial plots) show how the logistic prediction changes as each environmental variable is varied, while keeping all other environmental variables at their average sample value. The marginal response plots represent the marginal effect of changing only one variable whereas the model may take advantage of sets of variables changing together. The variable response curves were created using only a single variable. The variable response plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. Consequently, variable response plots may be easier to interpret if there are strong correlations between variables.

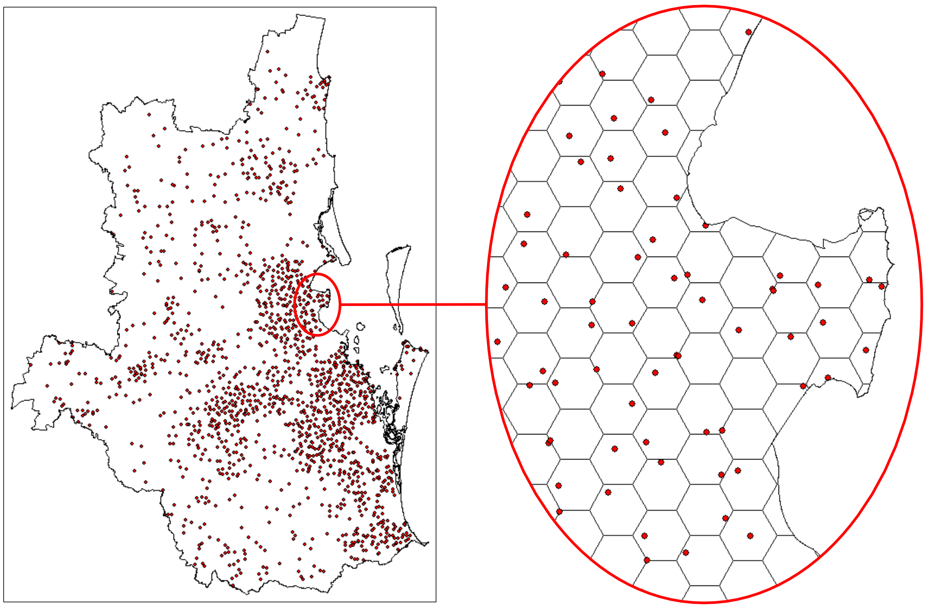


Figure 25: Spatial filtering of koala records (left) using a 2km hexagon (detail) to remove observer bias.

Records spatial filtering trials

Spatial filtering trials were conducted at three spatial scales: 500m, 1km and 2km, equivalent to a hexagon grid cell area of 25ha, 100ha, and 400ha, respectively. Filtering reduced the number of koala occurrence records from a total of 79,936 vetted records in SEQ to 5,417 records in the 25ha grid, 2667 records in the 100ha grid and 1395 records in the 400ha hexagon grid. Further restricting the koala records to mapped areas of remnant or non-remnant (regrowth) vegetation produced smaller subsets used as inputs into the trial Maxent models. By default, Maxent removes duplicate records that occur in a single cell, consequently the final Maxent models were run using a 1ha grid cell, with 1364 presence records used for training and 10,000 random background points used to determine the Maxent distribution (Figure 26). Maxent is relatively insensitive to spatial errors associated with location data and has been shown to perform well with errors up to 5km (Graham et al. 2008).

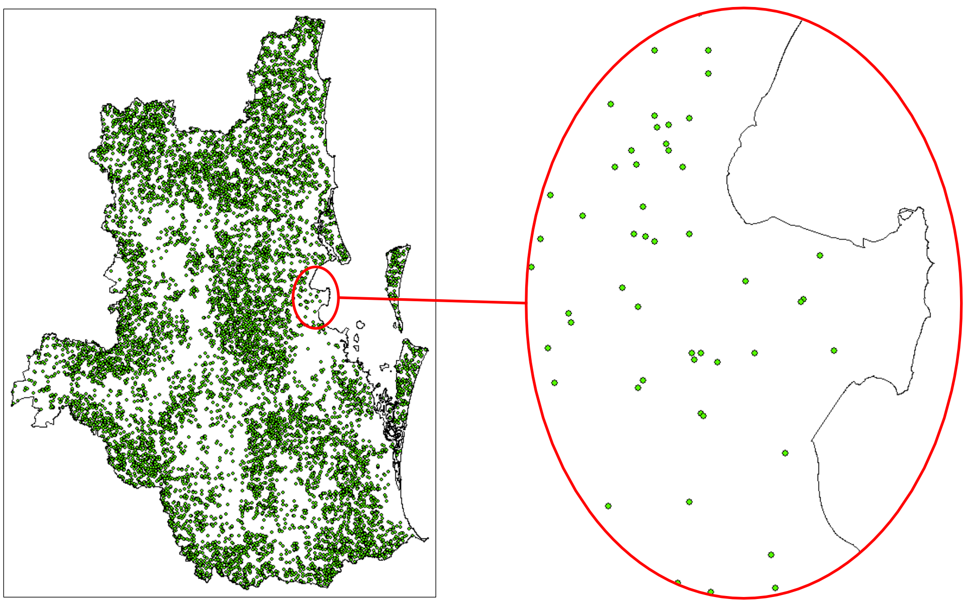


Figure 26: Random background points (left) used to determine the Maxent distribution. Detail (right).

Spatial filtering reduced the spatial aggregation of records but does not correct the lack of data due to low sampling effort in some areas. This method could also underestimate the contribution of suitable areas where the high density of records reflects the true ecological value for the species (Fourcade et al. 2014). In SEQ where large numbers of koalas occur in urban areas, intermediate road density has been associated with higher koala density (Rhodes et al. 2015) or a reflection of sampling bias towards roads (Briscoe et al. 2016).

Approach

To perform the Maxent run, a csv file containing koala occurrence records ("samples"), a directory containing environmental variables in ASCII format, an output directory for the results and a projection layers directory containing environmental variables in ASCII format were used. All environmental and climate variables were identified within Maxent as continuous variables, except for the GDE variable, which was categorical. The model was trained on a remnant and regrowth mask and predicted to a pre-clearing extent. We used linear, product, quadratic and hinge features (beta hinge = 1.0) to allow for more ecologically relevant response curves that reduced overfitting and that was more suitable for predicting into new environments or future climate scenarios (Elith et al. 2010). Repeated sub-sampling was undertaken using a random test percentage of 20% and 20 replicates to repeatedly split the presence points into random training (80%) and testing (20%) subsets.

Response curves

The marginal response curves (partial plots) (Figure 27) showed a very similar response to the variable response curves using only the corresponding variable (Figure 28). Usually the variable response curves are easier to interpret if there are strong correlations between variables. The shape of the response curves should be considered in the context of an ecological understanding of koala habitat suitability. Variables with complex surfaces may indicate over-fitting and sharp increases or decreases near the limits of the environmental range indicate increased uncertainty.

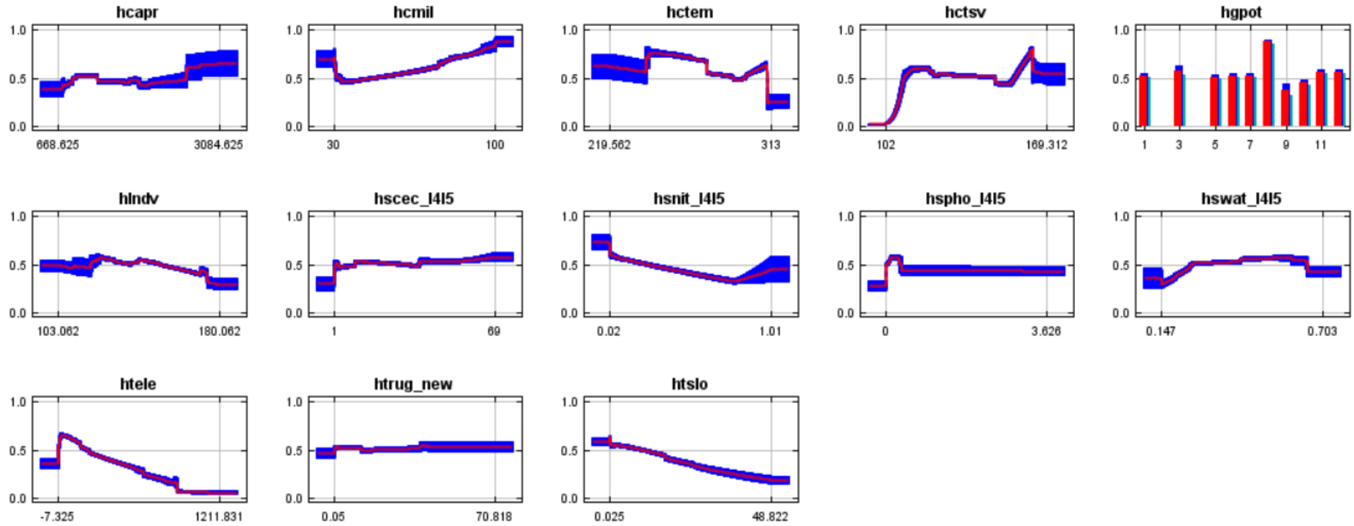


Figure 27: Marginal response curves (partial plots).

Marginal response curves show how predictions change across the range of each environmental variable, keeping all other environmental variables at their average value. (The y-axis represents the logistic value, and the x-axis represents the value of the environmental variable).

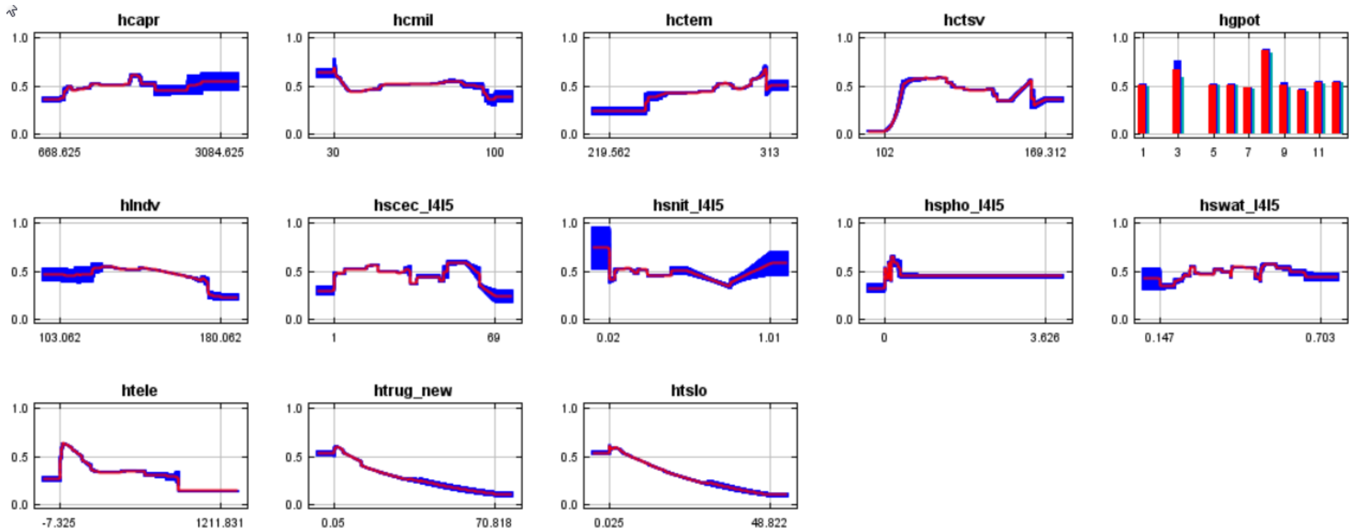


Figure 28: Variable response curves created using only the corresponding variable.

Variable response curves reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. They may be easier to interpret if there are strong correlations between variables. (The y-axis represents the logistic value, and the x-axis represents the value of the environmental variable).

Variable contribution

Elevation (htele) was the largest single predictor of koala habitat suitability, contributing 40% to the model. Other measures that contributed more than 4% to the model were temperature coefficient of variation (hctsv), slope (htslo), soil water (hswat), ruggedness (htrug), phosphorous (hspho), temperature (hctem) and potential groundwater dependent ecosystems (GDE) (hgpot) which had a large standard deviation. The top eight measures contributed 88% to the model and consistently ranked higher than the remaining five measures in all model runs. The remaining five measures: moisture index (hcmil), NDVI (hlndv), rainfall (hcapr), nitrogen (hsnit) and cation exchange capacity (hscec), each contributed between 2% and 4% to the final model. The low contribution of NDVI and soil fertility measures (such as nitrogen and cation exchange capacity) may be confounded by the better quality soils having been selectively cleared for agriculture (Law et al. 2017).

Maxent settings

Settings used for the final model run and sub-sampling are shown in Table 12.

Table 12: Maxent settings for final run and sub-sampling.

Parameters Main:	**Final run**	**Sub-sampling**
Samples directory	--	--
Environmental layers directory	--	--
Linear, quadratic, product, threshold, hinge, auto features	Auto features	Auto features
Create response curves	Yes*	Yes*
Make pictures of predictions	Yes	Yes
Do jackknife to measure variable importance	Yes*	Yes*
Output format (logistic, cumulative, raw)	Logistic	Logistic
Output file type (asc, mxe, grd, bil)	asc	asc
Output directory	--	--
Projection layers directory/file	--	--
Parameters Basic:		
Random seed	Yes*	Yes*

Give visual warnings	Yes	Yes
Show tooltips	Yes	Yes
Ask before overwriting	Yes	Yes
Skip if output exists	No	No
Remove duplicate presence records	Yes	Yes
Write clamp grid when projecting	Yes	Yes
Do MESS analysis when projecting	Yes	Yes
Random test percentage	0	20
Regularization multiplier	1	1
Max number of background points (Default = 10,000)	10,000	10,000
Replicates	1	20
Replicate run type (Crossvalidate, bootstrap, subsample)	(Crossvalidate)	Subsample
Test sample file	n/a	n/a
Parameters Advanced:		
Add samples to background	No*	No*
Add all samples to background	No	No
Write plot data	No	No
Extrapolate	Yes	Yes
Do clamping	Yes	Yes
Write output grids	Yes	No
Write plots	Yes	Yes
Append summary results to maxentResults.csv	No	No
Cache ascii files	Yes	Yes
Maximum iterations (default = 500)	1000*	5000*
Convergence threshold	0.00001	0.00001
Adjust sample radius	0	0
Log file	Maxent.log	Maxent.log
Default prevalence	0.5	0.5
Apply threshold rule (Fixed cumulative value 1, 5, or 10; Minimum training presence; 10 percentile training presence; Equal training sensitivity and specificity; Maximum training sensitivity plus specificity; Equal test sensitivity and specificity; Maximum test sensitivity plus specificity; Equate entropy of thresholded and original distributions)	-	-
Bias file	-	-
Parameters Experimental:		
Logscale raw/cumulative pictures	Yes	Yes
Per species results	No	No
Write background predictions	Yes*	Yes*
Show exponent in response curves	No	No
Fade by clamping	No	No
Verbose	No	No
Use samples with some missing data	No	No
Threads	1	1
Lq to lqp threshold	80	80
Linear to lq threshold	10	10
Hinge threshold	15	15
Beta threshold	-1	-1
Beta categorical	-1	-1
Beta lqp	-1	-1
Beta hinge	-1	-1
Default nodata value	-9999	-9999

**Non-default settings with the asterisk were changed and all other settings remained as default.*

Maxent model validation

Area under the curve (AUC) as a measure of model performance

The cross-validation AUC derived from the ROC shows only a small amount of variability between models (Figure 29), indicating that the model was a good fit. The mean AUC on the test data was 0.706 (95% CI: 0.700–0.712; SD

+/- 0. 0.013; range 0. 0.673–0.730, n = 20). The mean AUC on the training data was 0.740 (95% CI: 0.738–0.741; SD +/- 0.004; range 0.731–0.746, n = 20).

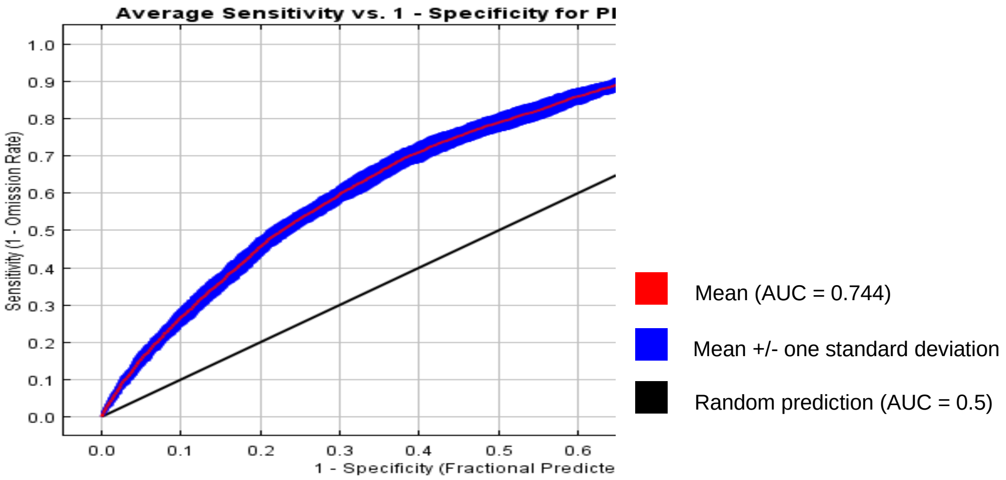


Figure 29: Cross validation AUC indicating the model was a good fit with only small amounts of variability (blue).

Mean habitat suitability and standard deviation

Mean habitat suitability logistic values from the repeated sub-sampling ranged from 0.009 to 0.962 (mean suitability = 0.450 and standard deviation of suitability = 0.173). The standard deviation of habitat suitability was low, with mean standard deviation = 0.031 (range 0.004–0.250) indicating again that the model was a good fit (Figure 30).

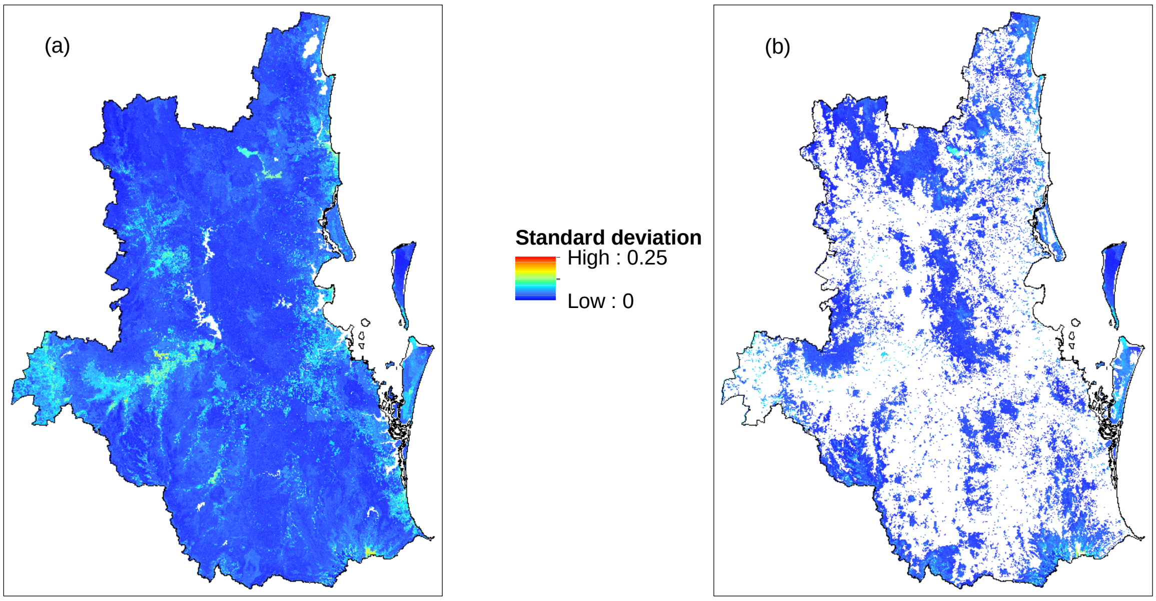


Figure 30: Maxent model standard deviation. Pre-clearing (a) and remnant (b).

Analysis of the variability associated with the predictor variables in the cross-validation

In the cross-validation, two measures elevation (htele) and potential GDE (hgpot) contributed 52% to the model, followed by seasonality coefficient of variation (hctsv) and slope (htslo) which contributed 21%. All other variables contributed less than 5% to the model (Table 13).

Table 13: Contribution of each variable (measure) to the Maxent model.

Measure	Measure code	Mean	Standard deviation	Min	Max	Range
Elevation	htele	26.2	6.3	19.7	38.5	18.9
GDE	hgpot	25.4	9.2	4.8	36.3	31.5
Seasonality	hctsv	12.2	1.7	9.9	15.5	5.6
Slope	htslo	8.9	2.1	4.8	12.2	7.4
Ruggedness	htrug	4.8	1.5	2.4	8.0	5.7
Temperature	hctem	4.2	0.5	3.4	5.5	2.1
Soil water	hswat	3.8	1.4	2.0	6.5	4.4
Phosphorus	hspho	3.0	1.0	1.6	5.5	3.9
Moisture index	hcmil	3.0	0.6	2.1	4.8	2.7
Cation exchange capacity	hscec	2.5	0.4	1.8	3.2	1.4
Nitrogen	hsnit	2.4	0.4	1.7	2.9	1.2
NDVI	hlndv	2.3	0.5	1.6	3.4	1.8
Rainfall	hcapr	1.3	0.4	0.6	2.0	1.4

The contribution of GDE (hgpot) was highly variable with a high standard deviation (9.2%) and large range (31.4%), with a contribution as low as 4.8% and as high as 36.3%. Consequently, a single model run could yield a low contribution for GDE, purely by chance (Figure 31).

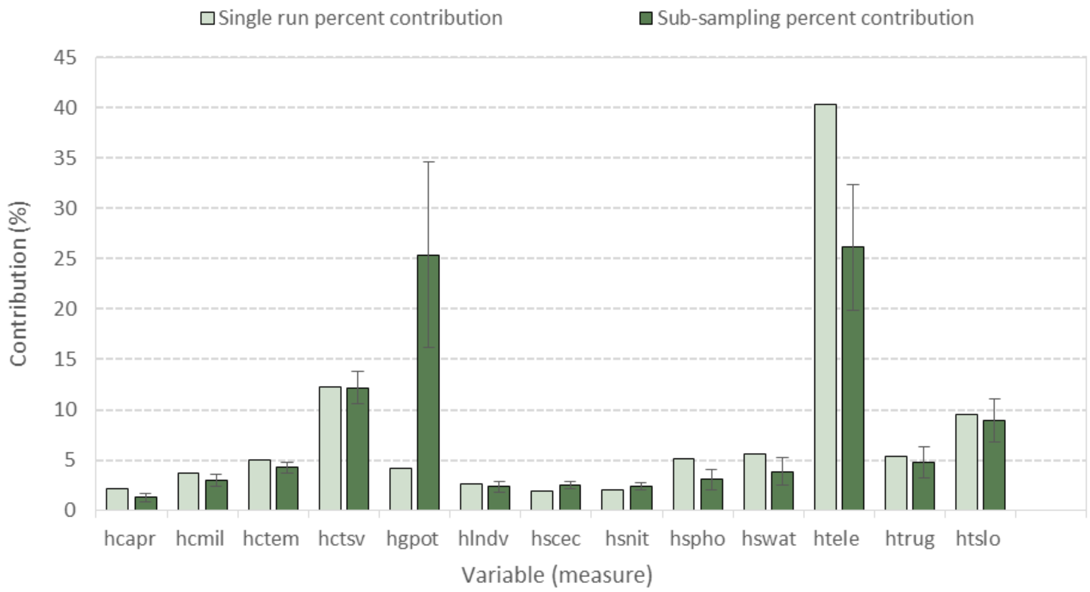


Figure 31: Variable importance from the single run used in the model compared with sub-sampling.

Analysis of the response curves of the predictor variables

The variable response curves, using only the corresponding variable, showed a very similar response to the marginal response curves (partial plots) indicating that correlations between variables has not been a major factor in fitting the model (Figure 32). The response curves for elevation (htele) and slope (htslo) (Figure 32) showed a strong inverse relationship indicating the highest suitability koala habitat predicted at elevations below 220m (mean = 107m +/- 115m SD), moderate suitability from 200 – 900m with the lowest suitability at elevations above 900m altitude. The highest ranked koala habitat suitability was predicted to occur on gentle slopes (low inclines).

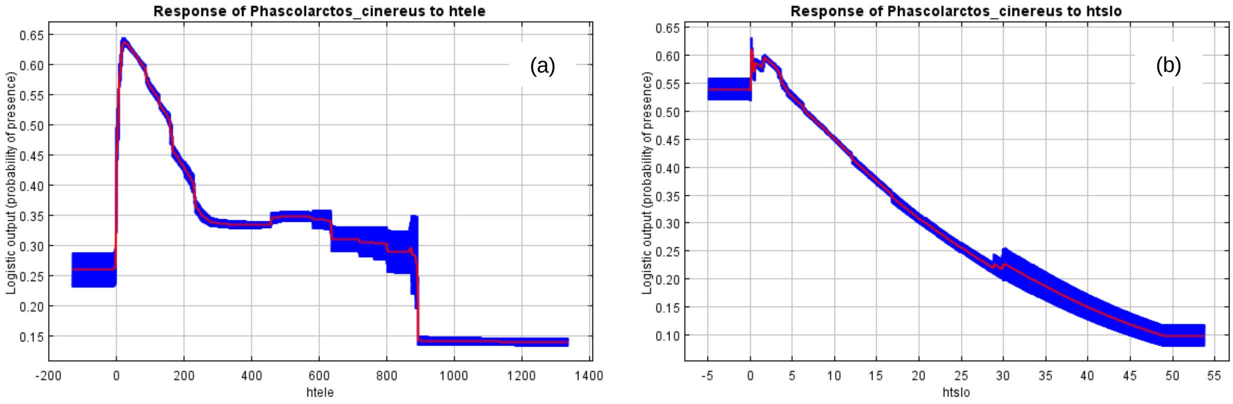


Figure 32: Examples of variable response curves. (a) Elevation (htele) and (b) slope (htslo).

The variable response curves show a strong inverse relationship between koala habitat suitability and both elevation and slope, indicating that the highest ranked koala habitat was predicted at low elevations (below 222m) and low slopes (inclines).

Maxent input data layers and training mask

Table 14: Maxent input data layers description and rationale.

Criteria	Indicator	Measure name, code and units	Source data	Summary description and data range	Rationale for inclusion
Habitat	Terrain	**Elevation (htele)** Mean altitude (m)	Digital Elevation Model (DEM) based on a 1 sec grid cell SIR: SRTM2_DSM_DEMv1_0 1 second (~30m) raster	Derived from the National DEM Shuttle Radar Topographic Mission (SRTM) 1 Second. The DEM represents ground surface topography, with vegetation features removed using an automatic process supported by several vegetation maps. Elevations are expressed as metres above sea level (MASL). For the Maxent 100m raster, range: -6.1–1225.3 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	In inland areas to the west, koalas are associated with the eucalypt communities associated with rivers and watercourses. To the east, koalas are regarded as being most abundant in the forests of the foothills and coastal plains (Martin et al. 2008). Low altitude areas are associated with some depositional flood plains and coastal lowlands that have higher fertility soils linked to higher koala densities (Rhodes et al. 2008, Crowther et al. 2009). Elevation is also linked to temperature and rainfall and may also be a proxy for the physical drivers of distribution. Other studies have included elevation as a predictor of occurrence for koalas (Cristescu et al. 2013; Santika et al. 2014; Rhodes et al. 2015; Law et al. 2017) and other marsupial folivores (Moore et al. 2004).
Habitat	Terrain	**Slope (htslo)** Mean slope (degrees)	DEM based on a 1 sec grid cell SIR: SRTM2_DSM_DEMv1_0 1 second (~30m) raster	Slope is a measure of steepness and is derived from the DEM and expressed as the average degrees over a 30m grid cell. For the Maxent 100m raster, range: 0–55.1 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Slope has an important indirect influence on koala occurrence and density because steeply sloping areas tend to have lower soil fertility and lower soil moisture and represent poorer koala habitat (Crowther et al. 2009) incidental koala records in SEQ (n=35,930) occur on low slopes between zero and five degrees (H. Preece 2015 pers. comm.).
Habitat	Terrain	**Ruggedness (htrug)** Terrain ruggedness (index)	Terrain ruggedness index derived from DEM based on a 1 sec grid cell SIR: SRTM2_DSM_DEMv1_0 1 second (~30m) raster	Topographic ruggedness is an index used to quantify topographic heterogeneity. It expresses the amount of elevation difference between adjacent cells of a DEM. The ruggedness index value is calculated for every location, by summarizing the change in elevation within a 3x3 pixel grid. The ruggedness index values were not grouped into categories, used as continuous data. For the Maxent 100m raster, range: 0–85.4 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Koala habitat is often associated with vegetation communities that occur on higher fertility and higher moisture soils at lower elevations and on lower slopes such as blue gum (*E. tereticornis*) communities on alluvial plains (Melzer et al. 2000).

Criteria	Indicator	Measure name, code and units	Source data	Summary description and data range	Rationale for inclusion
Habitat	Soil	**Cation exchange capacity (CEC) (hscec)** Concentrations of cations expressed in centimoles of positive charge per kilogram of soil (cmol (+)/kg)	Australian Soil Resource Information System (ASRIS). Vector representation of 250m raster. Soil_L4/L5 SIR: SLR.QLD_SOILS_ASRIS Feature Class: SLR.ASRIS_ASR_L4_2M_RESULTS_V and LR.QLD_SOILS_ASRIS\SLR.ASRIS_ASR_L5_250K_RESULTS_V	Cations are positively charged ions such as calcium (Ca2+), magnesium (Mg2+), potassium (K+), sodium (Na+) hydrogen (H+), aluminium (Al3+), iron (Fe2+), manganese (Mn2+), zinc (Zn2+) and copper (Cu2+). The capacity of the soil to hold on to these cations is the cation exchange capacity (CEC). Adding the concentrations of each cation gives an estimate of the CEC figure. A figure above 10cmol (+)/kg is preferred for plant production. Soils with high levels of swelling clay and organic matter can have a CEC of 30cmol (+)/kg or more. The five exchangeable cations are also shown in soil test results as percentages of CEC. The desirable ranges for them are: calcium 65–80% of CEC, magnesium 10–15%, potassium 1–5%, sodium 0–1% and aluminium 0%. The soil_l4l5 layer was dissolved on the CEC_3 field. (NULL, -1234 and -9999 values are not included) For the Maxent 100m raster, range: 1–69 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Koalas prefer high fertility soils because they influence the foliar nutrients and moisture available to koalas through the leaves they consume (Moore and Foley 2005). Cation exchange capacity (CEC) is a useful indicator of soil fertility because it shows the soil's ability to supply three important plant nutrients: calcium, magnesium and potassium.
Habitat	Soil	**Phosphorus (hspho)** Mean mass fraction of total phosphorus in the soil by weight (%)	Australian Soil Resource Information System (ASRIS). Vector representation of 250m raster. Soil_L4/L5 SIR: SLR.QLD_SOILS_ASRIS Feature Class: SLR.ASRIS_ASR_L4_2M_RESULTS_V and LR.QLD_SOILS_ASRIS\SLR.ASRIS_ASR_L5_250K_RESULTS_V	Mass fraction of total phosphorus in the soil by weight in layer 1 (soil depth 0–5 cm). For the Maxent 100m raster, range: 0–1.663 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Koalas are believed to prefer browse with higher phosphorus and potassium (Ullrey et al. 1981). Phosphorous is critical for the overall health of eucalypts, including the development of roots, stems, flowers and seeds and is vital for photosynthesis in plants and for growth in animals. Phosphorous is a critical limiting nutrient in most Australian soils which are naturally low in phosphorus due to extensive and prolonged weathering. While native plants are adapted to these low levels, introduced grasses are not, which is why Australian farmers use much more phosphorus than farmers in Europe and USA. Chemically, phosphorus is a very stable element, binding with iron and aluminium in the soil and becoming unavailable to plants - especially in dry soils.

Criteria	Indicator	Measure name, code and units	Source data	Summary description and data range	Rationale for inclusion
Habitat	Soil	**Nitrogen (hsnit)** Mean mass fraction of total nitrogen in the soil by weight (%)	Australian Soil Resource Information System (ASRIS). Vector representation of 250m raster. Soil_L4/L5 SIR: SLR.QLD_SOILS_ASRIS Feature Class: SLR.ASRIS_ASR_L4_2M_RESULTS_V and LR.QLD_SOILS_ASRIS\SLR.ASRIS_ASR_L5_250K_RESULTS_V	Total nitrogen content of soils is the mass fraction of total nitrogen in the soil by weight and is a key soil attribute influencing the nutrient content of eucalypt trees (Cork 1986). The soil_l4l5 layer was dissolved on the TOTAL_N_1 field. (NULL, -1234 and -9999 values were not included) For the Maxent 100m raster, range: 0.02–1.22 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Nitrogen is believed to be a major limiting factor influencing the abundance of koalas (Degabriele 1981). Koalas are believed to preferentially visit trees with leaves containing higher available nitrogen, used by the body to make proteins, and avoid trees with higher levels of toxic chemicals (Cork 1986). In habitats of low nutritional quality, a diversity of tree species is believed to be particularly important, in order to provide koalas with a choice of browse ranging in nutritional quality and minimizing the need to move to forests with higher quality leaves (Stalenberg et al. 2014).
Habitat	Soil	**Soil water (hswat)** Mean plant available water (mm)	Australian Soil Resource Information System (ASRIS). Vector representation of 250m raster. Soil_L4/L5 SIR: SLR.QLD_SOILS_ASRIS Feature Class: SLR.ASRIS_ASR_L4_2M_RESULTS_V and LR.QLD_SOILS_ASRIS\SLR.ASRIS_ASR_L5_250K_RESULTS_V	Plant available water is the amount of water in the soil which can be extracted by a plant. It is the difference between field capacity (the maximum amount of water the soil can hold) and the wilting point (where the plant can no longer extract water from the soil). Plant available water was calculated by subtracting the wilting point from the field capacity. The soil water measure was calculated by subtracting the sum of the wp1-5 fields from the sum of the fc1-5 fields, (NULL, -1234 and -9999 values were not included) For the Maxent 100m raster, range: 0.046–0.782 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Koalas are dependent on leaf moisture content for all their water needs where they do not have access to free-standing water or moisture on leaves (Gordon et al 1988, Ellis et al 2010). In dry seasons, drought and hot conditions, water may be a limiting factor that results in koala death. The health of the tree canopy, foliar moisture and nutrients are dependent on available soil moisture (Moore et al. 2004).
Habitat	Climate	**Temperature (hctem)** Maximum temperature of warmest period (°C x 10)	Bioclim (BioClimatic 3 seconds data): bc5_mtwp/Bio$_5$ http://fennerschool.anu.edu.au/files/anuclim61.pdf Bioclimatic parameters for Queensland (90m raster) derived using ANUCLIM/BIOCLIM version 5.1 (Houlder et al. 2000) and a 90m SRTM DEM. Data obtained from the Queensland Herbarium (2016).	Maximum temperature of warmest period (°C x 10). Value (in °C) multiplied by 10 in source data. Calculated as the highest temperature of any weekly maximum temperature. For the Maxent 100m raster, range: 216.25–313 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Temperature information is useful when examining whether species distributions are affected by warm temperature anomalies throughout the year (O'Donnell and Ignizio 2012). High maximum summer temperatures have been found to be important determinants of koala mortalities (Gordon et al. 1988) and distributions (Lunney et al. 2012, Lunney et al. 2014, Santika et al. 2014). Koala populations are believed to be currently confined to areas with a maximum summer temperature below 37.7°C (i.e. maximum temperature of warmest period) and maximum annual rainfall below 2480mm (i.e. mean annual precipitation) (Adams-Hosking et al. 2011).

Criteria	Indicator	Measure name, code and units	Source data	Summary description and data range	Rationale for inclusion
Habitat	Climate	**Rainfall (hcapr)** Annual average mean precipitation per year (mm/year)	Bioclim (BioClimatic 3 seconds data): bc12_ap/Bio$_{12}$ http://fennerschool.anu.edu.au/files/anuclim61.pdf Bioclimatic parameters for Queensland (90m raster) derived using ANUCLIM/BIOCLIM version 5.1 (Houlder et al. 2000) and a 90m SRTM DEM. Data obtained from the Queensland Herbarium (2016).	Annual mean precipitation per year (mm/year). Calculated as the sum of all monthly precipitation estimates For the Maxent 100m raster, range: 666.0625–2751.625 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Annual total precipitation approximates the total water inputs and is therefore useful when ascertaining the importance of water availability to a species distribution (O'Donnell and Ignizio 2012). Rainfall is important for koalas as they are sensitive to drought (Seabrook et al. 2011). Drought reduces the leaf moisture content and the nutrition of eucalypt leaves that are important for koala habitat quality (Moore et al. 2004). Koala populations are currently confined to areas with maximum annual rainfall of 2480mm (mean annual precipitation of 863mm; minimum 234mm) (Adams-Hosking et al. 2011).
Habitat	Climate	**Moisture index (hcmil)** Mean moisture index of the lowest quarter moisture (index)	Bioclim (BioClimatic 3 seconds data): bc33_mmilq/Bio$_{33}$ http://fennerschool.anu.edu.au/files/anuclim61.pdf Bioclimatic parameters for Queensland (90m raster) derived using ANUCLIM/BIOCLIM version 5.1 (Houlder et al. 2000) and a 90m SRTM DEM. Data obtained from the Queensland Herbarium, (2016).	The quarter of the year having the lowest average moisture index value is determined (to the nearest week), and the average moisture index value is calculated (Xu and Hutchinson, 2011, 2013) For the Maxent 100m raster, range: 29.0625–100 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Koalas are dependent on leaf moisture content for all their water needs where they do not have access to free-standing water or moisture on leaves (Gordon et al. 1988, Ellis et al. 2010). In dry seasons, drought and hot conditions, water may be a limiting factor that results in koala death (Gordon et al. 1988).

Criteria	Indicator	Measure name, code and units	Source data	Summary description and data range	Rationale for inclusion
Habitat	Climate	**Seasonality (hcstv)** Temperature seasonality coefficient of variation (Kelvin)	Bioclim (BioClimatic 3 seconds data): bc4_ts/Bio$_4$ http://fennerschool.anu.edu.au/files/anuclim61.pd Bioclimatic parameters for Queensland (90m raster) derived using ANUCLIM/BIOCLIM version 5.1 (Houlder et al. 2000) and a 90m SRTM DEM. Data obtained from the Queensland Herbarium (2016).	The temperature coefficient of variation is the standard deviation of the weekly mean temperatures expressed as a percentage of the mean of those temperatures (i.e. the annual mean). For this calculation, the mean in Kelvin (K) is used. This avoids the possibility of having to divide by zero, but does mean that the values are usually quite small (Xu and Hutchinson, 2011, 2013) For the Maxent 100m raster, range: 103–170 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	Temperature seasonality is a measure of temperature change over the course of the year. Temperature seasonality coefficient of variation captures the dispersion in relative terms because standard deviation can produce two similar values while the means may be different. However, if variance is the same, an area with a lower mean temperature is distinguishable from an area with similar variance but with a higher mean temperature. The larger the percentage, the greater the variability of temperature (O'Donnell and Ignizio 2012) Reported by Laidlaw and Butler (2012) in a study of Queensland threatened flora and fauna as an important driver of species distribution.
Habitat	Land cover	**Normalised difference vegetation index (NDVI) (hlndv)** (index)	NDVI Sentinel-2 data Department of Science, Information Technology and Innovation (2016)	NDVI provides a measure of the amount of live green vegetation. NDVI is the ratio of reflectance in two spectral bands located in the red and near infrared wavelengths. This index can be used to provide an indication of greenness and net primary productivity based on the fraction of absorbed photosynthetically active radiation. NDVI was calculated using 554 Sentinel-2 NDVI images captured between 29/9/2015 and 16/11/2016 and computing the 25th percentile of NDVI after cloud masking. Calculating percentiles over time establishes the typical vegetation conditions for that period. Units are NDVI*100+100. So 100 is 0.0, 200 is 1.0 etc. (P. Scarth 2016 pers. comm.). NDVI values of zero mean there is no green vegetation, intermediate values represent sparse vegetation, shrubs or grassland and values of +1.0 represent dense green vegetation. NDVI values are always between -1 and +1, with the lowest value (-1) representing deep water. Vegetation NDVI in Australia typically ranges from 0.1 to 0.7, with higher values associated with greater density and greenness of the plant canopy. NDVI decreases as leaves come under water stress, become diseased or die. Bare soil and snow values are close to zero, while water bodies have negative values. For the Maxent 100m raster, range: 100–178.3125 Datatype source/Maxent: Continuous/Continuous Derived for study: Raster	NDVI has been used in various species models to represent potential habitat. Koalas are obligate folivores feeding on the foliage of eucalypts and closely related tree species to obtain all their food and the majority of their water. NDVI can be used to provide an indication of potential food and habitat availability as well as leaf moisture availability and habitat quality (Santika et al. 2014, Youngentob et al. 2015, Law et al. 2017).

<table>
<tr><th>Criteria</th><th>Indicator</th><th>Measure name, code and units</th><th>Source data</th><th>Summary description and data range</th><th>Rationale for inclusion</th></tr>
<tr><td>Habitat</td><td>Ground water</td><td>Potential Groundwater Dependant Ecosystem (GDE) (hgpot)
(category)</td><td>Department of Environment and Heritage Protection (2016)</td><td>GDEs are ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (DSITI 2015). Ecosystem dependency on groundwater may vary temporally (over time) and spatially (depending on its location in the landscape).
Range: Groundwater connectivity and salinity were combined into twelve classes using a two digit code where the first digit represents connectivity and the second digit represents salinity. Connectivity values (GW_CON_T_D): 1 = Permanent, 2 = Near-permanent, 3 = Intermittent. Salinity values (GW_SALINTY): 1 = Freshwater (salinity < 1500 mg/L TDS), 2 = Brackish (salinity 1500 - 3000 mg/L TDS), 3 = Fluctuating salinity, 4 = Saline (salinity 3000 - 35000 mg/L TDS). C_MODEL = Recharge or Exclusion zones.
<table><tr><th>Class</th><th>Code</th><th>Rule</th></tr><tr><td>1</td><td>11</td><td>Permanent and freshwater</td></tr><tr><td>2</td><td>12</td><td>Permanent and brackish</td></tr><tr><td>3</td><td>13</td><td>Permanent and fluctuating salinity</td></tr><tr><td>4</td><td>14</td><td>Permanent and saline</td></tr><tr><td>5</td><td>21</td><td>Near-permanent and freshwater</td></tr><tr><td>6</td><td>24</td><td>Near-permanent and saline</td></tr><tr><td>7</td><td>31</td><td>Intermittent and freshwater</td></tr><tr><td>8</td><td>32</td><td>Intermittent and brackish</td></tr><tr><td>9</td><td>33</td><td>Intermittent and fluctuating salinity</td></tr><tr><td>10</td><td>34</td><td>Intermittent and saline</td></tr><tr><td>11</td><td>51</td><td>Recharge zones</td></tr><tr><td>12</td><td>52</td><td>Exclusion zones</td></tr></table>
Datatype source/Maxent: Categorical/Categorical
Derived for study: Raster</td><td>Vegetation within GDEs is suspected to be more resilient to climate change impacts and contain vegetation (leaves) with higher water availability and better able to supply the moisture koalas obtain from their browse. Koala trees will have better moisture where there is permanent or near permanent connectivity to an aquifer where the groundwater is fresh (T. Ryan 2016 pers. comm.).</td></tr>
</table>

Table 15: Vegetation data and Maxent training mask.

Name	Source	Description
Remnant (hvrem) **Pre-clearing (hvpre)**	Regional ecosystem version 10.0, Queensland Herbarium (published 14 December 2016). Based on 2015 Landsat imagery.	Remnant and pre-clearing regional ecosystem mapping (version 10.0) were used as a training mask in the Maxent model (v11.17). Remnant (hvrem) and regrowth (hvreg) vegetation were combined and used as a training mask (hvrrc) to restrict koala occurrence records to only areas with trees and prevent the model being trained in cleared area without trees. Remnant and pre-clearing vegetation mapping (version 10.0) were sourced from the Queensland Herbarium (December 2016). Map scale range 1:25,000 – 1:100,000. Map scales: 1:25,000 (Brisbane); 1:50,000 (Gold Coast, Moreton Bay, Redland, Sunshine Coast, Gatton, Toowoomba and pre-amalgamation portion of Logan); 1:75,000 (Noosa and Beaudesert portion incorporated into Logan); and 1:100,000 (Laidley, Scenic Rim, Somerset) (Tim Ryan 2016 pers. comm.). Positional accuracy of RE data, mapped at a scale of 1:100,000, is 100m.
Regrowth (hvreg)	Woody cover raster data (offsets regrowth mapping from Biodiversity Implementation & Offsets Team, Department of Environment and Heritage Protection, 2015)	Regrowth (EHP 2015) was used as a training mask in the Maxent model (v11.17). Remnant (hvrem) and regrowth (hvreg) vegetation were combined and used as a training mask (hvrrc) to restrict koala occurrence records to only areas with trees and prevent the model being trained in cleared area without trees. The regrowth mapping (from the offsets program) was a vector-format derivative of the state-wide, 30m resolution foliage projection cover (FPC) raster (generated from Landsat imagery). The dataset was initially created by the offsets program (EHP 2015) and spatially filtered (masked) to reduce non target landuses (such as cropping, horticulture, industrial and urban etc) for the koala habitat suitability model v1.2. (See spatial filtering below). The offsets regrowth layer consists of a binary classification of non-remnant areas as either woody or non-woody, on the basis of whether local FPC values are above or below empirically generated woody/non-woody FPC cut-off values held in separate 'cut-off' raster (EHP 2015). The regrowth layer was erased with the remnant RE (version 10) mapping to remove potential overlaps.

Appendix 5. **Koala habitat matrix areas**

The following tables summarise the area (hectares) of the different koala habitat matrix classes. The tables show the pre-clearing and current (remnant) extent for each class of koala habitat in SEQ. The amount of koala habitat for each matrix rule and suitability category can be found using Figure 6 and Figure 7 as a reference. Note, areas have been calculated using MGA56.

Pre-clearing area (ha)			Regional Ecosystem Suitability (RE rank)			
			High 5	Medium 4	Low 3	TOTAL
Maxent Suitability (Maxent Rank)	High 3	Record 1	366,062	908,390	53,893	1,328,346
		No Record 0	21,378	58,393	7,920	87,691
	Medium 2	Record 1	22,135	292,993	39,884	355,012
		No Record 0	5,080	46,177	12,490	63,746
		TOTAL	**414,655**	**1,305,954**	**114,187**	**1,834,796**

Remnant area (ha)			Regional Ecosystem Suitability (RE rank)			
			High 5	Medium 4	Low 3	TOTAL
Maxent Suitability (Maxent Rank)	High 3	Record 1	32,551	171,625	25,370	229,547
		No Record 0	4,888	27,323	4,772	36,983
	Medium 2	Record 1	9,687	163,482	21,581	194,750
		No Record 0	2,390	38,150	9,265	49,805
		TOTAL	**49,516**	**400,580**	**60,989**	**511,085**

High value regrowth area (ha)			Regional Ecosystem Suitability (RE rank)			
			High 5	Medium 4	Low 3	TOTAL
Maxent Suitability (Maxent Rank)	High 3	Record 1	15,992	80,068	4,666	100,575
		No Record 0	571	2,983	246	3,800
	Medium 2	Record 1	1,017	22,967	1,779	25,763
		No Record 0	137	3,848	463	4,448
		TOTAL	**17,580**	**109,852**	**7,154**	**134,737**

Appendix 6. **Koala habitat model for SEQ**

The habitat model integrated a species distribution model with the Queensland Herbarium's regional ecosystem (RE) mapping and validated koala occurrence records to produce a comprehensive ranking of koala habitat suitability across the SEQ study area (Figure 33). The categories of the habitat model represent core habitat, non-core habitat, and non-habitat. Classes 4–10 represent core habitat, with class 4 the lowest suitability core habitat without confirmed koala sightings and class 10 the highest suitability core habitat. Classes 2–3 represent non-core habitat, with class 2 representing non-core (marginal) habitat, class 3 representing non-core (rainforest) habitat. Class 1 represents non-habitat. The map of habitat categories is shown in Figure 34.

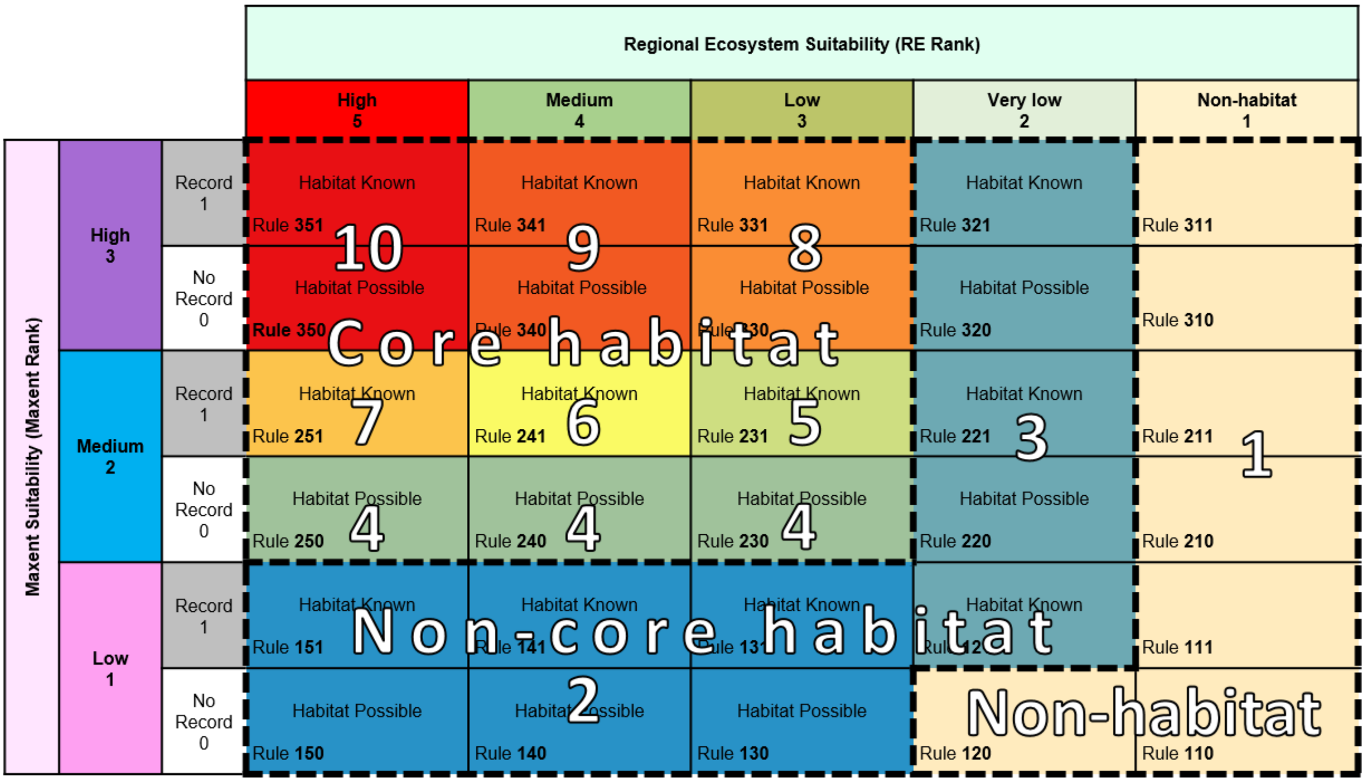


Figure 33: Decision matrix and koala habitat suitability categories.

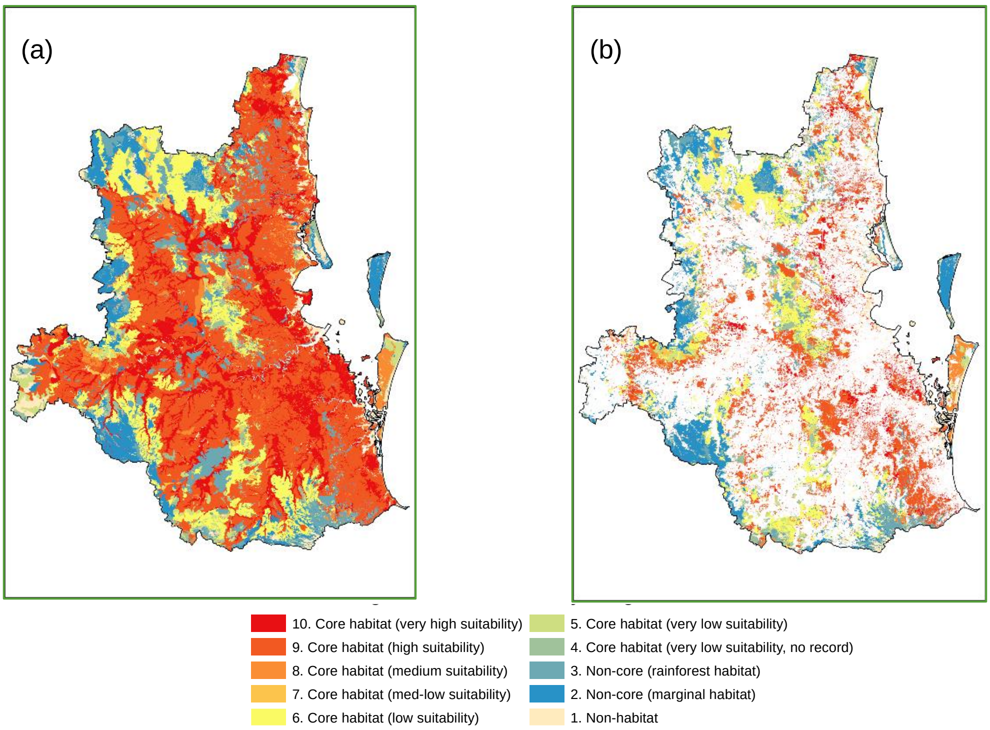
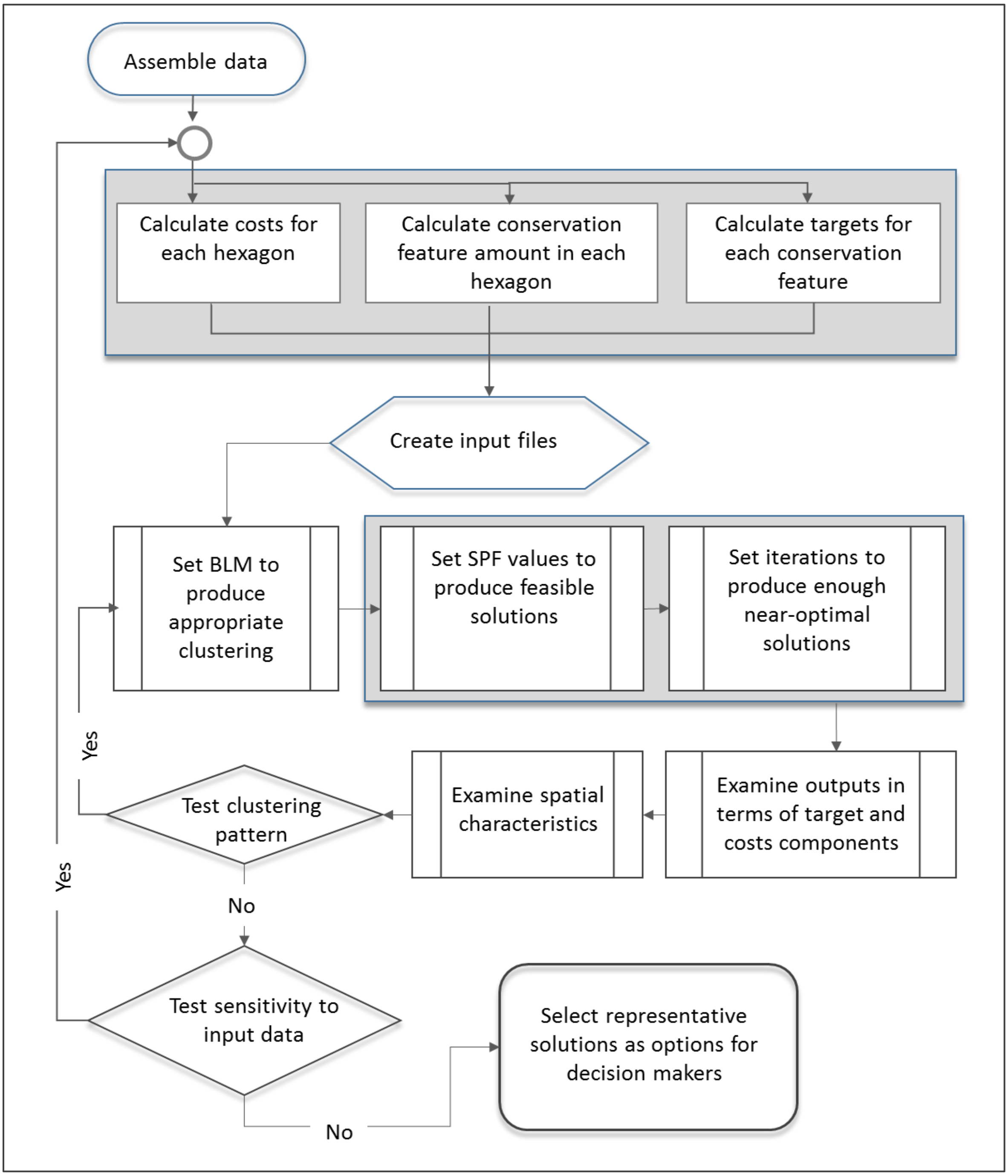


Figure 34: Koala habitat suitability categories map for (a) pre-clearing and (b) remnant and regrowth.

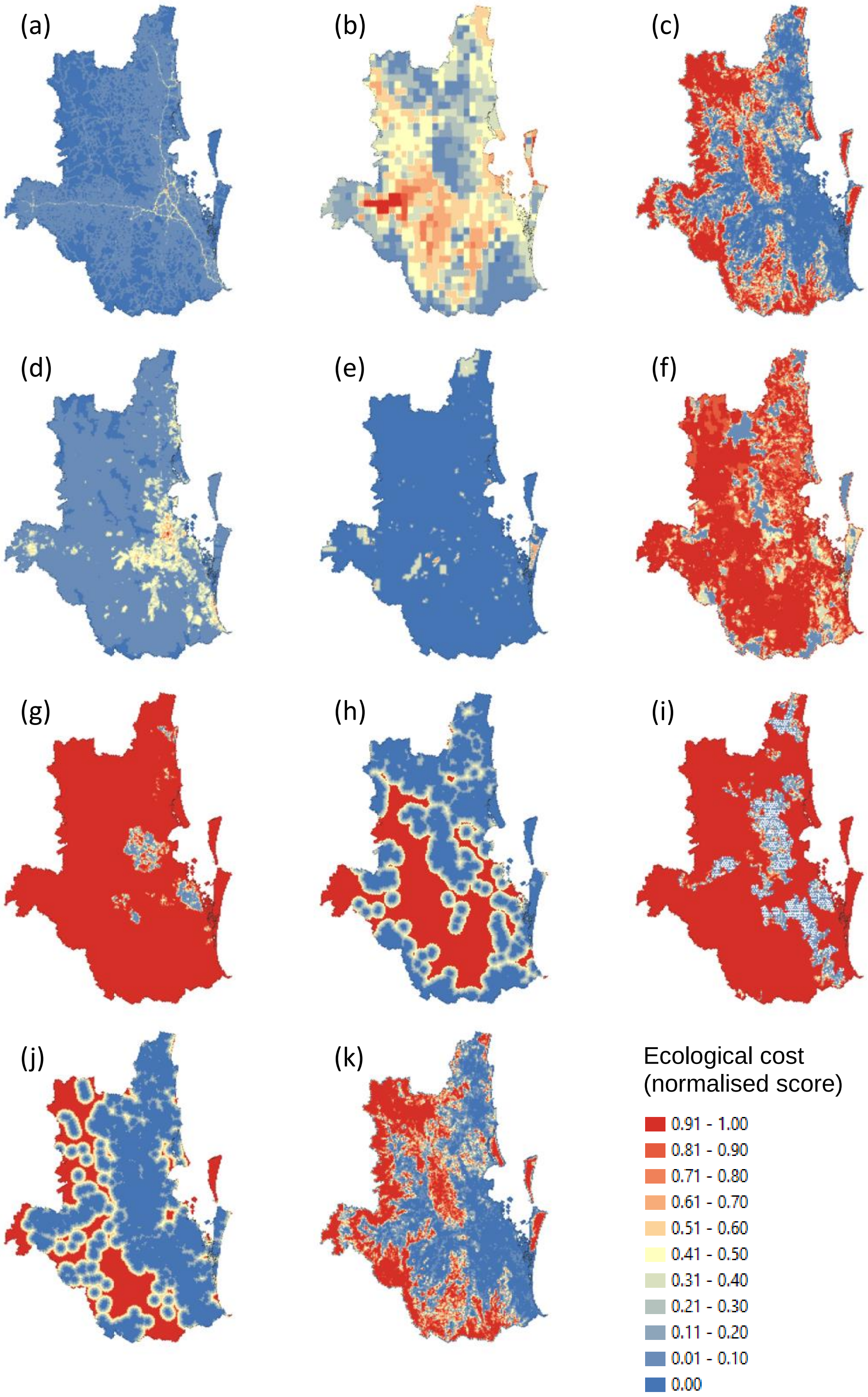
Appendix 7. **Marxan workflow**

Workflow for running Marxan, modified from (Fischer et al. 2013). BLM is the boundary length modifier, SPF is the species penalty factor



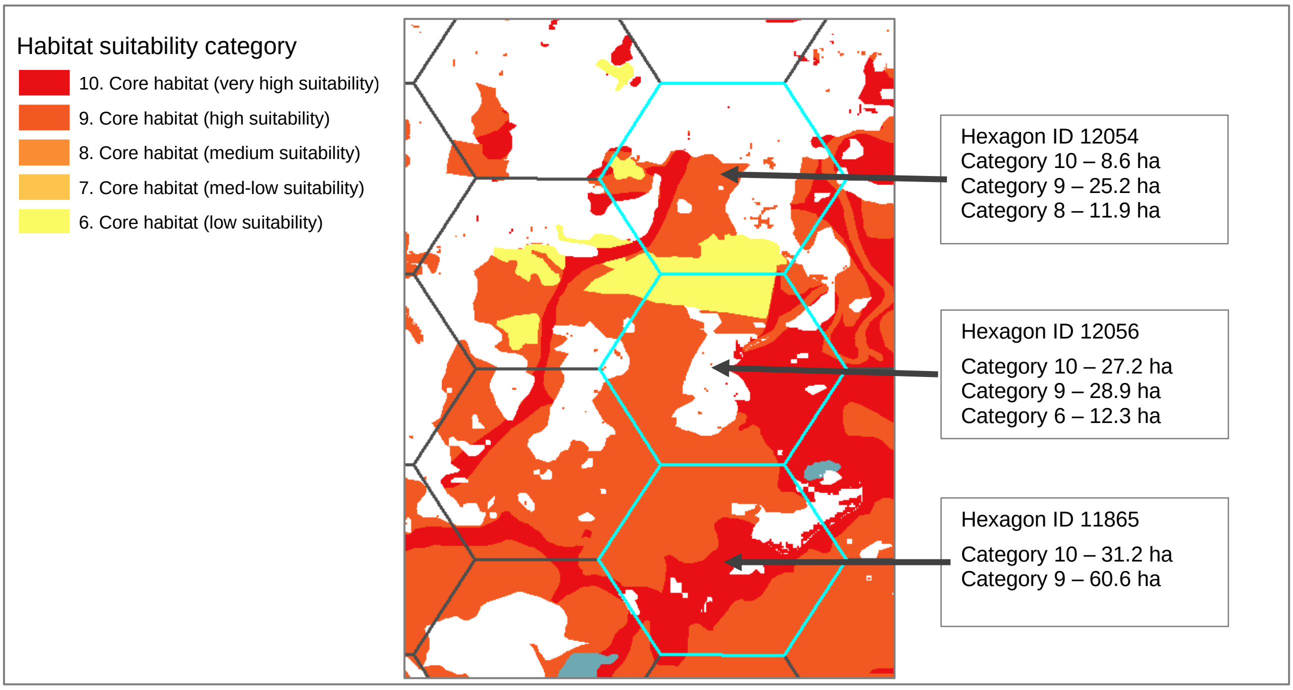
Appendix 8. **Ecological cost layers**

Individual maps of the spatial distribution of threats, constraints and opportunities used in the ecological cost layer for the chosen scenario. (a) Roads (R), (b) heat stress (P&R), (c) climate change (P&R), (d) urban development (P&R), (e) extractive industries (P&R), (f) conservation or environmental management areas (P&R), (g) bushland in KADA and PKADAs (P&R), (h) habitat within 5 km of protected areas (P), (i) restoration potential within 5 km of a KPA (R), (j) within 5 km of hexagon selection frequency for protection >20 (R), (k) climate change refugia (R). P = habitat protection, R = habitat restoration.

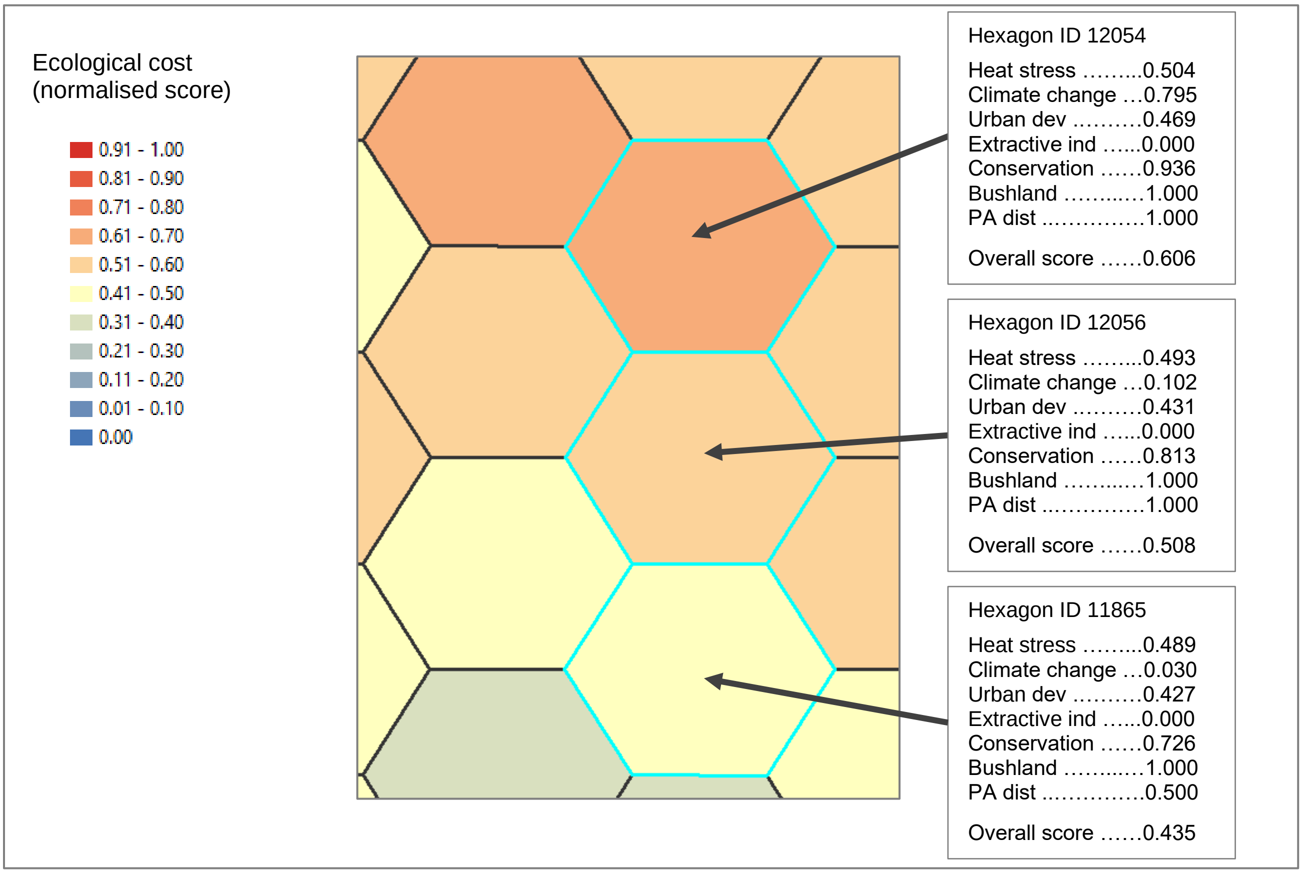


Appendix 9. Examples of Marxan target features and costs

Example of calculating the target conservation features using the area of different habitat categories per hexagon.



Example of ecological cost calculation per hexagon. The scores for each variable are normalised. The overall score is the sum of the weighted threats, constraints and opportunities scores based on the weights in Table 9.



Example of Marxan output based on selection frequency for the chosen scenario. Hexagon 11865 was selected in 83 out of 100 runs, making it an important contributor because of its high area of habitat (total 91.7 ha out of 100 ha), and its lower ecological cost compared with hexagons 12054 and 12056.